Virtual Technical Conference & 3D Exposition

October 13-23, 2020

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INVESTMENT CASTING INSTITUTE

MISSION STATEMENT

The Investment Casting Institute will market the investment casting industry and support its members by facilitating professional, academic, educational, and technical interests, and will provide a forum for advancement in technology and product quality for customers and manufacturers, while promoting free trade, fair competition, and adhering to U.S. laws and regulations regarding commerce and industrial trade.

General Rules of Antitrust Compliance

The following rules are applicable to all ICI activities and must be observed in all situations and under all circumstances, without exception or qualification other than as noted below:

1. Neither the ICI nor any committee, conference or activity of the ICI shall be used for the purpose of bringing about, or attempting to bring about, any understanding or agreement, whether written or oral, formal or informal, expressed or implied, among competitors with regard to prices, terms or conditions of sale, discounts, tying provision or purchase of a good or service with another, exclusive dealing arrangements, distribution, volume of production, allocation of territories or customers, restrictions on non-deceptive advertising, or credit of suppliers, customers or competitors or any understanding or agreement which could be perceived as restraining competition.

2. No ICI activity or communication shall (a) include discussion, survey, or action, for any purpose or in any fashion of costs, prices or pricing methods, rebates or other price discrimination, production quotas or other limitations on either the timing or volume of production or of sales; (b) take any action likely to raise prices or reduce quantity or quality of goods available, or (c) involve allocation of territories or markets or customers in any way. “Communication” includes but is not limited to electronic communications, such as emails, test messages, faxes, blog or web posts and/or social media posts.

3. No ICI committee shall undertake any activity, which involves exchange or collection and dissemination among competitors, of any information regarding prices, pricing methods, costs of production, or of sales or distribution or individual company statistics of any kind, without first obtaining the advice of legal counsel, provided by ICI, as to those proper and lawful methods by which these activities may be pursued.

4. No ICI activity or communication shall include any discussion or action which may tend to or may be construed as an attempt to prevent any person or business entity from gaining access to any market or to any customer for goods or services, or to prevent or boycott any supplier, competitor, customer, or other entity from obtaining, accessing, or selling a supply of goods or otherwise purchasing or distributing goods or services freely in the market.

5. No ICI activity or communication shall include any discussion or action which might be construed as an agreement or understanding to refrain from purchasing any raw materials, equipment, services or other supplies from any supplier.

6. Neither ICI nor any committee thereof, shall make any effort to bring about the standardization of any product or method of manufacture, credentialing, listing or certification of any product or program for the purpose of preventing the manufacture or sale of any product not conforming to a specified standard or which would tend to have the overall affect of either lessening competition or resulting in a degree of price stabilization.

7. No person or company shall be commercially disparaged nor shall any ICI Member make statements that are reasonably likely to have a negative reputational impact on another so as to exclude that person or company from ICI membership or participation in any ICI activity where such exclusion is designed to or may impair such person's or company's ability to compete effectively in the investment casting industry.

8. In conducting ICI committee meetings, the chairman thereof shall prepare and follow a formal agenda which shall be provided to all committee members prior to the meeting; else it shall not be considered. Agenda items listed as “Any Other Business: shall be prohibited. Minutes of each meeting shall be distributed to all persons who attended such meetings. Approval of the minutes shall be obtained from the membership of the committee at its next meeting. Copies of the minutes shall be transmitted to the headquarters staff.

9. ICI speakers and authors of conference papers shall be informed of the need to comply with ICI's antitrust policy in the preparation and presentation of their papers and addresses.

10. In informal or social discussions at the site of an ICI meeting (whether such meetings are conducted in-person or via telecommunications services), which are beyond the control of its officers and chairmen, all representatives are expected to observe the same standards of personal conduct required of ICI in its compliance with these antitrust guidelines. Members are reminded that even actions or discussions occurring outside of the U.S. may still be subject to federal antitrust laws. In addition, copies of the foregoing Antitrust Policy Statement and General Rules of Antitrust Compliance will be included in registration packets and will also be printed in the ICI Committee Directory. The Board may from time to time require all members to sign an acknowledgement that each member has read and understood these Rules of Antitrust Compliance.

ANTITRUST POLICY STATEMENT OF THE INVESTMENT CASTING INSTITUTE

The Investment Casting Institute (ICI) is a trade and technical association of investment casting foundries (and their suppliers) where castings of metal are made.

The ICI is organized to promote the common interests of the investment casting industry. The ICI is not intended to become, and will not become, involved in the competitive business decisions of its members, nor will it take any action which would tend to restrain competition in the investment casting industry.

Nevertheless, it is recognized by the Board of Directors of ICI that the Institute itself, as well as its varied activities, could be regarded by some as a forum or opportunity to promote anti-competitive conduct. For this reason, the Board of Directors promulgates this statement of policy to make clear its unequivocal support for the policy of competition served by federal and state antitrust laws, as well as its uncompromising intent to comply strictly in all respects with those laws.

In addition to stating the ICI's firm commitment to the principle of competition served by antitrust laws, the ICI also wishes to advise that the penalties which may be imposed upon both ICI and its individual and corporate members involved in any violation of such laws are now so severe that prudent business judgment demands that every effort be made to avoid any such violation. In addition to injunctions and other equitable remedies, violations of the Sherman Act, such as price-fixing, are felony crimes for which individuals may now be imprisoned for up to ten (10) years and fined up to one million dollars ($1,000,000.00), and corporations can be fined up to 100 million dollars ($100,000,000.00) for each offense, or twenty percent (20%) of affected commerce. The Department of Justice has recently obtained fines of up to five hundred million dollars ($500,000,000.00). Under the Sherman Act, state Anti Trust law, the Federal Trade Commission Act and Robinson-Patman Act, treble (triple) damage claims based on the amount of gain or loss by private parties (including class actions) for antitrust violations are extremely expensive to litigate and can result in judgments of a magnitude which could destroy the ICI and seriously affect the financial interests of its members. This includes attorney's fees and "joint and several liability" where one may be liable for an entire Judgement even though their role in the antitrust violation was rather small.

It is the responsibility of every member of the ICI to be guided by ICI's policy of strict compliance with antitrust laws in all ICI activities. It shall be the special responsibility of ICI officers, directors and committee chairmen to ensure that this policy is known and adhered to in the course of activities pursued under their leadership.

To assist the ICI staff and all its officers, directors and committee chairmen in recognizing situations which may raise the appearance of an antitrust problem, the Board will as a matter of policy furnish to each of such persons copies of ICI's General Rules of Antitrust Compliance. The ICI will also make available general legal advice when questions arise as to the manner in which the antitrust laws may apply to the activities of the ICI or to any committee thereof.

Antitrust compliance is the responsibility of every ICI member. If you have any questions or information concerning potentially anti-competitive conduct, please contact the Board's Executive Committee orally, in writing and even anonymously. Alleged violations of the ICI General Rules of Antitrust Compliance or of this policy statement will be vigorously investigated and reviewed with due process pursuant to the by-laws of the ICI; violations may result in revocation of membership in ICI and removal from any ICI office.

Conference Will Be Held in Eastern Time Zone

TUESDAY, OCTOBER 13, 2020

11:00 a.m. - 11:30 a.m.	**Tim Sullivan,** *ICI President* *Hitchiner Manufacturing* **Russ Gallagher,** *ICI Director* *BESCAST, Inc.*	**Opening & Annual Awards Ceremonies** Casting Contest Hall of Honor Innovator of the Year
11:30 a.m. – 12:15 p.m.	**Dr. Leroy Chiao** *Former NASA Astronaut &* *Space Station Commander*	**Keynote Speech** Endeavor to the Next Level!
1:00 p.m. - 2:00 p.m.	**Gavin Dooley** *REMET, UK*	**Paper No. 1** Fundamental Analysis into Properties Affecting Investment Casting Shell Strength
3:00 p.m. – 4:00 p.m.	**Sander Klemp** *Davis Alloys*	**Paper No. 2** Hypoallergenic Surgical Cast Stainless Steel

WEDNESDAY, OCTOBER 14, 2020

11:00 a.m. – 12:00 p.m.	**Iñaki Vicario** *Consarc Engineering*	**Paper No. 3** Vacuum Induction Melting Process Optimization In Precision Investment Casting Furnaces
1:00 p.m. – 2:00 p.m.	**Dan Sokol** *Renaissance Services* **Shawn Franks** *HTCI, Co.*	**Paper No. 4** Rapid & Affordable Castings from 3D-Printed Ceramic Molds
3:00 p.m. – 4:00 p.m.	**Dave Berta &** **Sam Duncan** *Ransom & Randolph*	**Paper No. 5** Slurry Analysis & Shell Material Testing Methods

THURSDAY, OCTOBER 15, 2020

11:00 a.m. – 12:00 p.m.	**John Dyck** *CESMII*	**Paper No. 6** The Smart Manufacturing Institute
1:00 p.m. – 2:00 p.m.	**Tom Mueller** *Mueller Additive Manufacturing Solutions*	**Paper No. 7** Evaluation of a Low-Cost Material Extrusion Printer for Investment Casting Applications
3:00 p.m. - 4:00 p.m.	**Brian Lewis** *Foundry Education Foundation* **Mingzhi Xu** *Georgia Southern University* **Dr. Robert Voigt** *Pennsylvania State University* **Dr. Victor Okhuysen & Dika Handayani** *Cal Poly Pomona University* **Andrew Wessman** *University of Arizona* **Russ Rosmait** *Pittsburg State University*	**Panel Discussion No. 1** Preparing our Future Engineers and Technologists

FRIDAY, OCTOBER 16, 2020

11:00 a.m. - 12:00 p.m.	**Nip Singh,** *ICI Director* *S&A Consulting Group LLP* **Joseph Fritz**, *Executive Director* *Investment Casting Institute* **Craig Lanham**, *Member Emeritus* **Brian Ferg** *Consolidated Precision Products* **Tom Planz** *Kovatch Castings, Inc.* **Thad Nykiel** *BESCAST, Inc.*	**Panel Discussion No. 2** Process Control Standards
1:00 p.m. – 2:00 p.m.	**John Lea** *Geo 40*	**Paper No. 8** How It's Made: Colloidal Silica, a New Method
3:00 p.m. – 4:00 p.m.	**John Slawvey** *Vestshell, Inc.*	**Paper No. 9** Life Cycle of our Ceramic Shells

MONDAY, OCTOBER 19, 2020

11:00 a.m. – 12:00 p.m.	**Jack Ziemba** *Aristo-Cast, Inc.*	**Paper No. 10** INVESTING In The Future
1:00 p.m. - 2:00 p.m.	**Donald Deptowicz** *Aspen Hybrid Technology Solutions, LLC*	**Paper No. 11** Industry Viable Strategic Tooling Enablers for MRB Elimination
3:00 p.m. – 4:00 p.m.	**Amarnath Bhat** *SoftCAST Technologies* **Stephen Barnett** *INCAST Consultancy*	**Paper No. 12** Casting Simulation: An Aid to Address Industry's Covid-19 Challenges

TUESDAY, OCTOBER 20, 2020

11:00 a.m. - 12:00 p.m.	**Julie Markee,** *ICI Director* *Key Process Innovations*	**Paper No. 13** COVID-19 - the Catalyst to Enhanced Performance
1:00 p.m. - 2:00 p.m.	**Dr. Suman Das** *DDM Systems*	**Paper No. 14** Tool-less Digital Investment Casting Using 3D-printed "ready to pour" Ceramic Shells
3:00 p.m. – 4:00 p.m.	**Dr. -Ing. Santhanu Jana** *ALTAIR Engineering GmbH*	**Paper No. 15** Digital Twin Design Process for Development of Next Generation Lightweight Investment Casted Parts

WEDNESDAY, OCTOBER 21, 2020

11:00 a.m. - 12:00 p.m.	**Joseph Fritz,** *Executive Director* *Investment Casting Institute* **Kenji Ito,** *Japan Foundry Society* **Carlos Olabe***, Executive Director* *European Investment Casters' Federation*	**Panel Discussion No. 3** Market Insights
1:00 p.m. – 2:00 p.m.	**Michael Fanz-Huster** *Inductotherm*	**Paper No. 16** Advancements in Melt System Control Technology
3:00 p.m. - 4:00 p.m.	**Steven Ashlock** *Kyanite Mining Corporation*	**Paper No. 17** The Effect of Removing Dust from Backup Stuccos on Shell Properties

THURSDAY, OCTOBER 22, 2020

11:00 a.m. – 12: 00 p.m.	**Gerald Richard** *MAGMA Foundry Technologies*	**Paper No. 18** The Digital Foundry: Building on the processes of today to meet the demand of tomorrow
1:00 p.m. – 2:00 p.m.	**Jiten Shah** *Product Development & Analysis (PDA)*	**Paper No. 19** Light-weighting using Advance Simulation and Tooling Free Investment Casting AM Process
3:00 p.m. – 4:00 p.m.	**Robert Johnson** *Shellcast, Inc.* **Steve Sikorski** *MAGMA Foundry Technologies* **Russ Rosmait** *Pittsburg State University* **Joseph Fritz** *Investment Casting Institute*	**Panel Discussion No. 4** Educating The Customer

FRIDAY, OCTOBER 23, 2020

11:00 a.m. – 12:00 p.m.	**Chad Beamer** *Quintus Technologies, LLC*	**Paper No. 20** The Effect of HIP and High Pressure Heat Treatment on The Investment Cast Super Alloys
1:00 p.m. – 2:00 p.m.	**Gregory Colvin** *Honeywell Aerospace*	**Customer Spotlight** Honeywell Aerospace
3:00 p.m.	**Investment Casting Institute**	**Closing Ceremony and Parting Words**

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SPEAKER BIOGRAPHIES

Dr. Leroy Chiao .... Keynote Address
Former NASA Astronout & Space Station Commander
Dr. Leroy Chiao is a renowned American astronaut and international space station commander. He speaks from experience on important business topics such as leadership, how to combat complacency, and essentials to bring your business to the next level. A pioneer in the commercial space sector, his accomplished track record in space, in the lab, and in the business world offers audiences an unparalleled perspective into space exploration and how lessons learned apply to businesses worldwide. His broad technical expertise allows him to offer compelling insights on future technology trends, the fascinating biomedical effects of spaceflight, and how businesses must pay attention to technology and innovation to stay on top. In presentations, Chiao shares breathtaking photos and awe-inspiring stories of leadership, innovation, and running international teams from his four space missions, including nail-biting tales of real emergency situations, and shows audiences how his out-of-this world knowledge can impact their organizations. Few people have reached the heights in their careers that Leroy Chiao continues to experience, and he is happy to offer the benefit of his experience to inspire and enlighten others in all fields.

Gavin Dooley .... Paper No: 1
Group Technical Director – REMET UK Ltd
Gavin is the group technical director of REMET®, with responsibility of Quality, R&D and New Product Development. Gavin earned his PhD entitled “Shell Improvements for the Investment Casting of Orthopaedic Implants” from the University of Birmingham in 2016. He has gained over 10 years investment casting experience as a senior process and materials engineer within a medical device foundry and with REMET. Gavin also completed an MBA with the Open University in 2019. During the COVID-19 pandemic, Gavin led the rollout of a 5-part webinar series covering many topics of investment casting to American, European and Asian customers which was well received. Gavin has presented in over 12 investment casting conferences throughout the world in the last decade.

Sander Klemp .... Paper No: 2
***Technical Alloy Sales Representative* - Davis Alloys Manufacturing, LLC.**
Sander Klemp is a Technical Alloy Sales Representative with Davis Alloys Manufacturing, LLC in Sharpsville Pennsylvania. Davis Alloys is a producer of specialty alloys mostly in ingot and powder forms for the investment, sand, and centrifugal casting industries. Sander currently resides in Muskegon, MI which is located on the shores of Lake Michigan. Sander has worked in the investment casting industry for 19 years, learning the industry from the ground up. He began his career at EPS Industries, an investment casting facility located in Ferrysburg, MI. He was able to learn each process of the investment casting industry first hand during his tenure at EPS. Sander attended Grand Rapids Community College and Grand Valley State University pursuing a degree in sales while working part time at EPS Industries. Sander’s father and a well-respected metallurgist Ted Klemp III offered him a position as his apprentice at Cayenne Systems, a foundry and metallurgical consulting business. It was at this time that he switched his educational focus to metallurgy attending Muskegon Community Colleges foundry program & then Western Michigan University. Sander worked at Cayenne Systems with his father for 15 years where he learned a hands on approach to give him a deeper understanding of foundry metallurgy & how it relates to investment casting. He worked on countless projects for commercial customers & for educational organizations like the American Foundry Society & the Investment Casting Institute. After his father passed away in 2019, Sander joined the team at Davis Alloys and has become a valuable technical resource with a unique knowledge base that he currently utilizes in his technical sales support role.

Iñaki Vicario .... Paper No: 3
Casting Technology Specialist - Consarc Engineering Ltd
Iñaki Vicario is the Casting Technology Specialist of Consarc Engineering. He belongs to the Technology Group of Consarc dealing with technical developments, and customer technical support. He has almost 13 years of experience in the aerospace industry, specifically in investment casting technology as a foundry process owner. He has also large experience in other metallurgical processes, such as vacuum heat treatment (10 years of experience in AMS 2750), VIM process for Ni based alloy manufacturing, HIP and gas phase aluminizing. Mr. Vicario has a Bachelor’s degree from the University of the Basque Country in Industrial Engineering, specialized in Manufacturing Technologies.

SPEAKER BIOGRAPHIES

Dan Z. Sokol……………………………………………………………………………………………………Paper No: 4
Managing Partner - Renaissance Services – Perfect 3D Div
Mr. Dan Z. Sokol is the Managing Partner of Renaissance Services Inc. He is involved in leading complex technology integration projects for automotive, aerospace, and casting companies such as General Motors, Lockheed, and PCC. Dan has most recently been the technical lead for various projects focused on the improvement of investment casting, which involves the 3D-printing of ceramic cores, filters, and molds. He was the technical leader and principal investigator on additive manufacturing development efforts sponsored by the US Air Force and Defense Logistics Agency. Dan has also successfully managed technology projects funded by the National Institute of Standards and Technology, Missile Defense Agency, and the National Science Foundation. Dan has received multiple patents for software and engineering systems. He has published over thirty technical papers and he was recently awarded the Society of Automotive Engineers Excellence in Presentation Award. He was also a finalist for the Ernst & Young Ohio Entrepreneur of the Year award. Dan received a BS in Industrial & Systems Engineering and a BS in Computer Sciences from the Ohio State University, and an MBA from the University of Dayton.

Shawn Franks……………………………………………………………………………………………………Paper No: 4
HTCI, Co.
Shawn Franks is a second generation foundryman at HTCI who has worked in the aerospace aluminum casting industry for over 21 years. His specialty is making aluminum aerospace grade castings using the investment mold, plaster mold, and precision sand mold processes. Shawn has been involved on projects ranging from classified military grade castings and high-volume commercial aerospace castings to OEM automotive castings, aftermarket high-performance automotive castings, as well as medical grade castings. He learned his trade skills through hard work and dedication while working with pioneers of the aluminum casting industry. With decades of experience and continuous educational enrichment, Shawn has been able to successfully bring innovative casting approaches from ideas to reality. His most recent efforts include the introduction of 3D-printed ceramics into aluminum casting production.

Sam Duncan……………………………………………………………………………………………………Paper No: 5
Product & Application Engineer – Ransom & Randolph
Sam has been with R&R for two years, and in his role, he works closely with the R&R applications team, as well as directly with customers, troubleshooting issues. He creates comprehensive solutions for customers that allow them to streamline and refine their processes in order to produce ceramic shells that fit their needs. In addition to that, Sam has also helped write and present technical papers for R&R at both the 2019 ICI Conference as well as the 2020 ICI Regional Meeting.

Dave Berta……………………………………………………………………………………………………Paper No: 5
Product & Application Specialist – Ransom & Randolph
Dave joined R&R in 1999 and is currently the primary contact on the ceramic shell technical team, providing both internal and external technical support worldwide. Over his 18 year tenure, Dave has worked on a variety of research and development (R&D) and application projects. In his current role as Product & Application Specialist, Dave is responsible for implementing customized solutions and application technologies as well as coordinating problem solving measures on behalf of R&R customers.

John Dyck……………………………………………………………………………………………………Paper No: 6
CEO - CESMII
John Dyck was appointed CEO of the Smart Manufacturing Institute (CESMII) in June of 2018. CESMII is a public/private partnership committed to transforming the U.S. manufacturing market and increasing global competitiveness through the application of smart manufacturing technologies. John brings a highly pragmatic perspective to CESMII, and a crisp focus on outcomes that will benefit the Nation's energy and economic security by sharing existing resources and co-investing to accelerate development and commercial deployment of innovative technologies. John is practical visionary with a passion for innovation in the Manufacturing IT space. He's known globally as a domain expert on both technology and business management in the nexus that often separates IT and Operations. For the past 5 years, he has been focused on how innovations like Cloud and the Industrial Internet of Things (IIoT) impact manufacturing and has pioneered the application of these technologies in a wide range of manufacturing operations across many industries. John was recently awarded a number of patents for the application of IIoT and analytics in manufacturing workflows and business processes. Prior to joining CESMII, John held senior leadership positions in large corporations like GE and Rockwell Automation, and was effective in raising VC funding and building a successful software startup called Activplant. John currently serves as the past Chairman of MESA International's (Manufacturing Enterprise Solutions Association) Board of Directors. Mr. Dyck holds a degree in Electronics Engineering from Conestoga College.

SPEAKER BIOGRAPHIES

Tom Mueller……..……………………………………………………………………………………………...…..Paper No: 7
President - Mueller Additive Manufacturing Solutions
Tom is the founder and president of Mueller Additive Manufacturing Solutions, a consulting company focusing on metal casting applications of additive manufacturing. He has been involved in 3D printing applications for more than 30 years. He led the first beta site for stereolithography at Baxter Healthcare in the late 80s. He then went on to found two 3D printing service companies. One of those companies, Express Pattern, was sold to 3D Systems in 2010. He worked for 3D Systems as Director of Business Development focusing on metal casting applications and later for Voxeljet as Director of Metal Casting applications. Tom has published more than 50 technical papers and journal articles related to 3D printing applications. He holds BSME and MSME degrees from the University of Illinois and an MBA from the Sloan School of Management at MIT. Tom is a member of the American Foundry Society and the Investment Casting Institute. He chairs two committees of the AFS; the Investment Casting Committee and the Expendable Pattern Committee of the newly formed Additive Manufacturing Division. In 2019, Tom received the Ray H. Witt award from the AFS which recognizes significant contributions to the metal casting industry. Tom is also active in the Investment Casting Institute as a member of its Additive Manufacturing Committee. He also teaches a section of the ICI's Investment Casting Certification Course.

Brian Lewis……………………………………………………………………………………………….Panel Discussion No. 1
Executive Director – Foundry Education Foundation (FEF)
Brian Lewis, originally from Pittsburgh, Pennsylvania was selected as the Foundry Educational Foundation (FEF) Executive Director in November, 2014. Brian is a degreed engineer with a unique background including experience in both the manufacturing and non-profit realms. Brian held positions in manufacturing facilities throughout the United States in operations management. His non-profit experience includes a leadership role at a sports-related membership and events organization.

Dr. Mingzhi Xu……………………………………………………………….……………………….Panel Discussion No. 1
Assistant Professor – Georgia Southern University
Dr. Mingzhi Xu, Assistant Professor and Foundry Education Foundation key professor at Georgia Southern University. Dr. Mingzhi Xu has extensive research experience with foundry engineering and ferrous alloys processing. Mingzhi has received 3 best paper awards, 1 best presentation award, and Howard Taylor award from AFS, and the Peaslee Junior Faculty award from AIST. He has published over 50 research articles.

Dr. Robert Voigt..Panel Discussion No. 1
Professor – Penn State University
Dr. Robert Voigt is Professor of Industrial & Manufacturing Engineering at Penn State University. He received his PhD. in Metallurgical Engineering from the University of Wisconsin in 1981. Bob currently directs metalcasting research programs and metalcasting consortia research programs with broad casting industry participation. He has published over 250 papers on various aspects of foundry technology ranging from alloy development to casting process control. He is the FEF Key Professor at Penn State, is a member of the ICI Technical Committee and is a Fellow of the Society of Manufacturing Engineers.

Dr. Victor Okhuysen ……………………………………………………………………...………...Panel Discussion No. 1
Professor – Cal Poly Pomona University
Dr. Okhuysen has held jobs in academia and industry. He has been a Professor of Industrial and Manufacturing Engineering at Cal Poly Pomona since 1998. Prior to his academic career he held various positions in the Metal Casting industry the last of which was as Engineering Manager at CMI-Tech Cast Foundry in Myerstown, PA. In his academic career Dr. Okhuysen has taught multiple courses in areas related to Manufacturing, Materials and Industrial Engineering. He has had multiple research projects, typically in partnership with industrial entities and some sponsored by government agencies. He has many articles and presentations in the area of Metal Casting. As a Professor he has won several awards including the 2015 Outstanding Academic Advisor from the College of Engineering, the Outstanding Faculty Award from the Veteran's Resource Center and the Distinguished Professor Award from the American Foundry Society and the Foundry Educational Foundation. Dr. Okhuysen has also held administrative positions. In academia, he was Co-Chair of the Graduation Initiative with the goal to improve students' academic performance and graduation rates and in industry as Engineering Manager. Dr. Okhuysen obtained his Bachelor's Degree in Materials Engineering from Cal Poly San Luis Obispo in 1992, MS and PhD in Industrial Engineering from Penn State University in 1995 and 1998 respectively.

SPEAKER BIOGRAPHIES

Dika Handayani ....Panel Discussion No. 1
Assistant Professor – Cal Poly Pomona University
Dika Handayani received her MS and PhD in Industrial and Manufacturing Engineering from Penn State University in 2017. She also holds a BS in Manufacturing Engineering from Cal Poly Pomona. Dr. Handayani spent one year as a foundry and FEF Key Professor at Texas State University before joining the Industrial and Manufacturing Engineering Department at Cal Poly Pomona in August 2018. She is also a member of the FEF Alumni Ambassador Committee. At Cal Poly Pomona she is the primary advisor of the manufacturing student club, which includes the AFS Student Chapter. She also works with undergraduate students on her research in the area of metal casting and machining.

Dr. Andrew Wessman……………………………………………………………………………….....Panel Discussion No. 1
Assistant Professor – University of Arizona
Dr. Andrew Wessman recently joined the University of Arizona Materials Science and Engineering Department following a previous position as a Staff Engineer at GE Additive. During 14 years at GE, he worked at GE Aviation to develop polycrystalline nickel superalloys for use in turbine engine rotating parts. This work also included developing the forging, welding and ICME capabilities necessary to utilize these materials in safety critical components. Dr. Wessman moved to GE Additive prior to the launch of the new GE business in early 2017, and led development of high temperature materials and processes for additive manufacturing. He has B.S. and M.S. degrees in Metallurgical Engineering from the University of Utah and a Ph.D. in Materials Science from the University of Cincinnati. He also serves as an Adjunct Professor of Materials Science and Mechanical Engineering at The Ohio State University.

Russ Rosmait ....Panel Discussion No. 1
Professor -Pittsburg State University
Russ Rosmait is a University Professor in the Department of Engineering Technology at Pittsburg State University (PSU). He has been teaching at PSU for the Past 33 Years. At PSU Russ is the faculty advisor to the American Foundry Society student chapter and is the Foundry Educational Foundation (FEF) Key Professor. He advises students in manufacturing and metal casting studies within the Department of Engineering Technology. He is one of 20 Foundry Educational Foundation (FEF) Key Professors within North America. For the past 19 years he has been the program director the Investment Casting Institutes Industry Certification program. He is very active within U.S. metal casting industry and the U.S. space program. He was selected to be a NASA Faculty Fellow and worked at NASA's Marshall Space Flight Center in Huntsville, Alabama for five summers. His is the current Academic Advisor to the ICI Board of Directors and is on the advisory board of Metal Casting Design and Purchasing Magazine. His education includes a Bachelors of Science degree and a Master of Science degree from the University of Wisconsin-Stout and a Doctoral degree from Oklahoma State University. Awards includes the John Langford Faculty of Distinction Award, PSU Greek Council O.F. Grubbs Outstanding Professor Award, Outstanding Teaching Faculty Award selected by the students of Pittsburg State University, FEF directors award for Distinguished Professor in Metal Casting, and The James Hough Stout Award Distinguished Alumni of the University of Wisconsin Stout. ICI Executive Director's Outstanding Contributor Award.

Nip Singh ....Panel Discussion No. 2
Consulting Partner & CEO – S&A Consulting Group LLP
Nipendra (Nip) Singh has been an affiliate member of ICI for almost 30 years. He is also member of ICI Board of Directors representing affiliate members and working/chairing many key committees for the welfare of Investment Casting in general and both Affiliate and Regular members. Nip has almost 50 years of experience in the high technology aircraft engine components manufacturing business including nearly 20 years with Rolls Royce , General Electric and TRW/PCC Corporations. Since 1991 Nip is Consulting Partner and CEO of S&A Consulting Group LLP, Cleveland, USA.

SPEAKER BIOGRAPHIES

Joseph Fritz ....Panel Discussion No. 2
Executive Director – Investment Casting Institute
Joseph Fritz has been the Executive Director of the Investment Casting Institute since 2013. Under his leadership, the ICI has focused its initiatives on member services, educational resources, technological collaboration, industry sustainability and growth. With over 35 years' experience, Mr. Fritz has served the industry in a variety of capacities with a number of Fortune 100 as well as privately held companies, including operations management, quality assurance, engineering, marketing and sales. During this time, he has contributed to a number of programs, including the Navy's Trident II, Phalanx and Aegis programs, the Air Force's Joint Strike Fighter program and Boeing's 787 Dreamliner program. Mr. Fritz holds degrees in Engineering from the University of Connecticut and an MBA with a concentration in Strategic Marketing from Union College. He is the recipient of a number of management awards from General Electric and Howmet Corporation.

Craig Lanham ....Panel Discussion No. 2
Member Emeritus
Mr. Craig Lanham, retiring in 2014 from Ceradyne Inc., a 3M Company, received his BS Degree from Carroll College, Waukesha, Wisconsin in 1971. During his career Mr. Lanham spent over 44 years involved in the manufacturing of casting with 38 years of that experience in the Precision Investment Casting Industry. His experience included a healthy balance between direct investment casting manufacturing experience and management responsibilities at two investment casting foundries; Northern Precision Castings and Kovatch Castings and experience in the marketing and sales of consumables to Investment Casting Foundries; first with REMET and then Minco / Ceradyne.

Brian Ferg……………………………………………………………………………………………...Panel Discussion No. 2
Engineer - Consolidated Precision Products
With 45 years 'experience in the investment casting industry, Mr. Ferg has worked in ceramics R&D, core manufacturing, and foundries. This includes stints at Sherwood Refractories, TRW, PCC, ESCO, and CPP. Mr. Ferg has been active in developing shelling processes and casting processes throughout his career and has been a leader in controlling key variables to reduce scrap and produce commercial, aerospace, and IGT castings for customers including GE, Honeywell, and Pratt & Whitney. Mr. Ferg holds a degree in Ceramic Science from the Pennsylvania State University and is a GE certified Black Belt.

Tom Planz……..……………………..……………………………………………………………….....Panel Discussion No. 2
President – Kovatch Castings, Inc.
Mr. Planz Joined Kci As Director Of Operations In December 2014. In January 2020, Tom Stepped Into The Role Of President Of Kci, As Doug Kovatch Becomes Chairman Of The Board Of Directors. Tom Is A Proven Leader With 38 Years Of Experience In The Investment Casting Industry. Early In His Career, He Spent 17 Years In Various Engineering And Manufacturing Positions (For 4 Different Foundries) Working In A Range Of Functional Areas, Including Lab Tech, Product Engineer, Process Engineer, Production Manager And Plant Manager. He Moved To The Supplier Side Of The Industry And Spent 16+ Years Working For Several Different Wax Suppliers. He Oversaw The Construction, Startup And Operation Of M. Argueso Inc.'S First Wholly Owned Subsidiary, Cerita West Llc In Tempe. Tom Then Joined Kindt-Collins Llc Where He Held The Position Of President And Coo. During His Tenure At Kindt-Collins, Annual Sales Tripled And He Played An Integral Role In The Sale Of Kindt-Collins Llc To Paramelt Bv. Post-Acquisition, He Spent 4 Years At Paramelt As Its Vp Of Sales And Global Casting Wax Business Manager. Tom Studied Aerospace Engineering At The University Of Michigan And Mechanical Engineering At Illinois Institute Of Technology.

Thad Nykiel ....Panel Discussion No. 2
Process Engineering Manager - BESCAST, Inc
Mr. Nykiel is the Process Engineering Manager for BESCAST, Inc., located in Willoughby Ohio, where he has spent the last 19 years of his career. A graduate of Cleveland State University, where he was awarded a Foundry Engineering Society Scholarship, Mr. Nykiel has served the investment casting industry for 40 years, working for a number of prestigious manufacturers, including Precision Metalsmith's, Duradyne Technologies and PCC. Over the course of his career, he has held a number of key positions, including Part and Area Process Engineer, Supervisor of SPC and A.C.E. Supervisor. Mr. Nykiel has also served the industry through volunteerism. For many years served in a variety of roles including Chapter President of the Northeast Ohio Chapter of the American Society for Metals. He has also presented a number of papers for the FEF and the ICI.

SPEAKER BIOGRAPHIES

John Lea .... Paper No. 8
Sales & Marketing Director - Geo40
John is a very experienced CEO and Director, having led companies in a broad range of industries including engineering and chemical manufacturing, retail (B2B and B2C), private equity/investment, agriculture, food processing and biotechnology in New Zealand and internationally. John left corporate life to follow his passion of bringing new ground-breaking technologies to commercialization. In 2014, John joined his friend, Mike O'Sullivan, in an innovative sustainable minerals company called Environmetals (later renamed as Geo40). John is a major shareholder and was Managing Director of Geo40 Ltd from 2014 to late 2019, taking Geo40 from an early stage start-up company through to commercialization. John has stepped back from the leadership of Geo40, and is now focused on driving the sales and marketing of its sustainably produced, high quality products. John holds university qualifications in Chemistry and Applied Chemistry, Chemical and Materials Engineering and Management.

John Slawvey .... Paper No. 9
Purchasing Director – Vestshell, Inc.
John Slawvey is the Purchasing Director at Vestshell. He has been with Vestshell for 15 years and has been in the foundry industry for 43 years. John is a Member of the Management comity and Internal auditor for Vestshell's ISO Quality program. He is responsible for the Sustainable Development program at Vestshell along with the Management team & the Environmental comity.

Jack Ziemba.. Paper No. 10
CEO – Aristo-Cast, Inc.
At the age of 16, Jack Ziemba started work at Eutectic Engineering, which was a start up investment casting company owned by 2 uncles and a 3rd partner, as a truck driver. Jack worked in every aspect of investment casting, from wax to dip to melting. He eventually became plant manager at age 23 of a operation employing approximately 35 people. Jack left Eutectic in 1968 to try his hand at injection mold making. While in the mold making trade he owned and operated Dry Cleaners along with his wife. In 1976, Jack formed Omni Mold, constructing injection tools for the investment casting industry. In 1979, he sold Omni to Valeron Corp and ran a division of Valeron in Colorado Springs Co. Jack was involved in investment casting and Isostatic pressed powered metal parts. He then returned to Michigan in 1982, returned to Eutectic and eventually became V.P. before leaving in 1994 to purchase 50 % of D & N castings in Romeo Mi. Jack incorporated Aristo-Cast in 1995 with his partners until 2008 at which time he and his wife bought out the partners. Currently CEO of Aristo-Cast, a frequent recipient of awards from the Investment Casting Institute, American Foundry Society and recently the International Magnesium association which recognized their accomplishments in the Rapid Prototyping and production casting arenas. 2020 winner of the "Innovator of the year" from the AFS for the P.I.C.S. process Member of American Foundry Society, Investment Casting Institute, SME and SAE,NFFS Inductee Investment Casting Institute Hall of Honor and Recipient of DINO from AMUG.

Donald Deptowicz .... Paper No. 11
President - Aspen Hybrid Technology Solutions LLC
Don Deptowicz is a Results Oriented Senior Executive with an outstanding track record in engineering, program management and quality. He excels at being an inspirational and resourceful leader. He is known for innovative and creative thinking in the areas of both product and process designs involving advanced materials and coatings. He is an exceptionally skilled communicator, with the ability to build effective and productive working relationships across all levels of the organization and the value chain. Don graduated from Purdue University, and began his career in 1976 at UTC's Pratt & Whitney Engine Division in West Palm Beach, Florida. Here, he led fundamental changes in both product and manufacturing process technology, covering the full life cycle of Military Aerospace Propulsion Systems. Don has over 44 years of experience in the aerospace, automotive and electronic industries. Prior to this, he was the Director of Technical Excellence for PCC Airfoils LLC, where he championed the collaborative effort across engine OEMs and casting suppliers in conjunction with the Air Force Man Tech vision of Attaining Next Generation Agile Manufacturing.

SPEAKER BIOGRAPHIES

Amarnath Bhat……………………………………………………………………………………………….Paper No. 12
Founder & Director - SoftCAST Technologies
A B. Tech from the Indian Institute of Technology, Bombay, and an MBA from the Indian Institute of Management, Bangalore, India, Amarnath Bhat has more than 30 years of experience in working with the Foundry sector in India and abroad. He is a Founder-Director and Principal Consultant of Oriental Software Pvt. Ltd., and SoftCAST Technologies Pvt. Ltd., technology development Companies that work in collaboration with the Indian Institute of Science, Bangalore. All the three technologies developed with IISc, SoftCAST (Casting Simulation & Methoding System), AutoSOLID (a CAD tool for automated 2D-3D conversion), and CastDESIGN (a DFM system for assessing and optimizing cast component designs for manufacturability) were assessed by UT Austin, and won the Lockheed Martin Gold Medal at the 2007-08 India Innovations Programme. Amarnath has conducted a number of technical training sessions for foundries, apart from technical seminars and papers at international forums, in India and abroad.

Stephen Barnett……………………………………………………………………………………………...Paper No. 12
Owner - INCAST Consultancy
A B. Tech from the Indian Institute of Technology, Bombay, and an MBA from the Indian Institute of Management, Bangalore, India, Amarnath Bhat has more than 30 years of experience in working with the Foundry sector in India and abroad. He is a Founder-Director and Principal Consultant of Oriental Software Pvt. Ltd., and SoftCAST Technologies Pvt. Ltd., technology development Companies that work in collaboration with the Indian Institute of Science, Bangalore. All the three technologies developed with IISc, SoftCAST (Casting Simulation & Methoding System), AutoSOLID (a CAD tool for automated 2D-3D conversion), and CastDESIGN (a DFM system for assessing and optimizing cast component designs for manufacturability) were assessed by UT Austin, and won the Lockheed Martin Gold Medal at the 2007-08 India Innovations Programme. Amarnath has conducted a number of technical training sessions for foundries, apart from technical seminars and papers at international forums, in India and abroad.

Julie Markee……………………………………………………………………………………………….…Paper No. 13
Managing Director – Key Process Innovations
Julie Markee is a highly conscientious, detail-oriented professional with over 24 years of experience who helps business owners get more of what they want from their business. She has built an excellent reputation for identifying and resolving complex technical problems while enhancing organizational performance. Julie strengthens organizations by unwrapping the potential which has been largely untapped. Her keen engineering mind provides her with the skills to quickly identify opportunities for improvement while overcoming obstacles which are impacting the performance of an organization. Her excellent communication skills and thoughtful approach allow her to garner support, affect change and implement solutions within the organization.

Dr. Suman Das……………………………………………………………………………………………….Paper No. 14
Founder & CEO - DDM Systems
Dr. Suman Das is a world-renowned expert in 3D printing and additive manufacturing. He serves as the Founder and CEO of Atlanta-based DDM Systems, an advanced manufacturing company introducing its digital investment casting technology to the market. Currently on leave from Georgia Tech, he serves as its Morris M. Bryan Chair Professor of Advanced Manufacturing Systems and Director of the Direct Digital Manufacturing Lab. He has conducted research and invented technologies in 3D printing for 30 years.

Dr. Ing. Santhanu Jana…………………………………………………………………………………………Paper No. 15
Technical Consultant - ALTAIR Engineering GmbH
Dr. Santhanu Jana is currently working at Altair, a global technology company providing solutions in product development, high-performance computing, and data analytics. At Altair, he works in the Global Technical Team, in area of Manufacturing Solutions. He holds a PhD in Materials Engineering from Technical University of Aachen, Germany. He has extensive experience in modelling of casting and other processes, and several presentations and publications in this area. His previous job, was related to modelling of pre-series production processes for next generation aero-engine and automotive parts through investment casting, using TiAl and FeAl alloys

SPEAKER BIOGRAPHIES

Carlos Olabe ....Panel Discussion No. 3
Executive Director – European Investment Casters' Federation (EICF)
Carlos Olabe is the current CEO of the European Investment Casters Federation [EICF], serving this position since the end of 2014. Mr. Olabe has been linked to the aerospace industry for a period over 20 years. He served as Programmes Director of the Engine company of Spain (ITP Aero) managing engine programmes such as EJ200, Trent 700, Trent 800, Trent 500, Trent 900 and as CEO of PCB, during 10 years. A brand new world class investment casting Company in Spain which he took the mission to create and project internationally. During this period Mr. Olabe was member of the Board of Directors of the EICF , being Chairman of the Federation for a period of 4 years supporting an interesting period of revitalization of the EICF and contributing personally to the establishment of the global circuit..... America / Europe / Far East for the celebrations of the IC World Conferences. Mr. Olabe background is an Engineer specialized in electricity and energy where he has devoted another 15 years of his professional life in key managerial positions with experience in the field of nuclear equipment and lately renewables. Mr. Olabe is a believer in cooperation and innovation as elements that enhance operations and achievements of organizations.

Kenji Ito ....Panel Discussion No. 3
Technical Division – Japan Foundry Society (JFS)
Mr, Kenji Ito attended the Kyushu Institute of Technology and graduated with a BE in metal process engineering. Kenji started his career at Hitachi Metals Ltd., as a member of the Automotive Division. He transferred from the Chief Engineer of Hitachi Metals Ltd. to the Japan Foundry Society, Inc., as a Group Leader of Technical, Non-ferrous Metal and International Division. Kenji retired from Hitachi Metals Ltd. in 2014 and transitioned to Group Leader of the Engineering and Environmental Division of the Technical, International and Equipment Group at the Japan Foundry Society. As of 2019, Kenji has been working on a part-time basis at Japan Foundry Society, Inc., as a member of the Technology & Environment Group.

Michael Fanz-Huster .... Paper No. 16
District Manager – Inductotherm
Michael Fanz-Huster lives in Sewell, NJ and is married with two small children. He enjoys playing the game of golf and spending time with his family. Michael started at Inductotherm Corp. in Rancocas, NJ in 2012, working in the Warehouse, Purchasing Department and Inside Sales Department for three consecutive summers as an intern. In 2014, Michael took a full-time position in the Inside Sales Department as an Order Analyst where he managed incoming orders for materials, merchandise, installations and services. In 2015, Michael transitioned into the Aftermarket Sales Department where he managed remanufactured equipment in the field and equipment sent back to Inductotherm. Michael also organized teams to head out to jobsites to remanufacture and repair the equipment. In 2017, Michael took on a District Manager position in the Sales Department covering Indiana and Kentucky, and in later years, the East Coast from Virginia up to New York City. As a District Manager, his work took him to all types and sizes of melt shops, including steel mills, foundries, shot makers, recycling operations, precious metal refiners and other scrap reclaiming operations. Michael also called on companies that used induction heating equipment in their process.

Steven Ashlock .... Paper No. 17
Ceramic Engineer - Kyanite Mining Corporation
Steven Ashlock has worked for 6 years on the research and development of investment casting materials and refractories. He is a Ceramic Engineer and currently serves as the Director of Research and Technology for Kyanite Mining Corporation. Steven has experience in materials analysis, characterization, and testing, slurry design and control, casting procedures, and industrial processes. He has written several papers for the investment casting and refractories industries that primarily focus on the impact that raw material choices have on the performance of the end part, with an aim to reduce downtime and scrap. Steven graduated with a B.S. in Ceramic Engineering from the Missouri University of Science and Technology. He is a member of the ASTM Committee on Refractories, an Associate Member of The Refractories Institute, a member of the Corporate Technical Achievement Award Committee for The American Ceramic Society, and is currently the Vice Chair of the Refractories Ceramics Division of the American Ceramics Society.

SPEAKER BIOGRAPHIES

Gerald Richard .... Paper No. 18
Application Manager - MAGMA Foundry Technologies
Gerald Richard is an Application Manager at MAGMA Foundry Technologies Inc., a software company that is committed to casting excellence and achieves this through its casting process simulation tool MAGMASOFT®. Before devoting his life to the foundry industry, Gerald achieved a Bachelor of Science degree in Mechanical Engineering from Marquette University. He went on to work in the chemical industry as an engineer for 5 years before pursuing an opportunity to work at Badger Alloys, a high alloy jobbing foundry locate in Milwaukee, WI. Gerald fell in love with castings and the casting process as he worked as a foundry engineer focusing mostly on gating and risering design. After 4 years of working at Badger Alloys, Gerald moved to the greater Chicago area and began working for MAGMA Foundry Technologies Inc. in 2015, where he focuses on client development and support.

Jiten Shah .... Paper No. 19
Founder & President - Product Development & Analysis (PDA)
Mr. Jiten Shah, founder and president of Product Development & Analysis (PDA) LLC located in Naperville, IL.; brings over 35 years of experience in casting design and manufacturing related to new product development, casting conversion, reverse engineering, redesign, failure analysis for various alloys and processes. Mr. Shah specializes in casting & rigging design, process simulation, CAE (CAD, FEA, CFD), ICME, Rapid Prototyping, Digital Manufacturing including AM, contract research & development. Mr. Shah has masters degree in Mechanical & Aerospace and Foundry Technology; has published and presented over 45 papers at various professional societies including ICI, AFS, SAE, DMC and ASM.

Robert Johnson.. Panel Discussion No. 4
President & Owner – Shellcast, Inc.
Second generation foundry man with experience in sand casting, permanent mold, high pressure aluminum die-casting, and investment casting of air and vacuum melt steels, nickel materials, as well as conventional and advanced titanium alloys. Career experience with a number of large companies such as Golden State Castings, Howmet (Arconic), and Teledyne Cast Products (now CPP). He co-holds 2 US patents for permanent mold casting of titanium and nickel alloys . Currently the president and owner of Shellcast, Inc., a 59-year old casting operation located in Montague, MI; multiple winner of ICI Casting of the Year awards and the ICI's Innovator of the Year award. Bob, a Western Michigan native, has studied manufacturing and engineering throughout high school and at the Muskegon Community College.

Steve Sikorski.. Panel Discussion No. 4
President – MAGMA Foundry Technologies
Steve Sikorski is the President of MAGMA Foundry Technologies Inc. and SIGMA Plastic Services Inc. He graduated from Pittsburg State University in 1996 with a Bachelors of Science degree in Engineering Technology, emphasis in manufacturing and has a Masters of Engineering Technology. Steve has worked for MAGMA Foundry Technologies Inc. and SIGMA Plastic Services Inc. since 2000. Steve started at MAGMA as a project engineer focusing in nonferrous applications and was involved in Engineering, Technical Support, Education and Sales. He then advanced into engineering mangers positions, Vice President of Operations to current role as President. Steve is active in the Industry and is involved with the Foundry Educational Foundation (FEF), lectures for the Investment Casting Institute, and is a member of various AFS Committees.

Chad Beamer .... Paper No. 20
Applications Engineer - Quintus Technologies, LLC
Chad Beamer has a MS from the Ohio State University in Material Science and a BS from University of Cincinnati in Material Engineering. Chad worked as a Material Application Engineer with GE Aviation for approximately 7 years and as a Technical Services Manager with Bodycote for approximately 5 years. He started with Quintus Technologies in February of 2020 as an Applications Engineer for the Advanced Material Densification division focusing on Hot Isostatic Pressing (HIP). As an Applications Engineer he manages the HIP Application Center located in Columbus, Ohio, educates on the advancements of HIP technologies, and is involved in collaborative development efforts both within academia and industry

SPEAKER BIOGRAPHIES

Gregory Colvin ....Customer Spotlight
Technical Fellow - Honeywell Aerospace
I am the Technical Fellow for Advanced Manufacturing within Advanced Technology at Honeywell Aerospace. I am responsible for supporting the development and maturation of advanced manufacturing and additive manufacturing technologies helping to make these new technologies viable options to support Honeywell applications. This role includes support for IIOT, Factory 4.0, advanced sensing, data analytics and other key elements of the digital manufacturing enterprise. I am Honeywell's representative on the Board of Governance for CESMII the National Institute on Smart Manufacturing sponsored by the DOE. Additionally, I am the industrial base representative on the DoD's obsolescence supply chain working group and co-author of the DoD official guidance SD-on obtaining supply of mechanical parts for military applications. My experience includes 10 years at the DOE's National Security Campus operated by Honeywell-FMT supporting supply chain, advanced manufacturing and business development activities. I began my career working for Howmet Castings in manufacturing technologies development and implementation. There I invented multiple new casting technologies and alloy compositions authoring 17 patents and supporting the transition of several new manufacturing processes to production. My education includes a B.S. in Metallurgical Engineering from the University of Wisconsin, a M.S. in Material's Science from the University of Virginia and a Master's in Manufacturing Management from Kettering/GMI University.

INVESTMENT CASTING INSTITUTE

Fundamental Analysis into Properties Affecting Investment Casting Shell Strength

Gavin Dooley
REMET, UK

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 1

REMET

FUNDAMENTAL ANALYSIS INTO PROPERTIES AFFECTING INVESTMENT CASTING SHELL STRENGTH

Gavin Dooley PhD
Group Technical Director

REMET.COM

YOUR CONCEPT TO CASTING PARTNER

THANKS

A word of thanks to Matthew Everden for his work on this project

Your concept to casting partner

PRESENTATION OUTLINE

- Introduction
- Testing Review
  - Flexural Strength Review
  - GRR of strength measurement
- Drying analysis
  - Dry time analysis
  - Polymer analysis

Your concept to casting partner

FLEXURAL STRENGTH REVIEW

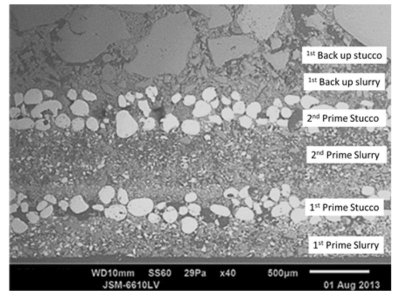
REMET.COM

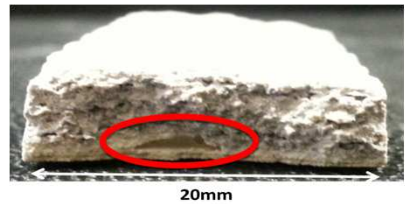
YOUR CONCEPT TO CASTING PARTNER

MOR STRENGTH TESTING

FUNDAMENTALS

- The strength of the shell is critical for the successful casting of metal parts
- Shells are made up of a laminar structure of slurry and stucco layers
- These layer structures change depending on the stucco application [1]
- The ceramic shells fail in tension at the point of the largest force
- Ceramic will fail when subjected to a stress σ, if a crack reaches some critical size *a*, or, alternatively, when material containing cracks of size a is subjected to some critical stress σ [2]





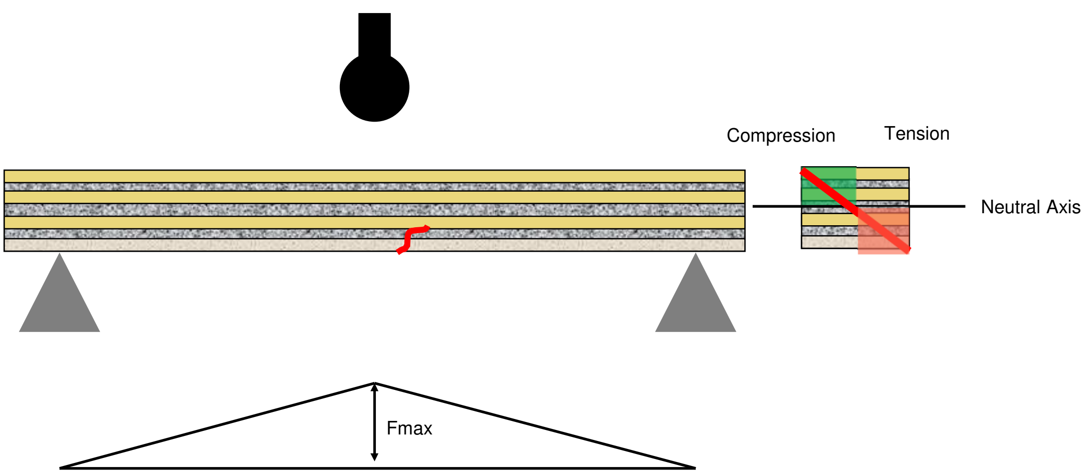
[1] Dooley, G., S Blackburn (2013). Effect of Stucco Application Method on the Mechanical Performance & Microstructure of Investment Casting Shells, *60th ICI Technical Conference, Pittsburgh, PN*

[2] Ashby, M.F. and Jones, D.R., 2012. *Engineering materials 1: an introduction to properties, applications and design* (Vol. 1). Elsevier.

Your concept to casting partner

MOR STRENGTH TESTING

FUNDAMENTALS



Your concept to casting partner

MOR STRENGTH TESTING

FUNDAMENTALS

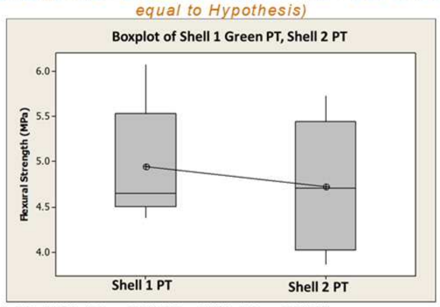
- Depending on the shell composition and microstructure, there may be differences in strength measurement depending on which layers are in tension – Prime or back up
- Previous testing has shown there can be statistical differences between these tests depending on the orientation
- It is important to understand and make sure testing occurs in the same orientation for continuity

Your concept to casting partner

MOR STRENGTH TESTING

FUNDAMENTALS

Green Dry Prime Tension (2 Sample T-Test T 95% CI for not equal to Hypothesis)



Two-sample T for SHELL 1 Green DRY PT vs SHELL 2 Green DRY PT

	N	Mean	stDev	SE Mean
SHELL 1 Green DRY PT	5	4.944	0.666	0.30
SHELL 2 Green DRY PT	5	4.726	0.747	0.33

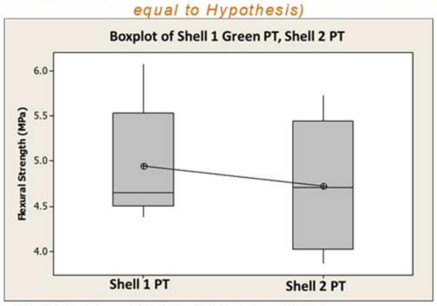
Difference = mu (SHELL 1 Green DRY PT) - mu (SHELL 2 Green DRY PT)
Estimate for difference: 0.218
95% CI for difference: (-0.840, 1.276)
T-Test T of difference = 0 (vs not =): T-Value = 0.49 P-Value = 0.641 DF = 7

Your concept to casting partner

MOR STRENGTH TESTING

FUNDAMENTALS

Green Dry Prime Tension (2 Sample T-Test T 95% CI for not equal to Hypothesis)

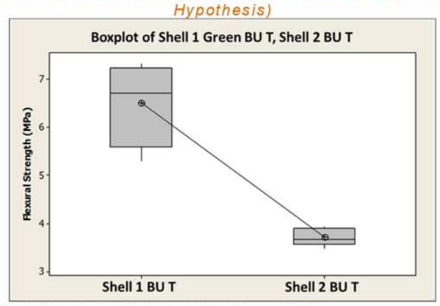


Two-sample T for SHELL 1 Green DRY PT vs SHELL 2 Green DRY PT

	N	Mean	stDev	SE Mean
SHELL 1 Green DRY PT	5	4.944	0.666	0.30
SHELL 2 Green DRY PT	5	4.726	0.747	0.33

Difference = mu (SHELL 1 Green DRY PT) - mu (SHELL 2 Green DRY PT)
Estimate for difference: 0.218
95% CI for difference: (-0.840, 1.276)
T-Test T of difference = 0 (vs not =): T-Value = 0.49 P-Value = 0.641 DF = 7

Green Back up Tension (2 Sample T-Test T 95% CI for Greater than Hypothesis)



Two-sample T for SHELL 1 Green DRY BU T vs SHELL 2 Green DRY BU T

	N	Mean	Step	SE Mean
SHELL 1 Green DRY BU T	4	6.510	0.884	0.44
SHELL 2 Green DRY BU T	5	3.724	0.181	0.081

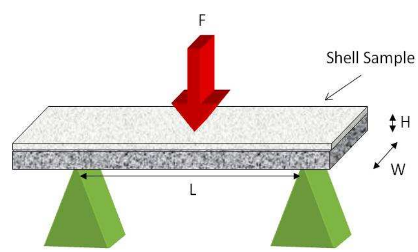
Difference = mu (SHELL 1 Green DRY BU T) - mu (SHELL 2 Green DRY BU T)
Estimate for difference: 2.786
95% lower bound for difference: 1.728
T-Test T of difference = 0 (vs >): T-Value = 6.20 P-Value = 0.004 DF = 3

Your concept to casting partner

MOR STRENGTH TESTING

FUNDAMENTALS

- Work was carried out within REMET to understand and reduce the error of the flexural 3 PB testing of ceramics
- Testing of ceramic is fundamentally prone to error from various sources
- Assumptions –
  - The build regime of the material is consistent
  - Vernier is calibrated
  - Technicians are trained



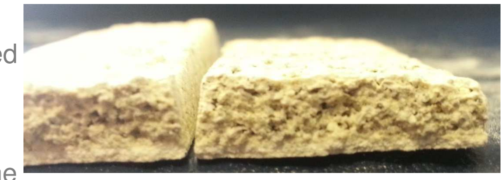
$$\sigma_{3\_Point\_Flexural} = \frac{3P_{MAX}L}{2WH^2} = \frac{3L}{2} * \frac{P_{MAX}}{WH^2}$$

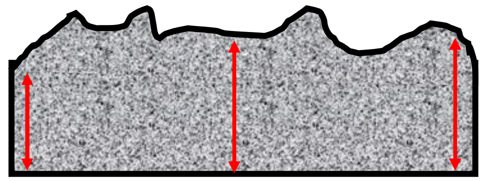
Your concept to casting partner

FLEXURAL STRENGTH TESTING

GAUGE R&R

- There are different ways in which the GRR could be carried out
- To best understand the variation in measurement lab technicians were all trained to measure the thickness at the same three points along the fracture surface of the sample
- Samples – 11
- Measurements -3
- Technicians - 3
- 3 measurements of thickness - Side x 2 and middle
- 2 measurements of width – Width of 2 x fractured surfaces

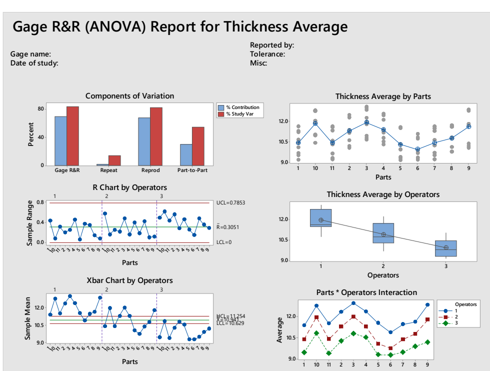


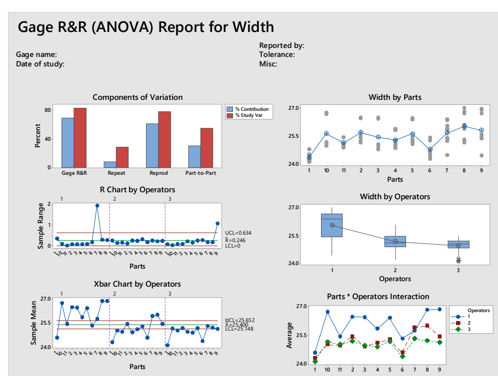


Your concept to casting partner

FLEXURAL STRENGTH TESTING

GAUGE R&R





Your concept to casting partner

FLEXURAL STRENGTH TESTING

GAUGE R&R

- R bar ($\bar{R}$) is the average range within the data and can be described as the difference which can be accurately measured
- The initial analysis shows an R bar average range of data of 0.31 mm thickness range and 0.246 mm width range
- Utilising this within the MOR equation, using a typical force of 250 N (56 lbs) we can estimate the “worst case scenario” for the measurement error of ± 7.20 % due to measurement error
- This error is high when you account for sample variation and possible machine error
- Retraining was required before we proceeded

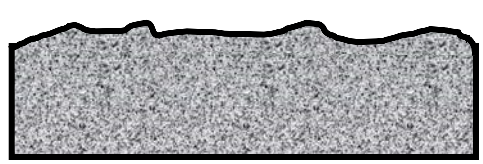
Force [N]	Width [m]	Thickness [m]	MOR [MPa]
250	0.025	0.01	7.50
250	0.025216	0.01031	6.97
Difference due to measurement error			7.20%

Your concept to casting partner

FLEXURAL STRENGTH TESTING

GAUGE R&R

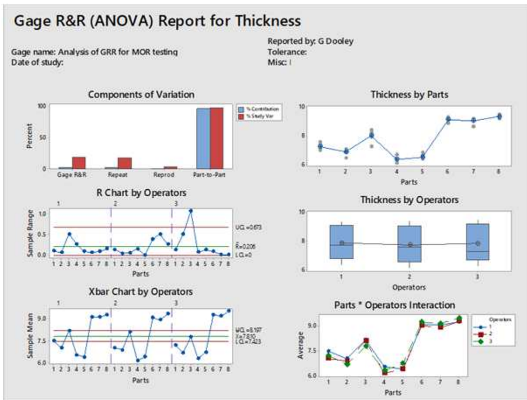
- Measurement training was “too rigid” to account for variation in thickness
- Decided to rely on “Best representation” of thickness measurement
- Accounts for variation in thickness at any point along the surface
- No change in measurement of width was carried out

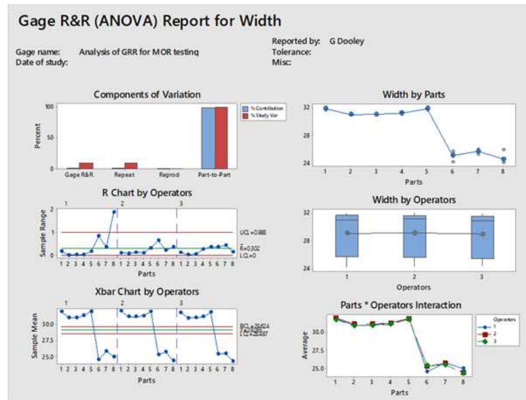


Your concept to casting partner

FLEXURAL STRENGTH TESTING

GAUGE R&R





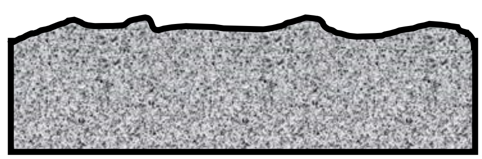
Your concept to casting partner

FLEXURAL STRENGTH TESTING

GAUGE R&R

- This revised measurement method reduced the R bar ($\bar{R}$) from 0.31mm to 0.21 mm
- This reduced the error by 2% due to the squared effect of thickness
- We wanted to challenge the other assumption of the study that the material being tested was consistent

Force [N]	Width [m]	Thickness [m]	MOR [MPa]
250	0.025	0.01	7.50
250	0.025302	0.010206	7.11
Difference due to measurement error			5.14%



Your concept to casting partner

FLEXURAL STRENGTH TESTING

GAUGE R&R

- Within REMET UK, over 30 different shells are made in R & D lab scale environments annually
- Typically running a side by side using an OFAT (One Factor At a Time) approach to development
- Used to assess how small changes in materials or properties can effect shell properties
- With this in mind, the samples must be produced in a repeatable way

Your concept to casting partner

FLEXURAL STRENGTH TESTING

GAUGE R&R

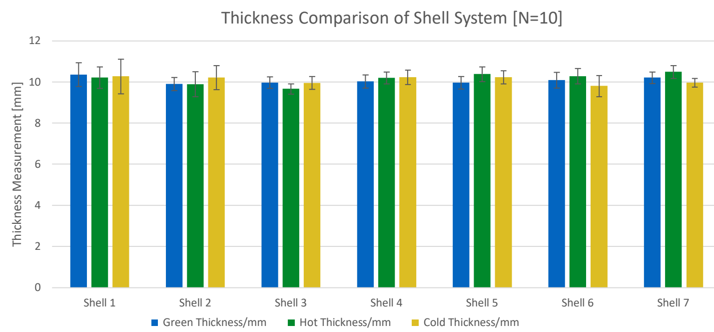
- For R&D, samples are consistently made with new formulations, materials and other changes in a materials
- Typically always made with same “base” formulation
- Back up system change - No prime coat added. This ensures failure is present in the material analysis
- For prime coat changes, 3 layers added to ensure failure point is within the prime layer and the same Back up slurry is always used

Your concept to casting partner

FLEXURAL STRENGTH TESTING

GAUGE R&R

- MOR is a measure of strength per unit area
- Should be independent of thickness but this is rarely the case…
- Thickness & width consistency is key
- With a strict procedure for dipping, draining and stuccoing, changes to shell performance can be measured

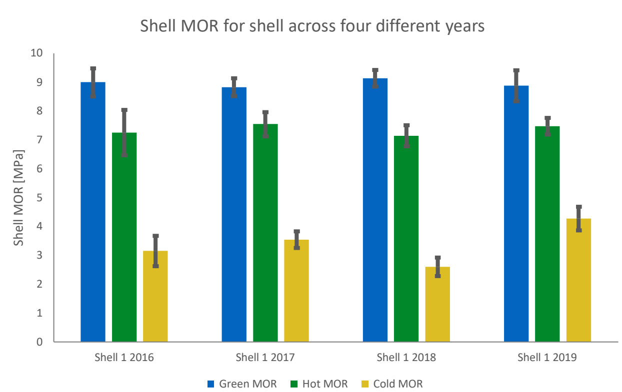


Your concept to casting partner

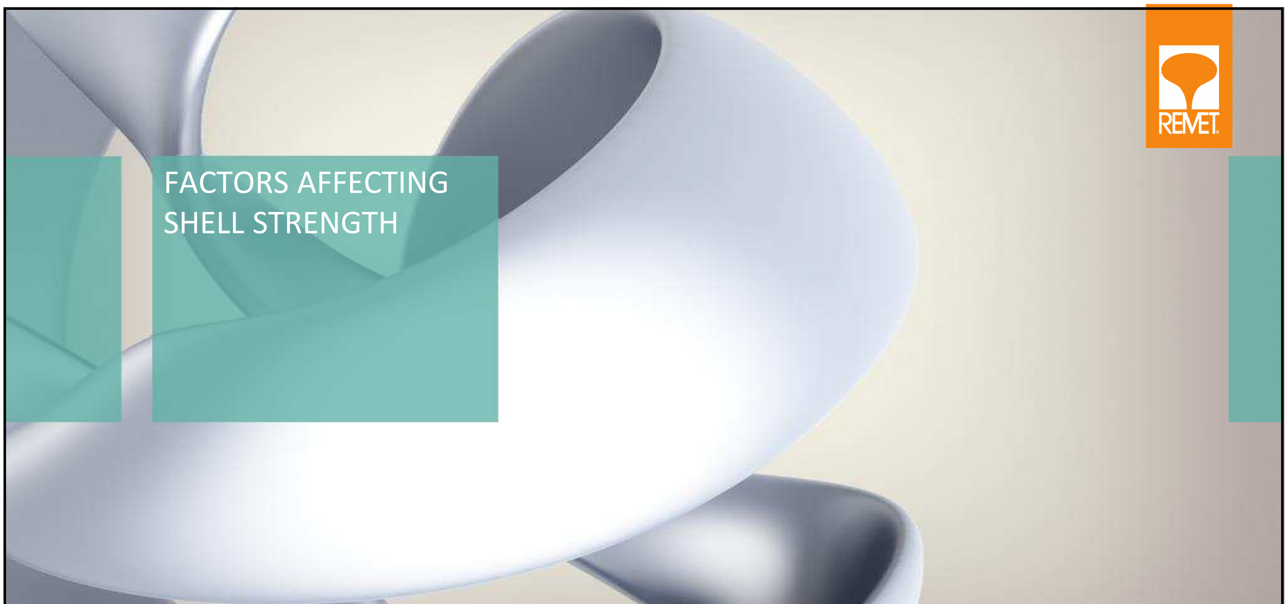
FLEXURAL STRENGTH TESTING

GAUGE R&R

- To ensure consistency in testing, benchmark slurries are continuously dipped to the same recipe and specifications to ensure no drift in base data is experienced
- This acts as a go/no-go step annually to ensure shells are consistently built, tested and analysed the same
- ANOVA (ANalysis Of VAriance) shows that there is no statistical difference between these sets



Your concept to casting partner



FACTORS AFFECTING SHELL STRENGTH

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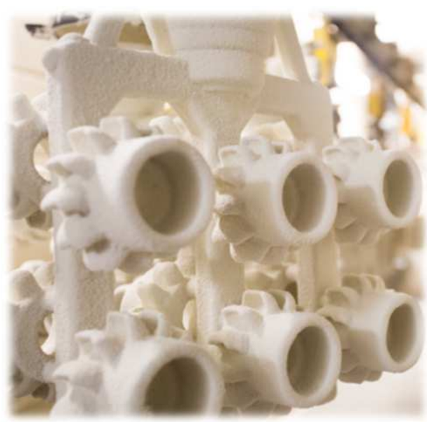
YOUR CONCEPT TO CASTING PARTNER

FACTORS AFFECTING STRENGTH

INTRODUCTION

- There are numerous factors affecting shell strength
- “Drying effectiveness”
  - Time
  - Airflow
  - Humidity
  - Temperature
  - “Surface exposure”

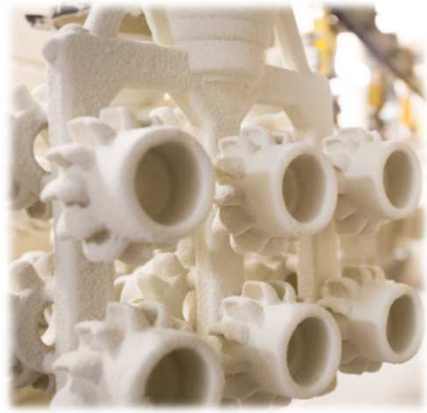


Your concept to casting partner

FACTORS AFFECTING STRENGTH

INTRODUCTION

- Slurry properties
  - Material age – Binder and polymer
  - Viscosity
  - Colloidal Silica type, size, concentration
  - Polymer type and concentration
  - Bubbles
  - Any other additives like fibres etc.
  - Refractory type & shape

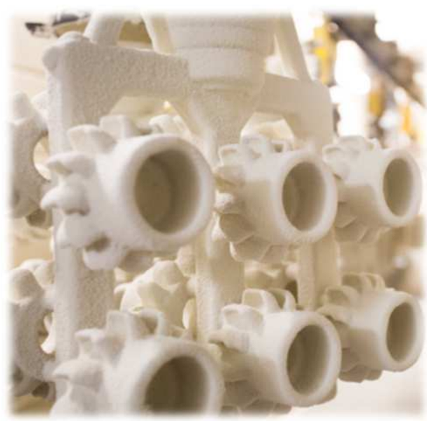


Your concept to casting partner

FACTORS AFFECTING STRENGTH

INTRODUCTION

- Build properties
  - Dip sequence - Soak time etc.
  - Edge and corner thickness
  - Draining characteristics
  - Stuccoing method
  - Stucco PSD & dust



Your concept to casting partner

FACTORS AFFECTING STRENGTH

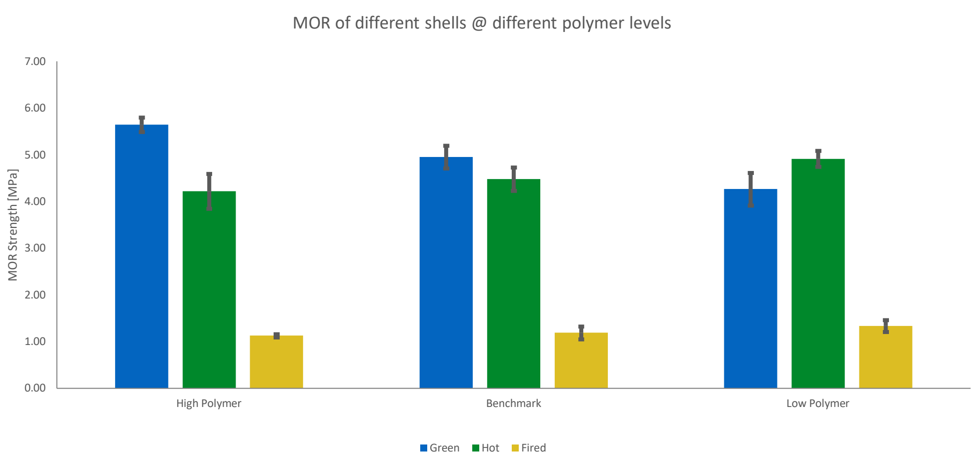
POLYMER LEVELS

- Slurry was made with 3 different levels of polymer level
- Polymer - Quickset
- Flour – Fused Silica RP-2
- Stucco – Fused Silica RG-2
- 2 Hour drying
- Polymer solids were varied from 5%, 7.5% & 10%

Your concept to casting partner

CONCLUSIONS

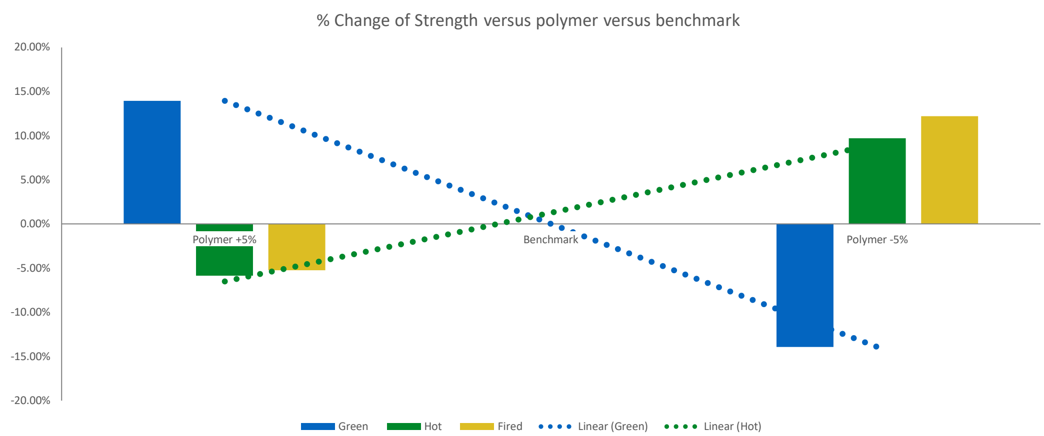
OVERVIEW



Your concept to casting partner

CONCLUSIONS

OVERVIEW



Your concept to casting partner

MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS

- Drying analysis for shells at 1,2,4,8 and 24 hours
- Over 630 Samples tested
- Assess the drying capability of the system
- No prime layer
- 8 layers and seal

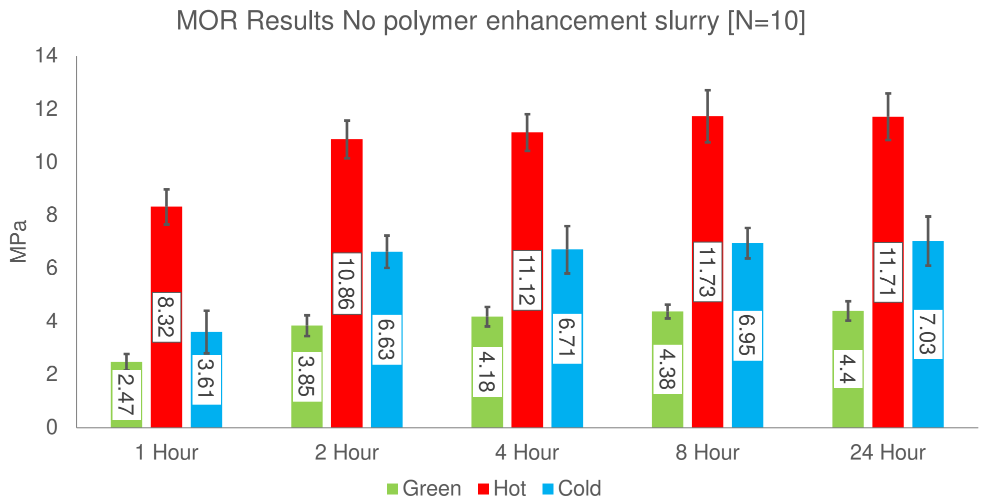
Temperature	Humidity [% RH]	Airflow [m/s]
20-25	45	0.6

Material	No polymer	Polymer Enhanced	QuikSet
Remasol® SP30	36.0%	31.5%	26.2%
AdBond® Ultra™ Polymer	-	4.5%	-
AdBond® QuikSet™ Polymer	-	-	5.3%
Burst 100	0.2%	0.2%	0.2%
Victawet 12	0.9%	0.9%	0.5%
Fused Silica 200 Mesh	62.9%	62.9%	67.8%

Your concept to casting partner

MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS – NO POLYMER



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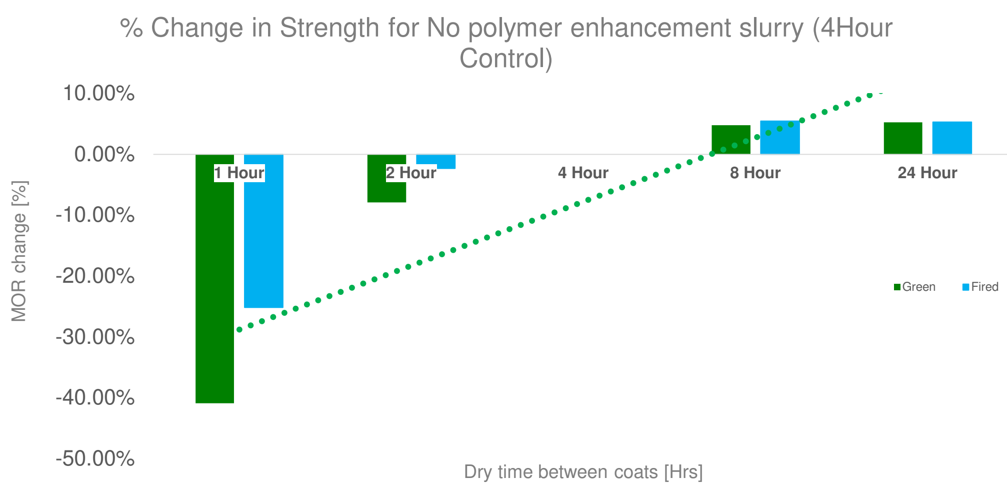
MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS – VERSUS 4 HOUR BENCHMARK



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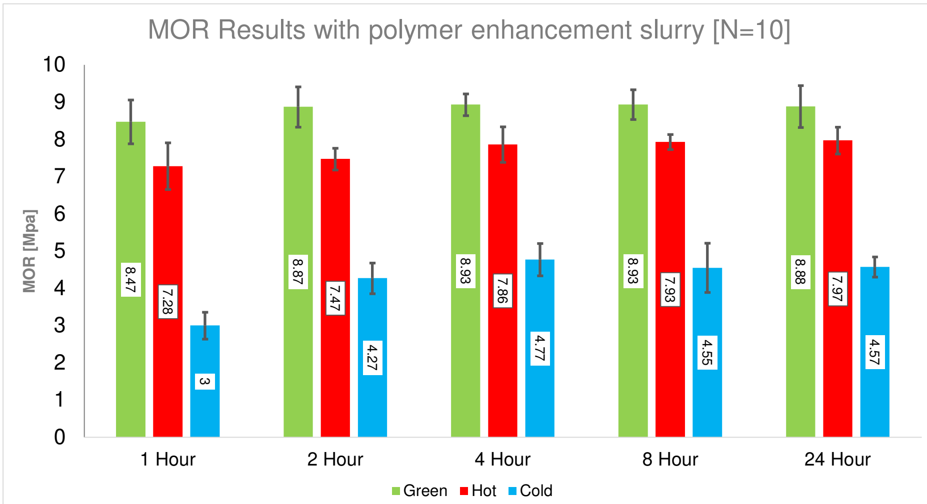
MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS



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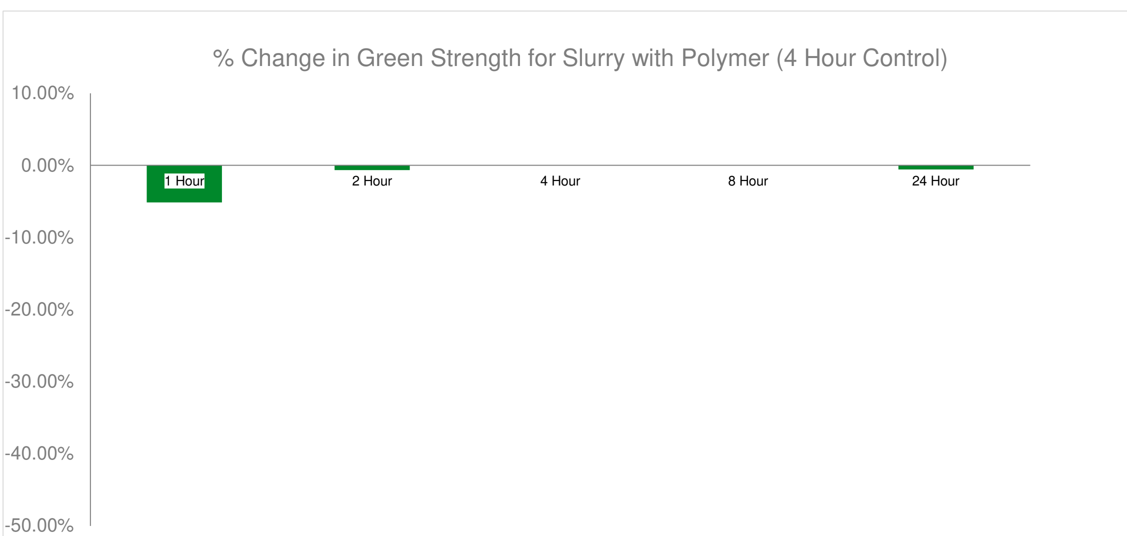
MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS



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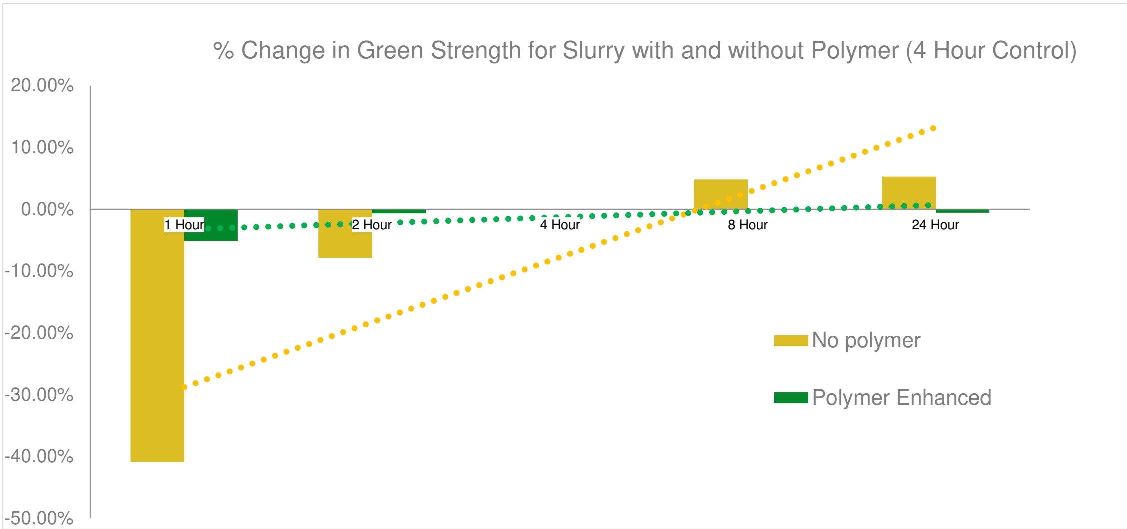
MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS

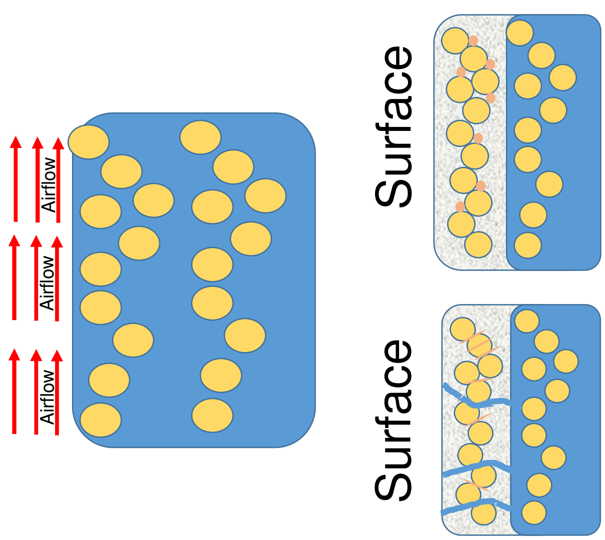


Your concept to casting partner

MATERIAL DRYING TECHNOLOGY

OVERVIEW

- Water gets trapped within the shell matrix during drying. This inhibits evaporation and drying
- QuikSet's novel formulation can ensure the water can evaporate while the slurry has gelled
- This also has the ability to increase strength



Your concept to casting partner

MATERIAL DRYING TECHNOLOGY

OVERVIEW

- However, the drying improvements have remained relatively static with no slurry consumable to improve drying
- An innovative AdBond® QuikSet™ polymer has been introduced which improves the drying of shells dramatically!
- Shells can be dipped with as little as 30 minute drying time

Your concept to casting partner

MATERIAL DRYING TECHNOLOGY

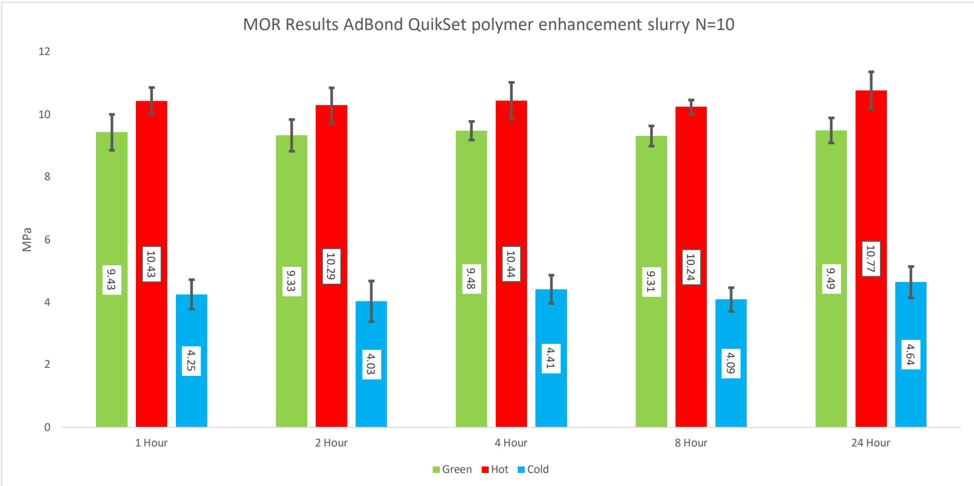
OBJECTIVES

1. Strength versus other shell systems
2. Strength development per drying time
3. Strength at shorter dry times

Your concept to casting partner

MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS - BENCHMARK



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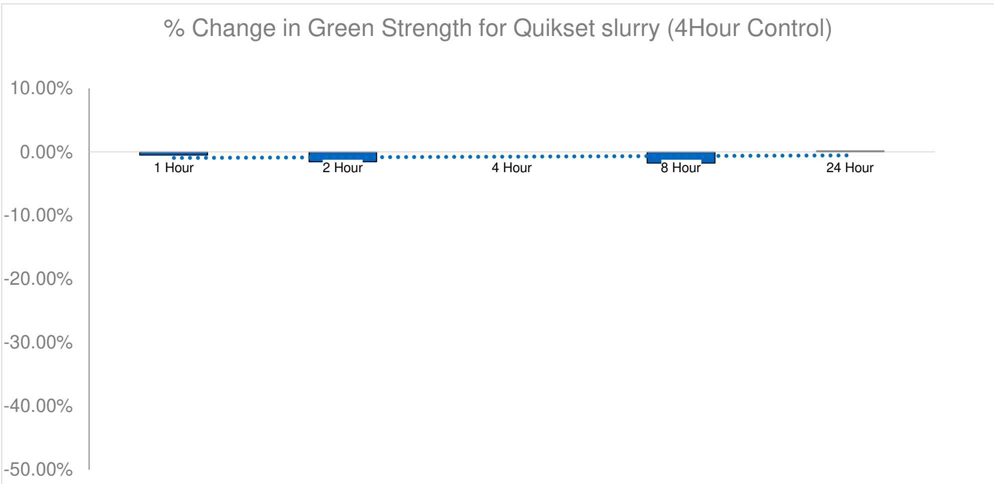
MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS – STRENGTH DEVELOPMENT



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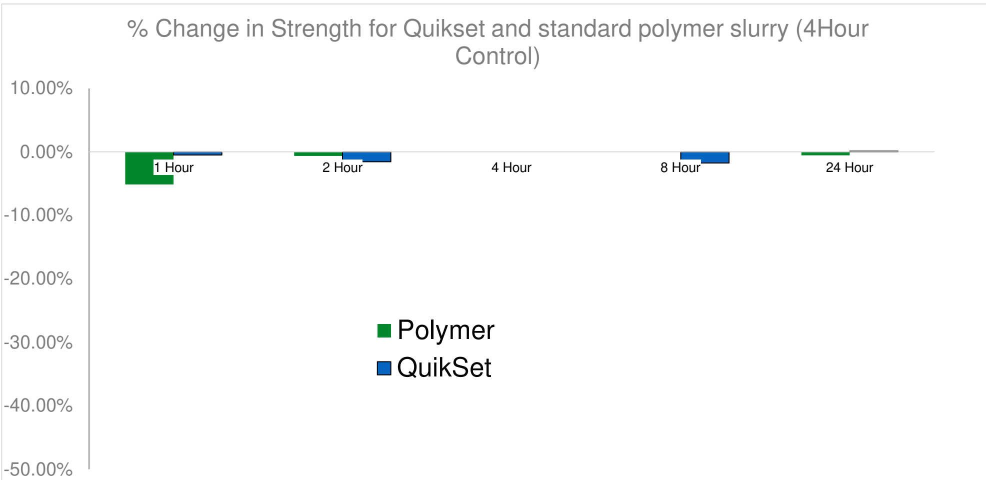
MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS – STRENGTH DEVELOPMENT

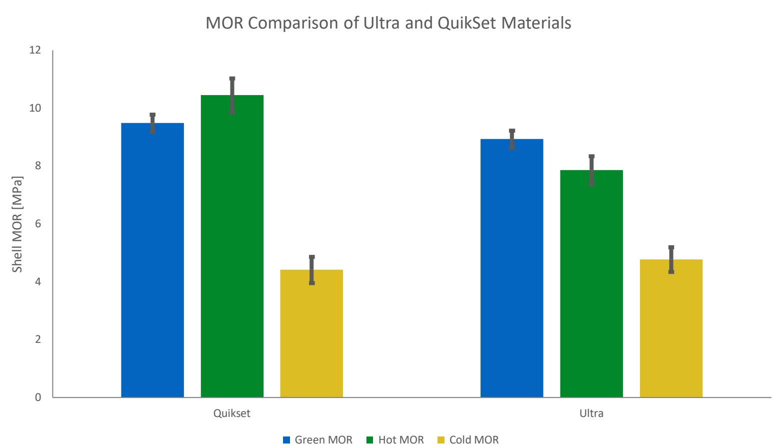


Your concept to casting partner

MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS – STRENGTH BASELINE

- But the strength of both systems are different
- QuikSet exhibits a higher green and MOR strength
- Therefore, lets also look at strength development of QuikSet versus Ultra benchmark…



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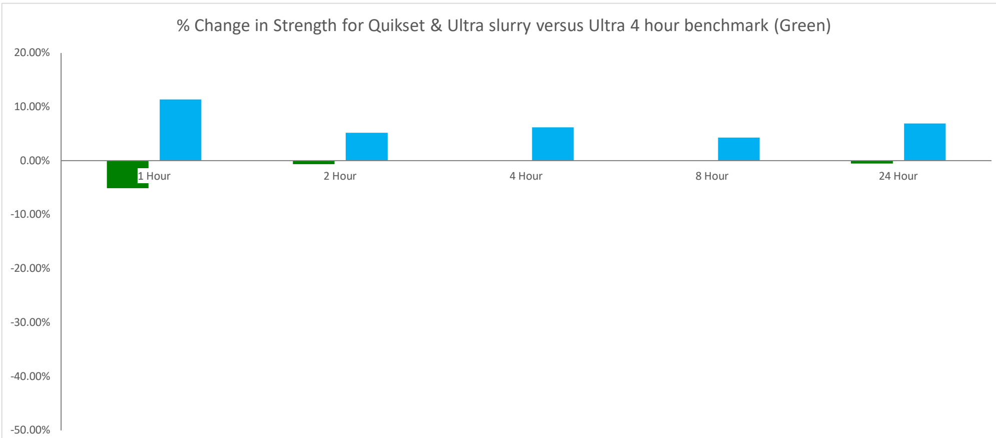
MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS – STRENGTH WITH A POLYMER BASELINE



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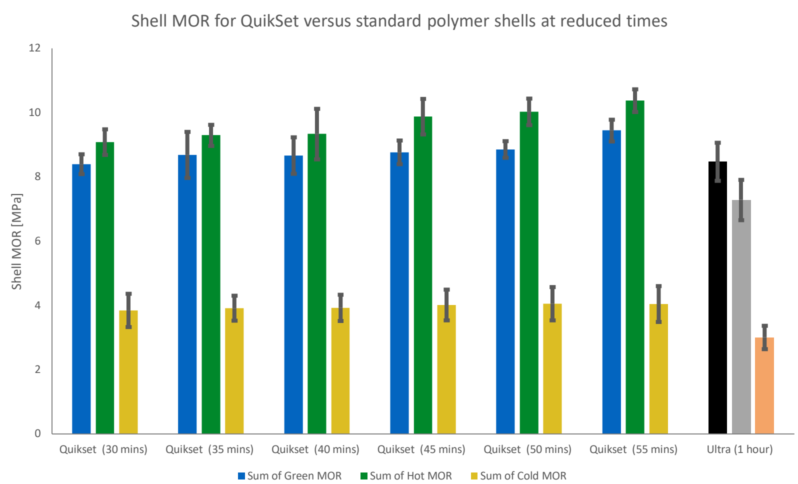
MATERIAL DRYING TECHNOLOGY

DRYING ANALYSIS – STRENGTH BASELINE

- These results show a really promising trait for the QuikSet Polymer
- Therefore it was decided to see how strength development occurred at less than 1 hour dry times



Your concept to casting partner

CONCLUSIONS

OVERVIEW

- It is important to understand and reduce the error of MOR testing within the testing setup
- There exists a strong link between the error within the test and the interactions of the operator in the measurement of the final dimensions of the sample
- There exists many different variables which affect shell strength

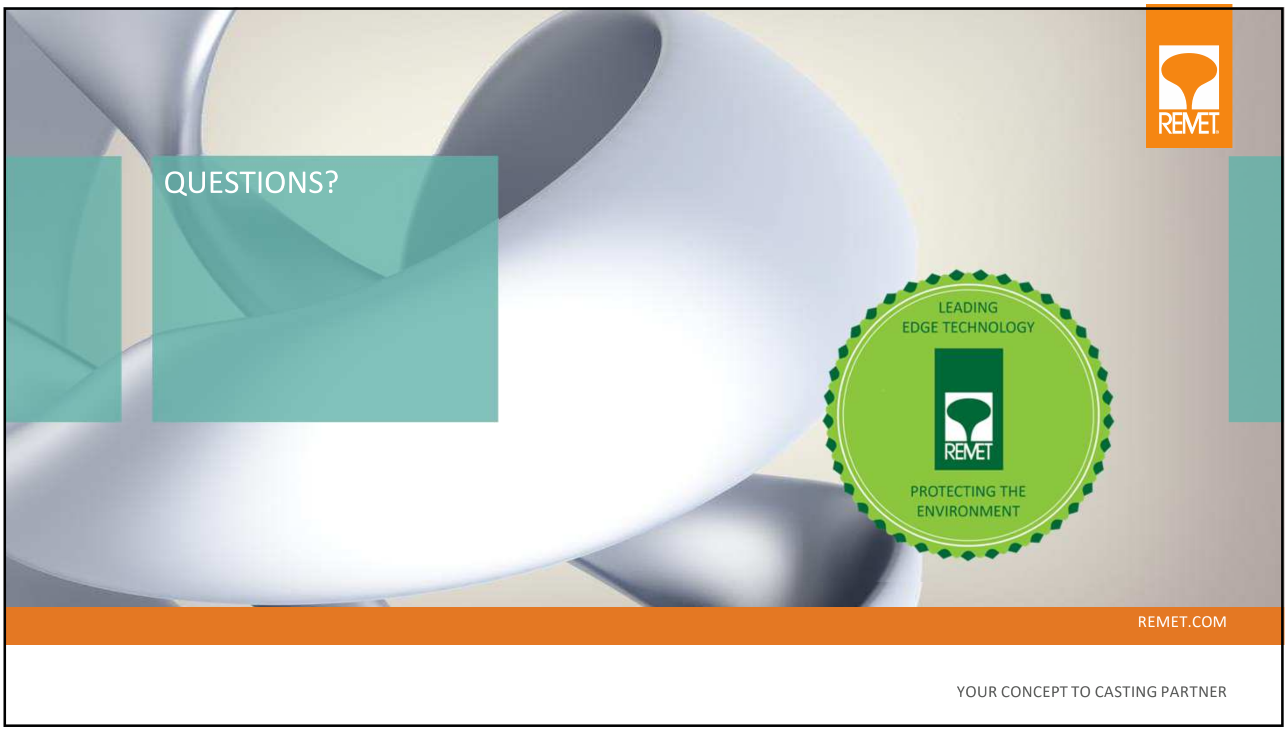
Your concept to casting partner

CONCLUSIONS

OVERVIEW

- Polymer levels within the material can affect the final properties of both green and fired strengths
- MOR testing versus drying time can give a good insight into the performance of materials
- The presence of polymer generate strength within the shells quicker than without polymer
- AdBond® QuikSet™ can be shown to generate strength far quicker than polymer benchmarks and can dry shells to a stronger level in less than 1 hour

Your concept to casting partner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Hypoallergenic Surgical Cast Stainless Steel

Sander Klemp
Davis Alloys

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 2

Hypoallergenic, Nickel Free Surgical Cast Stainless Steel

Sander Klemp
Davis Alloys Manufacturing, Sharpsville, PA

Abstract

It has been known for many years that nickel and alloys containing nickel can produce an adverse or allergic reaction in certain portions of the population.. The Center of Disease Control and Prevention (CDC) estimates that 10-20 percent of the population have varying degrees of nickel allergies. Due to nickels alloying effects, cost and availability there has been little desire or demand in the industry to discover a replacement or substitute for this element for austenitic stainless steel..

As greater awareness of nickel allergies and nickel ion toxicity permeates the minds of the population, a greater probability of liability lawsuits associated with adverse reactions to nickel bearing surgical implants could likely follow. Therefore, an alternative alloying element(s) may be necessary for the medical, surgical & jewelry industries.

This paper will explore an alternative nickel free variant of 316L/CF3M surgical stainless steel.This will be accomplished through the use of alloying elements that are both biocompatible and strong austenite formers. This alloy modification may enable a broader range of applications for this well known alloy. Comparative physical, mechanical and microstructure testing will be performed & results documented.

INVESTMENT CASTING INSTITUTE

Vacuum Induction Melting Process Optimization in Precision Investment Casting Furnaces

Inaki Vicario
Consarc Engineering, Ltd.

VIRTUAL TECHNICAL CONFERENCE & 3D EXPO 2020

Paper № 3

Consarc´s Technical Paper Proposal for the ICI's 67th Technical Conference and Expo, Autumn, 2020 Presented as a virtual conference

Vacuum Induction Melting Process Optimization in Precision Investment Casting Furnaces

Abstract

The alloy vacuum induction melting process is one of the most critical events in the Vacuum Precision Investment Casting (VPIC) furnace, and also in the Investment Casting Process.

The induction melting process is concerned with how solid alloy is induction melted in preparation for pouring into a preheated shell mold. It is the first point for a successful and defect free casting process. It begins with the ingot and refractory one-shot liner loading stage into the induction coil, then continues with the power input from the VIP® source into that coil, which finally melts the solid ingot by means of induction. Once alloy is melted, process continues with the melt dross evaluation witnessing the cleanliness of the alloy, and it finishes with temperature regulation of the metal to have it ready to be poured into the shell mold.

This work will summarize features and recommendations around the design of the VIP®, induction coil, ingot/liner charging system, melting recipe and final temperature regulation systems, as key parameters and their effective management and control. Additionally, some best practices will be discussed to enable investment casters to have a fast, accurate, consistent, reliable and clean melting processes.

Iñaki Vicario

Consarc Engineering

September 2020

Introduction

The vacuum induction melting process of the alloy to be cast is a critical stage within the Vacuum Precision Investment Casting (VPIC) furnace.

How solid alloy is induction melted in preparation for pouring into a preheated shell mold is the basic background of this process. An effectively controlled melting process provides a solid foundation for the investment caster to achieve the demanding quality requirements of a modern high-class precision casting foundry.

This paper includes recommendations and best practices around the design of the induction power supply (VIP®), induction coil, alloy, ingot/liner charging system, melting recipe and final temperature measurement systems, camera and view ports, identifying key parameters and their effective management and control.

The paper also indicates the basic features, best practices and technicalities of the vacuum melting with the three key process objectives: productivity, quality and consistency.

All best practices shown are applicable for both Equiaxial or Directional Solidification-Single Crystal (DSSX) process technologies.

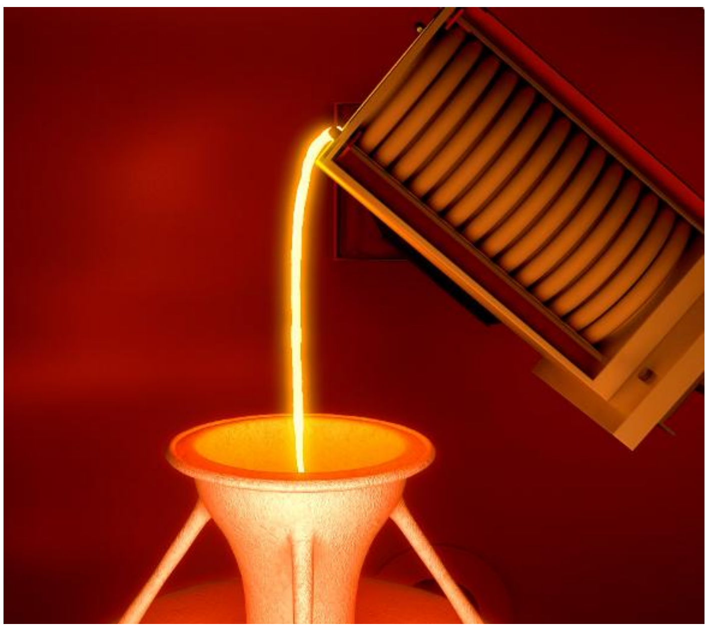

Figure 1. Picture showing vacuum melted alloy being poured into a shell mould.

Melting Process Goals

Three different aims can be identified in the vacuum induction melting process for investment casting processing. Each is sufficiently critical to be analysed below:

1. Quality: means having a robust chemistry control and maintaining a clean melt ready to be poured into the shell mold. The target quality can be detailed in two different objectives:
    a. *Metallurgy*: the melting process should not impact negatively the chemistry of the alloy, such that the chemical composition should not be modified negatively by the melting process. Changes in the chemistry may produce a non-compliance of the strict specifications of the customers, as well as risk of producing metallurgical defects in the final castings.
    b. *Liner/crucible integrity*: the melting process should prevent any damage or breakage of the liner/crucible, through both heating and melting stages. A breakage of the liner/crucible incurs a direct cost for the alloy and liner/crucible, and also a loss in production having the furnace down while it is recovered. Damage to liner/crucible could also produce a risk of having metallurgical defects in the final castings.
2. Consistency: the strict requirement to always follow the same melting process cycle to cycle. The 3 different major sources of changes in the process:
    a. *Human Factor*: there is a need to avoid variation created by different operators, or, at least, keeping this variation to the absolute minimum.
    b. *Material*: prevent any factors related to the change of alloy materials, sourced from different vendors, or to manage variation from the same vendor.
    c. *Machine*: monitoring and avoidance of any deleterious machine effect due to its incorrect behaviour during melting processes.
3. Productivity: as the ability to conduct the melting process as fast as possible to maintain short cycle times, and enable the production of as many castings as possible, thus reducing the unit cost. This is especially applicable to equiax casting where this process cycle time is shorter, and the melting time represents a bigger percentage in total process time.

Figure 2. Induction Coil Unit

Melting Main Steps

The following flowchart shows the equiaxial process and indicates materials and processes involved:

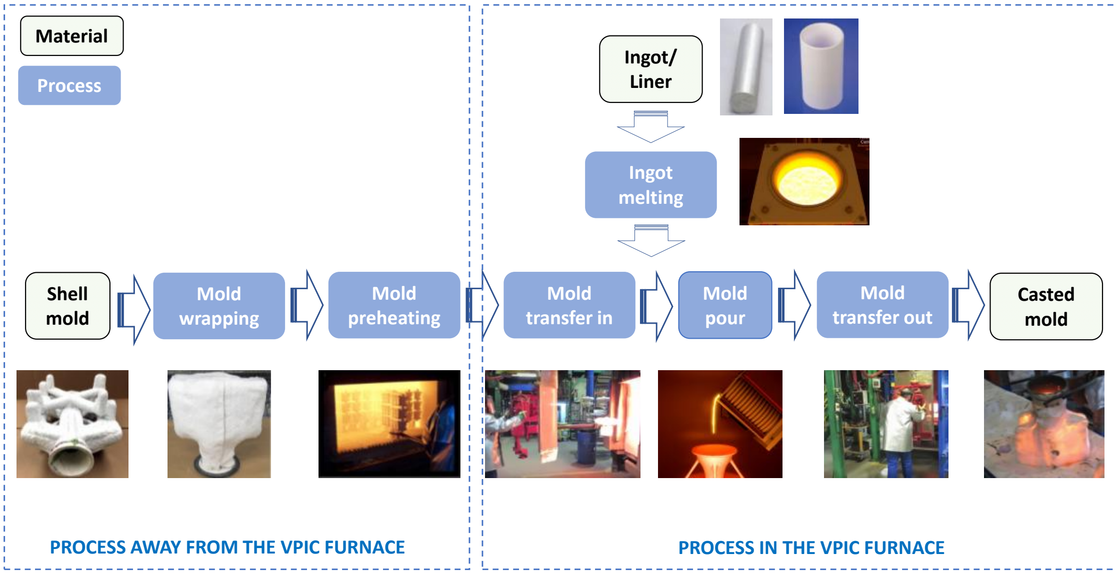

Figure 3. Equiaxial vacuum precision investment casting process flowchart.[1][2][3][4]

The chart above explains how the process starts quite close to the VPIC furnace with the shell mold input from the shell room process. This shell mold traditionally undertakes a mold wrapping process where the mold is thermally insulated with ceramic fibre blanket. This insulation prevents heat loss during the transfer of the shell mold into the VPIC. It also helps controlling how the casting solidifies after pouring process. Once the shell mold is wrapped, it is loaded into the mold preheating furnace where it is preheated in preparation for casting.

Subsequently, the ingot and liner materials are loaded into the VPIC furnace, and melting can occur after which the melted alloy is ready to be poured into the shell mold. In that moment, the preheated shell mold is taken out from the preheating furnace and quickly moved into the VPIC furnace, known as mold transfer in stage. Once the preheated shell mold is ready in the pouring position, the pouring stage occurs, where the melt alloy is poured into the shell mold. Finally, the shell mold is removed from the furnace back to the initial loading position, which is known as mold transfer out process.

In the case of DSSX casting process, the following flowchart represents the process:

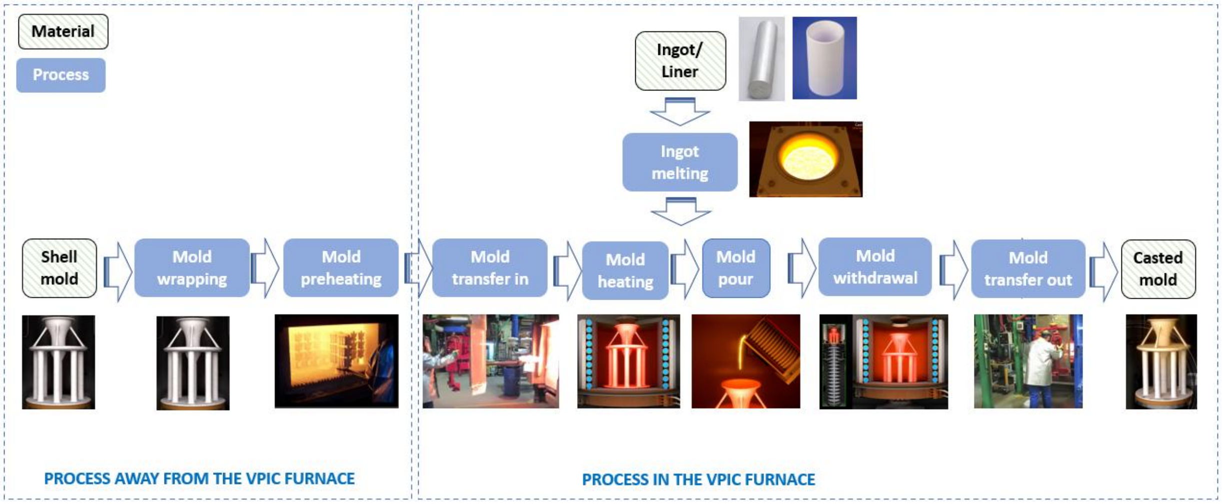

Figure 4. DSSX vacuum precision investment casting process flowchart. [2][3]

As it can be witnessed in the previous flowchart, in the DSSX process, shell mold follows similar wrapping and preheating steps to the equiaxial process, however typically preheated to a lower temperature as it shall be heated later inside the VPIC furnace. The shell mold is then moved into the VPIC furnace, moved to the heating-pouring position, and mold heating stage starts. Once heating is complete, or it is about to finish, ingot melting process begins (with the liner and ingot loaded previously). Once alloy is melted and conditioned to be poured, the pouring process occurs. Subsequently, the mold undergoes a slow highly controlled withdrawal process out of the base of the heater. Finally, once complete, mold transfer out is carried out.

This is the specific flowchart for the melting process:

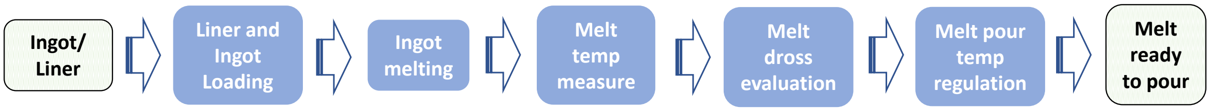

Figure 5. Alloy specific flowchart details.

The previous figure explains the specific process around melting. It begins with material charge: the alloy and the refractory used to hold the alloy (liner). Once they are both loaded, melting happens by means of induction melting. Once alloy is fully melted, temperature measurement is done (this may start from solid state if desired), and subsequently dross evaluation is carried out to make sure that the alloy is clean enough to be poured into the shell mold. Finally, the process finishes with the temperature regulation to the desired pouring temperature, which means that the alloy is ready to be poured.

Melting Main Key Elements

The image below indicates the key elements considered in the melting process shown on a Consarc VPIC furnace:

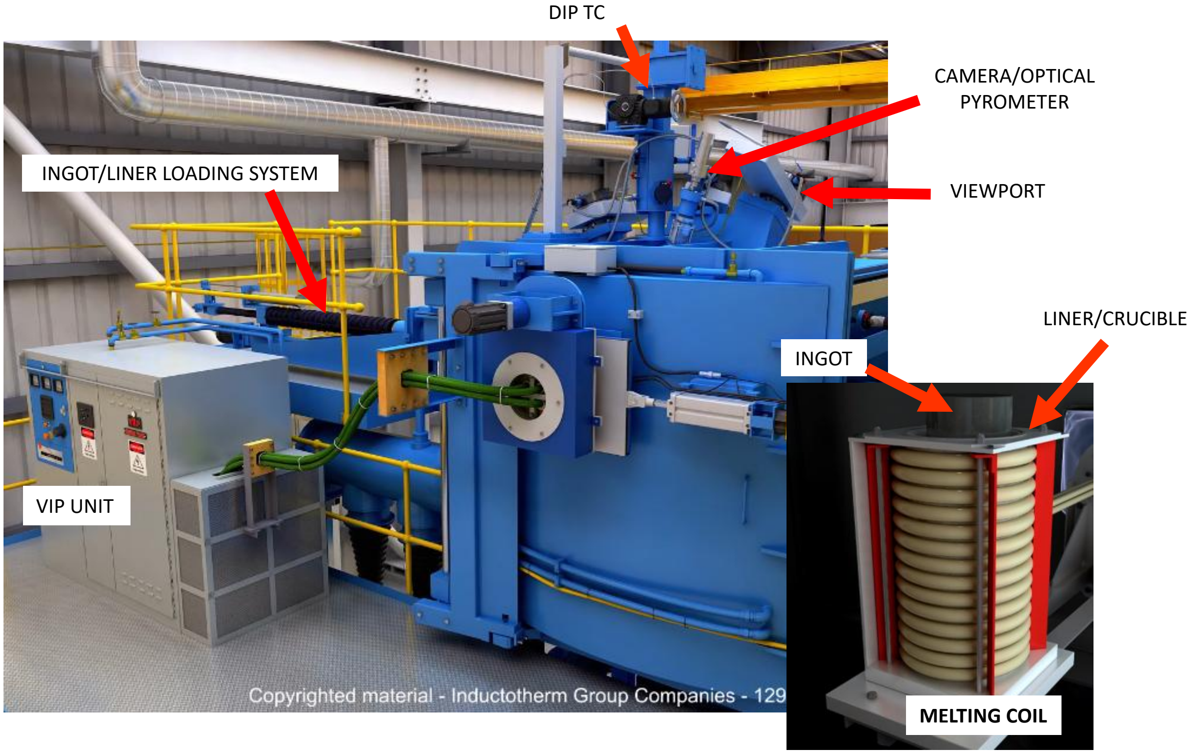

Figure 6. Melting related main key elements shown in a Consarc VPIC furnace.

The key elements to be considered in the melting process include:

1. Induction Power Supply (VIP®).
2. Induction Melting Coil.
3. Ingot.
4. Liner/Crucible.
5. Ingot/Liner Loading Stage.
6. Temperature Measuring Devices.
7. Cameras and Viewports.
8. Vacuum System.
9. Melting Procedure

The following paragraphs detail each of the all key elements listed above:

1. Induction Power Supply (VIP®): the Inductotherm VIP® is a voltage fed designed unit that converts multi-phase line voltage into a single-phase variable frequency current injected into the induction coil.[5]
    - o The power supply creates the power needed to melt the alloy by means of an induction field that is generated within the induction melting coil.
    - o The power and frequency are selected in the design stage to ensure effective matching with the desired load to be melted.
        - ▪ The power directly heats metal inside the induction coil, and it is sized depending on the melting rate and total charge to be processed.
        - ▪ The frequency is calculated to achieve the best coupling and stirring effect. Consarc offers multifrequency VIP® designs based on the customer charge demands.
    - o Effective matching of the VIP® unit, allows the quickest, and most reliable-efficient and accurate melting process:

The following chart shows a chart that gives the best frequency value for each coreless induction furnace size.

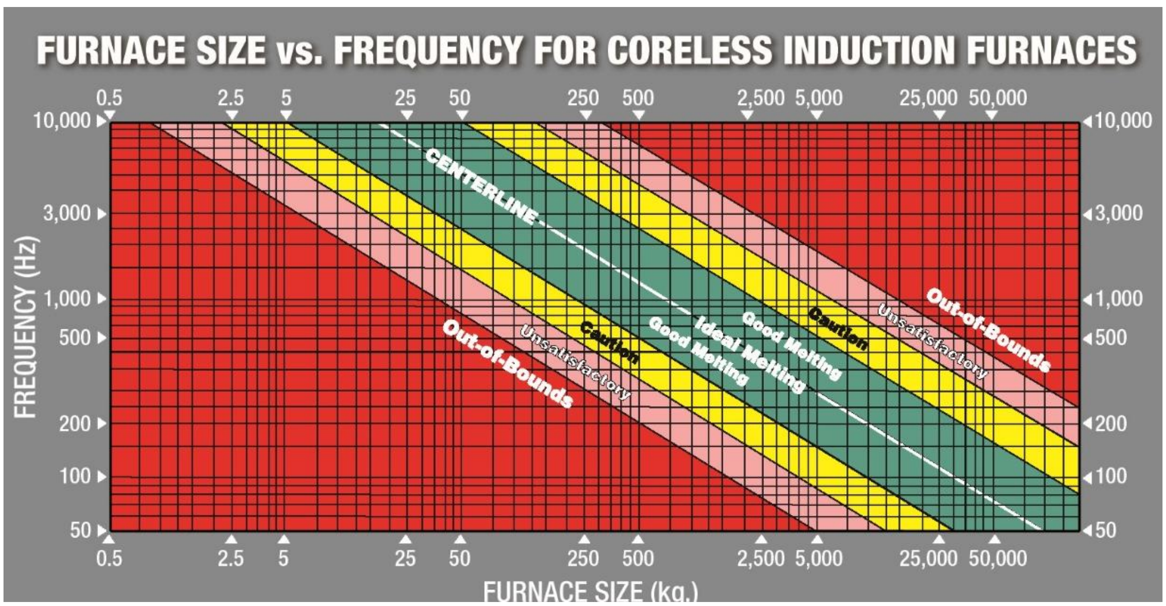

Figure 7. Chart showing Furnace size vs Frequency for Coreless Induction Furnaces [5]

The following pictures show VIP® units in the version of SCR used as inverters, and VIP®-I which use IGBT technology:

Figure 8. Example of Inductotherm VIP®-I unit on the left and VIP® on the right.

2. Induction Melting Coil: contains the liner/crucible rammed inside it. The melting process happens in the coil due to the coupling of the magnetic induction fields created with ingot inside the liner/crucible, heating it until it completely melts. The coil is connected to the VIP® through the water-cooled power leads.
    - The size of the coil and the number of turns is calculated by the maximum and minimum alloy capacity to be melted.
    - If the melting range is large, the best solution is to have different size coils and exchange them when required.

Consarc enables easy and safe coil changes due to elimination of flexible hoses inside the furnace and making coil-lead connections outside of the vacuum furnace.

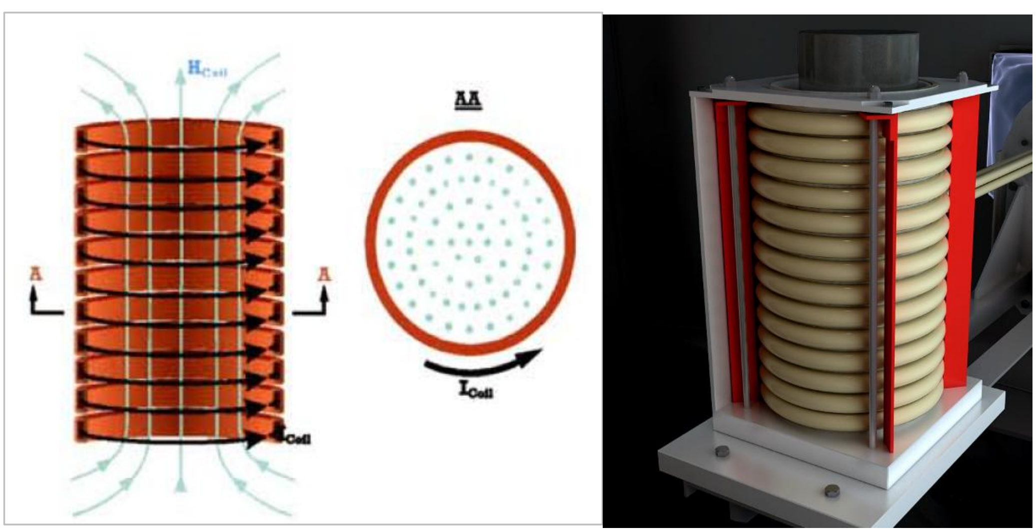

Figure 9. Induction fields sketched view on the left and Consarc induction melting coil on the right. [5]

3. Ingot: is the material/alloy to be melted and then poured into the shell mold:

- The target should be to maximize the ingot size within the liner/crucible internal diameter for optimum induction coupling, and therefore, fastest melting.
- Single ingot loading is preferable to multiple ingots. If multiple ingots are used, the smallest piece ingot should be loaded into the bottom of the liner.
- A chamfered ingot base where in contact with the liner is always recommended for a safe contact with liner/crucible, preventing any scratching/inclusion formation.
- Care to be taken when using ingots formed by a notch and fracture type process, due to presence of sharp edges.
- Soft, accurate and careful loading is needed also to prevent scratching.
- Both incoming ingot and final casting chemistry shall be controlled, to guarantee a good melting practice, so as to ensure that there is no impact on the chemistry caused by the melting process.
- It is critical to make sure that the alloy ingot is clean before melting to prevent inclusions.
- It is also very important to evaluate the cleanliness of the alloy when it is melted, known as dross evaluation.

Figure 10. Picture of chamfered ingots.[6]

4. <u>Liner/crucible</u>: is the refractory receptacle that holds the alloy during the melting process until pouring is complete. There is a growing trend in the investment casting industry for the use of one-shot liners instead of crucibles. One-shot liners are preferable due to their quality advantage against single rammed crucibles, as they ensure the use of new refractory for every melt, preventing any issues caused by worn crucibles or material contamination / dross carry over for one melt to another.
   - Material selection is a key factor to prevent or minimize reaction between the alloy and the refractory:
     - Fused silica. Most standard and cheapest type.
     - Alumina and Zirconia. Recommendable for reactive alloys.
   - Drying of liner before its use is recommended to improve yield.
   - Liner size shall meet the charge requirements guaranteeing an appropriate fill level.

- Backup crucible shall have minimum 13mm gap inside the coil to allow ramming properly.

Figure 11. Pictures of silica one shot liner inside a cut backup (left), and Zirconia crucibles (right). [7][8]

It is critical to understand the interactions that may happen during the alloy and refractory during melting process. The following figure includes a diagram showing those interactions in detail by defining three different areas: above the melting line, on the melting line and below melting line:

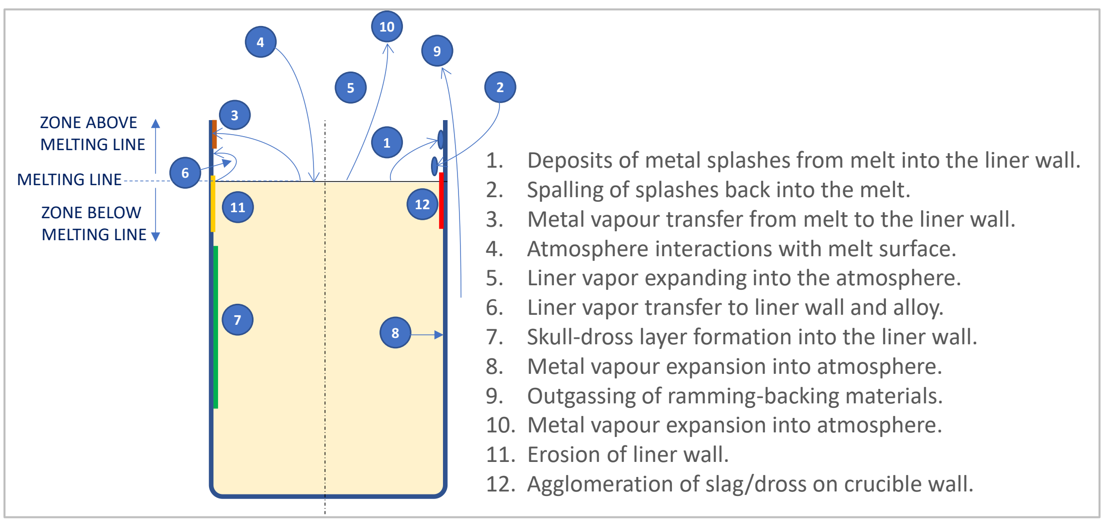

Figure 12. Refractory/Melt interactions schematic view. [9]

As it can be seen in the figure above, up to 12 different reactions may occur in the interaction between the alloy, refractory and atmosphere during the melting process. Therefore, it is evident this is a rather complex process to control. There are 3 rules to follow:

1. Choose the best refractory depending the alloy and conditions of melting.
2. Melt and hold the alloy at the lowest possible temperature.
3. Hold alloy in the refractory the shortest time possible.

5. Ingot/Liner loading stage: the method used to load and unload liners, and also alloy. Soft loading is always required to avoid scratching and liner damage, and for this reason, horizontal loaders are often preferable to vertical loaders. Approximate limits for each type of charging systems:
    - Vertical loading systems for large charge capacities approx. >150 kg.
    - Horizontal loaders for smaller charge capacities approx. <=150 kg.


Figure 13. Consarc horizontal (left), and vertical (right) loading systems.

In addition, Consarc offers liner disposal systems for rapid liner removal, saving process cycle time.

6. Temperature measuring devices: there are two technologies available to measure melt temperature: Optical Pyrometry and Immersion Thermocouples:
    - Optical pyrometers allow for continuous melt temperature measuring:
        - External sight glass with isolation valve protection to allow periodic cleaning by the operator.
        - Argon bleed with mass flow control to prevent condensation onto the pyrometer sight glass coming from the melt. Mass flow control systems to provide an accurate and controlled method to measure the quantity of argon used.
        - Alloy emissivity/slope correction factor (also in the recipe). This allows a precise adjustment of the reading of the pyrometer.
        - Automatic correlation/compensation to Immersion Thermocouple reading. This is a very useful tool to calibrate/adjust the pyrometer reading.
        - Dual pyrometer systems for a consistent process. Having two devices reading at the same time into the same melt point, producing a very reliable way of achieving right and accurate temperature readings.
        - Laser sighting/integrated camera option, that enables a precise adjustment of the point where the pyrometer focusses. Also, integrated camera enables to record melting process.

    - Air curtain system option, which prevents contamination with dust coming outside onto the external side of the pyrometer sight glass.
  - Immersion thermocouple devices for optical pyrometer discrete checking/calibration:
    - It is a contact process, very accurate, not affected by light, alloy type or emissivity changes and whose immersion can be easily automated.
    - There are two possible solutions:
      - Quick change type B, R, or S thermocouple probe.
      - Multi-dip sheath design, single thermocouple or interchangeable designs of the same TC types.
    - Trend towards less use of immersion thermocouple system because its potential contamination with use.

Figure 14. Picture of Consarc dual pyrometer system (left), and immersion TC measuring melt temperature.

7. Cameras and Viewports: provided to record/witness the melting process.
  - Cameras are recommended to witness the process and assure a consistent melting cycle. Also, they allow the operator to evaluate the dross level on the surface of the melt before pouring.
  - Viewports for the operators shall be located in appropriate positions to monitor the process properly and allow their reaction upon seeing an issue during melting.

Figure 15. Consarc camera arrangement on the left, and viewport in the right hand-side.

8. Vacuum System: to create the necessary inert atmosphere to prevent any oxidation of the alloy during melting, as well as harmful impurity element removal from the alloy, during melting. There are normally two groups of vacuum pumping systems installed in VPIC furnaces:
    - o High vacuum system to achieve up to 10e-4 - 10e-5 mbar range or greater vacuum levels:
        - ▪ Diffusion pumps offer high vacuum (~10e-4 – 10e-5 mbar range) during melting.
        - ▪ Oil Vapour Boosters pumps offer high vacuum but lower than that of Diffusion pumps (~10e-3 mbar range), but a more stable vacuum during melting stage.

Figure 16. Examples of high vacuum pumps: Diffusion (left) and oil vapour booster (right). [10][11]

    - o Low vacuum or roughing vacuum systems, based on mechanical and roots type pumps, achieve 10e-2 mbar vacuum ranges.

Figure 17. Consarc typical roughing vacuum pumping system arrangement (left), and dry vacuum mechanical pump (right). [12]

There is an important need of avoiding too deep vacuum: alloy composition could be affected by vaporization of elements during melting. The following figure includes a table that shows some typical elements contained in superalloys, with the temperatures at which specific vapor pressure exists depending on the pressure level from 10e-3 torr to 760torr:

Element	Temperature (°C) at which specific vapor pressure (torr) exists						
	0.001	0.01	0.1	1.0	10	100	760
Al	889	996	1123	1279	1487	1749	2327
Be	1029	1212	1367	1567	1787	2097	2507
B	1239	1355	1489	1648	3030	3460	2527
Cd	220	264	321	394	484	611	765
Ca	528	605	700	817	983	1207	1482
C	2471	2681	2926	3214	3946	4373	4552
Cr	1090	1205	1342	1504	-	-	2222
Co	1494	1649	1833	2056	2380	2720	3097
Cu	1141	1273	1432	1628	1879	2207	2595
Ga	965	1093	1248	1443	1541	1784	2427
Ge	1112	1251	1421	1635	1880	2210	2707
Au	1316	1465	1646	1867	2154	2521	2966
Fe	1310	1447	1602	1783	2039	2360	2727
Pb	625	718	832	975	1167	1417	1737
Mg	383	443	515	605	702	909	1126
Mn	878	980	1103	1251	1505	1792	2097
Hg	18	48	82	126	184	216	361
Mo	2295	2533	2880	3102	3535	4109	4804
Nd	1192	1342	1537	1775	2095	2530	3090
Ni	1371	1510	1679	1884	2007	2364	2837

Figure 18. Element Vaporization Temperature as a function of the Pressure. [13]

As it can be witnessed above, there are some elements which have quite low temperatures at which vapor pressure exists. The longer time at temperature and at the vacuum level, the greater the loss of the metallic elements by evaporation.

It is also critical to avoid leaks: leak up rate test is the key factor rather than vacuum level. Making dynamic tests rather than static tests is always preferable to ensure that there are not leaks or, at least, are controlled and acceptably low.

9. Melting Procedure: the specific procedure used for heating and melting the alloy. It is critical to always run an automatic melting recipe to have a consistent melting stage, for the following reasons:
    - Prevents human factor as the melting cycle runs automatically.
    - Regulation of power during the solid and liquid stages of melting to accommodate the different situations that melting process witnesses from heating starting until the melt is ready to pour.
    - Avoids metal splashes by the programmed reduction of power when necessary.
    - Targets repeatable total melting time/energy, which is important from the point of view of process control and energy cost saving.
    - Assures the same minimum metal-refractory interaction time avoiding undesirable inclusions.
    - Assures that the same thermal cycle is always conducted.

Additional process control features include:

- KPV data logging – the ability to record and subsequently analyse all Key Process Variable (KPV) data. This is a necessity for the lifetime data record required of certain industry sectors.
- Tracking Variables – the ability, in an automated manner, to create alarms for defined parameters that are out of tolerance through a cycle. The following figure includes a picture that shows a typical Consarc Human Machine Interface (HMI) screen for melting stage with several features and parameters for a good automation process:

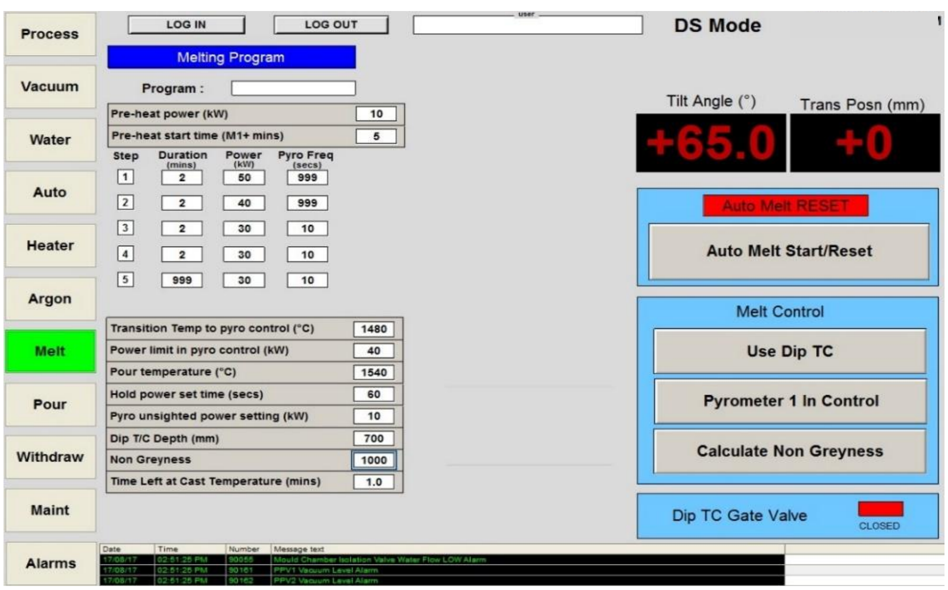

Figure 19. Consarc Typical Melting Recipe Management

These all factors explained above can be wrapped summarised up by a Fishbone diagram, grouping them as Material, Measurement, Machine, Method, Environment and Human Factors:

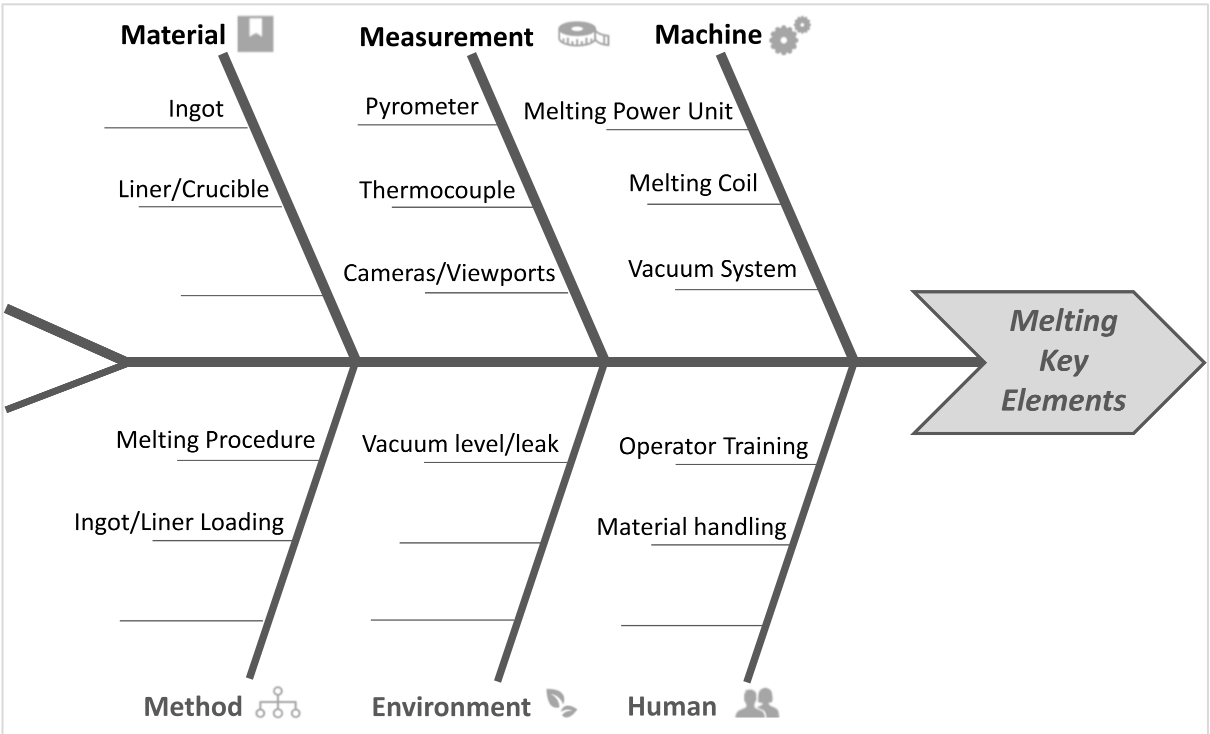

Figure 20. Melting Main Key Elements shown in a Fishbone diagram.

Final Conclusions

The following conclusions can be made regarding an optimised Vacuum Induction Melting process applied to Vacuum Precision Investment Casting:

- The melting stage is one of the most critical activities in the Investment Casting Process.
- It is a key point for a successful and defect free casting process.
- It involves several important stages/activities to be controlled and optimised:
    - VIP® power unit and coil designs, to be matched and accommodate all the melting requirements (productivity and consistency).
    - Ingot preparation and sizing, to prevent scratching, and to have the best induction coupling during melting stage (quality and consistency).
    - Liner/Crucible material and shape selection, chosen to minimise control the melt-refractory reaction (quality and consistency).
    - Ingot and Liner/Crucible loading, to have the fast and reliable charge (consistency and productivity).
    - Melting witnessing/controlling with viewports/cameras and optical pyrometer and immersion thermocouple systems, to have process control (quality and consistency).
    - Vacuum system, to protect the alloy from oxidation and accurate chemical control (quality and consistency).
    - Appropriate melting procedure/automation/logging/control for an accurate, fast and consistent melting process (quality, consistency and productivity).

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INVESTMENT CASTING INSTITUTE

Rapid & Affordable Castings from 3D-Printed Ceramic Molds

Dan Sokol – Renaissance Services
Shawn Franks - HTCI, Co.

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 4

Rapid & Affordable Castings from 3D-Printed Ceramic Molds
Abstract for 67th Technical Conference and Expo

PERFECT-3D and HTC Castings

With the emerging challenge of 3D-printed metals, it is essential for the investment casting industry to become more agile and responsive for small quantity orders. To remain competitive and further reduce the lead time from concept to finished casting, one opportunity area for investment casters is the use of 3D-printed ceramic molds. This approach enables the foundry to bypass the efforts involved in the front-end patterns and dipping processes and go straight to pouring metal. In addition, 3D-printed ceramics also allows for the creation of more complex molds and customized metal flow & gating systems.

In an example case, HTC Castings was approached by an after-market automotive parts manufacturer in need of a small quantity of aluminum throttle body castings for Jaguar automobiles. To be responsive to the short timeframe, HTC elected to work with PERFECT-3D to leverage 3D-printed ceramic tooling. The HTC/PERFECT-3D project team arrived at a design using a complete 3D-printed ceramic mold assembly, including pour cup, cup-filter, sprue manifold, and shell. This approach resulted in successful castings in a fraction of the normal design-to-production time.

This case study presentation from the Renaissance Services PERFECT-3D Division along with HTC Castings will provide an overview of the overall process used as well as the castings that resulted from the effort. In addition to the advantages of additively manufactured tooling, this presentation will discuss some of the current limitations involved as well as casting features that offer the best opportunities to leverage 3D-printed ceramic molds.

INVESTMENT CASTING INSTITUTE

Slurry Analysis & Shell Material Testing Methods

Dave Berta & Sam Duncan
Ransom & Randolph

VIRTUAL TECHNICAL CONFERENCE & 3D EXPO 2020

Paper № 5

Slurry Analysis & Shell Material Testing Methods

Dave Berta, Product and Application Specialist

Sam Duncan, Product and Application Engineer

Ransom & Randolph, Maumee, Ohio USA

Abstract

Investment casting slurries are complex mixtures of materials that need to be controlled in order to produce ceramic shells able to withstand the forces and temperatures required to yield desired castings. In order to control colloidal-based slurries, it is important to understand basic colloidal silica chemistry and properly utilize testing techniques and procedures to measure and control various ceramic shell properties.

This presentation will review the keys to a good slurry control program, including testing frequency and adjustments. It will also study historical and newly developed testing procedures used to measure and control various ceramic shell properties. These tests can be used to benchmark shell properties within a shell system or to compare different shell systems to one another.

INVESTMENT CASTING INSTITUTE

The Smart Manufacturing Institute

John Dyck
CESMII

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 6

CESMII – The Smart Manufacturing Institute

John Dyck

CEO – CESMII

Abstract

CESMII was created in 2017, funded by the US Government - Department of Energy with $70 million dollars, as a non-profit Institute to drive Smart Manufacturing. We are branded as the Clean Energy, Smart Manufacturing, Innovation Institute. But you'll know us as "CESMII - The Smart Manufacturing Institute," because Smart Manufacturing is the ultimate solution for productivity, security, agility, delivering innovation, and the cleanest energy of all, the energy that was not used in production, wasted with scrap or during periods of inefficient operation.

The Investment Casting Institute has recently become affiliated with CESMII. Mr. John Dyck, CESMII CEO, will introduce the organization to ICI Members, addressing his vision for how the investment casting industry can benefit from the relationship.

INVESTMENT CASTING INSTITUTE

Evaluation of a Low-Cost Material Extrusion Printer for Investment Casting Applications

Tom Mueller
Mueller Additive Manufacturing Solutions

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 7

Evaluation of a Low-Cost Material Extrusion Printer for Investment Casting Applications

Tom Mueller, Mueller AMS

Background

It is nearly 30 years since the QuickCast build style was introduced by 3D Systems for use in investment casting. Since that time, much has happened.

- Several new technologies for printing investment casting patterns have been introduced.
- The use of printed patterns to create prototype investment castings has become standard in the industry.
- Printed patterns are now commonly used for very low volume investment casting applications, an application that had been out of reach for investment casting in the past due to the cost of tooling.
- Printed patterns have enabled investment casting to manufacture complex geometries that cannot be molded.

Because printed investment casting patterns are an intermediate step in the manufacturing process rather than the final product, they do not get the exposure that some other applications get. However, it can be argued that in terms of acceptance and number of uses per year, printed patterns is one of the most successful additive manufacturing applications.

Four technologies dominate the creation of printed patterns for investment casting. They include:

- **QuickCast** – This is a hollow build style for stereolithography with an internal hexagonal structure. It is the oldest pattern printing technology and the most widely used in North America. The most popular printer for QuickCast is the ProEx 800 system from 3D Systems.

- **CastForm** – Castform is a selective laser sintering process using polystyrene powder. It has lost favor over the last several years but is still used heavily by a few foundries. The most common printer used for Castform is the s60 system from 3D Systems.

- **Printed Wax** – an inkjet printing process can be used to print wax patterns. This is the only process that creates patterns in an actual wax material. The most common printer used for printed wax is the ProJet 3600 series printers from 3D Systems.

- **Voxeljet** – Voxeljet, a German manufacturer of AM systems developed a binder jetting process using PMMA (polymethylmethacrylate) powder. It is the newest of the most popular printers and has gained favor in several casting applications.

These four pattern printing technologies account for more than 98% of printed patterns used in North America. In 2016 I did a detailed comparison of these four printing technologies and will use data from that study later in this paper.

New printed pattern technology

A few years ago, while touring investment foundries in Asia, I began to hear of low-cost material extrusion printers being used to print prototype investment casting patterns. Material extrusion printers typically use a filament of material which is heated to melting at the print head and then extruded out onto the workpiece. This printing process is also known as Fused Deposition Modeling (FDM), a term introduced by Stratasys, one of the major 3D printer manufacturers.

I believed that these low-cost systems had limited accuracy, produced rougher surfaces, and were slow in comparison to the more popular systems. I doubted that they could effectively compete with the systems listed above.

Last year, I was approached by one manufacturer of low-cost material extrusion printers and asked to evaluate their system for pattern printing applications. The system to be evaluated was an Ultimaker s5 printer running the Polycast filament from Polymaker.

The Ultimaker printer is what might be classified as a low-end industrial printer. It is much more expensive than home printers but is much less expensive than the printers more commonly used in industry such as those mentioned above. There are several similar printers on the market.

The Polycast filament is a PLA based material and was developed specifically for investment casting applications. One advantage it has compared to more commonly used PLA filaments is that it is vapor polishable.

Evaluation Criteria

What is important in evaluating such a system? The criteria I used in my 2016 study was based on concerns that several foundries had expressed to me over the years. Those criteria were:

- **Build Envelope** – The build envelope is the length, width and height of the build space of the printer. It defines the largest part that can be built by the printer. Foundries want to know if most of the castings they normally build could be built in one piece by that printer.
- **Accuracy** – Clearly, the casting can be no more accurate than the pattern it starts with. Consequently, the accuracy of the patterns is especially important to a foundry. At the minimum, it must be within the tolerances claimed for the casting it will produce.
- **Surface Finish** – The surface finish of the casting can be no better than the surface finish of the pattern it comes from and most likely will be worse. For some casting applications, surface roughness is an important acceptance criterion.

- **Build Speed** – For prototype applications build speed is not as critical as it would be for production, but the printer must be fast enough to deliver patterns in time to meet customer delivery expectations.
- **Printer Cost** – The cost of the printer is important, especially considering that for most foundries prototype and very low volume orders account for less than ten percent of their revenues. They cannot justify large investments in a technology that will affect only a small part of their revenues.
- **Pattern Cost** – Just as important as printer cost is the cost of the patterns produced by the printer. If the pattern cost is too high, it simply will not make sense to use printed patterns instead of molded wax patterns.
- **Ease of Casting** – Difficulty in casting printed patterns has been the largest roadblock to greater usage. For most pattern printing processes, creating an acceptable casting requires significant variations from the process used for molded wax patterns. Those variations increase the cost and complexity of casting and are a disruption to the foundry. Consequently, ease of casting is an important consideration.

The first four of the above criteria are measures of the printer performance. The next two are measures of operating cost. The final criterion is a measure of casting performance.

Evaluation Process

To evaluate the system, Ultimaker provided two s5 printers to Wisconsin Precision Casting Corporation (WPCC), a leading user and proponent of printed patterns. WPCC used the systems for creating prototype patterns for a period of over three months for the evaluation. WPCC selected a hollow build style called 10% triangular infill and used a 0.2mm skin thickness. They used the system to build patterns for prototype patterns and have now been using the system for nearly a year.

Printer Performance

Build Envelope – Build envelope determines not only how large a part can be built in one piece but also how many smaller parts can be built at one time. The build envelope of the s5 is 13 x 9.5 x 11.8 inches. For simplicity, the three dimensions are multiplied together to obtain the volume of the build envelope. Figure 1 shows how the envelope of the test system compares to the four leading pattern printing systems.

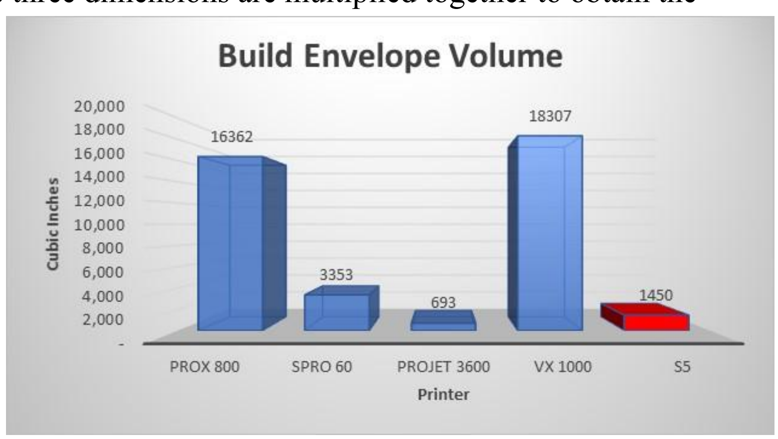


Figure 1. build envelope of the test system compared to leading pattern printers.

The build envelope of the s5 is small compared to the larger printers such as the Prox800 or the VX1000 but is larger than the envelope of the 3600. It is not large enough to accommodate all sizes of castings done by WPCC. However, they claim that it will build approximately 70% of the patterns they need in one piece.

Accuracy – Accuracy of AM systems is notoriously difficult to measure. It can vary with the orientation of the dimension relative to the build plane and can be affected by the layer thickness. WPCC claimed that the accuracy of the s5 was adequate for the castings they produce. Of course, accuracy requirements vary with the application for the casting. Other applications may require greater accuracy.

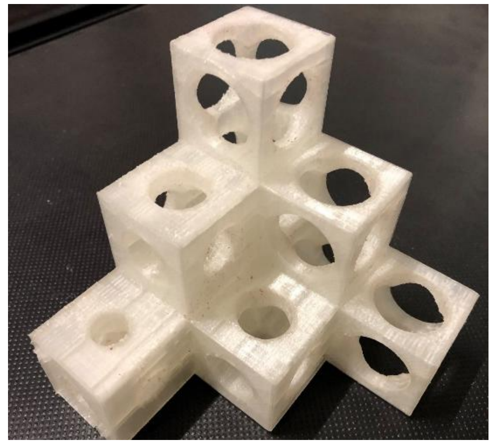


Figure 2. Accuracy test part.

To get a better understanding of the accuracy of the test system relative to the more popular pattern printing systems, a test part was devised with 36 dimensions covering 3 coordinate directions and both inside and outside dimensions. The test part is shown in Figure 2.

WPCC built the test part using the s5. The University of Northern Iowa (UNI) also built the test part using QuickCast, printed wax and Voxeljet printers. UNI then measured each test part using their CMM system. The average absolute value of the dimensional error over the 36 dimensions is shown in Figure 3. Surprisingly, the s5 had the lowest average error. Given the extremely limited amount of data in the test, conclusions about the relative accuracy of the systems cannot be drawn. However, I think it is safe to say that the s5 accuracy is at least competitive in comparison to the more popular systems.

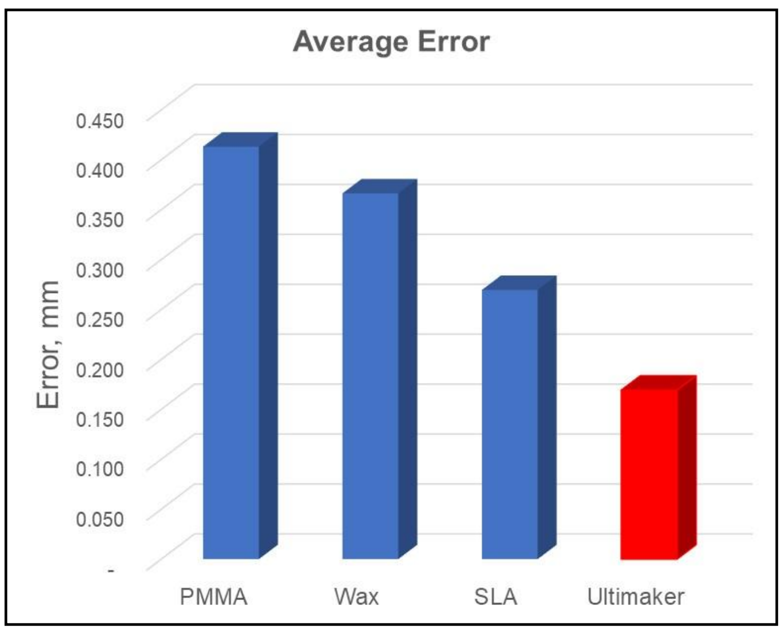


Figure 3. Average dimension error measured on the test part.

Surface Roughness – One of the advantages of the PolyCast filament is that it is vapor polishable. The process that WPCC used to finish the patterns after printing was to do some light sanding to knock down build lines and then about 20 minutes of vapor polishing using a small inexpensive unit. While we were not able to measure surface roughness, WPCC claimed it was well within requirements for the castings they produced.

Build Speed – Build speed can be difficult to define. Speed varies with the geometry of the part being built, the number of parts being built at the same time and other variables. The best approach is to determine an average build rate estimated from many builds. The approach I took in the study in 2016 was to gather data from service providers who used the systems in question to build printed patterns for investment foundries. I asked them to provide data from several runs. The data requested included 1) the total volume of patterns built on that run, and 2) the total build time for that run. The apparent build rate (ABR) for each run was calculated by dividing the total volume of patterns built by the total time to yield a rate in cubic inches per hour. The ABR is then averaged over the number of runs to estimate the average build rate for that system when building printed investment casting patterns. The number of data points for each system varied from a few dozen to several hundred.

WPCC provided the same data for several pattern builds. Build speed varied depending on the size of the nozzle used but the average for all runs was 2.14 cubic inches per hour. Figure 4 shows how the s5 average build rate compares to the more popular systems. The speed of the s5 is only 8% of the VX100, the fastest system, but is nearly twice that of the Projet 3600.

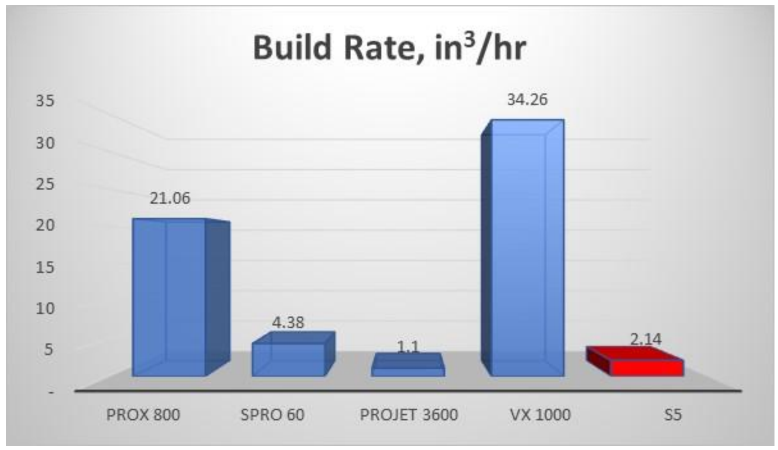


Figure 4. Average Built Rate of Pattern Printing Systems

Operating Cost

Printer Cost

The cost of the printer is an important consideration. Most foundries in North America are small businesses that have limited capital available. In addition, for most foundries castings made from printed patterns generate less than 10% of their revenues. It is hard to justify a major capital investment for a system that will only impact a small percentage of their revenues. An investment in a robot or software that will reduce cost on all their production may provide much better returns.

Figure 5 shows the purchase price for the s5 and the four printers from the previous study. Note that list prices are used for the comparison. Few people pay list price for the systems they purchase. However, finding actual average purchase price is exceedingly difficult so list prices are used. In addition, the prices only include the cost of the printer

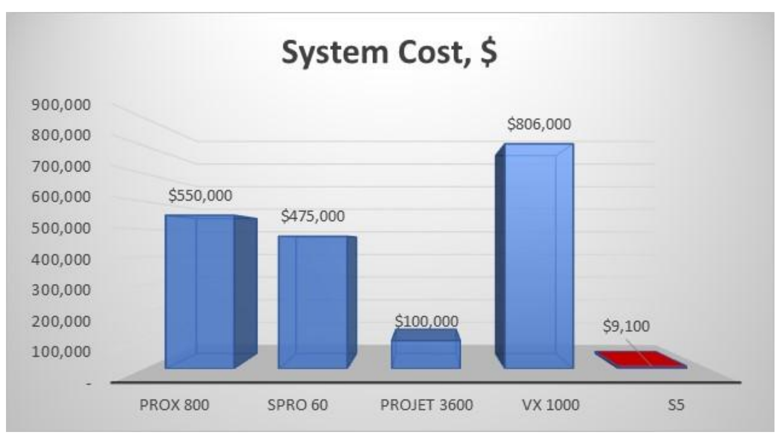


Figure 5, List prices for printers exclusive of assocaited equipment and facility modifications.

itself. Any needed associated equipment is not included, nor is any facility modification that may be required for the printing operation.

The s5 is significantly less expensive than the popular printers. Its cost is only 9% of the cost of the least expensive system and a little more than 1% of the cost of the most expensive system.

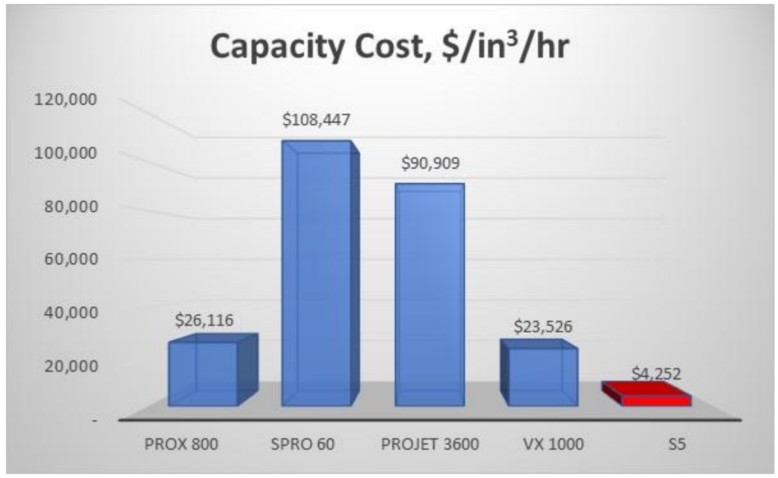


Figure 6. Capacity Cost for printers.

However, it is dangerous to only compare printer prices. The build speeds of these printers vary widely, and more expensive printers can print many times the volume of patterns per day than the less expensive systems. For a true apples-to-apples comparison, it is necessary to look at the "capacity cost". Capacity cost can be defined as the cost per one cubic inch per hour build rate and is determined by dividing the printer price by the build speed. Figure 6 shows the capacity cost for the s5 and the more popular systems. The s5 has the lowest capacity cost at less than 20% of that of the VX1000, the lowest of the more popular systems. Consequently, building a desired level of printing capacity will cost far less with low end industrial material extrusion printers than with any of the more popular systems.

Pattern Cost

The cost to print patterns is at least as important as the cost of the system itself.

The cost to print the pattern has four components: materials, depreciation, maintenance, and labor. Of these, labor is the most difficult to quantify and a case can be made that the labor required for file preparation, printing and post-processing is roughly equivalent regardless of the system used. Consequently, it is not considered in this analysis.

Figure 7. Material cost per cubic inch of pattern.

Materials – the cost of all materials consumed in the process, including the material process, the cost of supports, and any other materials involved in printing the patterns. In this analysis, the list prices of materials were used. For those processes that use supports, the volume of supports required in a print is very dependent on the design of the part being printed. For this analysis, it was assumed that the volume of supports was, on average, 50% of the volume of patterns. Figure 7 shows the cost per cubic inch of materials for the pattern printing processes.

Depreciation – a major cost of printing is depreciation on the printer used. For simplicity, a seven-year straight-line depreciation was assumed. For that case, the monthly depreciation cost is simply the purchase price of the system divided by 84 months. To get the cost in terms of dollars per cubic inch, however, we need to divide by the number of cubic inches of pattern built per month. To estimate the average number of cubic inches of pattern built per month, I assumed that the printer would, on average, be actively printing 16 hours per day for five days of the week, or a total of 80 hours per week. Some might think that printers would be used more than half of the available time, but in reality without staffing 24 hours per day and over weekends to start new jobs as soon as the previous one completes, it is difficult to consistently achieve more production than that.

The average monthly production can then be estimated by multiplying the average monthly printing hours by the average build rate. Figure 8 shows the estimate of the average monthly production of patterns for each of the five printers.

To estimate the depreciation cost per cubic inch, the monthly depreciation cost is divided by the

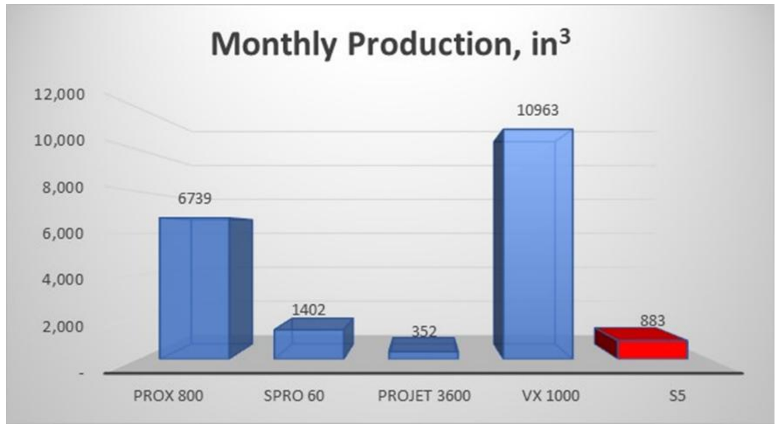


Figure 10. Average monthly pattern production

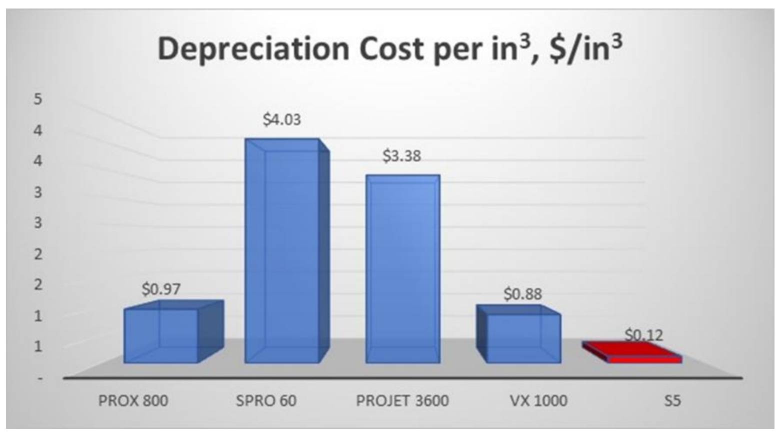


Figure 9. Depreciation cost per cubic inch of pattern.

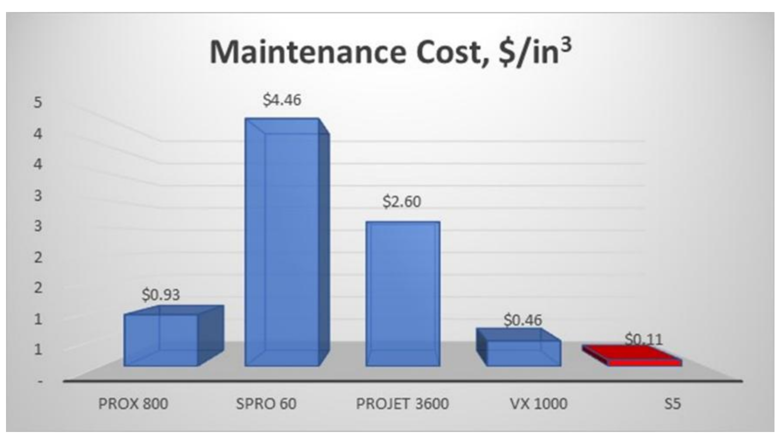


Figure 8. Maintenance Cost per cubic inch of pattern.

average monthly production. Figure 9 shows the result for the five printers. The depreciation cost of the s5 is much lower than the other printers.

Maintenance Cost – Maintenance is a significant cost for AM systems, but it can be exceedingly difficult to get accurate information on maintenance costs. Users often do not maintain accurate records and if they do, they are reluctant to share the information. To estimate maintenance costs, I used the cost of the most comprehensive maintenance plan offered by each printer manufacturer. The most expensive plan typically covers even the most expensive components such as the laser on a stereolithography system or the printhead on a binder jetting system.

To estimate the maintenance cost per cubic inch, the monthly cost of the maintenance contract is divided by the average monthly production. Figure 10 shows the maintenance costs for the five printers.

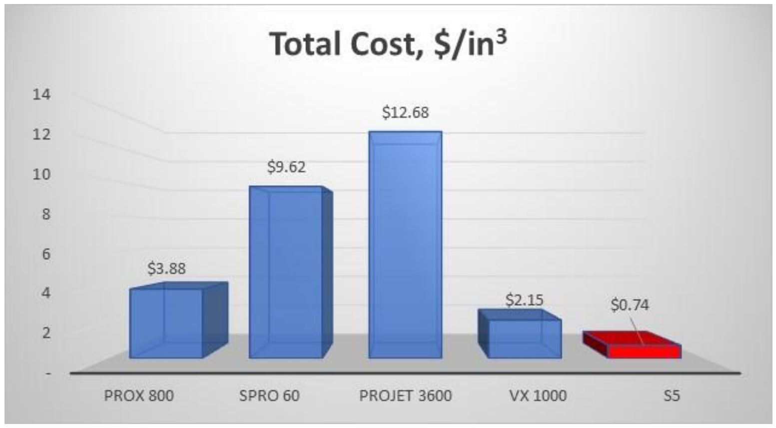


Figure 11. total non-labor cost per cubic inch of pattern.

Total cost – Adding the three cost components yields the total non-labor costs for each of the systems. Figure 11 shows the results.

The s5 has the lowest total cost, approximately 1/3 of the cost of the least expensive of the more popular systems and less than 6% of the most expensive system.

The 2016 study included a chart that compared the popular systems based on two of the most important measures of performance for a foundry; build rate and pattern cost. Figure 12 displays that chart including the s5. The chart shows build speed on the x axis and build cost on the y axis. Each of the 5 printers is plotted on that chart. Systems with a high build speed and low cost will be the most attractive to a foundry. Those systems would be in the lower right portion of the chart. Those in the upper left portion of the chart would have a higher build cost and lower build speed.

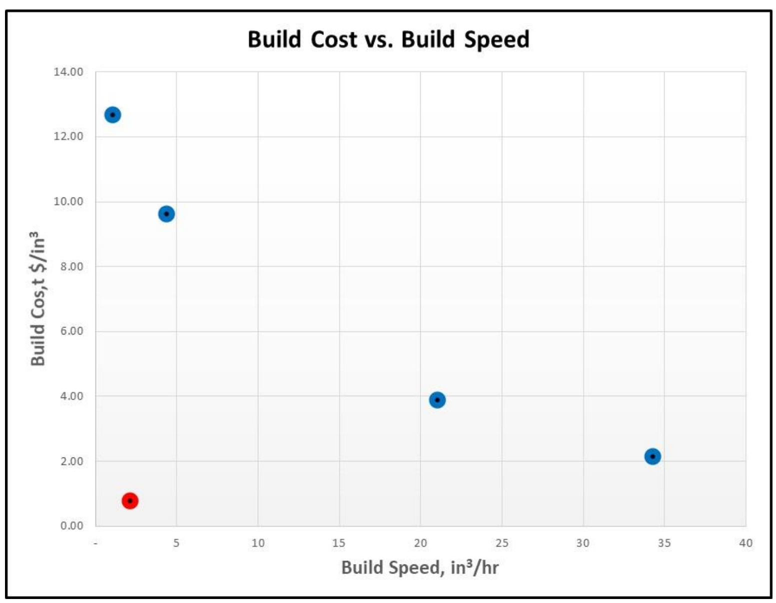


Figure 12. Build cost vs. build speed for the 5 systems.

This compares only two measures of system performance. A foundry might choose one of the less attractive systems in this chart for other reasons such as ease of casting.

The s5 is in the lower left portion of the chart with the lowest build cost but a low build speed. It is not in the more desirable lower right part of the chart but the use of multiple systems can effectively move the position. For example, consider a purchase ten s5 systems. The build cost per cubic inch of pattern would be the same but the effective build speed would be ten times higher, putting it at 214 cubic inches per hour, slightly higher than for a ProX 800. However, both the purchase price and pattern cost would be less than one-fifth that of the QuickCast system. In addition, if the QuickCast system goes down, printed pattern production stops until the printer is repaired. If one of the material extrusion printers goes down, 90% of the pattern printing capacity is still available. On the other hand, the QuickCast system could build larger patterns than the s5.

Ease of Casting

One of the biggest considerations for a foundry in choosing a pattern printing technology, whether using in-house printing capacity or buying patterns from a service provider, is how difficult it is to convert the printed pattern to a saleable casting. For most of the pattern technologies, variations to the process used for molded wax patterns are required to yield an acceptable casting.

Obviously, using printed patterns eliminates the need for creating tooling and molding patterns. Casting printed patterns generally requires modifications to two of the major steps in the investment casting process. Those steps are:

1. **Assembly** – Typically, printed patterns are attached to a common molded wax sprue and attaching the patterns is straightforward. However, because most patterns must be burned out of the shell rather than melted, it is important that oxygen is available in the shell to support the combustion. In many cases, it is necessary to add vents to each mold in the assembly to provide a path for airflow through the shell. For QuickCast patterns, the vents also allow steam to enter the pattern in the autoclave, softening the pattern material so that the pattern can collapse as it expands instead of cracking the shell.

2. **De-Wax** – The de-wax step is to remove the patterns from the shell. For printed wax, the same process used for molded wax patterns can be used. For the other pattern printing methods, however, the pattern will not melt out of the shell at normal autoclave temperatures and must therefore be burned out of the shell. For those foundries using a flashfire de-wax system, pattern burnout can typically be achieved with the flashfire system. For foundries using an autoclave, however, burnout is usually a three-step process.

a. ***Autoclave*** - First, the shell is autoclaved to remove any wax components of the assembly, including the sprue and runners. If vents have been added to the assembly, the vents must typically be opened prior to the autoclave step.

b. ***Burnout*** – The autoclaved shell is then placed in an oven to burn out the patterns. It may be necessary to lower the oven temperature to avoid cristobalite formation for fused silica shells. It may also be necessary to add oxygen to the furnace atmosphere and encourage airflow through the shell to replenish oxygen consumed in the combustion process.

c. ***Cleanout*** – After burnout, the shell typically is cooled to room temperature and any ash remaining in the shell is blown out or rinsed out. Any vents are patched at this point as well.

Figure 13 details the modifications to the casting process necessary for each of the five pattern printing technologies.

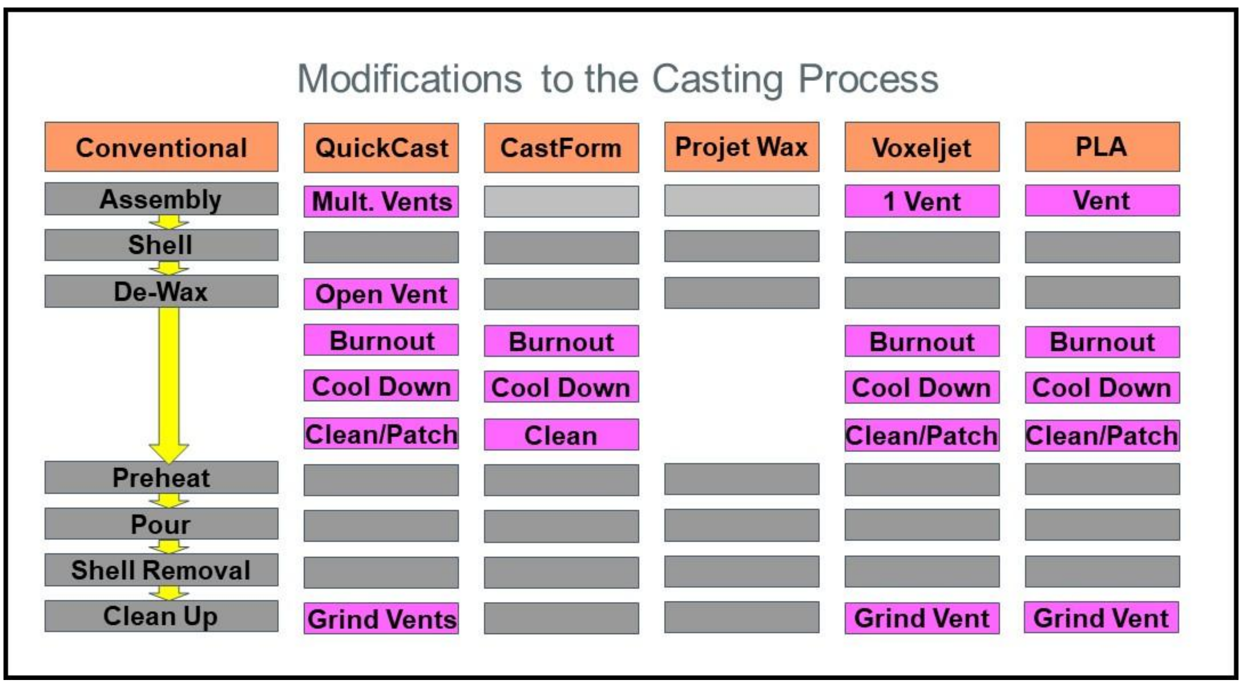


Figure 13. Comparison of investment casting process variations necessary for each of the pattern printing technologies.

The inkjet Projet wax patterns are the easiest to cast. They require no modifications to the conventional casting process.

Castform patterns are a little more difficult. The patterns must be burned out of the shell, but they are reportedly pretty easily burned with little residual ash. No venting is typically necessary.

The three remaining processes all require some venting to provide airflow through the mold during burnout. In addition, they typically require a cool down of the shell after burnout to clean out any residual ash and patch vents prior to preheat and pouring. The amount of venting varies with the process.

QuickCast patterns typically require the most venting. In QuickCast patterns, venting also serves to allow steam to enter the pattern in the autoclave. The steam softens the internal support structure and allows the pattern to collapse inwardly as the pattern expands with heat. It is important that steam penetrates the pattern immediately upon pressurization. As a result, larger patterns may require multiple vents per mold. Without the venting, cracking of the shell due to thermal expansion of the pattern is possible if not likely. Shell cracking is the most common cause of failure for QuickCast patterns. The vents will at a minimum leave witness marks, if not a stub, which must be removed in the process of finishing the casting.

Voxeljet PMMA patterns have an extremely low expansion rate but are solid, unlike the QuickCast or PLA patterns. As a result, more oxygen is required for combustion and more ash will be generated, even if the residual ash percentage is similar to those for resins for QuickCast. Because it is not necessary to allow steam into the interior of the pattern, fewer vents are necessary.

In WPCC’s experience, the difficulty in casting PLA patterns lies between that for Voxeljet and QuickCast patterns. Initially, they tried using the same process as for molded wax patterns and had quite a bit of success for small castings. They did not see significant ash related defects or other issues.

For larger castings, however, they found some shell cracking issues and reverted to the process they use for QuickCast patterns. As in casting Voxeljet patterns, they used only one vent per mold. They have had good success with that process.

The five processes can be ranked in order of increasing ease of casting:

1. Projet printed wax
2. Castform
3. Voxeljet PMMA
4. PLA
5. QuickCast

Summary

Table 1 summarizes the findings for the s5 printer running the PolyCast filament.

Evaluation Criteria	Results
Build Envelope	Acceptable for many foundries
Accuracy	Competitive
Surface Roughness	Acceptable for many investment casting applications
Build Speed	Faster than printed wax
System Cost	Lowest printer price and capacity cost
Pattern Cost	Lowest pattern cost
Casting Difficulty	Slightly easier than QuickCast

Table 1. Summary of results

Conclusions

1. The Ultimaker s5 printer running the PolyCast material provides acceptable performance in printing investment casting patterns relative to more popular systems.

2. Low-cost industrial material extrusion printers running filaments specifically developed for investment casting are viable for printing investment casting patterns.

3. Such low-cost systems provide a low risk means for foundries to bring pattern printing capability in-house because:
    a. Printer cost is extremely low compared to more popular systems
    b. Capacity cost is much lower than the more popular systems
    c. Necessary associated equipment cost is low
    d. Facility modifications are typically not required
    e. Pattern cost is lower than more popular systems
    f. The printer provides acceptable performance
    g. Patterns are no more difficult to cast than QuickCast patterns

INVESTMENT CASTING INSTITUTE

Preparing Our Future Engineers & Technologists

Brian Lewis - FEF
Mingzhi Xu – Georgia Southern University
Dr. Robert Voigt – Pennsylvania State University
Dr. Victor Okhuysen & Dika Handayani – Cal Poly Pomona University
Andrew Wessman – University of Arizona
Russ Rosmait – Pittsburg State University

VIRTUAL TECHNICAL CONFERENCE & 3D EXPO 2020

Panel Discussion No. 1

Preparing our Future Engineers and Technologists - A Panel Discussion

Brian Lewis
Foundry Educational Foundation

Abstract

Industry sustainability, as it pertains to human resources, has been a long, growing concern for many of our foundries. For the past decade, when completing the ICI's "How's Business?" survey, participating foundries have ranked "Attracting, Training and Retaining Talent" as a top concern. Not only have today's universities tailored their engineering and technical programs to address such concerns, but their contributions to the investment casting industry are not limited to the future. These institutions of learning are also centers of excellence for technological development and industrial collaboration.

University panelists will review their overall metalcasting and materials science program and address why investment casting holds importance to the university. Unique aspects of their program as they pertain to investment casting are highlighted and important projects, research and activities are addressed. Ultimately, the attendees will learn how students are more than ready for the investment casting industry when they graduate.

Moderated by FEF Executive Director Brian Lewis, the panel will consists of a number of professors from ICI Member universities.

INVESTMENT CASTING INSTITUTE

Process Control Standards

Nip Singh – S&A Consulting Group, LLP
Joseph Fritz – Investment Casting Institute
Craig Lanham – Member Emeritus
Brian Ferg – Consolidated Precision Products
Tom Planz – Kovatch Castings, Inc.
Thad Nykiel – BESCAST, Inc.

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Panel Discussion No. 2

Process Control Standards Status

Nip Singh
S&A Consulting Group

Abstract

As Process Control is very critical to our manufacturing of Investment Castings worldwide, we would like to involve all sectors of Investment Castings in all countries. This paper will present the current status of the ICI Process Control Standards (PCS) Program and also will detail how casters and suppliers can cooperate.

The task force on PCS, a subgroup under Education Committee has made considerable strides since our last presentation at ICI 65th conference in October 2019. The Core PCS Team has developed a system that facilitates foundry continuous improvement in a tool that can be easily adopted for self-use or facility certification. The program has undergone and completed Beta Testing Phases I and II, and the system is ready for final Verification and Validation (V&V).

This panel discussion addresses the road travelled from inception to 2021 implementation. With international rollout taking place at next year's World Conference on Investment Casting, it is imperative that final V&V be accomplished in the near term. To this end, the Core PCS Team seeks two foundries to serve as final test platforms for the system. The details of V&V testing will serve to fine tune areas of the Program prior to rollout to ICI member foundries mid-year 2021.

Each member of the current PCS Core Team will present an aspect of this initiative and be available for questions about the program and their experiences with the system in their own foundries.

INVESTMENT CASTING INSTITUTE

New Generation Colloidal Silica Binders – How They Are Made

John Lea
Geo 40

VIRTUAL TECHNICAL CONFERENCE & 3D EXPO 2020

Paper № 8

2020 ICI Virtual Technical Conference & 3D Expo

New Generation Colloidal Silica Binders

How They are Made

John Lea – Sales and Marketing Director, Geo40 Limited

Ken White – Business Development Manager – USA, Geo40

Introduction

Geo40 was established in 2010 as a progressive New Zealand technology company that brings together a stable of experts across a wide range of disciplines to make harvesting of minerals from hot geothermal water a reality. Geo40 has been able to achieve what nature has been doing all along, by emulating nature's own processes in harnessing valuable minerals from the earth through benign methods. In doing this they have created the next generation of sustainable, high quality mineral products. One of these products is colloidal silica.

Geothermal Energy Background

New Zealand is considered a world leader in renewable power generation with 95% of the power generated in New Zealand coming from renewable sources. Geothermal power generation makes up around 40% of the renewable power generation in New Zealand.

New Zealand sits on the "Ring of Fire" which is a large geothermally active 40,000 km (25,000 mi) horseshoe shape in the basin of the Pacific Ocean.

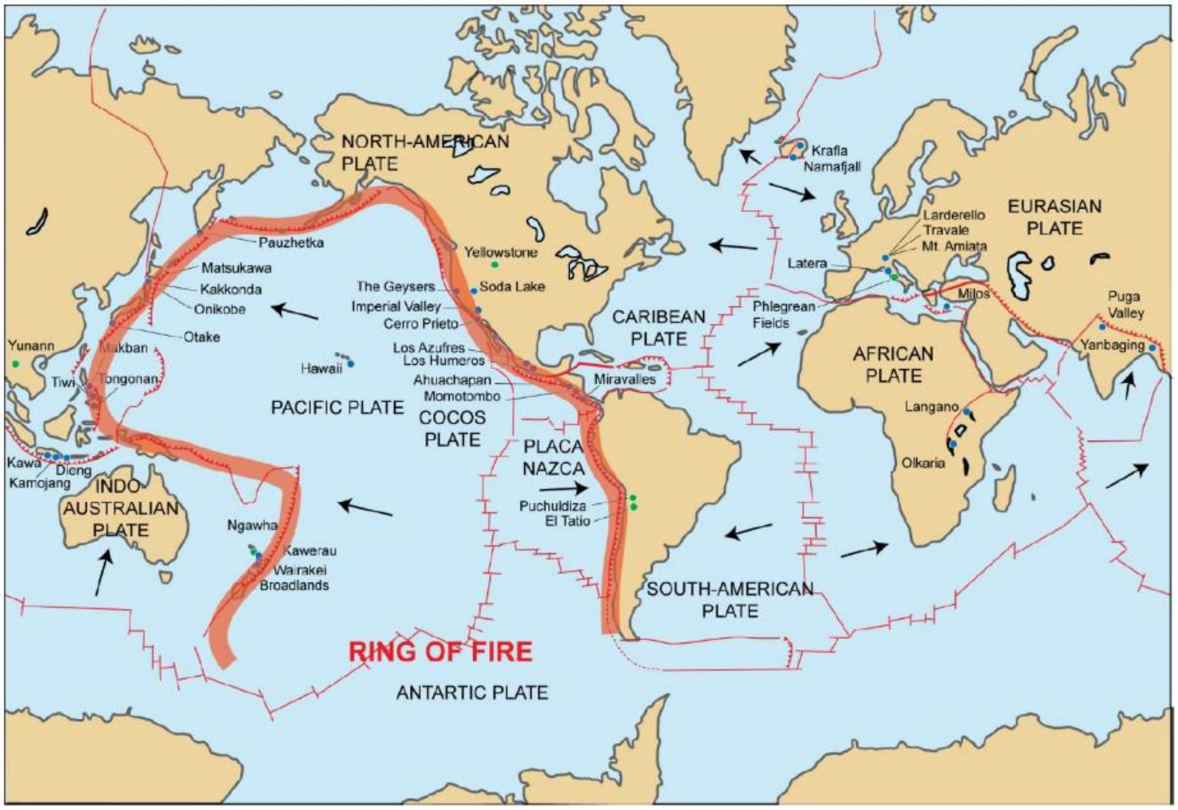


Figure 1: Map of the "Ring of Fire" and global tectonic plates

This geothermally active area stretches from New Zealand up through Papua New Guinea, Indonesia, Philippines, Japan and across to Alaska and down the west coast of USA and South America.

In this "Ring of Fire" the earth's crust is thin and molten centre of the earth comes closer to the surface, often displaying itself in the form of volcanoes and bubbling hot pools and geysers.

Figure 2: A geyser bubbling with hot geothermal water in Yellowstone National Park, USA

Figure 3: Traditional Japanese Onsen heated by geothermal activity, Japan

In the 1950's, engineers became interested in harnessing the "free energy" created by this natural phenomenon and focussed on the steam created in geothermally active areas. In the 1960's the world's first renewable geothermal power station, utilising hot geothermal water brought up to the surface, was built at Wairakei in New Zealand. Since then, New Zealand has been at the forefront of geothermal power generation technology and its application as baseload renewable power generation source.

Around 80% of geothermal power generated globally utilises the New Zealand developed technology of drilling wells deep into the geothermal reservoir where hot geothermal water is then brought, under pressure, to the surface. Typically, this water, which has been heated by the earth's energy, is at 200°C - 350°C (392°F - 662°F). On the surface the power generator releases the pressure to create medium and low-pressure steam. This steam is piped from the geothermal field to the power station where it is used to generate electricity in steam turbines.

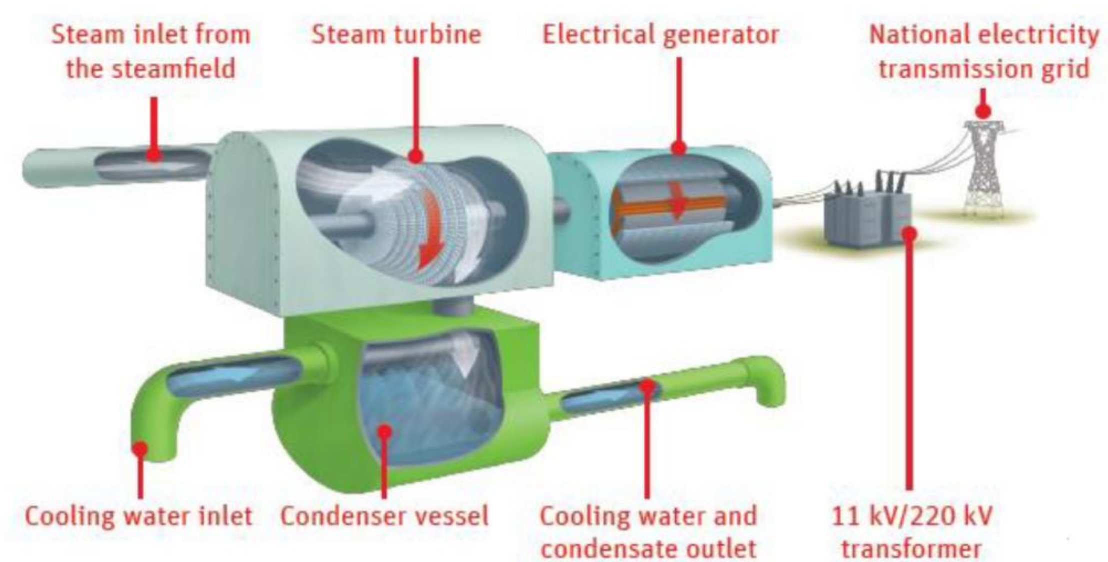


Figure 3: Geothermal steam used for power generation

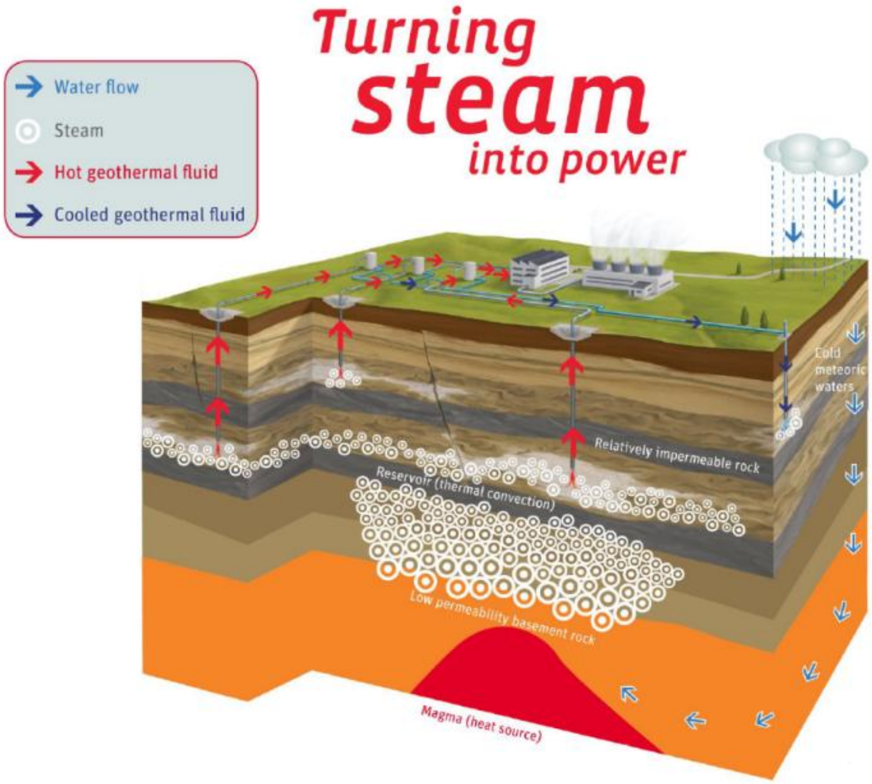


Figure 4: How geothermal energy is harnessed for geothermal power production

The naturally heated hot geothermal water, that is brought up to the surface, contains minerals that have been naturally dissolved deep under the ground. When the generator releases the pressure on the geothermal water it boils and creates steam energy and the result is the temperature of the water lowers. The combination of lower temperatures and decreased water volume (30% of the volume is taken off as steam) concentrates the minerals.

The most abundant mineral is dissolved silica. A key limitation to geothermal power generation is the level of dissolved silica and the temperature that this becomes saturated in the water. If the generator continues to take steam off and lower the water temperature below the saturation point of the silica, it will come out of solution and deposit silica scale into the steam separator and associated pipework. This must be avoided, so generators have to stop taking steam before this happens.

Despite this, silica scaling in geothermal power generation is a significant issue. Work carried out by Jacobs[1] for Geo40 has shown that silica management costs can be as high as 20% of a power plant's operating cost. Jacobs have also shown that up to 20% more power could be produced from reinjection water through the

[1] RZ015400-GE-RPT-001B Cost of Mitigation of Silica Scaling, S

introduction of binary power plants if silica levels were able to be reduced.

The majority of this scaling occurs in the pipework leading to and in the reinjection wells. This photograph is of a 450mm reinjection pipe at Coso geothermal power plant in California, USA, and shows the level of scaling after eight years of use. This is because the hot geothermal water is pumped to the far edge of the field and reinjected back into the reservoir, where it gets reheated to create the renewable loop for power generation. As it is pumped, localised surface cooling takes the fluid through the saturation point and scaling occurs.

Aside from silica, other important and valuable minerals are also contained in the water including lithium for batteries and rare earths for other specialised applications.

Geo40 was formed in 2010 to develop technologies for the benign harvesting of these minerals and turning them into important sustainably produced and competitively priced alternatives in the market.

Colloidal Silica (Silica Sol) – Basic Facts

Many of the properties of colloidal silica are counter intuitive. Oversimplifying, a solution of particles is stable at a pH above 9 or below 3.5. The particles are not dispersed but are stabilized because of steric or ionic repulsion. At neutral pH, the negatively charged particles destabilize and become reactive and gel or agglomerate or react with a surface. Dilution when adjusting pH can distance the particles and help maintain stability.

Most significant, is that the individualized particle size is measured in nano-meters or 10^{-9} meters. Colloidal silica for investment casting is produced to targeted particle sizes and particle distributions.

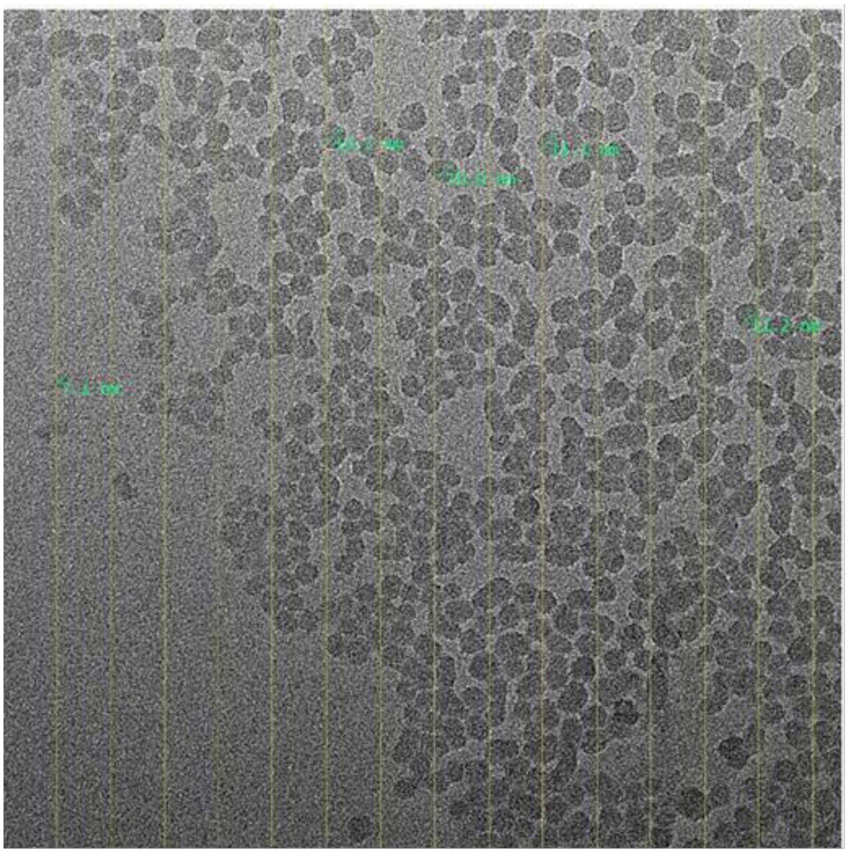


Figure 5: Transmission electron micrograph (TEM) of Geo40 10nm colloidal silica (sol)

For particles sizes below 10nm or 12nm, the particles are so small that when concentrated to 30% solids, the solution is still water clear as it does not refract light. Larger particles of 40nm or higher can be concentrated to 40% or 50% solids and are more easily seen and appear milky white. The particles when dried on a surface can be felt to the touch.

Figure 6: Geo40 colloidal silica at 30wt% concentration and various particle sizes

Surface area is what makes colloidal silica so unique. It was one of the original "nano" products making headlines today. A smaller particle size colloidal product (5 nm) can have a surface area of 625 square meters per gram (190,739 square feet per ounce or 4.25 acres per ounce!). To put this in perspective, approximately 2 teaspoons of colloidal silica would have the surface area of a football field. For colloidal silica, the relationship between surface area (SA) and particle size (PS) is: SA = 3125/PS

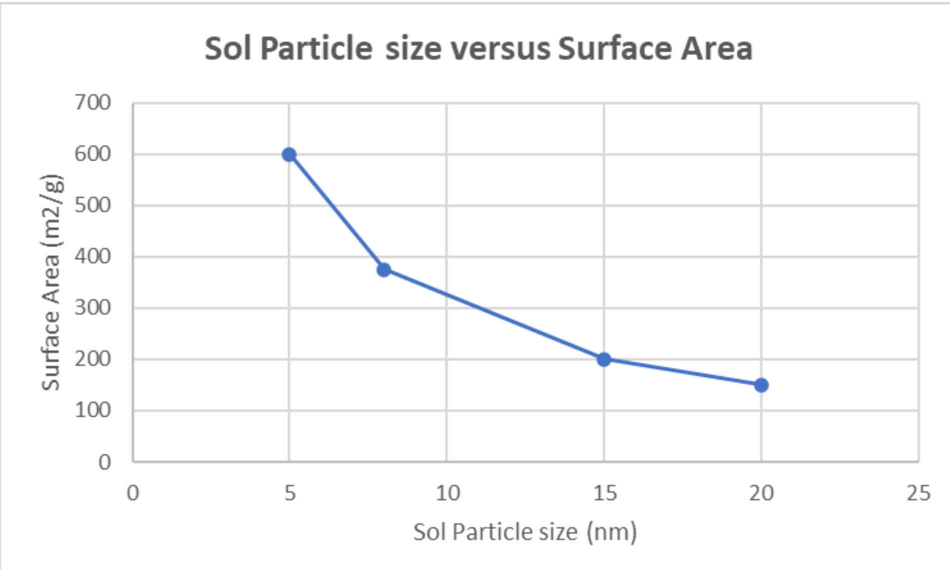


Figure 7: Plot of the effect of colloidal silica particle size on surface area

This combination of being a stable inert amorphous liquid, high surface area but easily becoming a reactive silica particle makes colloidal silica so unique and useful. Uses of colloidal silica are wide ranging including being an excellent binder, rigidizer, polishing agent, frictionizer, coagulant, anti-soilant, carrier, scratch preventer, densifier and many more. Only limited by your imagination.

Industrial Production of Colloidal Silica

Early patents date to the 1940s and 1950s with names like Iler, Bird, Alexander and others. The historic commercial process for making colloidal silica starts with the production of sodium silicate (Na_2SiO_3) through the melting of quartz sand and sodium carbonate (soda ash) in a natural gas heated or electrically heated liquid pool furnace at temperatures of around 1,600°C (2,912 °F). The sodium silicate glass is cooled and broken into chunks which are later dissolved with caustic in a high temperature, pressurized autoclave to form a concentrated liquid silicate solution with a pH between 10-12, depending on grade. Grades are defined by the ratio of silica (as SiO_2) to sodium (as Na_2O). Standard SiO_2/Na_2O ratios range from 1.6 to 3.3 with various silica concentrations.

Numerous different routes exist to make colloidal silica. Slightly simplified, the traditional process is to deionize sodium silicate (by membrane or direct resin contact), adjusting pH to be slightly alkaline, mix with heat to promote nucleation, add acid and additional deionized sodium silicate to grow particle size, wash to remove impurities, stabilize by adjusting pH and then concentrate (evaporation or ultrafiltration). For colloidal silica, the final product concentration can increase as the particle size increases. The smaller the particle size (2 - 150 nm are possible) the higher the surface (1560 to 60 square meters per gram).

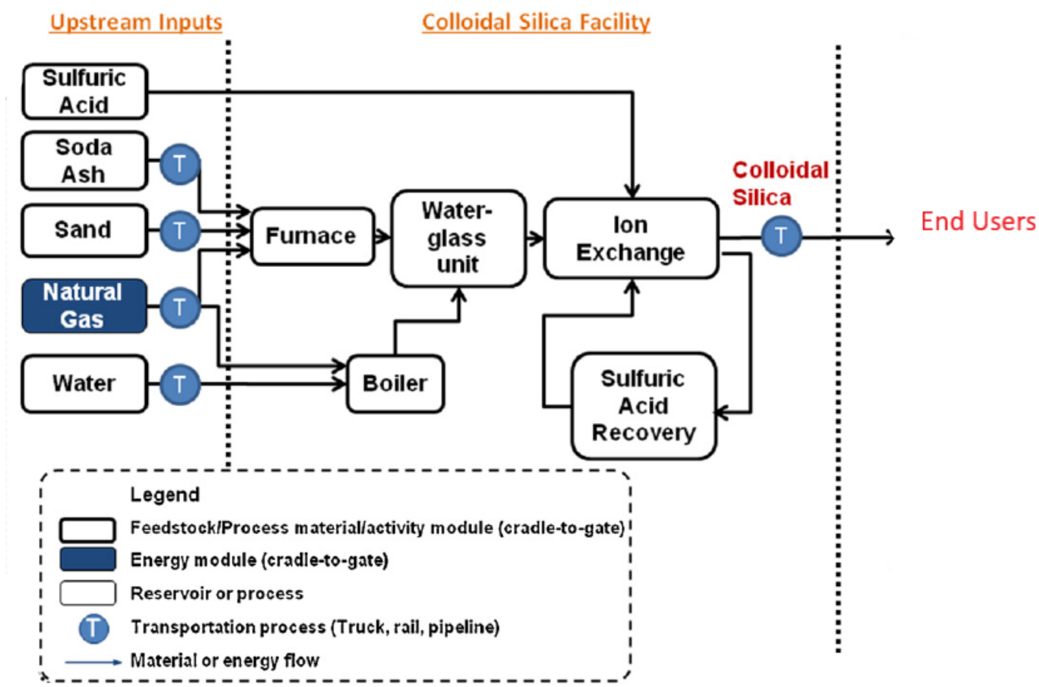


Figure 8: Typical colloidal silica manufacture from quartz sand

New Generation Sustainably Produced Colloidal Silica

In 2010, Geo40 recognised the opportunity to work with the geothermal power generators globally to reduce their maintenance costs for managing silica scaling by harvesting the pure dissolved silica and turning it into sustainably produced colloidal silica products.

Work started with literature searches and laboratory tests to determine the best methods for harvesting the silica. In 2014, the first large scale pilot plant was built on Contact Energy's Wairakei geothermal field in New Zealand.

Figure 9: The first pilot plant located at Contact Energy's Wairakei geothermal field in New Zealand

Further work was carried out over 2015 to refine the process and improve the colloidal silica production to make products with targeted particle sizes and distribution. The colloidal silica markets are differentiated by application and colloid size. Geo40 developed processes for producing a product range of 6nm 15wt%, 8nm 20wt%, 10nm 30wt%, 12nm 30wt% and 14nm 30wt% products. This resulted in Geo40's third patent application being filed. The Geo40 process was finalized on this process.

Following the successful work at Wairakei a simplified pilot plant was relocated to Kawerau in New Zealand where the process was tested on different geothermal water to ensure the robustness of the process. Further large-scale pilot plant trials were carried out at Mercury's Kawerau Geothermal plant, at the Ohaaki geothermal field in New Zealand and Kakkonda geothermal field in Japan.

Following successful pilot plant trials at Warakei, Kawerau and Ohaaki geothermal fields in New Zealand and Kakkonda geothermal field in Japan, Geo40 signed an agreement with Contact Energy in New Zealand for a staged commercialization of the technology at Contact Energy's Ohaaki geothermal field. The agreement was a three-way agreement with Contact Energy, Geo40 and with the local indigenous (Maori) landowners, Ngati Tahu Tribal Lands Trust.

In the agreement, there was a requirement for the outflow from the first commercial plant to feed an historic Maori hot spring (Ngawha). Historically, before geothermal development occurred in the area in the 1980s, the hot spring had flowed clear and had been used by generations of Maori or Tangata whenua (people of the land) for bathing and cooking. When the first geothermal development was established, the historic spring dried up. Flow was later restored to the spring from the power station, but the flow was high in silica and the spring flowed a milky white colour. On building the first plant and harvesting the silica in the water, the Geo40 process was able to supply hot geothermal water, now with lower silica, and restore the hot spring back to its original pristine natural beauty.

Figure 10: First commercial plant built in 2018 at Ohaaki, New Zealand

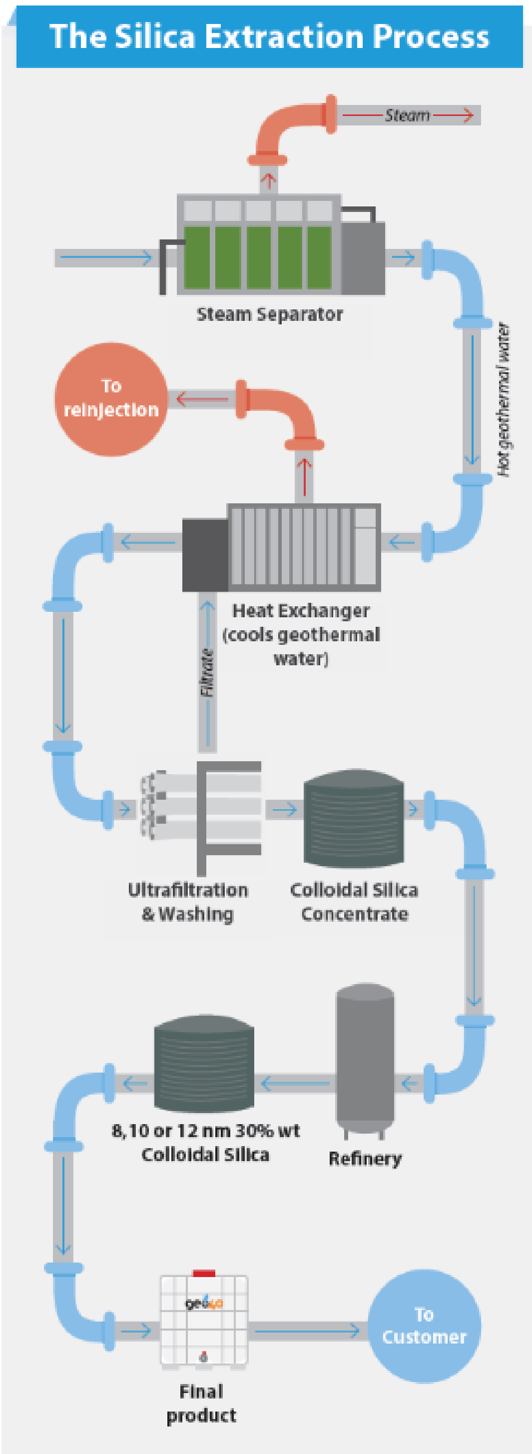


Figure 11: The top photographs show the hot spring before and after the first Geo40 plant was built, demonstrating the harvesting of the silica and supply of the hot geothermal outflow from the plant to the hot spring. The top left photograph shows the hot spring before and the top right shows the hot spring after. The white areas in the second photograph show the natural white silica terraces cascading into the depths of the pool. The bottom two photographs show the overflow from the hot spring into the Waikato River, before and after the Geo40 process and how the white silica plume has disappeared.

How it is made

The Geo40 process works on the treatment of geothermal water from the steam separator in a geothermal power plant. Water leaving the plant is close to silica saturation. Geo40 receives the water, cools it to below the saturation point. During the cooling stage the silica forms discrete colloidal silica particles that are around 1nm - 2nm in size. These particles are then aged and filtered out using a continuous ultrafiltration (UF) and washing circuit to concentrate the silica from its incoming concentration to a 4wt% solution. This concentrate is then further processed, using conventional technology, into sustainably produced and cost competitive, high quality colloidal silica products. Filtrate from the process is now low in silica and able to be used for further mineral extraction before being sent to cool the incoming geothermal water and be reheated and pumped to the reinjection wells at the edge of the geothermal field.

The hot filtrate water leaving the plant is low on silica and cannot cause further silica scaling in the pipework and reinjection wells, saving significant costs for the geothermal power generator. Before it gets reinjected back into the field, the hot low silica geothermal water can now also be used for direct heating opportunities or further power generation improving the efficiency of the renewable power being generated.

Geo40 is well advanced in technologies for removing the dissolved lithium in the geothermal water after the silica has been harvested. To date, near battery grade, sustainably produced and cost competitive, lithium carbonate has been produced from the lithium harvested.

Figure 12: Geo40 process

Geo40 is now also exploring the sustainable and competitively priced harvesting of other minerals from the geothermal water before it is reinjected.

Next generation, sustainable production, and high quality

In current industrial processes for producing colloidal silica, large amounts of energy are required to get the silica from the quartz sand, dissolved into water so that it can be made into colloidal silica. Further processing and heat is required, including other chemicals in the process and for ion exchange resin regeneration.

In contrast, colloidal silica produced from geothermal sources utilises nature’s own energy to dissolve the silica and other minerals in the underground spring water. The hot water is brought to the surface and used to generate renewable power. The Geo40 process utilises this renewable power in the plant for the further processing and finishing its products. Harvesting of the silica results in improved power plant efficiencies and opens up the opportunity for harnessing further green and renewable energy.

Figure 13: Photo of the next generation, sustainable, high quality colloidal silica

Geothermally harvested colloidal silica products are the "same but better" than industrially produced equivalents. They are the same in that they have been proven to perform as well in all applications, and in some applications, better than current industrially produced products. Current geothermally produced products are competing competitively in high quality precision investment casting applications, refractory fibre bonding and refractory casted production, catalyst production, enhanced oil recovery, electronic component production and as additives in concrete, adhesives and paints.

The "better" is coined as better for the environment and better for renewable geothermal power generation and a better choice for users. As the world moves to more environmentally responsible solutions, this must include looking at our manufacturing processes and seeing where we can utilise products that have a better environmental footprint. Minerals harvested from geothermal sources offer a next generation opportunity for sourcing quality sustainably harvested products at competitive prices.

Next stages

Geothermal power production is sustainable, renewable and baseload. Unlike solar and wind power, that rely on the wind blowing or the sun being out to generate power, geothermal power production is 24/7 and provides constant renewable baseload power generation.

Global geothermal power generation is growing fast, opening the opportunity to work in symbiosis with the industry to sustainably harvest minerals. The global geothermal power industry sees Geo40's technology as "ground-breaking" and has the potential to change how geothermal power stations are built and run in the future.

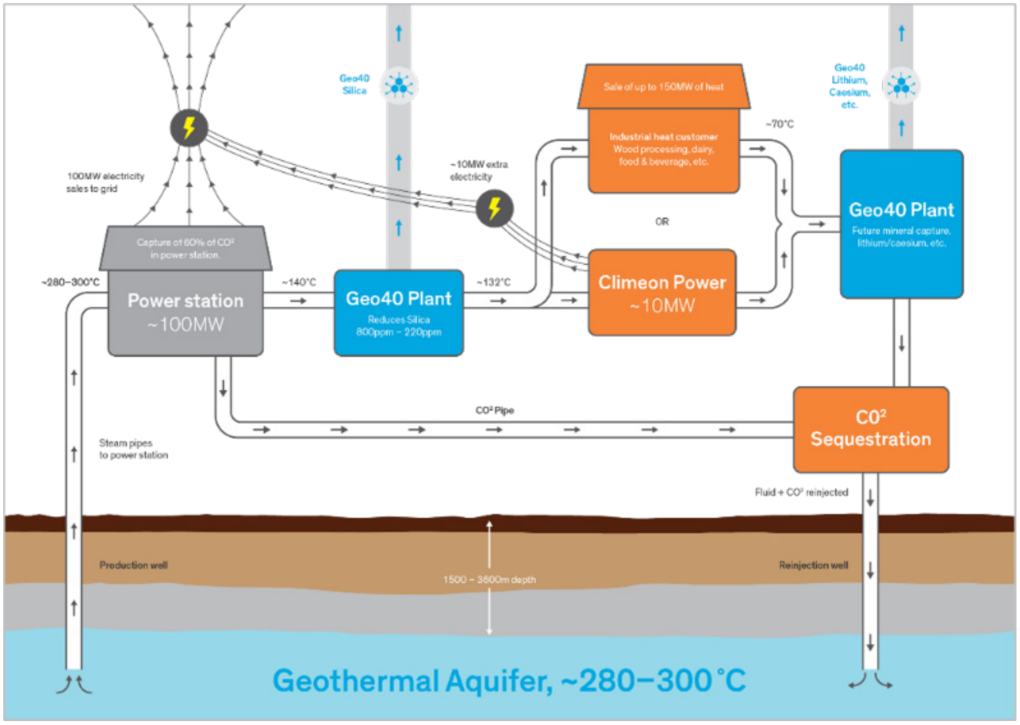


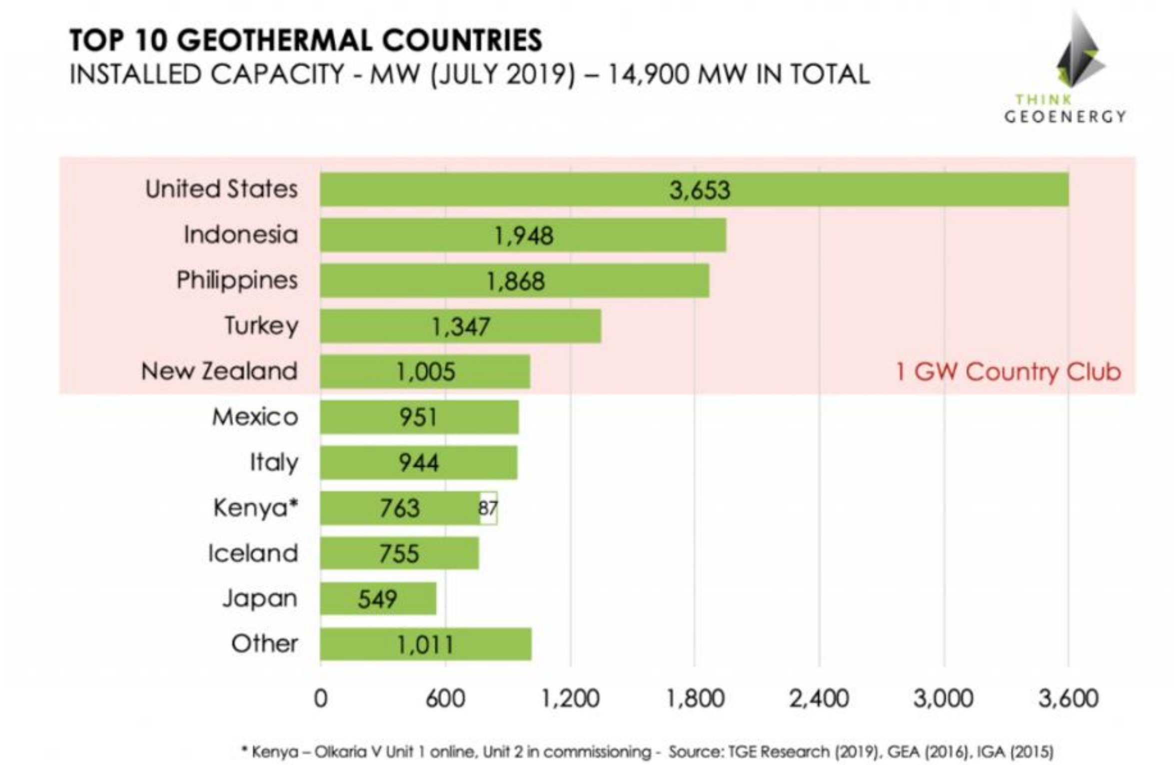
Figure 14: Diagram of Geo40 processes and added options when installed

1. Hot geothermal water is pumped to the surface from the geothermal aquifer.
2. Hot geothermal water enters the power station. Geothermal operator generates electricity, from the steam, to sell into the grid.
3. Geothermal water flows on to the Geo40 plant. Silica is harvested, removing it from the water and allowing Geo40 to obtain silica and minerals to process into products.

4a. Geothermal water flows on to a partner plant, generating heat to sell to industrial heat customers, OR;

4b. Geothermal water flows on to a Climeon partner plant, generating an additional 10MW of electricity.

5. In the future, geothermal water flows on to another Geo40 plant, where lithium and caesium are harvested for Geo40 to sell.
6. Geothermal water flows on to a partner plant that enables carbon sequestration.
7. Geothermal water is reinjected back into the aquifer.



Global Geothermal Power Generation Capacity - 29 July 2019 (source: ThinkGeoEnergy)

Figure 15: Geothermal Power Generation capacity globally

Photo: New 5,000-10,000 metric tonne capacity colloidal silica plant under construction in NZ

Summary

Colloidal silica is an important component in investment casting. The nanoparticles of silica are used in the mould systems as a binder and to help provide a high-quality finished surface on castings. The technology used to produce current colloidal silica products used in investment casting was first developed in the 1940s and 1950s.

Over the years, binder systems have evolved to meet the more demanding requirements of investment casters and their customers. However, the base process for producing the majority of the nano sized colloidal silica particles has not changed much.

The process starts with silica in the form of quartz sand and uses high amounts of energy to first convert this to a more soluble form, called water glass, and then further energy to get the silica dissolved into water to process into the nano sized particles of colloidal silica. Further processing is required to grow the particles to the right size, particle distribution and trace mineral content.

For millions of years, nature has been doing this right under our feet. Heat from the earth's core has been heating water under pressure in the earth's crust and dissolving silica and other minerals. Nature's forces have brought this water to the surface creating natural geysers and bubbling hot springs with the silica depositing out as natural silica terraces at these features all around the world.

The team at an innovative company in New Zealand, observed this phenomenon and in 2010 set about utilising this natural source of dissolved minerals to harvest and produce sustainable high-quality products.

The process involves working in symbiosis with the geothermal power industry to take hot geothermal water, used for renewable power generation, cool this as nature does and harvest the resulting minerals as they come out of solution in the water. Further processing, using conventional colloidal silica growth technologies has resulted in a new generation and sustainable way for producing sustainable, high-quality, and competitively priced colloidal silica-based binders for precision investment casting applications.

The added benefit of this has been an improvement in the economics and power output of renewable and sustainable geothermal power production.

INVESTMENT CASTING INSTITUTE

Life Cycle of Our Ceramic Shells

John Slawvey
Vestshell, Inc.

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 9

Life Cycle of our Ceramic Shells

In 2014, Vestshell decided to adopt a Sustainable Development program. Looking at this program, we understood it would help Vestshell to be more environmentally friendly and be a better and greener investment casting foundry. Vestshell is certified ECO-responsible level 1.

The second life of our waste products has helped Vestshell reduce our materials that we send to the landfill. It has also helped in reducing our operating costs for the benefit of our customers. It also has a large impact on the environment by reducing CO_2 emissions, reducing vehicles on the road and saving trees.

With some research and help from recycling companies, most foundries can do the same as Vestshell.

Many of our customers have Sustainable Development programs in place. Since 2014, the efforts we have taken have helped Vestshell gain higher visibility with them as we contribute in helping them reach their corporate goals and to create a more sustainable supply chain.

Vestshell has adopted the Sustainable Development program that is now part of our culture, corporate goals and yearly planning.

INVESTMENT CASTING INSTITUTE

INVESTING In The Future

Jack Ziemba
Aristo-Cast, Inc.

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper No. 10

ARISTO CAST
INVESTMENT CASTING

INVESTING in the future

For a process that's approximately 6000 years old it never ceases to amaze me the refinement that has taken place in the last 15 years. We've gone from very rudimentary injection molds to a very sophisticated tooling that we use today. We've gone from machinable wax being utilized for one off patterns to the ability to use additive manufacturing equipment to print very complex patterns in a wide variety of materials which are all compatible with the investment casting process. The advent of metal printing has encroached into the investment casting market.

As owner of Aristo-Cast Inc. and a member of the Additive Manufacturing Users Group (AMUG) we're going to get that business back using the P.I.C.S. (Printed Investment Casting Shells) process, a method that revolutionizes the traditional investment casting process. This is accomplished by printing the ceramic shell directly from cad data, eliminating the need for wax injection molds to create the patterns and the skill to dip the critical early coats of ceramic shell. The P.I.C.S. process allows even the most complex interior design to be cast successfully.

With speed, accuracy and cost as our goals we intend to show the progress we have made. We have successfully been able to print a ceramic shell that will reduce the time and cost of investment casting prototypes and in the future….production.

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Quality System Certified to: AS9100:D / ISO9001:2015

INVESTMENT CASTING INSTITUTE

Industry Viable Strategic Tooling Enablers for MRB Elimination

Donald Deptowicz
Aspen Hybrid Technology Solutions, LLC

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 11

Industry Viable Strategic Tooling Enablers for MRB (Material Review Board) Elimination
Abstract for 67th Technical Conference and Expo

Donald L. Deptowicz/Ronald J. Rudolph
Aspen Hybrid technology Solutions, LLC

1.0 Introduction

Investment casting tooling is extremely expensive and time consuming to manufacture as well as to repair. This is especially true for high pressure ceramic core dies where the question often comes up as to where, within the allowable tolerance band, should the die be targeted. If the focus is on maximizing tooling life, then the smallest tolerances are used (since die wear will only increase these dimensions over time). Unfortunately, this can result in a significant increase in MRB activity at both the casting house and OEM due to the increased likelihood of having many castings fall out of specification. Another other option is to target closer to nominal tolerances, but this is at the expense of tooling life. On top of these concerns, quite often the MRB cores are sent off to the wax room for repairs by hand in an attempt to save them, which often results in further downstream MRB activity for both companies. What if a core/wax die had more or less no surface roughness to create friction, resulting in lower ceramic slurry injection pressures and making the die easier to fill, even for the smallest feature? With 10x lower friction than Teflon, the STS coating system will result in fewer green core MRB related issues. A DLC coated commercial core die was Beta tested and preliminary results showed a *dramatic reduction, if not the elimination of core die wear*. Core dies can now be targeted at the nominal tolerances, since tooling wear is no longer the primary concern. The Surface Treatment System (STS) is the one and only three step coating system that can be used to improve the durability of nearly a limitless number of products. From increasing the hardness and life of casting core dies, cutting and drilling tooling, shafts, gears, gas turbines for the airline and power industries, medical instruments and lenses to name just a few of the nearly endless list of application possibilities. Another parallel initiative that is in development to support further (and possibly even more significant) reductions in investment casting core related MRB activity, is the co-development of a new core system that has significant improvements to green strength, shrinkage, firing temperature and duration that also requires no setters!

2.0 The Cost of Quality

The cost of quality can have a significant impact on a company's Return On Investment (ROI) as reported by David Garvin[1] , "Quality on the line" stated that a 1983 survey of U.S. companies in ten manufacturing sectors found that total quality costs averaged 5.8% of sales. This means that if a \$1 Billion corporation reduced quality costs by one tenth of one percentage point, it would save \$1 million annually. Other studies show the direct cost of good quality to a company's ROI can be significant. In the same article, David states that for businesses with less than 12% market share, those companies with inferior product quality averaged a ROI of 4.5%, while an average quality product had a 10.4% ROI, and a superior quality product producing a staggering 17.4%

ROI. What this means, is that there is a significant opportunity for increased profit margins, improved product reliability, and reduced warranty costs for the OEM.

3.0 No Single Surface Measurement Technique Captures all Surface Profile Information

Surface roughness is typically not even thought about when we purchase a product. It is also not typically known is that there are many different ways to look, measure and calculate surface roughness. Figure 1 below show two of the more well-known and two of the lesser known surface roughness measurement methods. R_a is the primary surface roughness measurement method used in the U.S., while R_z is the primary method used in Germany. The two lesser known surface roughness measurement techniques R_{pk} and R_{vk} have become more and more recognized as manufacturers are coming to have a better understanding that paying attention to surface roughness can lead to cost reductions. Rp and Rpk are of special interest for the thin DLC coating since it is important for coating integrity that no sharp peaks protrude through the coating, since the uncoated material can lead to early base material degradation. A closer look at the figure 1 below shows that the Ra measurement method doesn't capture either the surface roughness peaks or valleys. The Ra method eliminates the fewer high and low points, and generates an average surface roughness profile based on the remaining information. That's is why we have typically neglected surface roughness in the U.S., because the method used to calculate Ra ignores them.

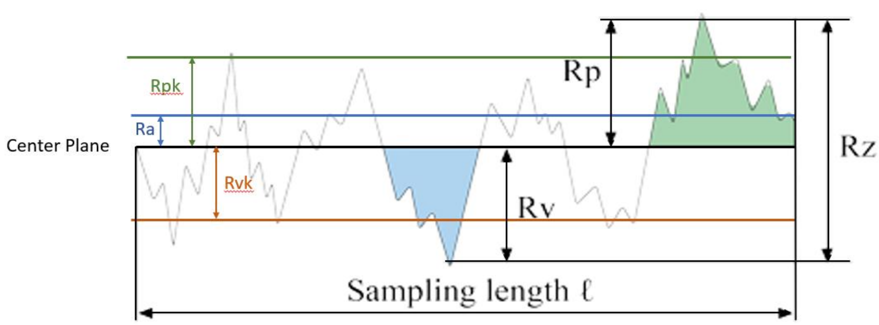

Figure 1: Example of Several Surface Roughness Measurement Methods

However, depending on the thin film application technique used in the manufacturing process, these peaks can easily penetrate the coating, leaving an opportunity for external attack. The coating attack can be started by chipping off that high feature leading to early erosion of the exposed base material, coating loss and eventually early tool repair or replacement. It is also easy to see how the deeper valleys can harbor foreign material, such as chlorides and oxides that if left on the material surface, will begin to attack the substrate and coating from within.

4.0 STS Process Overview

The Surface Treatment System (STS) three step process solves many of the limitations of current coating systems.

The first step of the three step STS process is the rapid and simultaneous removal of surface contaminants, including metal-oxides and corrosion products with a laser ablation system that does not affect the underlying material. This surface preparation process has been demonstrated on both ferrous and non-ferrous metals, as well as composite materials and is used in production today.

The second step is a surface treatment system that will significantly reduce the surface roughness while not re-contaminating the surface in the process, as most surface finishing processes do.

The third and final step is the application of a thin film vapor deposited carbon coating, called Diamond-Like Carbon (DLC). Even if one of the three steps can't be completed, the application of any of the three steps will still improve the product. The complete three step STS process results in an omniphobic (meaning that nothing will stick to it), extremely durable surface finish with 10x lower friction than Teflon which oils, machining chips, ceramic mixtures, etc. will not stick to, resulting in a nearly self-cleaning surface that provides significantly reduced friction, improved wear resistance and life of numerous consumer products.

4.1 Laser Ablation System Process

A typical laser ablation system pulses on and off between 10,000-25,000 times per second resulting in a vaporization of any surface contaminants that have accumulated during the manufacturing and post manufacturing processes. The remaining chlorides, oxides, oils and cleaning solvent residue lie within the valleys left over from the manufacturing process are completely eliminated. Depending on the specific material being used for the tooling, the material surface can be left in what is called a "passivated" condition. Tests conducted by the U.S. Navy have concluded that the "laser process is effective in removing chloride contamination from grit-blasted surfaces and that this results in substantial improvements in the corrosion resistance of the coatings that were applied to laser-prepared surfaces" as compared to non-laser ablated steel and aluminum used for surface war ship construction.

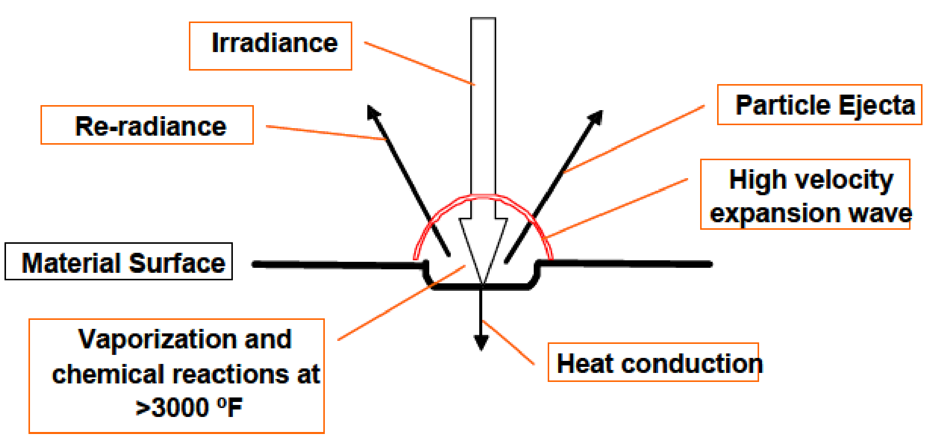

Figure 2: Example of Typical By-products of Laser contacting Substrate Material Surface

Figure 3 below shows how significantly different the surface of these scrap commercial jet engine CFM-56 fan and compressor blades look after the laser cleaning process has been completed.

Figure 3: Laser Ablation cleaned CFM-56 Fan and 1st Stage Compressor Blades

The yellow circled areas in Figure 3 are the locations where the laser ablation cleaning was not conducted. The larger fan blades took approximately 2 minutes to clean completely, so the process is simple and fast.

4.2 Surface Micro Finishing Process

The micro surface finishing system has several primary roles in the three step STS application process. Firstly, to significantly reduce the highest surface features which if left as is, will result in those peaks protruding outside of the thin Diamond Like Carbon (DLC) coating, which is ~2 µm or 0.000078 inches thick. Secondly, there can't be any loss of base material and thirdly, to not re-contaminant the surface after the laser ablation process. Figure 4 shows an example of one of several scrapped CFM-56 commercial aircraft engine test airfoils that are currently being processed using a variety of micro finishing process to support process optimization. The key is reduced variation.

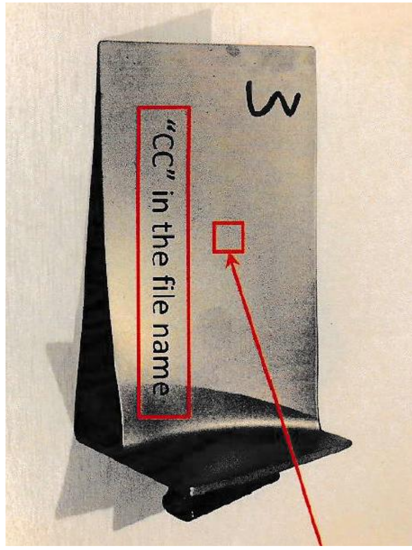

Figure 4: CFM-56 1st Stage Compressor Blade High Resolution Scan Location

Figure 5 is a high-resolution scan of a section of the airfoil prior to micro finishing. Note that there are two sets of results, the top figure is a surface scan over the entire target area (as noted in figure 4), while the bottom figure is a 2D line scan along a section in the target area. What is of most interest in figures 5 and 6 for the STS process are the high, sharp machining peaks, (which is best represented in the lower figure) and the Rpk value found in those tables on the right.

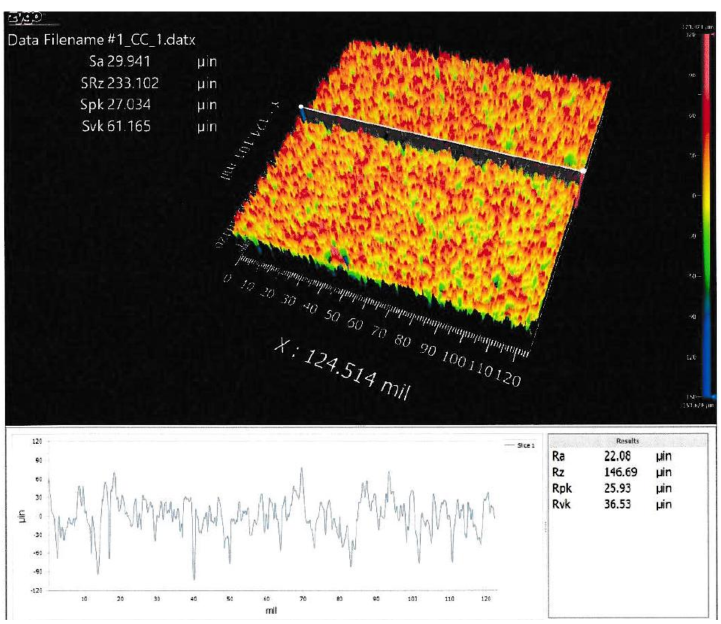

Figure 5: High-Resolution Scan prior to Micro Finishing

Figure 6 is a high-resolution scan of a section of the airfoil after micro finishing. It should be noted that the scales are different between figure 4 and 5, so an absolute comparison is difficult. However, Rpk was reduced by roughly 5x (from 25.93 to 5.67 micro-inches) as compared to the pre-micro finishing scan, and possibly just as important is that the sharp peaks have been eliminated. Depending on the final review of the ~20 CFM-56 fan and compressor airfoils that will have gone through the STS DOE process, further optimization is likely and may also need to be optimized for each specific STS application?

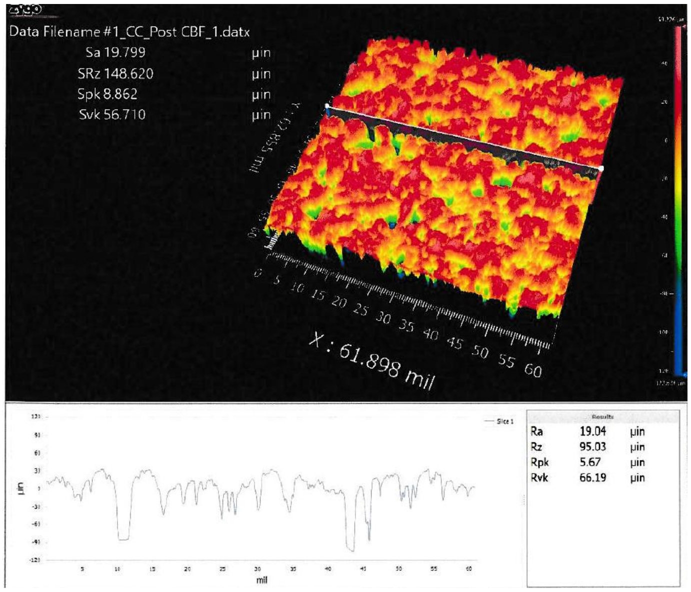

Figure 6: High-Resolution Scan after Micro Finishing

Figure 7 is a comparison of several endurance tested compressor airfoils that were only cleaned (shown on the left) and several other airfoils on the right that went through both the cleaning as well as micro finishing process. The progression of the quality of the airfoil surface finish going from left to right is amazing in the photo and even more so when one is in your hand! Several micro finishing studies were conducted early on and it was found that if a component is left in the micro finishing machine for too long, the surface finish becomes so smooth that the adhesion strength of the original coating system was reduced so much that the hardware needed to be roughened up.

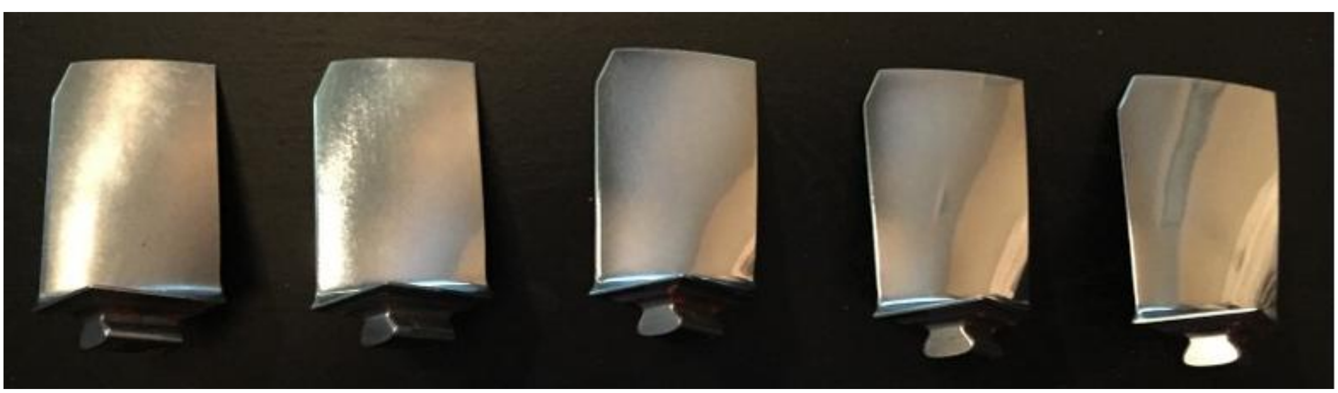
Figure 7: Comparison of Cleaned and Cleaned / Micro Finished Compressor Airfoils

4.3 Dimond Like Coating (DLC) Application Process

The Diamond Like Carbon (DLC) coating uses a "Plasma Enhanced Chemical Vapor Deposition" (PECVD) process that was originally developed as an inexpensive thin film coating application process. Many of our everyday high-volume commodity products use the PECVD process to apply the coatings. The DLC coating was originally developed to support the need for a protective coating to be applied to the various Infra-Red (IR) lenses of U.S. military fighter jets operating in the Middle East. DLC coating has been applied to the IR targeting pod on the Navy's F18 fighter jets. In addition, the DLC coating has been applied to every one of the +20 lenses on the Air Force F-22 air superiority fighter (Figure 8), with over 10,000 lenses coated to date. It is also interesting to note that there hasn't been a single lens returned for DLC coating re-application.

Figure 8: F-22 Fighter with both P&W F119's in full afterburner

The version of the DLC coating that is used for our STS coating has been specifically modified for use on metallic products with the addition of an adhesive layer that is applied prior to the DLC application resulting in a 0.000078-inch total coating thickness (as a comparison an average human hair is around 0.003 inches in diameter). For improved durability it is important to keep the DLC coating as thin as possible to make sure that it remains sufficiently flexible to allow for hardware thermal expansion as well as any micro deformation that may occur under operating conditions.

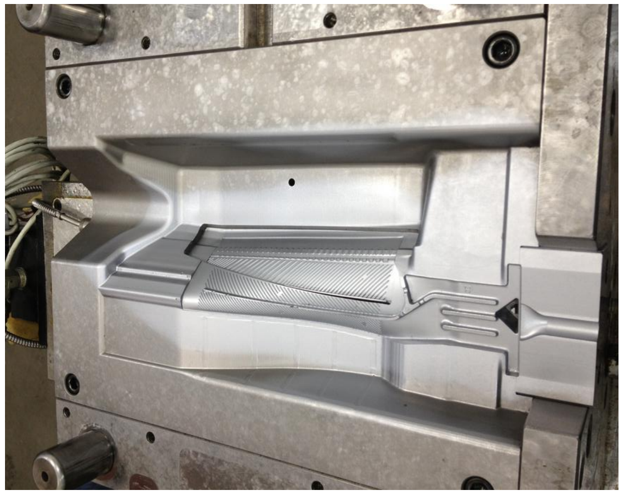

Figure 9: Photo of the core die used in Beta testing without DLC coating applied

The version of the DLC coating that is used for our STS coating has been specifically modified for use on metallic products with the addition of an adhesive layer that is applied during the DLC application. For improved durability it is important to keep the DLC coating as thin as possible to make sure that it remains sufficiently flexible to allow for hardware thermal expansion as well as any micro deformation that may occur under operating conditions. As mentioned previously, the DLC coating has been Beta tested at an investment casting OEM on core die tooling as shown in Figure 9. These initial results showed a dramatic reduction in core die insert wear, and with the complete three step STS process, the improvements are expected to be even more impressive.

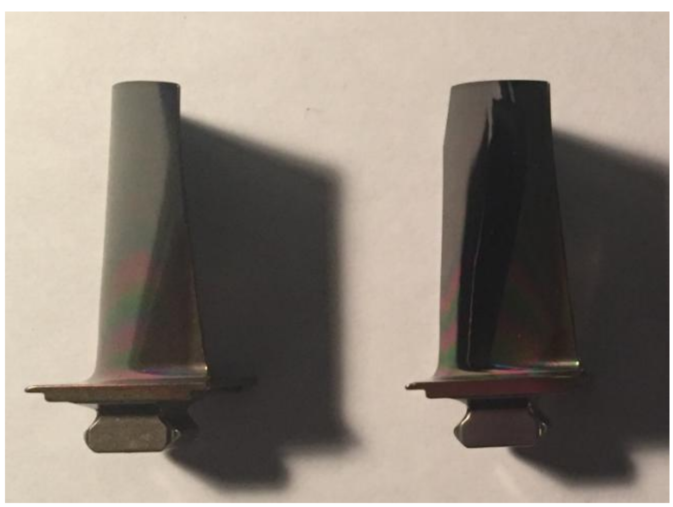

Figure 10: Example of DLC Coated Compressor Airfoils for NASA Glenn

Figure 10 shows several early DLC coated compressor airfoils that NASA Glenn requested to be coated for their review. However, these airfoils did not go through either the laser ablation or micro finishing processes prior to the application of the DLC coating. As indicated earlier in this paper, the current group of ~20 fan and compressor airfoils are going through the entire three step process and are now at the DLC coating vendor.

5.0 Conclusion

The Surface Treatment System is the only three step process that focuses on surface contamination and roughness, coupled with a nearly impervious Diamond Like Carbon (DLC) coating system. In order to get the full benefit from the STS coating, all three steps are needed to adequately address the primary issues associated with tooling wear, and the costly MRB activity that typically results from worn tooling and dies. However, by eliminating any of the remaining surface contaminants, any existing coating will likely benefit with increased durability and longer life, as was concluded in a report issued by the Navy which stated the following, the "laser process is effective in removing chloride contamination from grit-blasted surfaces and that this results in substantial improvements in the corrosion resistance of the coatings that were applied to laser-prepared surfaces". Secondly, by reducing the surface features that remain after the manufacturing process, the significant reduction in friction related forces that are encountered every day in the investment casting and manufacturing processes will occur. By reducing surface roughness, tooling wear will also be reduced, resulting in a reduction in MRB related activity due to worn dies and tooling. As stated previously after the application of the DLC coating, the surface has 10x lower friction than Teflon and becomes omniphobic (meaning that nothing will stick to it). It is not hard to imagine how much less energy it will take, and therefore, how much less of a concern tooling and die wear related issues will be by such a significant reduction in surface roughness. Separating multi-pull plane core dies will be significantly easier due to the lower surface roughness, and especially important for the newer cores containing multiple fine features that often require rework and repair activity. This extremely durable DLC coating was developed specifically to address a serious issue with sand related damage to the lenses on high speed military fighter jets targeting hardware operating in the Middle East. The application of DLC coating eliminated 100% of the dirt and foreign object wear on these lenses, with not a single lens being returned for damage or loss of coating to date. The STS application process has combined several proven and existing technologies together to form a truly remarkable system that has yet to find all of the applications where this product can be utilized.

As mentioned earlier, there is also the co-development of a new ceramic system that has several unique properties that when coupled with the STS coating system, could provide even more of a significant reduction in quality related issues in the investment casting industry, thereby resulting in an overall improvement in OEM product performance and reliability.

5.1 Next Steps

- Need to review surface roughness **test** results to determine how each variable impact's surface roughness reduction.
- Need to verify that the DLC coating conforms to the more rounded peaks and if further micro finishing is needed.
- Conduct STS durability testing on existing STS coated CFM-56 compressor airfoils.
- Conduct STS Beta testing on a commercial tooling.
- Conduct STS Beta testing on selected cutting tools for durability evaluation?

6.0 Definition of Terms:

- **Beta test** Typically the first limited duration test of a new product to see how well it performs
- **DLC** "Diamond Like Coating"
- **MRB** **"**Material Review Board" is an industry term for a manufacturing deviation that needs to be reviewed in more detail
- **OEM** "Original Equipment Manufacturer"
- **Omniphobic** A surface that nothing will stick to
- **Passivation** The final cleaning process used to reduce the chemical reactivity of the surface, typically resulting in improved corrosion resistance
- **PECVD** " Plasma Enhanced Chemical Vapor Deposition"
- **STS** "Surface Treatment System" the three-step patented coating system
- **R_a** Most common surface roughness method used in the U.S.
- **ROI** "Return On Investment"

- **R_{pk}** “Reduced Peak Roughness”
- **R_{vk}** “Reduced Valley Roughness”
- **R_z** Most common surface roughness method used in Germany.

References:

1) David A. Garvin, Quality on the line, September 1983 Harvard Business Review

INVESTMENT CASTING INSTITUTE

Casting Simulation: An Aid To Address Industry's Covid-19 Challenges

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Stephen Barnett – INCAST Consultancy

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 12

CASTING SIMULATION: AN AID TO ADDRESS INDUSTRY'S COVID-19 CHALLENGES

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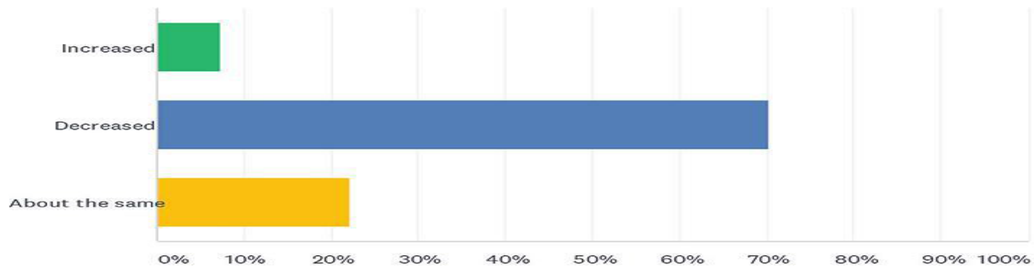
Key words: Simulation, Yield, Quality, Trials, Savings, Optimization

In most parts of the world, the Foundry industry is cost-intensive; in many, it is also labour-intensive. Apart from the obvious manifest costs such as energy and material, the not-so-obvious latent costs of wastage are substantial. In today's Covid-19 driven economic downturn, it has also become a reduced-demand industry. A JULY2020 Poll of 27 foundries by the AFS showed that over 70% reported a decrease in business over the previous month; a respondent said "it will take a year or more to return to pre-pandemic levels" [1]:



To quote Stephen S. Pilbury: *"Overall, the Global market for PIC is overwhelmingly recessive. It is far too early to see light at the end of the tunnel, even though some foundries are returning to work, orders are uncertain, and production is far from a normal operating rate."* [2]. Scarcity of working capital due to the banker's reticence to lend coupled with supply chain disruptions are adding to the foundryman's misery.

How does one cope? Often, the answer lies in looking inwards. In the words of Sanjay Shroff: *"In these trying times, introspection is the only option, affording scope for course correction in order to survive. Agility and nimbleness would be of paramount importance"* [3]. Since the not-within-our-control externalities are becoming increasingly stringent, the foundryman needs to focus on that which is within his control, *i.e.* on the internal factors wherein costs can be saved.

Minimization of specific consumptions of energy, material and labor, elimination of shop trials and production disruptions, prevention of as-cast defectives, and a sustained state of Every Time Right: these quality outcomes directly yield cost savings, apart from other benefits. As Philip B. Crosby says: *"quality is conformance to requirements; it is precisely measurable; error is not required to fulfill the laws of nature. Quality improvement (is) through defect prevention."* [4]. Probably never before has the old adage "Prevention is better than cure" been more relevant than in today's pandemic and stressed-economy situation.

The goals of quality and yield improvement, and most critically, defect prevention and elimination of trials, are not well served by manual systems alone; the latter do not hold a promise of significant mitigation of the situation. Computer-aided simulation and methoding systems are the need of the hour. By enabling correct understanding of the casting's behaviour, by delivering accurate methoding, and by virtual confirmation of the given method design, all

before actual production, physical trials are eliminated while optimizing yield and achieving the desired quality.
Of the various functional areas in a Foundry – in design, production and finishing, the most vital is methoding; it is directly linked to the quality of the end product, to yield and to shop trials. Moreover, it is the most significant factor that is almost completely within the foundryman's control. For a method to be effective and robust, *i.e.* consistently deliver defect-free castings, it is imperative that it is "accurate" in all aspects of the design, while factoring in the foundry's constraints and capabilities. This necessarily implies a computer-aided approach, as manual means by themselves are prone to error.

We therefore focus on design and improvement of methods using computer-aided tools such as simulation systems. Use of a Simulation & Methoding System helps the foundry in improving and assuring quality, improving yield, reducing /eliminating shop trials and making the method robust – outcomes that directly contribute to reduction in overall operating costs: an important goal to achieve during these Covid-19 times.

We present a few Case Studies that illustrate the positive impact on cost savings resulting from defect prevention, quality and yield improvement, and elimination of shop trials, with the aid of a simulation and methoding system. The Foundry Collaborators for this Paper are: Magyarmet Bt., Bicske**,** Hungary, and three Units in Rajkot, India: Delta Technocast Pvt Ltd, Micro Melt Pvt Ltd, and Rainbow Technocast.

1. Developing a New Component using Casting Simulation as an aid

This Case Study illustrates the benefits of virtual manufacturing through simulation of a new product before shop floor implementation. The Hungarian Foundry's challenge was to develop a new large component in the investment casting process, with no tooling supplied, with very little drawing details specified and no CAD files at all. The component (refer Fig. A1) was required to be manufactured in Hastelloy® according to aerospace quality standards.

The customer supplied only a finished cast component. With the help of physical measurements and casting simulation, a soft structure was created. With this information it was possible to obtain a working procedure for the manufacture of the component. It was essential to carry out a casting simulation as otherwise the high number of metallurgical defects and shop trials would have increased the overall manufacturing cost. Further, the loss of time due to possible high reject rate would have jeopardised the project's delivery time. The component's finished weight was 40 kg. Seventeen components were required as replacement spares for a ground turbine aero engine.

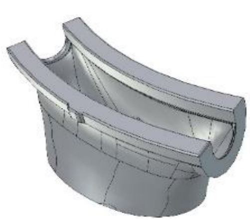


Fig. A1: The 40 kg Hastelloy® aerospace component

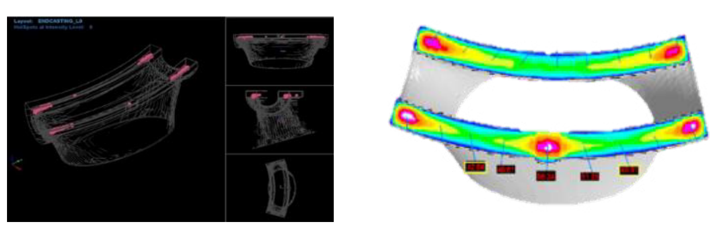


Fig. A2: Casting Simulation

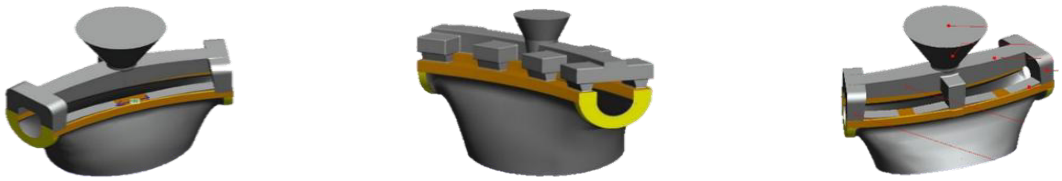


Fig. A3: Methods developed

Fig. A4: The final method adopted

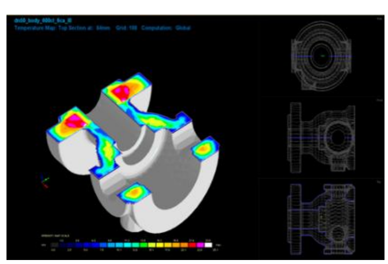
Fig. A5: End Casting: The savings resulting from simulation

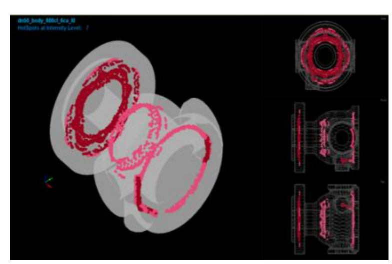
This END CASTING component required a dye penetrant test and 100% X-Ray to be defect free. Using a simulation software, a few methods were developed and simulated (Figs. A2, A3) before adopting a final casting technique (Fig. A4). Based on past experience with manual design, it was initially envisaged that 30 components would need to be made to supply 17 certified castings to fulfil the order requirement.

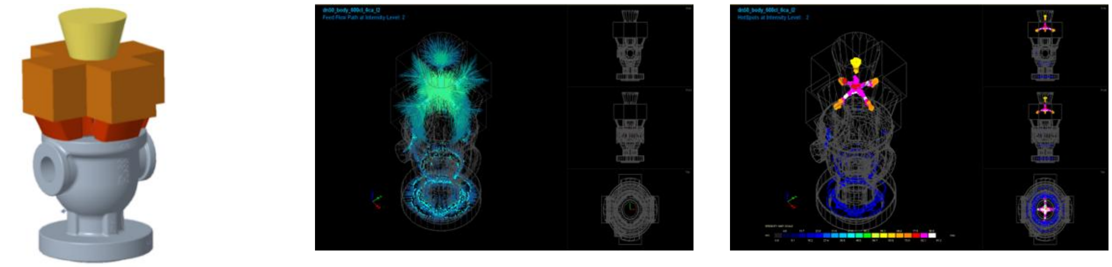
However, with the simulation and methoding system in place, a total of 23 components were made, allowing for an extra six castings for contingencies. Use of the casting simulation software enabled proper method design and resulted in 1st Time Right of 100% as-cast OK castings. The Trees were also simulated to check their efficacy. The only reason for the extra castings was as a buffer against breakage /damage of the assembly due to the difficulties in handling. By manufacturing seven less components, the saving was €15,366 on material cost alone (Fig. A5) [Note: Labour time & cost have been excluded for commercial reasons]. This justified the Foundry's use of a casting simulation software.

2. Quality (& Yield) Improvement using Casting Simulation

This project at one of the IC Foundries at Rajkot was aimed at Quality Improvement (QI). The first method, developed for a new casting order, did not deliver the required quality, leading to considerable rejection of the ~14 kgs VALVE BODY castings, with L4-L5 defects.





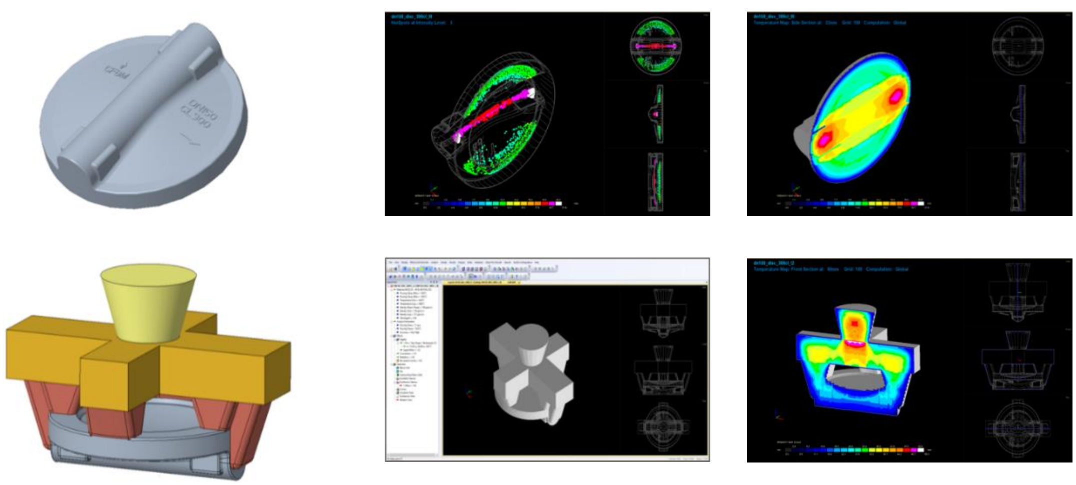


Figs. B1/1 – B1/6: BODY Casting & Tree Simulation & Development

The new method, designed after simulation, and with mapping of shop floor results onto simulation results from the 1st iteration, delivered 100% acceptable castings. [Ref. Figs. B1/1 – B1/6]. The main improvements made were a change in orientation and in a gate and feeder bar. This improved design was implemented without further shop floor trials. Primarily a quality improvement project, it also resulted in a slight Yield Improvement (YI), from 38.65% (the first method) to 39.37% (the 2nd method, designed from simulation). The improvements resulted in a saving of ~ $500.

3. Yield Improvement using Casting Simulation

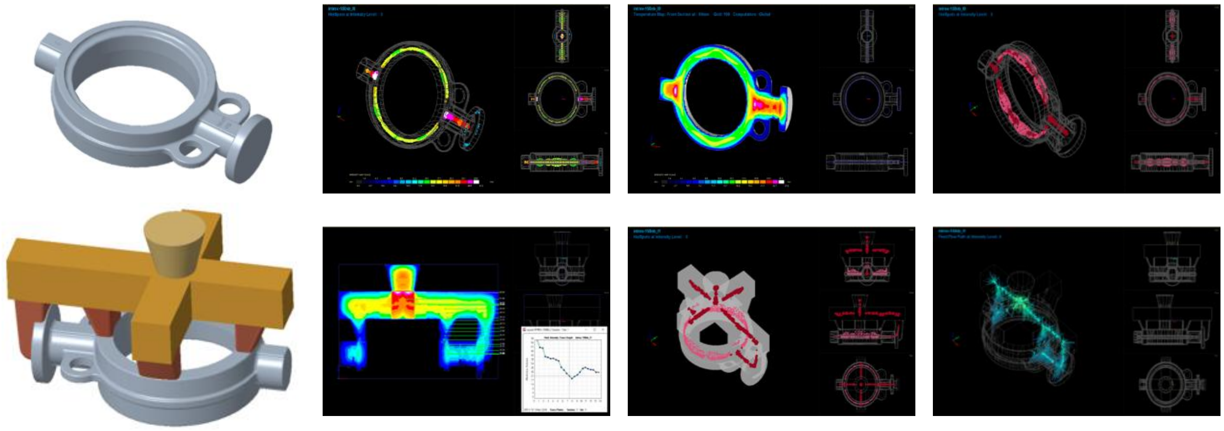
This project was performed at the same IC Unit as above. Two Tree designs were developed for a new casting order. Whereas the quality achieved for this ~3.5 kgs DISC casting was acceptable in both cases, the Yield was higher in one Tree design by about 3.5%. [Ref. Figs. B2/1 – B2/6]. This better design, of ~35.5% yield, resulted from an optimized gate and feeder bar as concluded from the simulation results, and was implemented without any shop trial. The improvements resulted in a saving of ~ $635, on account of higher yield.



Figs. B2/1 – B2/6: BODY Casting & Tree Simulation & Development

4. New Product Development using Casting Simulation

The third case study from this same IC Unit was a New Product Development (NPD) case. Simulation of this 8 kgs BODY casting and subsequent method development on the computer [Ref. Figs. B3/1 – B3/8] yielded 1st Time Right; the castings were produced without any shop floor trial. Elimination of shop trials resulted in a saving of ~ $95 for this casting project.



Figs. B3/1 – B3/8: BODY Casting & Tree Simulation & Development

5. Summary of the three Case Studies from each of the three Rajkot Foundries

Three Case Studies were taken up at each of the three participating IC Units in Rajkot: one each of NPD, QI and YI. A brief description of each of these cases at one of the Foundries is given in Sections 2, 3 and 4 above. Similar briefs may be noted for the cases in the other two Foundries.

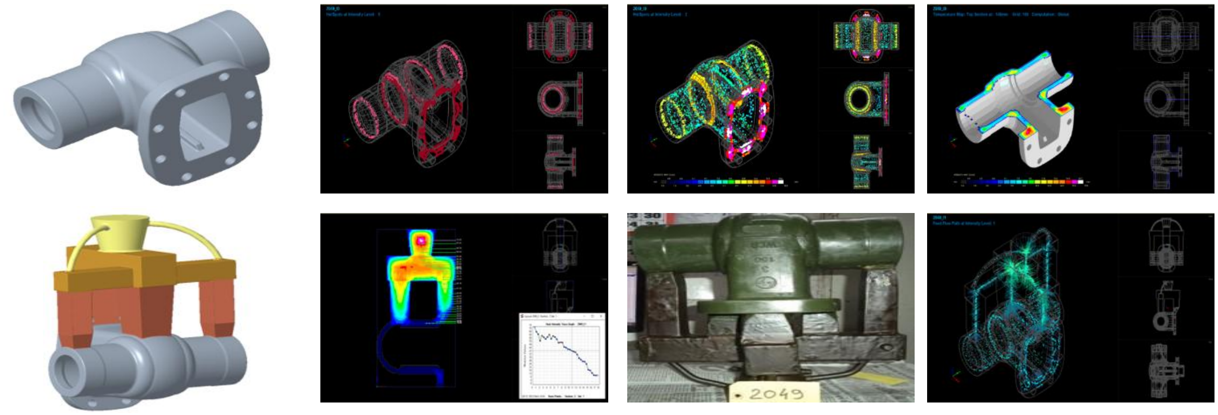
6. Financial Gains secured by the Rajkot Foundries in their specific casting projects

We present a Summary of some key information of all the nine casting projects (in Tables 1, 2 and 3 below – relating to the specific casting projects at each of these three Units B, C and D), as also the – significant – savings that accrued to the Foundries in each case.

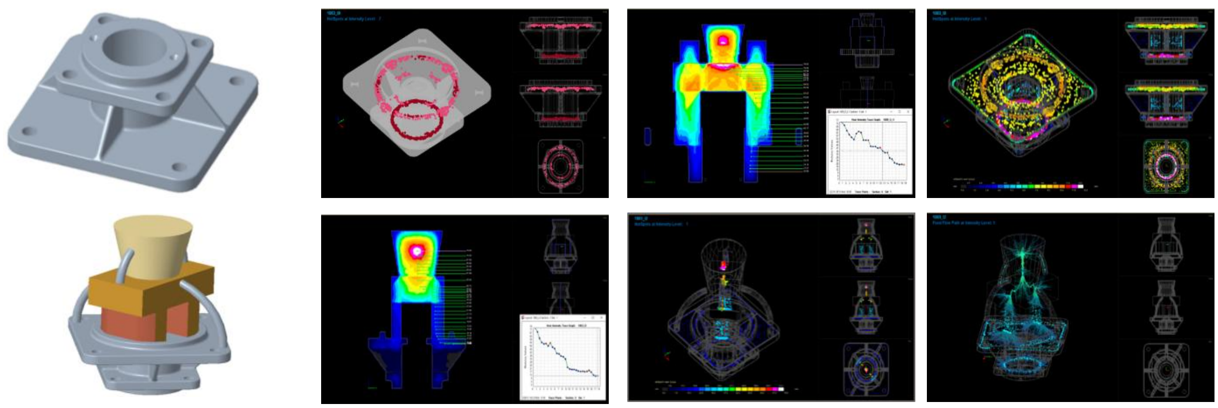
Table 1

UNIT B	NPD	QI & YI	YI
Casting	**3" GTV Body # 150-Butt Weld Cast**	**STUFFING BOX S**	**DRIVE SHAFT YOKE SERIES**
Metal /Alloy	WCB Carbon Steel	Stainless Steel CF8	Stainless Steel CF8M
Weight (kgs.)	14.56	4.60	18.03
Thickness Range (mm)	9 to 22	5.12 to 23.50	10.76 to 29.21
Order Quantity (Nos.)	200 / Month	250 / Month	50 / Month
Quality Test Reqd.	RT	RT	RT
Qualty Level Reqd.	Level 2	Level 2	Level 2
TREE ITERATION	**1**	**1**	**1**
Weight (kgs.)	32.93	11.59	44.42
Quality Level Achieved:	**Level 1**	**Level 3**	**Level 2**
Quality (RT): OK?	**YES - RT Date 23/4/20**	**NOT OK**	**YES - RT Date 19/2/19**
Method Yield %	**44.23**	**39.68**	**40.57**
TREE ITERATION		**2**	**2**
Weight (kgs.)		10.90	44.24
Quality Level Achieved:	**No Shop Trial OR 2nd Iteration; Right 1st Time**	**Level NSD**	**Level 2**
Quality (RT): OK?		**YES - RT Date 18/1/18**	**YES - RT Date 19/2/19**
Method Yield %		**42.19**	**40.75**
TREE ITERATION			**3**
Weight (kgs.)			42.73
Quality Level Achieved:			**Level 2**
Quality (RT): OK?			**OK**
Method Yield %			**42.18**
Improvements made [Tree 2 OR 3 vs Tree 1]:		1) Feeder Ht increased	1) Gate Cross-section increased
			2) Gate Height increased
			3) Gate Corners: rounded
			4) Feeder dimensions reduced
Financial Gain (USD) from Improvements	**No Shop Trial: Savings**	**Annual Savings**	**Annual Savings**
	126	**1,894**	**880**
	Note: Savings due to lesser R.M. and burning loss are omitted in these computations		

UNIT B – NPD: Sample simulation images



UNIT B – QI & YI: Sample simulation images



UNIT B – YI: Sample simulation images

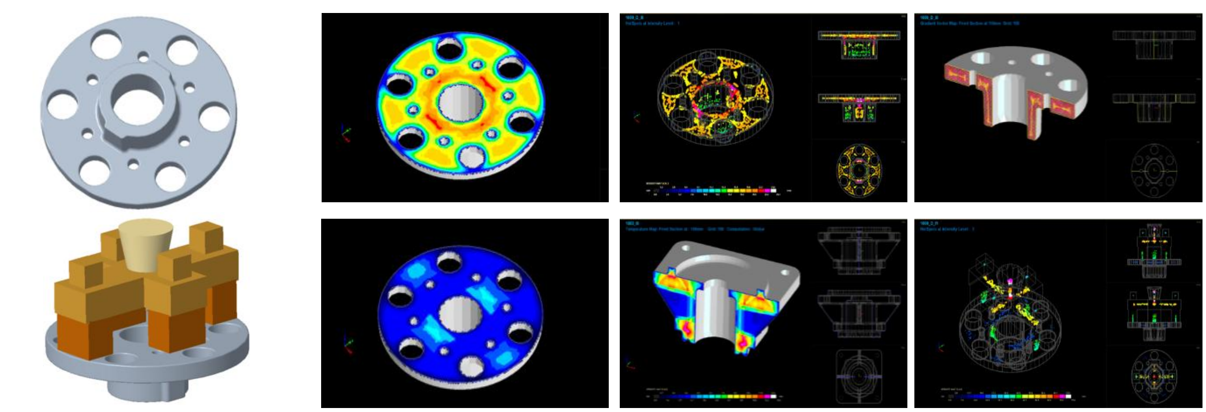
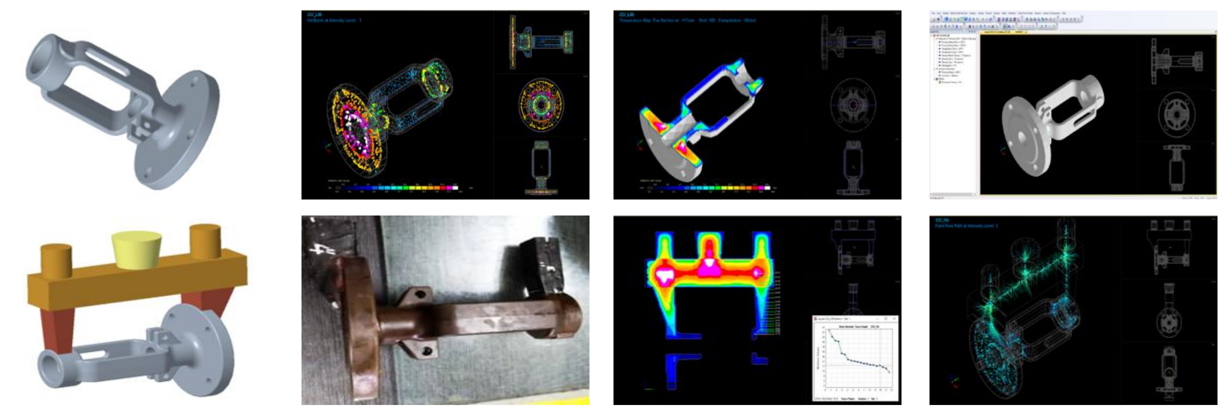


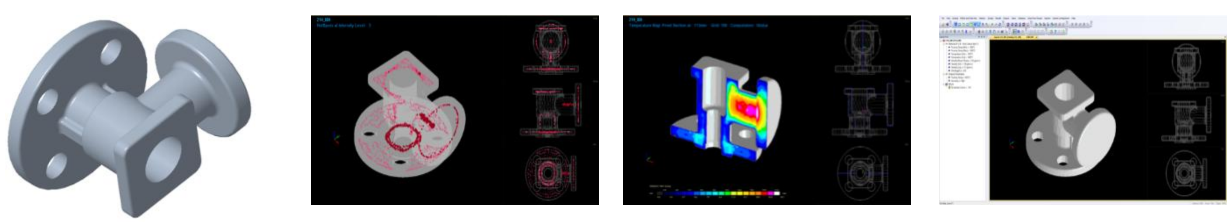
Table 2

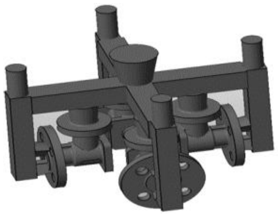
UNIT C	NPD	QI	YI
Casting	**2X300GLVBONNET**	**20FB150BODY**	**80rb150body**
Metal /Alloy	Corrosion Res. CF8M	Steel WCB	Steel WCB
Weight (kgs.)	4.272	1.435	10.695
Thickness Range (mm)	9 to 20.5	6.5 to 32	6 to 30.75
Order Quantity (Nos.)	50 / Month	100 /Month	50 / Month
Quality Test Reqd.	RT	RT	RT
Qualty Level Reqd.	Level 2 min	NSD, Level 1	Level 2 min
TREE ITERATION	**1**	**1 [4 Nos. in Tree]**	**1**
Weight (kgs.)	12.4	15.476	22.088
Quality Level Achieved:	Level 1	**No NSD, Level 1**	Level 1
Quality (RT): OK?	**YES - RT Date 18/7/19**	**NOT OK**	**OK**
Method Yield %	**34.23**	**37.09**	**48.42**
TREE ITERATION	**No Shop Trial OR 2nd Iteration; Right 1st Time**	**2 [4 Nos. in Tree]**	**2**
Weight (kgs.)		15.75	18.963
Quality Level Achieved:		**NSD, Level 1**	**Level 1**
Quality (RT): OK?		**OK**	**RT 9815 1/11/2018**
Method Yield %		**36.44**	**56.40**
Improvements made [Tree 2 vs Tree 1]:		1) Gate size increased 2) Feeder size increased	1) Gate size decreased 2) Feeder size decreased
Financial Gain (USD) from Improvements	**No Shop Trial: Savings**	**No More Shop Trials: Savings**	**Annual Savings**
	76	**146**	**1,898**
	Note: Savings due to lesser R.M. and burning loss are omitted in these computations		

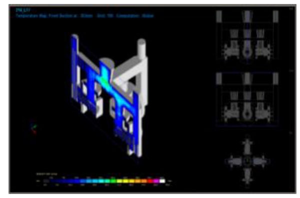
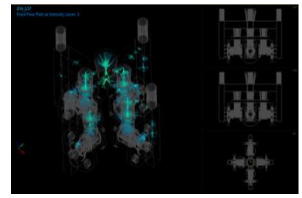
UNIT C – NPD: Sample simulation images



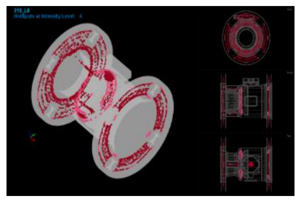
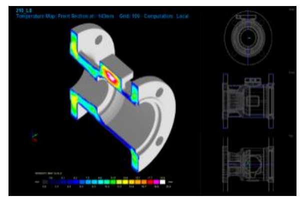
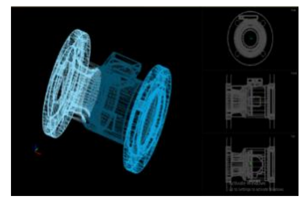
UNIT C – QI: Sample simulation images

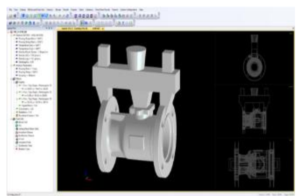


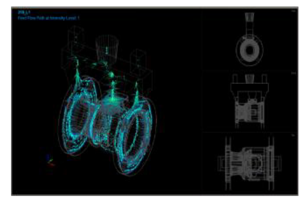


UNIT C – YI: Sample simulation images



UNIT D	NPD	QI & YI	YI
Casting:	DN150_INTREX_BODY	DN50_BODY_600CL_6CA	DN150_DISC_300
Metal /Alloy	WCB Carbon Steel	WCB Carbon Steel	WCB Carbon Steel
Weight (kgs.)	8.01	13.85	3.56
Thickness Range (mm)	10 to 61	12.5 to 60	15 to 46
Order Quantity (Nos.)	100 / Quarter	150 / Quarter	150 / Quarter
Quality Test Reqd.	RT	RT	RT
Qualty Level Reqd.	Level 1-2	Level 1-2	Level 1-2
TREE ITERATION	**1**	**1**	**1**
Weight (kgs.)	21.65	35.84	11.10
Qualty Level Achieved:	Level 1	Level 4-5; gross shrinkage	Level 1
Quality: OK?	YES - RT Date 28/7/19	NO - RT Date 18/1/20	YES - RT Date 16/1/20
Method Yield %	**36.97**	**38.65**	**32.08**
TREE ITERATION		**2**	**2**
Weight (kgs.)		35.18	10.03
Qualty Level Achieved:	**No Shop Trial OR 2nd Iteration; Right 1st Time**	Level 1	Level 1
Quality: OK?		YES - RT Date 4/2/20	YES - RT Date 16/1/20
Method Yield %		39.37	35.49
Improvements made [Tree 2 vs Tree 1]:		1) Vertical To Horizontal 2) Changes as per Orientation 3) Extra small feeder added & Remove One Feeder from previous method , gate Sizes Same Rectangular taper	1) Gate & Feeders Sizes optimized
Financial Gain (USD) from Improvements	No Shop Trial: Savings **93**	Annual Savings **499**	Annual Savings **637**
	Note: Savings due to lesser R.M. and burning loss are omitted in these computations		

Table 3

Refer Sections 2 to 4 for simulation & other images and a write-up pertaining to the above casting projects of Unit D

7. Overall Monthly Savings:

The summary Table below shows the considerable savings that the Foundries derived from the overall Improvements that resulted from the use of a Simulation & Methoding System. These fgures are based on the corresponding Foundry's operating parameters, averaged across their annual production. The estimated savings are derived from the "Before Simulation System" and "After Simulation System" scenarios at each of these three Foundries, as assessed by the corresponding Managing Director /Owner of the Unit.

Table 4

Sl.No.	IC Foundry	Production Capacity (TPM)	Estimated Monthly Savings, USD
1	UNIT B	80	8,316
2	UNIT C	150	8,105
3	UNIT D	130	14,287

8. In Conclusion:

The considerable financial gains that these four IC Units have secured through the use of a Simulation & Methoding System indicate that this could be one way of riding the economic storm created by the current pandemic, or at least of mitigating its negative impacts to a good extent. Assuming that the difficult economic situation could last quite a while, foundries would be well-advised to look into ways and means of reducing costs while meeting customer requirements. Aids such as simulation systems could greatly contribute in these endeavours.

9. Annexures:

A. From the M.D.'s Desk:

The following are brief statements made by the Managing Directors /Owners of the three Rajkot Foundries, in support of Simulation & Methoding Systems:

27/8/20 Mr. Maulik Patel, Mo. +91 99099 23225, Email: maulik@rainbowtechnocast.com:

We are an IC Foundry established in 2007, certified for ISO, AD 2000, PED, and NORSOK M650 AND IBR. We produce around 840 TPA of radiography quality castings for the VALVE, PUMP, FOOD, CAM AND GROOVE, ELECTRICAL INSULATOR FOR NON FERROUS AND GENERAL ENGINEERING industries, We have been using [redacted]' Simulation and Methoding System since 2016, and are happy to state that the System has provided us benefits by way of reducing the number of shop floor trials and enhancing the quality of the castings delivered. We have also been able to increase the methoding yield in general by about 3 to 5% over the period.

28/8/20 Mr. Sachin Patel, Mo. +91 98244 11595, Email: sachin@deltatechnocast.com:

We are an IC Foundry established in 2004, certified for ISO, PED NORSOK and IBR. We produce around 1200 TPA of radiography quality castings for the Valve & Pumps, Automobile, Instrumentation and General Engineering industries, We have been using [redacted]' Simulation and Methoding System since 2014, and are happy to state that the System has provided us benefits by way of reducing the number of shop floor trials and enhancing the quality of the castings delivered. We have also been able to increase the methoding yield in general by about 3% over the period.

27/8/20 Mr. Anuj Patel, Mo. +91 98254 15355, Email: anuj@micromelt.com:

We are one of leading largest lnvestment & Precision Castings manufacturer by Lost Wax Process since 1994, accredited with ISO-9001:2015 Certification by TUV (SUD) & our foundry is approved under Pressure Equipment Directive-2014/68/ E U (P.E.D.) & AD 2000-Merkblatt wo by TUV Nord & l.B.R. (lndian Boiler Regulations) to manufacture Pressure Containing Castings. We produce around 1200 TPA of radiography quality castings for the Valve & Pumps, Auto Sector, Pharmacy, Fire & Safety, Textile, Medical, Defense & Many more industries, including prestigious companies such as L & T Valves Ltd, Shakti Pumps (l) Ltd., C.R.l. Pumps Pvt. Ltd., Mahindra & Mahindra Ltd. (FES), Newage Fire Protection lndustries Pvt. Ltd. and many more. We have been using [redacted]' Simulation and Methoding System since year 2011, and are happy to state that the System has provided us benefits by way of reducing the number of shop floor trials and enhancing the quality of the castings delivered. We have also been able to increase the methoding yield by about 4-5% over the period.

B. Acknowledgements:

1. Collaborating Foundries:

1. Magyarmet Bt., Kanizsai u. 12, H-2060 Bicske, Hungary
2. Delta Technocast Pvt. Ltd., Plot G-1066, Lodhika Indl. Area, Metoda GIDC, Rajkot
3. Micro Melt Pvt. Ltd., Survey No. 196, Plot No. 1 & 2, NH-27, Shapar (Veraval), Rajkot
4. Rainbow Technocast, Survey No. No. 256, NH-27 Shapar (Veraval), Rajkot

2. Contributors:

1. Bharat Davda, CEO, FBC24x7 Foundry Business Centre, Rajkot
2. Shoba Mathai, Director, SoftCAST Technologies Pvt Ltd, Bangalore (STPL)
3. Annie Shibu, Manager (Tech Support & Services), STPL
4. Nimish Vekaria, Marketing & Support Executive, FBC24x7, Rajkot

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COVID-19: The Catalyst to Enhanced Performance

Julie Markee
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COVID-19 - the Catalyst to Enhanced Performance

By Julie Markee, Key Process Innovations

The global pandemic has turned our worlds upside-down. Everything from dining out to educating our children to running our businesses has changed. In the investment casting industry, some businesses have been thriving, while others have struggled to stay afloat. Regardless of the impact, we have all been forced to change the way we do things.

In an effort to minimize the spread of this virus, social distancing in the workplace has become the norm. While this is easily accomplished in some organizations, from a manufacturing perspective, it has presented some challenges, including training employees, safeguarding processes, guaranteeing consistent quality, and ensuring consistent communication between operators and departments.

But, as we know, challenges lead to opportunities. This paper will cover how to leverage the effects of this virus to ensure your company is poised for exponential growth. This includes a number of best practices in addition to new tools to help engineers, supervisors, and managers create an effective process for managing product quality and output remotely or with minimal interaction among the operators and the management team as a whole.

Caring for the Individual

In the first quarter of 2020, COVID-19 was an increasingly popular topic of conversation. In early March, the Investment Casting Institute (ICI) wrestled with whether to hold its annual Process Control Class. One thing was certain, if the class had been scheduled for one week later, it would have been cancelled. By mid-March, schools were closing and parents were scrambling to figure out how to balance work and remote learning for their children. Businesses were putting plans in place to protect their employees, the supply chain, and their customers. By the end of March, companies across the country were shuttered as some states issued Shelter in Place orders. Fortunately, most investment casting foundries were considered essential businesses and remained open. However, this required yet more planning to ensure employee safety as COVID-19 response plans had to be developed and implemented.

Implementing these changes was critical, but the impact they've had on individual employees may have been overlooked. While the phrase "social distance" is widely used, the more accurate phase is "physical distance." Humans are social people, and forcing people to physically separate from each other added a lot of stress.

According to a Gallop poll, one of the keys that keeps employees engaged is having friends at work. So, when employees were forced to maintain distance, even during breaks, the outcome was increased stress in the workplace. For example, one foundry had a near-miss with a COVID outbreak because two employees were sharing lunch and one family member ended up with COVID symptoms.

Remote learning was another challenge for employees with children. Neither schools nor parents were prepared for the difficulties this caused. In a typical example, one manager was forced to stay home with his children and try to work from home. This meant juggling the demands of his manager position with the responsibility of keeping his children engaged in their school work.

One former educator-turned-business owner had some great advice: Draw a box for your children (figurative not literal). Depending on their age, the box will be bigger or smaller. But let them stay in that box. They don't need constant supervision, though it's best to keep at least one eye on the younger kids. This business owner put his kids on a schedule, so every morning they knew what they would be doing all day. The kids had a stopwatch so they knew how much time they had for each activity.

While this may work for some people working from home, there were plenty of employees who had to go to work and then come home and oversee their children's schoolwork. The result of this was exhausted and overworked parents/employees who were being torn in different directions.

As a manager, taking time for yourself is critical. One CEO reported working 100 hours per week as he developed and implemented his COVID response plan. Nearly every CEO/president/owner I spoke with said this was the most stressful time of their careers. They were balancing the safety of their employees, the safety of their customers, and the safety of their families, while being concerned about the viability of their businesses. Another CEO shared, "I've realized I won't be taking any time off for the balance of the year."

"Put your mask on before assisting others with their mask." Although this phrase typically applies to the loss of cabin pressure, it is also true during periods of stress. Ensure that everyone, including managers, is caring for themselves, because burned-out, overworked employees may not be able to sustain the stress over the long haul. When stress is on the rise, double down on the importance of diet, exercise, and sleep.

Understanding that this is a stressful time, it is important that every manager, president, or CEO schedule some clarity breaks on a daily, weekly, or monthly basis. These clarity breaks allow the manager to stop working in the business and start working on the business. This allows a view of the business from above the trees. These breaks can help establish priorities, look for ways to be more proactive and less reactive, and think about where the business is going. Schedule this time in your calendar and honor that time[1].

The next section explores how effective communication can be a powerful tool for strengthening an organization.

Strengthening Communication
"Communication works for those who work at it." John Powell

Effective management requires the ability to pull oneself out of the weeds and look at the needs of the organization. It requires calm in the midst of the storm. And this calm requires an immense amount of discipline and self-control.

[1] See this link for more information on Clarity Breaks: https://www.eosworldwide.com/eos-tools

This became especially important when COVID first began to impact daily lives – both at home and at work. During this initial period, owners, CEOs, and managers were struggling to stay ahead of what needed to be done to protect employees, customers, and businesses. And in the midst of this was a lot of stress for the organization.

As organizations developed new ways of operating, communication was required to make sure everyone had the same information. This means ensuring there is a clear communication path from the CEO through the leadership team to the teams and ultimately to the individual.

The most successful businesses provided a common focus. Even in the midst of a crisis, a team will rally behind a common focus, if they can see it. If the vision is clear, and the employees know where and how they fit into the vision, they will be able to support it and embrace it. One manager shared, “I'm not looking for buy-in, I'm looking for ownership.” If they can't see it, they won't own it.

Change can be difficult for many people, and helping them work through the discomfort is important. Many employees feared they would lose their job when the pandemic started. And unfortunately, many did. But operating from a place of fear leads to declining performance, reduced decision-making ability, and in some cases, irrational behavior. Leaders need to provide a vision for their employees to get behind, so they can see how the company will weather the storm. This communication needs to be open, honest, and consistent.

During a period of crisis, the temptation is to throw the existing processes aside and move to reactionary mode. But it isn't realistic to reduce chaos by adding more chaos. Instead, leadership should double down on the processes that are currently in place and focus on what has been successful in the past. A time of crisis is not the right time to develop new processes.

As stress increases, tension amongst members of the leadership team may also increase. In order to remain focused on the success of an organization, it's important to address conflict. During periods of tranquility, it may be possible to avoid this; but keeping the team on the same page during stressful periods requires open, honest dialogue to resolve any conflict that arises. After all, avoiding these conversations won't make the conflict go away, and it will likely manifest itself in other ways.

With the leadership team on the same page, the focus can move toward communication with the rest of the organization. Spend time discussing what should be shared, how it should be shared, and who will handle it. Misinformation or late information can impact the employees and their performance. Even if there is still a lot of unknown, employees want to know what the leadership team is working on.

There are a number of different ways to communicate, including the following:

- All-Hands. This meeting format can be very effective in that everyone hears the same message at the same time. But they can also be expensive, and logistics can be difficult for multi-shift operations.

- Communication chain. Another approach is for the leadership team to share the information with their teams directly or with their direct reports and have them share it down the chain.
- One on One. This type of communication can place a time burden on the manager but it does provide the opportunity to hear directly how each employee is faring and learn what kind of support is needed.
- Bottom Up. Another method is for the front-line supervisors to gather questions directly from the employees and share those with the leadership team. Answers to those questions can be developed and shared with the entire organization, either by the manager, the leadership team, or HR.

A company's communication strategy is as personal as its culture. One company prefers Instagram communication while another prefers typed memos. Use the avenue that would most resonate with your employees.

The appropriate level of communication will vary from company to company, but some things to keep in mind include:

- Is there anything new to communicate?
- What is the impact to the team if not shared immediately?
- Will the employees hear this from someone else if not shared now?
- How critical is it to have all the information prior to sharing?

Once COVID hit, Zoom became the platform of choice. During the initial eight weeks, there were enough webinars scheduled that one could spend 40 hours watching them and still be behind. After the first month, people learned how to use the technology, and video conferencing became the norm.

One CEO remarked that his entire management team was on their call every morning at 9AM. Everyone knew what they needed to discuss, and the meeting ended promptly at 9:30 AM. Prior to COVID, he said, it was never that efficient.

Most people would agree that meeting in person is preferable if you're hoping to connect with individuals, but from a time standpoint, video conferencing is much more effective. As Steve Van Valin states in his video "Zoom Gloom"[2], video conferencing makes it difficult to develop rapport with others. Van Valin goes on to provide some tips on how to develop a greater rapport as a team.[3]

A number of articles have been written on effective video conferencing practices, but Seth Godin's[4] is especially helpful. His tips include always be on mute except when talking, don't eat during a meeting, and sit close to the screen. If the goal is to improve engagement, ensure that everyone has their camera on. Without that, it is much easier for people to disengage from the conversation and the group.

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[2] "Zoom Gloom", https://vimeo.com/437308988.

[3] Send email to steve@culturologyusa.com to get a copy of the Virtual Team Player Playbook

[4] https://seths.blog/zoom/

In times when frequency or duration of direct communication is reduced, it is critical that each employee understand the core values of the organization, their role and the specific goals that they need to complete within a specified duration. Utilizing a tool like the 5-5-5[5] can help provide clarity and direction. Another key to connecting an individual to the organization is ensuring that each employee has a metric to measure performance.

In the following section, the value of a scorecard will be discussed.

Keeping Score

"Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it."
– H. James Harrington

Nearly every business has some goals. Typically, they are around revenue, quality, and safety. Having goals and metrics that permeate all aspects of the organization is key to improving and sustaining performance. Gino Wickman, in the book Traction, outlines eight reasons everyone should have a measurable number, including accountability, teamwork, and a little healthy competition.

A manager at a mid-sized investment casting foundry shared they have 30 pages of metrics that they review on a monthly basis. Imagine the amount of time it takes to compile that data, review it, and decide what action needs to be taken to address the issues. The adage "If everything is a priority, then nothing is a priority" may be applicable.

One of the challenges of the investment casting process is that there are a number of processes within the greater process, and each of those processes are subject to variation. In the ICI Process Control class, 117 variables are identified within the overall process. While it may be possible to control all the variables, that may be cost-prohibitive. A more effective approach would be to identify and control the key input variables.

When selecting which variables to control, it is important to understand the difference between leading and lagging indicators. Lagging indicators are typically output-related measurements, which are easy to measure but hard to improve or influence. That would include revenue, recordable accidents, or even first pass yield. On the other hand, leading indicators are typically input-related, hard to measure and easy to influence. Another way to think about leading indicators is they often involve activities undertaken by an employee. This may include PMs completed, number of molds patched, or temperature adjustments made to a wax press.

Another powerful tool for improving performance is assigning a metric to each employee. This can help the employee understand her contribution to the achievement of the overall company goals.

[5] See this link for more information on the 5-5-5 tool: https://www.eosworldwide.com/eos-tools

During a recent visit to a foundry, each department had metrics posted and tracked. For the foundry, the goal was to pour 54 molds per day. The challenge was that the employees didn't understand what they specifically needed to do impact this goal; they claimed the number was largely impacted by mold size and number of heats. Through a departmental meeting, the employees agreed that completion of their daily audit checklists would help uncover specific issues within the department and allow them to take action before impacting throughput.

The other advantage of everyone having a metric is that it is much easier to identify a performance or skill issue. The following section discusses how to address identified skill gaps.

Skills Matrix

The lack of skilled workers is a common issue among investment castings foundries. Many managers lament being unable to find people who want to do the jobs within the foundry and who can show up on-time every day. In some instances, business owners have shared that they have scaled back growth due to the lack of available labor. The other challenge is the amount of time required to train an employee.

The first step in addressing this issue is understanding the organization's training priorities. This can be done by using some type of evaluation system for each employee in each position within the plant.

In the ICI PC class, students are taught about a skills matrix. This matrix breaks skills into 4 levels.

Level 1: Training has begun but employee can't be left alone on the job

Level 2: The employee <u>can</u> be left alone on the job but may be too slow to work entirely alone

Level 3: The employee can be left alone on the job with only normal and customary supervision

Level 4: The employee knows the process or task and can train the skill or task

Utilizing this type of evaluation, the following sample matrix can be populated.

Name	Heat weighup	Loader	Puller	Pourer	Melter
Bill	1 2 4 3	1 2 4 3	1 2 4 3	1 2 4 3	1 2 4 3
Fred	1 2 4 3	1 2 4 3	1 2 4 3	1 2 4 3	1 2 4 3
Jack	1 2 4 3	1 2 4 3	1 2 4 3	1 2 4 3	1 2 4 3
Joe	1 2 4 3	1 2 4 3	1 2 4 3	1 2 4 3	1 2 4 3

Once this is complete, the manager(s) can establish a goal for the number of 3s and 4s desired for each position. From that goal, priority for training can be established.

During World War II, there was a shortage of skilled and trained workers at a time when the demand on manufacturing was very high. As a result, the process called Training Within Industry was developed to quickly and efficiently train operators.

There are four programs that make up Training Within Industry:

1. Program Development – how to solve production problems that are unique to a particular organization
2. Job Relations – an analytical method for addressing personnel issues
3. Job Methods – a methodology that employees use to make their job easier
4. Job Instruction – this component teaches trainers how to train

Program Development

The last program created in Training Within Industry is Program Development, which is defined as "how to address a production problem through training." The program includes defining the production problem, developing a specific plan, putting the plan into action and then checking to ensure the action has the desired results.

When defining the problem, it is helpful to gather evidence and underlying causes for the specific issue. This data can help determine if you have a training issue or perhaps a different production issue. All too often the problem isn't fully defined before implementing a quick fix, resulting in a nagging organization issue.

Using a troubleshooting tool such as the Issues Solving Track[6] can assist in identifying the true root cause of the problem and taking steps to solve it forever.

Job Relations

Dealing with conflict is an important part of a healthy work environment. And making sure people have the skills to resolve those issues is so important that Job Relations Training is included as one of the four programs. Donald Dinero in his book Training Within Industry said Job Relations Training "gives supervisors an easy method to use on a daily basis to inform their decisions and make their jobs easier."

For most employees everything at work has changed, including the layout of their work areas, break and lunch schedules, and in some cases, there's been a reduction in the interaction with supervisors and managers. This can result in additional team tension that may be hard to detect until it reaches the breaking point.

It is critical to have a process for resolving tension between employees. If you find that two individuals are struggling to get along, getting involved early is key. Get the individuals in a room and start an open, honest dialogue.

- One technique that is helpful is having each person list three strengths of the other person, then three weaknesses. In order to do this effectively, the person receiving the feedback needs to listen and, if necessary, ask clarifying questions, but can't argue with the feedback.
- When it comes time to solve the issue, focus on the problem, not the individual. If you stay focused on the issue and the root cause, 95% of the time, the issue will be solved.

It can be difficult to take an unemotional approach to a situation when emotions are involved. However, being effective in a supervisory role requires the ability to look beyond emotions and focus on what is best for the organization. The importance of a supervisor is often overlooked, but he or she probably has one of the most difficult positions within a manufacturing plant.

It is the supervisor's responsibility to produce consistent results in order to meet business objectives. But they are also responsible for addressing the day-to-day concerns of hourly employees. The supervisor may be pulled in both directions when, at times, these two groups are perceived to be diametrically opposed. The supervisor is expected to be calm under pressure, patient, demanding, understanding, unyielding, etc.

Take a look at the organization through the supervisor's glasses. Do they have the skills they need in order to keep your organization moving in the direction you want it to move? What support do they need to handle additional stressors in the workplace, including fear of getting sick, managing the team from a distance, and achieving production goals?

[6] See this link for more information on the Issues Solving Track: https://www.eosworldwide.com/eos-tools

Job Methods

The Job Methods program was developed to teach employees to understand and improve their work and to sell their improvement ideas to their supervisors, peers, and upper management. The goal is to give plant personnel the tools they need in order to produce more products in less time with the same level of quality while utilizing the available resources.

In the age of COVID, employees are working farther from their peers and supervisors. This distance may create the temptation to create a personalized "best way," which may deviate from established best practices. In order to prevent this from happening, it is critical to provide a clearly defined process for making improvements to an established process.

The Job Method process includes:

1. State the organizational goals and how improving the process of how things are done will help achieve those goals. Make sure these goals are congruent with the workforce goals, i.e., increased profitability.
2. Give employees the freedom to question how things are done. Don't allow the phrase "but we have always done it that way" to be used. Perhaps set up a friendly fine for the person who expresses that sentiment.
3. When looking at ways to improve a process, utilize a Job Methods Breakdown sheet in order to capture all the steps in the process and then question every step. Ask Why? What? Where? When? Who? How? as you work through each of the steps.
4. Provide employees a method for making suggestions for process improvements. I have often heard employees say that they have made suggestions but no one ever accepts them. However, in order for a process improvement idea to be made, it needs to be well thought out and presented in a setting where constructive feedback can be made and received.
5. Make sure employees receive recognition for their ideas. The more recognition they receive, the more ideas they will generate.
6. Regularly schedule process-review discussions to help employees realize that changes can be made to a process, but they must be discussed and approved by the team.

Employee involvement in continuous improvement activities is an important key to the success of manufacturing companies. But without the proper training and support, employees may end up feeling disconnected from these activities. Effective communication, robust training, and an open and supportive workplace will go a long way toward achieving your productivity goals.

Job Instruction

Job Instruction breaks training into the following steps:

1. Prepare the Operator. People tend to be nervous before learning something new and this can impact the learning process. So, try to relax the operator while learning more about him, including any relevant experience. You also want to explain why what they are learning is important and how this task relates to the overall manufacturing process.
2. Present the Operation. Explain each of the steps in the operation, identifying key points along with the reasons for each step. Describing each step while the operator watches will help the operator learn much faster as using more senses during learning will increase the retention rate and speed.

3. Perform the Operation. Once the operator has seen the steps performed and had the key points and reasons explained, it's time to try it himself. As the operator works through the steps, have him explain the key points and reasons for each step. Be patient as the operator walks through each of the steps, taking the time to check for understanding by asking questions.
4. Follow-Up. Once you feel the operator has a good understanding of the process, you can leave him alone. But make sure you check back with him periodically (more frequently initially) to ensure the steps are being followed and he doesn't have any questions.

This is a fairly straightforward process, but it is also very time-consuming and more complex given the need to maintain a six-foot social distance. Fortunately, there are some new technologies that can aid in this step.

Virtual reality provides a computer-generated version of reality. Augmented reality, however, supplements only a portion of the environment and coexists with the real world. It augments the visual field of the user with information needed to complete the current task.

The options for using augmented reality include the following:
- Onboarding/new employee training
- Equipment/machinery training
- Job aides
- Interactive learning tools

Augmented reality training can include images, videos, animations, and sound. This video[7] shows how it can be applied in a manufacturing-type setting.

Even if a foundry isn't ready for this level of technology, there are other possibilities to improve the way an operator learns how to do a task. For example, Zetronix[8] sells eyeglasses with a built-in camera and microphone that can capture how to complete a task from the perspective of the worker, not an observer.

Another option is interactive PDFs. These can impact the experience the operator has as he works through the training documents. It is possible to add key points, videos, links, and animation in order to assist in learning the material and highlight the pertinent information.

Conclusion

As our daily in-person interactions are reduced, the need for leadership increases. Caring for employees and their mental health is fundamental to creating a productive environment. Being intentional about communication will assist employees in feeling connected to the company. By using a scorecard, the entire organization can be clear about its goals and how individual contributions will assist in reaching those goals. Utilizing the newest technology can improve the way operators are trained.

[7] https://www.youtube.com/watch?time_continue=289&v=2eSlMSJ65Kc&feature=emb_logo

[8] https://www.zetronix.com/kestrel-hidden-camera-hd-video-recording-glasses-with-finger-touch-technology.html?gclid=EAIaIQobChMI7tqlhtm-6wIV4R6tBh2VkApDEAQYAiABEgIso_D_BwE

Focusing on these areas will position an organization for success, now and in the future.

INVESTMENT CASTING INSTITUTE

Tool-less Digital Investment Casting Using 3D-Printed "Ready to Pour" Ceramic Shells

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VIRTUAL TECHNICAL CONFERENCE & 3D EXPO 2020

Paper № 14

Title: **Tool-less Digital Investment Casting Using 3D-printed “ready to pour” Ceramic Shells**

Authors: Suman Das, Tom Stepien, and Dag Reckhorn, DDM

Abstract:

Additive manufacturing has had a significant impact on investment casting through 3D-printed patterns and cores. Recent developments in ceramic 3D printing have allowed the manufacture of both complete “ready to pour” shells and modular molds where individual shells are assembled onto ceramic sprue components. The use of printed shells eliminates multiple process steps in conventional investment casting including pattern molding, assembly, shelling, and de-wax. The shell printing process allows cores to be integrated and printed in place. The 3D printing process also allows shells to be created for casting geometries that cannot be molded and can include core geometries that cannot be molded monolithically such as multi-wall cooling passages for gas turbine blades. This paper reviews the results of casting trials by 4 foundries in a variety of alloys. Cast alloy chemistry, mechanical properties, casting accuracy and surface finish results will be presented.

INVESTMENT CASTING INSTITUTE

Digital Twin Design Process for Development of Next Generation Lightweight Investment Casted Parts

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VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 15

Digital Twin Design Process for Development of Next Generation Lightweight Investment Casted Parts

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Abstract

Industrial cast parts and processes are undergoing major transformations due to lightweight designs to improve energy efficiency of major industries like automotive and aerospace. Hence, boundaries of castability are pushed, as these lightweight designs occasionally leads to thin walled and geometrically complex parts. Investment casting, with it's ability to cast free form geometries, is one such process suited for production of such parts. However, here moldability and castability is also key issue and an early feasibility in the design phase is necessary to avoid costly reruns later-on.

This paper is based on Altair's Inspire™ platform and demonstrates the application of Simulation-driven-design and manufacturing boundary conditions during the design phase to drive next generation lightweight designs through Investment Casting process. At first, an integrated workflow on simulation-driven-design and manufacturability to obtain lightweight part in a single environment is demonstrated. Next, this digital twin approach is demonstrated for investment casting and sand-casting examples and hybrid manufacturing process. This simulation platform to design parts based on load analysis, manufacturability checks, material response and process optimization provides a powerful tool for concurrent engineering.

Introduction

Traditional design and manufacturing process depend on (see figure [1]) an initial design geometry (CAD), provided by a designer or product developer and serves as the basis of the simulation model. Once the virtual model performs as expected, for example through structural analysis and or process simulation analysis, a prototype is built and tested. This prototype is finally tested and if it does not meet the acceptable results then one has to return to the designer. To address these issues simulation-driven-design [1,2] is advocated.

What is Simulation-driven-design?

Simulation-driven-design is a recent upcoming field that incorporates innovative development of parts based on three major aspects i.e., performance of the part, efficiency and finally manufacturability of the part. This helps reducing both and cost in reducing physical prototyping and testing by accurately identifying and resolving problems very early in the design process and early determination of manufacturing possibilities.

This process starts with a concept design coming from either a topology optimization, i.e. material is removed from the structure in load (force) free areas, or topography optimization. Then the virtual test is carried out to evaluate the design, for instance to check whether the resulting deformation due to applied forces is within the allowed limits. If the results are acceptable then a prototype is built and tested. Overall, this process not only leads to very material efficient structures (innovative design), shorter design phase, higher competitiveness.

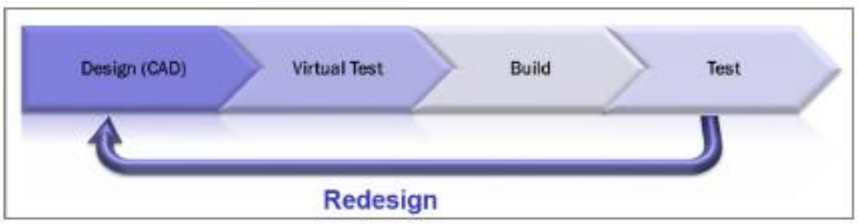


Figure 1: shows the work-flow of traditional design and testing process

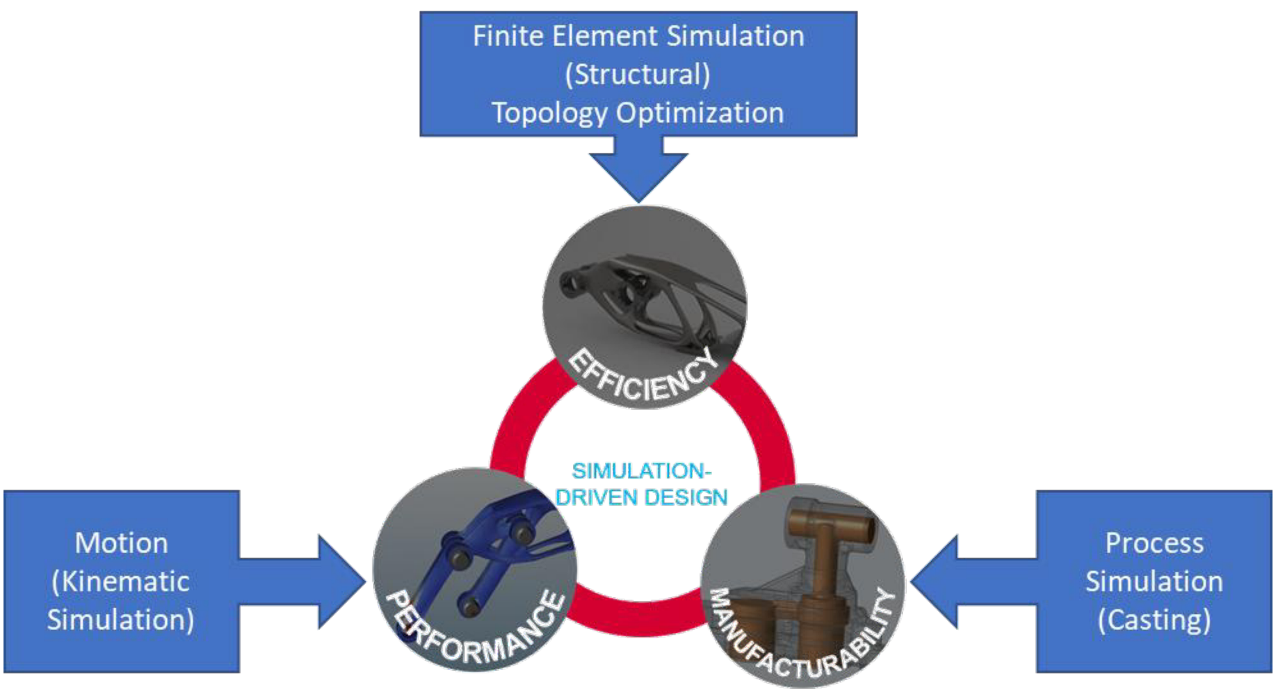


Figure 2: Typical work flow of Altair's simulation-driven-design and manufacturing

The individual steps are explained as follows:

Performance:

In order to obtain the performance of the part, multi-body dynamic simulations are the first step. A motion analysis will show how a mechanism will behave with forces, joints, and contacts applied. Here we can link components of a mechanism together using various types of joints and contacts to simulate the real-world connections in an assembly. The motion is defined in the appropriate degrees of freedom (the direction in which the motion can occur) for each connection point. Some type of force can be applied to the mechanism using gravity, a motor, actuator, or a spring to replicate the forces applied in the real assembly. The output of the performance simulations are usually different load cases and moments that are acting on the part of interest. Figure 3: shows a snapshot of multi-body simulation on a rear suspension part that is subject to redesign and simulations resulting in different load cases (for example forces and moments acting on part).

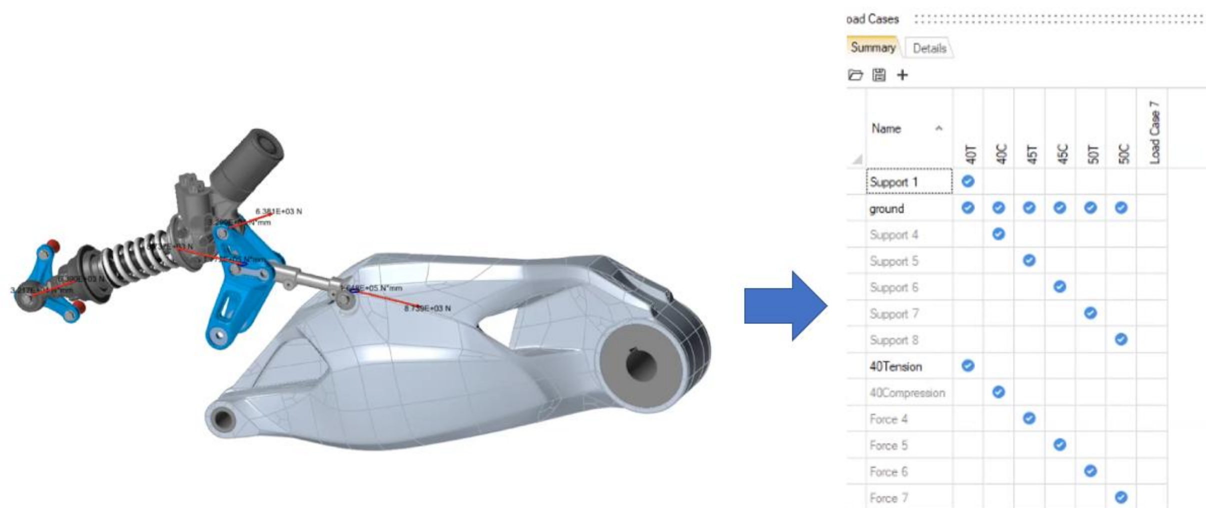


Figure 3: Multibody dynamics simulations (left) on a real suspension part of a motorbike (blue) and resulting in different loads and moments (right).

Efficiency:

Determining the efficiency of the part usually involves Finite Element Simulations including structural simulations and topology optimization. Structural feasibility simulations are quite well known but topology optimization needs explanation.

The topology optimization process carves material away from design spaces, creating the lightest structure capable of withstanding the forces you apply to your model. This approach is ideal for maximizing the stiffness of components while trying to achieve a desired mass target. It can also be used to minimize the mass of a model, depending on your optimization objective. Typical steps in the topology optimization involves

1. Start with a design which is characterized by the maximum allowable dimensions of the final product (package space). At this point not into consideration about where to put holes (to reduce its weight) or stiffening ribs. Of course, here one can specify areas which need to stay the same, i.e. they will look the same after the concept optimization run. These areas are consequently called “non-design” area whereas the rest may be modified. These portions of the

structure are called "design area". Figure 4 shows design and optimization process of rear suspension design subject to redesign.

2. Apply loads (i.e. forces, temperatures etc. acting on it) as well as material properties. In general, it is best not to apply loads and displacements directly to design spaces, as this often leads to incorrect results. Instead, one should split the part into design and non-design spaces and apply loads and displacements to the non-design spaces.
3. Define Manufacturing Constraints (Shape Controls). Without including manufacturing constraints, the optimized design may look great showing significant weight savings. However, the structure (new design) may not be manufacturable due to, for instance, undercuts.

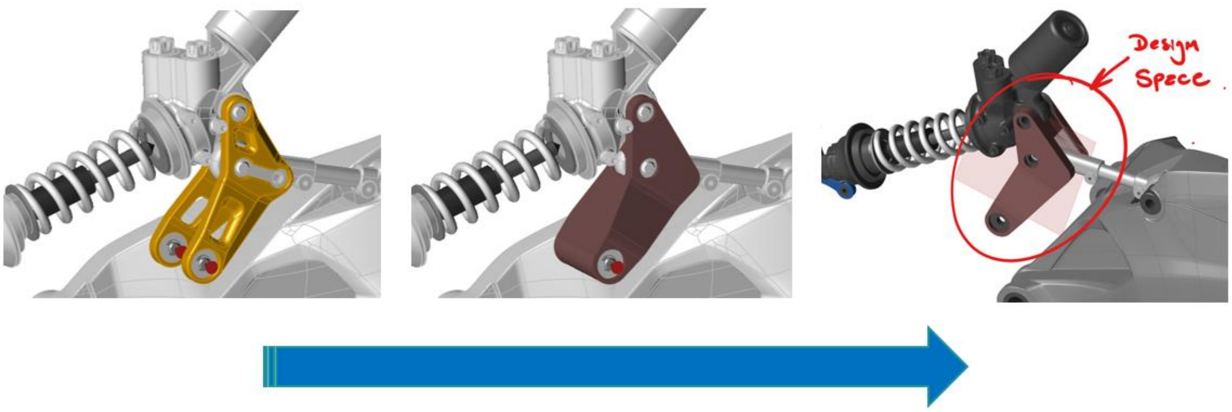


Figure 4: Design and optimization process showing original part (left), selection of design and non-design space (middle and right)

Process of optimization requires defining targets of optimization, this may be: maximizing stiffness, maximizing frequency and with a specific target of reduction of mass or displacement constraints. Typical manufacturing constraints that needs to be taken into consideration during optimization process are minimum and maximum member size, Symmetry, draw direction, Pattern repetition, bead space, overhang angles etc. A combination of different manufacturing constraints might be necessary for the specific manufacturing process under consideration (casting, forging, extrusion, additive etc.). The most relevant manufacturing constraints for investment casting is explained in the next section:

Manufacturing Constraints for Investment Cast Parts:

Typical manufacturing shape controls, that might be relevant for investment casting process:

- **Thickness Constraints** - When running a topology optimization, you can control wall thicknesses and the diameters of beam-like members using thickness constraints. These might be necessary to avoid misruns and avoiding hotspots leading to porosity
- **Holes constraints -** This constraint might be necessary to align the holes in a particular direction to aid removal of the shell mold
- **Draw directions –** These constraints might be necessary to avoid undercuts for part detatchment issues, placement of parting lines etc.

- **Space for gating-** This may be considered as non-design space as a region to bring melt into the part from the gating system.

During topology optimization, influencing directional solidification in Investment casting might need to consider the design of part and also the gates, allowing only one heavy section where a gate can be placed during pattern design and removing it after casting [3]. The thinnest part may be placed farther from the gate.

Additional manufacturing constraints may be imposed based on if the wax is 3D printed and or on the performance requirements for example: lattice structures and solid parts [see Figure 6] involved in hip implants needs to be optimized to minimize stress shielding to allow bone growth and for the manufacturing rout through investment casting.

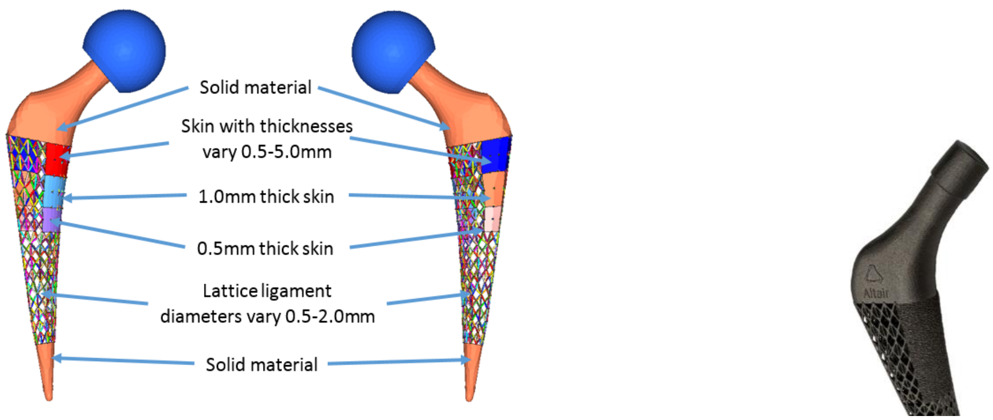


Figure 5: Shows a combination of solid and lattice structures in hip implant developed using Altair's Inspire™ optimization platform (left) for 3D printing using Ti 6Al-4V and 3D printed by EOS (right).

Balancing Performance and Manufacturing

Manufacturability can be assured by applying shape controls and this controls the performance weight ratio. This is explained in Figure 6, showing impact on performance by adding more manufacturing constraints. Different manufacturing methods can be compared to helps to decide which design has the best performance or it also helps to guide to make changes in the design see Figure 7.

Why designs need to be adapted to the manufacturing process?
Figure 8 compares the two designs one by selective laser melting (AM) and investment casting. Here the differences are small yet significant for the AM process and investment casting process.

This is explained by the two arrows (in blue), for the design for AM middle area is V shape, which indicates no more supports needed. In the upper section the geometry is adapted for a more even energy input across the layers. Also, in the lateral strut: no more supports required and more even energy input across the layers.

In the Investment casting design U shape is good for metal casting (smooth metal flow and distributed manageable porosity). Some typical features in this design are big enough gating system to avoid cold runs

- Shorter member length to avoid melt freeze
- Continuous member cross section to improve melt flow
- Control member sizes to control shrinkage porosity to meet manufacturing tolerances

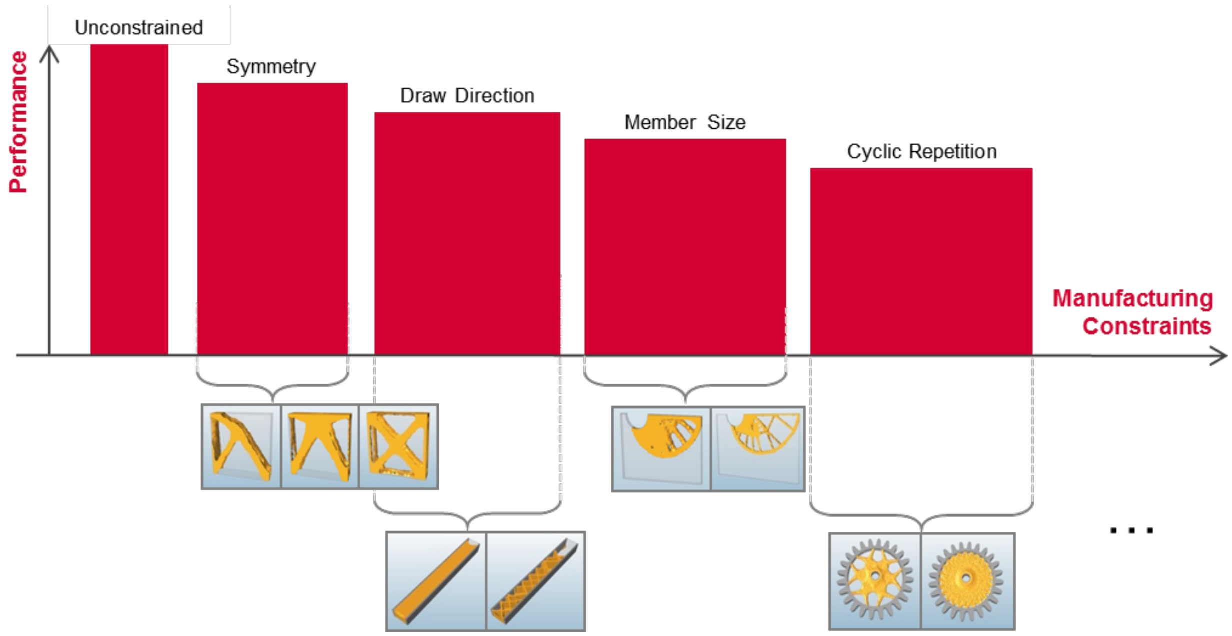
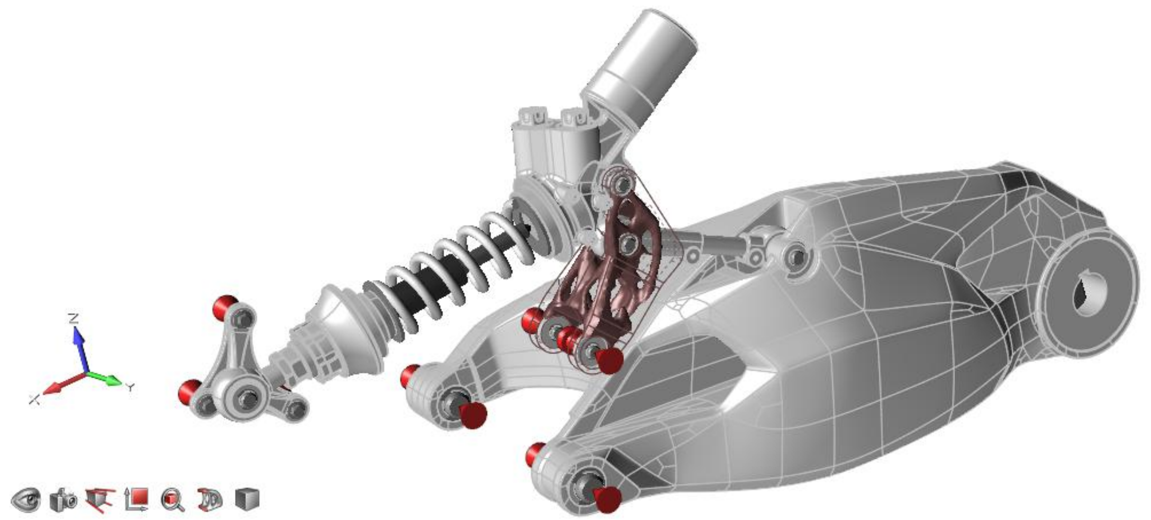


Figure 6: Shows influence of manufacturing constraints and performance



Run	Draw Directions pivot_DSPACE	Mass pivot_DSPACE		Compliance	
pivot_DSPACE overhang50 Max Stiffness ...	Overhang	4.509e-01 kg	100.00%	5.714e+00	100.00%
pivot_DSPACE Max Stiffness Mass by Part ...	Split	5.679e-01 kg	125.93%	3.434e+00	60.09%
pivot_DSPACE Max Stiffness Mass 25% (7)	Extrusion	6.767e-01 kg	150.06%	1.785e+01	312.45%
pivot_DSPACE draw2 Max Stiffness Mass 2...	Split	7.124e-01 kg	157.97%	3.403e+00	59.55%

Figure 7: Shows process of choosing between designs and choose the most performant one

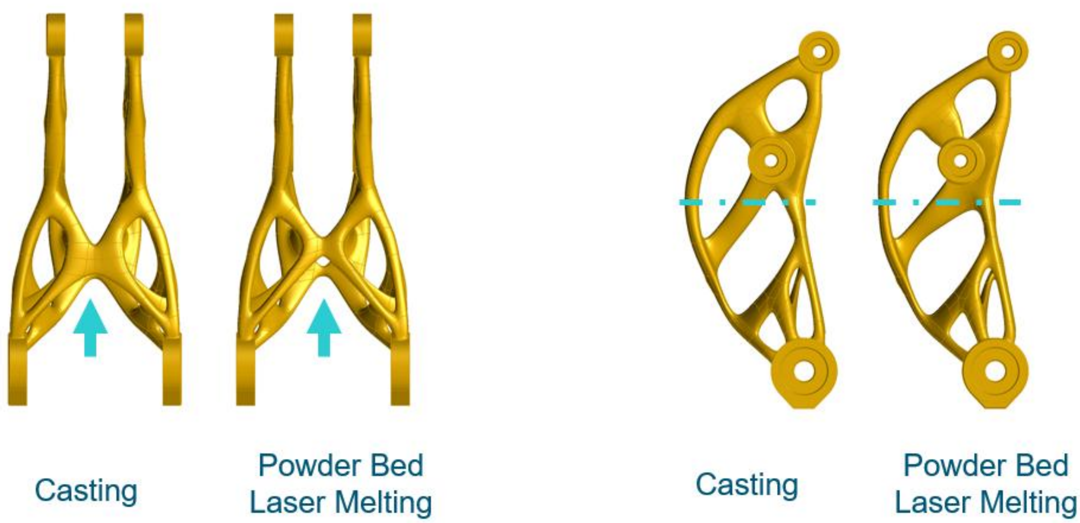


Figure 8: comparison of designs obtained for casting (investment casting) and powder bed laser melting

Manufacturing Process Simulation

Manufacturing process simulations needs to primarily address two issues a) validate the design to address part related defects and b) develop gating and feeding systems. These simulations can include investigating castability through filling, solidification, thermomechanical simulations and/or wax-injection simulations, dipping simulations, dewaxing etc.

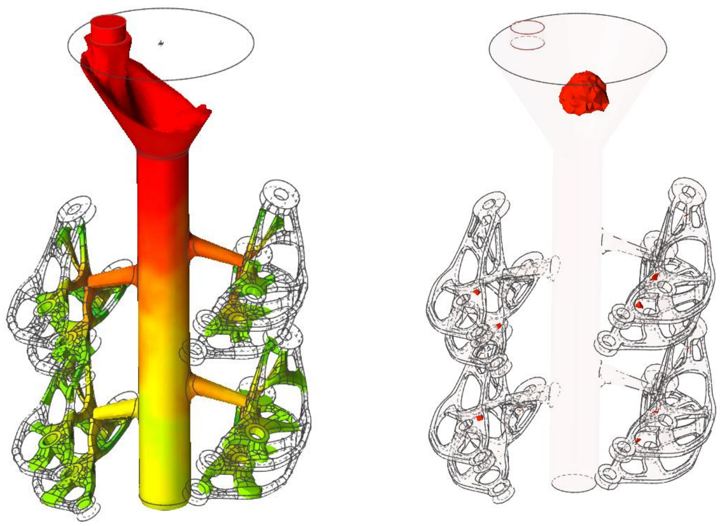


Figure 9: Castability (manufacturability) feasibility checks and development of gating and feeding systems using process simulation, filling simulations (left) and solidification simulations indicating porosity locations, in red (right).

Outlook

The current paper presents a digital twin-based development that uses simulation-driven-design approach to develop investment casting parts. Understanding the system behavior as starting point helps to identify part performance limitations and possibilities for improvements.

Applying manufacturing constraints for investment casting during topology optimization can improve the castability of part early on and avoid costly reruns. The typical investment casting constraints that can be considered during topology optimization can be thickness, holes alignment, place for gating system, avoiding undercuts for easy part removal.

Generative design based on topology optimization using multiple constraints and manufacturing feasibility check can be considered to come up with the best possible design. This can also lead to lightweight organic structures, which can be new business for investment casting.

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INVESTMENT CASTING INSTITUTE

Market Insights

Joseph Fritz – Investment Casting Institute
Carlos Olabe – European Investment Casters' Federation
Kenji Ito – Japan Foundry Society

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Panel Discussion No. 3

Market Insights

Joseph E. Fritz
Investment Casting Institute

Carlos Olabe
European Investment Casters' Federation

Hiroshi Yokota
Japan Foundry Society

Due to the dramatic changes that the world has witnessed in 2020, many ICI, EICF and JFS Member companies have been reaching out to their respective trade associations for updates on the changing investment casting markets. In response to those inquiries, the leadership of the three trade association participating in this panel discussion has chosen to give a third quarter update at this time. This panel discussion will address the outlook for 2020 in comparison to 2019, highlighting factors affecting market performance.

INVESTMENT CASTING INSTITUTE

Advancements in Melt System Control Technology

Michael Fanz-Huster
Inductoherm

VIRTUAL TECHNICAL CONFERENCE
&
3D EXPO 2020

Paper № 16

Advancements in Melt System Control Technology

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Abstract

Advanced melt shop automation provides the investment casting industry with the competitive edge to repeatedly produce castings with high dimensional accuracy and intricate design, while at the same time optimizing power usage, automating many functions, and improving operational safety.

These technical advancements of monitoring and control systems provide operators, managers and service engineers with analyzation tools that give them more control, and improves the quality of their melt shop with anything from real time data for advanced troubleshooting to advanced controls for maximum utilization.

Most data can be accessed remotely – anytime, anywhere – via an easy to use colorful graphic interface. The data will show your equipment's health status and provide access to diagnostics, historical trends, and analytics that enables them to react immediately to changing conditions by being able to monitor energy usage, furnace lining conditions, power levels, and other critical electrical parameters, charge weight, temperatures, alarms and more.

Technologically advanced equipment is designed to reduce costs, and improve the quality, efficiency, and safety of the induction melting process.

Melt system controls are available in various levels of features and capabilities that can help investment casters enhance their melt shop operation.

INVESTMENT CASTING INSTITUTE

The Effect of Removing Dust from Backup Stuccos on Shell Properties

Steven Ashlock
Kyanite Mining Corporation

VIRTUAL TECHNICAL CONFERENCE & EXPO 2020

Paper № 17

The Effect of Removing Dust from Backup Stuccos on Shell Properties

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ABSTRACT

A recent trial using Virginia Mullite showed a higher than desired amount of nuisance dust in the 20x50 stucco. In response, Kyanite Mining Corporation implemented changes in the existing screening production process to remove the minus 65 mesh mullite and smaller particles. The following paper examines the effect of the removal of the minus 65 mesh particles in the new standard 20x50 product compared to the original 20x50 material. Testing and comparable data was derived which contrasts the two stuccos in both a rotary drum sander and fluidized bed.

INTRODUCTION

Virginia Mullite™ has been used in the investment casting industry as flour and stucco for many decades. A recent trial of the 20x50 stucco product generated a customer comment on the amount of dust coming out of the rainfall tower. This dust was a nuisance to the operators, it was reported. Kyanite Mining Corporation (KMC) was asked if it could investigate this issue and if changes to the material were possible to limit the employee's exposure to these fines. Historical data showed that KMC's 20x50 mullite stucco commonly contained between 20-30% in the pan (-50 mesh) and was at the bottom end of the specification for particle size. It was decided that this is too many fines in the product and the specification needed to be tighter.

The task to reduce fines was given to the plant. The plant first tried to vary the screen size to adjust the number of fines (defined as able to fall through a 50 mesh screen). They were able to produce material that had less fines, but they had to greatly reduce the feed rate to achieve the desired screening. Multiple attempts at changing screen size and feed rates resulted in limited success. Virginia Mullite™ is made by calcining Virginia Kyanite™, which is a blade shaped mineral. The mullite created after the conversion process keeps this blade shape, creating individual crystals that have a high aspect ratio. This caused difficulties as the blades may be able to pass through a screen when turned up on end that are much too large in any other orientation. Reducing the feed rate caused higher amounts of vibration on the screen, leading to an increase of particles passing through endwise.

After some internal work, KMC reached out to two screen suppliers for advice. Trials were done at both supplier's facilities to find the right solution. In the end, three things were changed:

1. Changed the size of the bottom screen to allow the fines to pass more easily
2. Added an additional screen in the middle of the screen stack. This helped to reduce the load on the final screen and improve screening efficiency
3. Adjusted the position of counterbalance weights to control the bounce of the product and retention time on top of the screen

With these changes, the plant was able to create a product with less than 6% in the pan while also retaining less than 1% on the top screen (20 mesh). The new setup also allowed the plant to produce this material at only a slightly reduced rate as compared to the old, "dustier" product. After the successes proved repeatable, changes to the 20x50 specification were suggested, shown in **Table 1**.

Table 1: Particle Size Specifications for the old and new 20x50 stucco

	Retained on Screen (%)			
	20m	40m	50m	pan
Old	1	27-42	30-50	30 max
De-Dusted	<1	93 min		<6

KMC wanted to make sure that removing these fines would not have a negative effect on the performance of the product. A literature review showed many studies examining how changes in particle size distribution of flour effects slurry rheology,[1,2,3] but less work has been done on the influence of particle size on stucco. Studies show that increasing particle size tends to lead to thicker shells, weaker post-fired Modulus of Rupture (MOR), and increased permeability.[4,5] Most of this work was done on fused silica stuccos and there was little data on the effects of changing the particle size distribution of aluminosilicate stuccos. It was decided that this needed to be tested in the R&D lab at KMC to evaluate the old vs de-dusted material before another trial.

TEST SETUP

The primary goal of the study was to determine the effects of fine particles on a 20x50 stucco. KMC wanted to verify that removing the -50 mesh particles did not have a drastic negative effect on the performance of the stucco. To test this, two stuccos were used. The first the stucco that had been the standard product for KMC for many years. The second is the new standard product with the dust removed. For clarity, the old material is labeled "Old" and the new material "DD" in the graphs and tables. The stucco was applied using either a rotary drum sander (RD) or a fluidized bed (FB), as both are common in the industry. This created four unique conditions: Old material applied by rotary drum, old material applied by fluid bed, de-dusted applied by rotary drum, and lastly, de-dusted applied by fluid bed. The 20x50 stuccos were used in all layers. Dust collection systems were turned on for both application methods.

Each of the stuccos was screened on a Ro-Tap before dipping began and in between each coat. Screening was done after each coat was applied to check for loss of fines to the surroundings (nuisance dust).

As this is a test of stucco, the slurry used for each coat was kept constant. This slurry was a 200 mesh Virginia Mullite™ based slurry that utilized large particle colloidal silica and a latex polymer. Surfactant was added to aid in wetting the wax and antifoam was used to combat bubbles. This slurry was used on all coats throughout the shell build. The viscosity was held constant at 20 seconds on a Zahn EZ #5 cup. The bars were made of 8 layers of slurry and stucco followed by a seal coat.

Metal bars approximately 12x1x0.125 inches were dipped in a non-filled wax to create the substrate for the MOR samples. The same was done on larger bars measuring 12x2x0.125 inches for the permeability samples. Bars were placed in a temperature and humidity-controlled cabinet before dipping began and after each dip. Bars remained in the cabinet until dry and for a minimum of 4 hours. Loose stucco was brushed off with a paint brush before each dip.

MOR was done according to ASTM C133-97 (2015) in three-point bend on both green and post-fired bars. The post-fired bars were fired in a box furnace at 2400°F (1315°C) with a two-hour hold. The test was conducted with the flat wax surface facing downwards and in tension. 10 bars were tested for each condition, both green and fired.

Permeability testing was done at the Buntrock Industries Inc. Technology Lab using a permeability testing method presented at the 52nd ICI Technical Conference and Expo.[6] Images of the test setup are shown below in **Figure 1**. This test was chosen to avoid any issues with inadequate burnout of the ping pong ball.

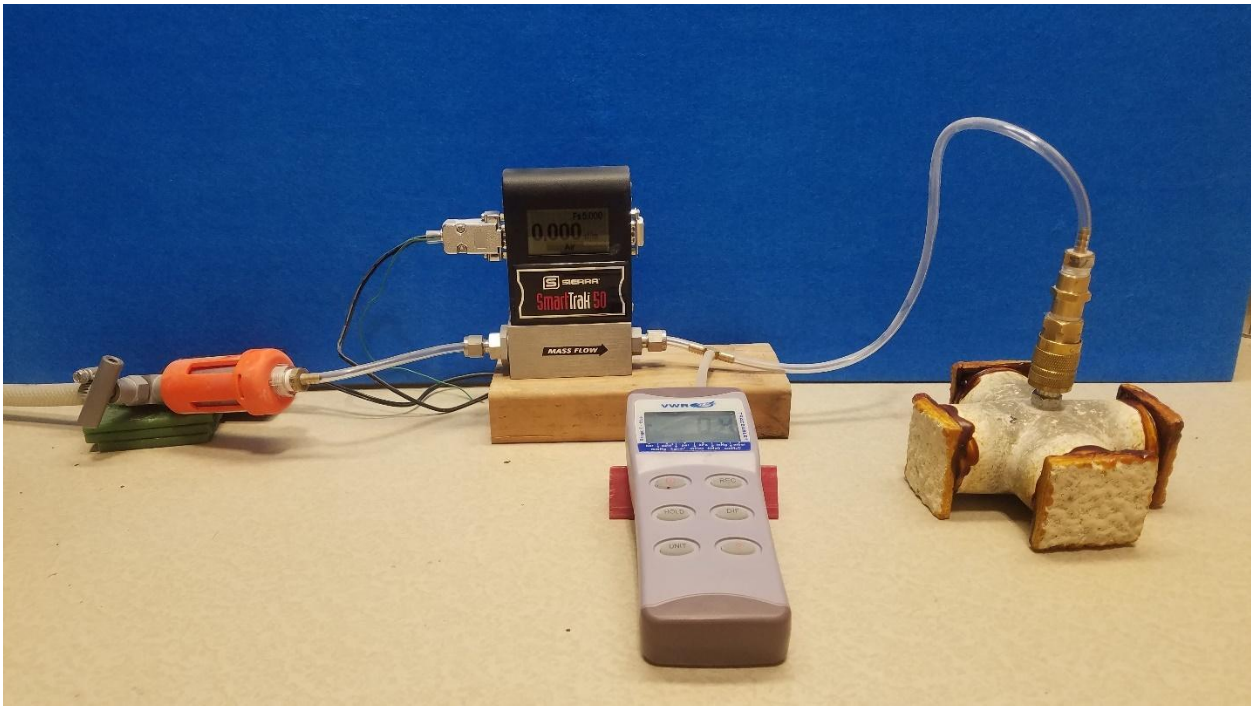

Figure 1: The permeability test setup.

RESULTS AND DISCUSSION

Screening

Screening samples were taken before each coat of slurry was applied. **Table 2** shows a comparison between the old and the de-dusted material that was used. The de-dusted stucco material was much coarser than the old stucco. The two samples of the old 20x50 show a much higher amount of -50 mesh particles, as was expected. The de-dusted material also has a significant amount of +30 mesh material that is not present in the older material. This coarser size stucco should help improve shell building. Evidence of this is seen in the thickness of the MOR bars, discussed further below.

Table 2: Particle size distribution of the starting stuccos for all four conditions

	Mesh Size							
	20	**30**	**40**	**50**	**70**	**100**	**140**	**pan**
Old RD	0.00	0.38	25.13	47.98	25.18	0.99	0.16	0.19
Old FB	0.00	0.16	26.71	46.15	25.60	1.06	0.12	0.20
DD RD	0.00	9.56	41.16	43.67	5.15	0.19	0.13	0.15
DD FB	0.00	8.03	45.33	41.21	5.12	0.17	0.05	0.09

As the dipping began, screening samples were taken to observe any changes in particle size distribution. **Figure 2** shows how the stucco changed for all four conditions. In general, the number of fines (defined as -50m) in the fluid bed stuccos did not drastically change. There were some inconsistencies in the intermediate coat data, but the material saw less than 1% change from the first to last coat in both cases.

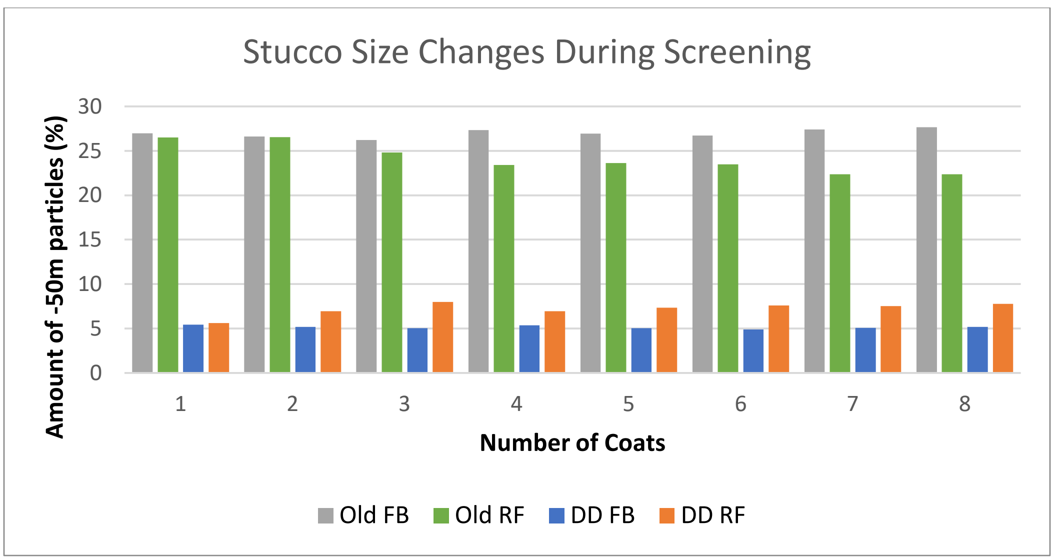

Figure 2: The change in particle size of each stucco was observed before each coat was applied

The materials in the rotary drum sander did change over time. The old material lost some of its fines (4.16%) to the environment from first to last application. This loss of fines was a linear change and can likely be attributed to nuisance dust being lost to the environment or pulled out by the dust collection system. In contrast, the number of fines slightly increased in the de-dusted material as the testing progressed. There was a 2% gain in the number of fines when comparing the first to last application. The fines reached their highest amount on the third coat and remained steady throughout the rest of the test. This can be explained by the friable nature and shape of the mullite. When kyanite converts to mullite, there is expansion of the crystal, making it a more friable material. When the stucco falls on the screen inside the rotary drum sander, sharp corners are knocked off and weak particles break. By the third stucco application, these weaker particles appear to have already been broken, causing a plateau in the data. The same likely happens in the old dustier stucco, but the phenomenon is not noticed due to nuisance dust being lost.

Videos were taken during each dip of all four conditions to observe the amount of nuisance dust floating in the air. As expected, the videos showed a higher amount of dust escaping both application methods when using the old stucco. There was as noticeable amount of fine mesh material coating the lip of the drum sander that was not observed using the de-dusted material.

The results of the screening tests indicate that the de-dusted material will not cause a lot of issues with nuisance dust for the operator. Another benefit is less dust will end up in the dust collection system and more of the product shipped in the bag will go directly on the castings and not be lost to the dust collector. This also means less cleaning out the bag house which saves time and money.

The dust loss data on the old stucco suggests that dustier stuccos should be run for a while in the rotary drum sander before the operator has to be in the area for an extended period when new material is introduced to the sander. This would allow the dust collection system to extract some of the fines from the stucco and reduce the operator's exposure to dust. The extra amount of time to perform this step would have to be evaluated on a per case basis.

MOR

The Modulus of Rupture (MOR) was tested to investigate the effect of dust on the strength of the shell. This data is shown in **Figure 3**. All four green conditions had similar MOR except for the de-dusted stucco applied with the fluid bed. That sample had a 16% lower MOR value than the old stucco applied the same way. This large difference was not expected as the rotary drum sander produced bars with similar green strength using both stuccos. Further testing needs to be done to confirm or update this result.

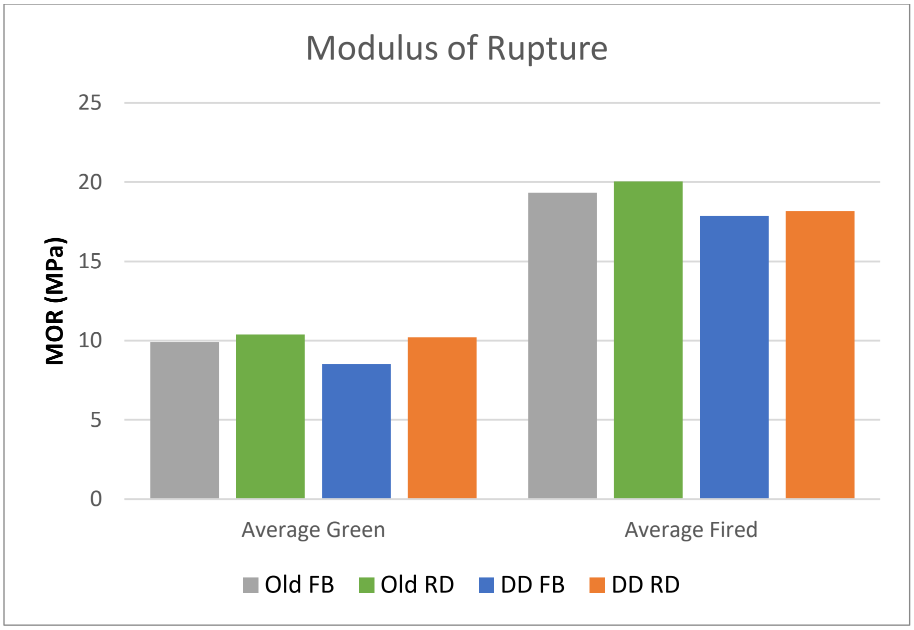

Figure 3: Modulus of Rupture was used to examine the effects of removing dust on the strength of the shell in both the green and post-fired condition.

In the fired state, the old stucco had higher MOR than the de-dusted material in both application methods. The old stucco was 10.3% stronger than the de-dusted stucco using the rotary drum sander and 8.3% stronger using the fluid bed. It is understood that wider particle size distributions create a ceramic body with better particle packing.[7] Having more variance in particle size allows small particles to fill gaps between larger ones, reducing the pore sizing between the ceramic particles. The presence of a higher number of fines also increases the overall surface area of the mullite stucco. The decreased pore space in combination with higher surface area would lead to a greater amount of sintering during firing than a coarser stucco with a narrower particle size distribution. This would create a stronger structure and produce higher MOR values. With a lower post-fired MOR, the de-dusted stucco would create a shell that is easier to knock off than the old material.

Lastly, the MOR of the bars made via the fluid bed had lower MOR values than those made with the rotary drum sander using both stuccos. This can be attributed to the depth of stucco penetration into the slurry layer. The rotary drum application method allows the stucco to fall and gain kinetic energy before contacting the wet slurry. This allows the stucco particle to penetrate the slurry level deeper, coating more of the particle in slurry and creating a stronger bond.[8] This result is in line with others who have examined MOR differences between shells created using fluid bed vs rainfall sanders. [8,9,10]

Shell Thickness

Thickness measurements from the MOR bars show that the de-dusted stucco created a thicker shell with the same number of coats. On average, the coarser de-dusted stucco shell was around 6% thicker than the shell with the old stucco. This was expected as similar results were seen in the literature.[5] The higher amount of+30 mesh material in the de-dusted stucco would tend to create a larger coat by itself, but the removal of dust also aids in shell build. There was a noticeably higher amount of airborne dust when using the old stucco in both application methods. This dust started to coat the wet bar as soon as it was introduced to the sander and reduced the ability of the larger particles to properly adhere, resulting in a thinner shell.

The bars using the de-dusted stucco applied by the fluid bed were the thickest, as expected. Research has shown that fluid beds produce thicker shells than rainfall sanding methods.[9] As mentioned previously, the increased kinetic energy gained by falling in a rainfall situation allows the stucco to imbed itself further into the slurry layer. This reduces the height of the stucco sticking out and creates a thinner shell.

Permeability

Unfortunately, due to issues in the lab at KMC, permeability data was not available at the time of publication. This data will be presented at the technical conference.

However, it has been shown in the literature that increasing the particle size increases permeability of the shell. It was also shown by Whitehouse/Snyder that additions of 50x100 stucco had a negative effect on the shell's permeability.[5] It is therefore hypothesized that the coarser size of the de-dusted stucco will create a shell with higher permeability than one made with the old stucco.

A review of the literature also indicates that using a rainfall sander to apply the stucco will create a shell with less permeability than one created with a fluidized bed.[8] This is due to the increased kinetic energy at impact due to falling from an elevated height. Data from the thickness testing has already shown one effect of the increased kinetic energy at contact. It is hypothesized that the samples make the in rotary drum will have a lower permeability than samples made in the fluid bed for this same reason.

CONCLUSIONS

The main goal of reducing nuisance dust was achieved by tightening the specification on the -50 mesh particles. The number of fines in the de-dusted material changed very little over the course of the dipping sequence in either the rotary drum or fluid bed while dust was lost to the environment when using the old stucco. There was a slight increase of smaller particles when using the dedusted material in the rotary drum that reached a plateau on the 3rd application. This can be attributed to the friability of the mullite. This phenomenon would be seen in the old stucco as well if the evidence were not being washed out by the loss of fines to the environment.

MOR testing showed that removing the fine particles from the stucco had a negative effect on the fired strength of the cast bars. This could be a good outcome as knockout would be made easier. The green strength remained mostly unchanged, except for the de-dusted stucco when using the fluid bed. Further testing will be done to confirm or update this result. Differences in shell thickness were also observed on the MOR samples. The bars made using the de-dusted stucco were thicker, indicating a faster shell build with this new material.

In conclusion, it is likely that the de-dusted stucco did meet the goal of less nuisance dust without any drastic negative impacts on the final product. By reducing the amount of dust lost, the operators will be able to work in a cleaner environment and the dust collection system will need cleaning less frequently, saving time and money. Further investigation will be performed to make sure that permeability has not been negatively affected.

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INVESTMENT CASTING INSTITUTE

The Digital Foundry: Building on the Processes of Today to Meet the Demand of Tomorrow

Gerald Richard
MAGMA Foundry Technologies

VIRTUAL TECHNICAL CONFERENCE & EXPO 2020

Paper № 18

The Digital Foundry: Building on the processes of today to meet the demand of tomorrow

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ABSTRACT

Investment casting foundry engineers have been using casting process simulation tools to optimize casting designs and processes for years with the goal of finding the best compromise between casting quality and cost. Time is the most precious commodity in foundries and it is strictly limited by the (more and more limited) number of skilled employees available, as well as the delivery requirements the foundry's customers demand. The time it takes to evaluate all potential options to finding the optimal casting process configuration by manually simulating them always exceeds the total time available to the engineer. Autonomous optimization the main component of a new methodology called Autonomous Engineering, which is introduced by MAGMA®, the provider of the casting process simulation tool MAGMASOFT®, relieves the foundry engineer of the majority of this “manual labor”. The software offers two autonomous optimization options, complementing, and potentially replacing, the traditional manual simulation option. This presentation will show examples of investment castings where Autonomous Engineering was utilized to eliminate casting trials and resolve casting defect issues.

INTRODUCTION

Lowering manufacturing costs and reducing delivery times are generally a primary concerns for investment casters, casting designers, casting buyers, and virtually anyone involved with producing a casting. When designing gating systems the primary concern is often on quality with manufacturing costs as a secondary concern due to looming PPAP submission deadlines. If during this design phase hundreds or even thousands of different gating systems can quickly be evaluated, then both quality and manufacturing costs can be considered and even weighed against one another. Since pouring hundreds of sample castings with different gating systems is not practical, using casting process simulation with integrated autonomous optimization capabilities is a much more practical solution. One challenge to the accurate simulation specific to the investment casting process is the sensitivity of the process to the thermophysical properties of the ceramic shell. Each investment caster uses, sometimes multiple different, proprietary compositions making shells customized for their process requirements. This usually requires simulation users to manually fine-tune thermophysical property datasets. With autonomous optimization, there is now a tool available to automate that process through running an inverse optimization. The first example in this paper will demonstrate that process in a commercial application. Two more examples show how simulation was used in art foundries to prevent defective castings.

EXAMPLE 1 – DATA ACQUISITION

American Foundry Group (AFG) produces as much as 2000 tons of steel castings each year, primarily serving the pump and valve industry. These steel castings range in size from less than 1 lb to 6500 lbs with both sand and investment capabilities.

AFG uses MAGMASOFT® to analyze the solidification and filling of castings. They have been able to reduce the amount of time to sample new jobs and have reduced the number of problem jobs. Still, it appeared that the software was too conservative in predicting porosity defects. In an effort to increase the accuracy of predicting shrinkage porosity, AFG decided to fine-tune the thermal properties of the shell material datasets. Because of a variety of shell compositions, particle size distributions and processing parameters it is unlikely that one general thermophysical property dataset can be used to describe every foundry’s ceramic shell. The first step to validating a shell’s thermal property is to accurately collect continuous temperature data from the mold. In this study AFG chose to measure the center of the mold cavity and the outside of the mold. Figure 1 shows the test block used and where the thermocouples are placed.

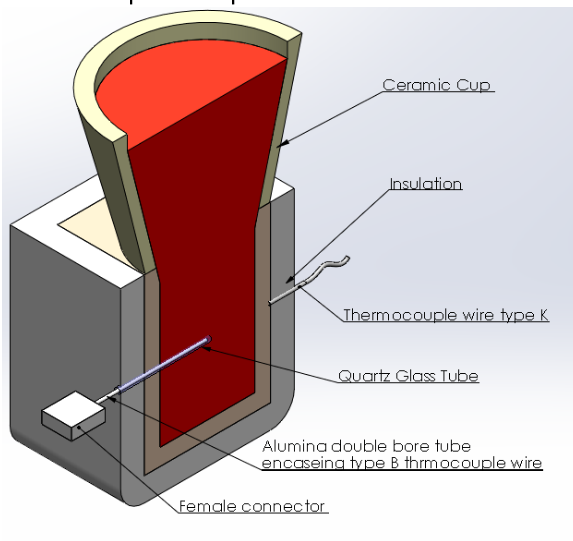


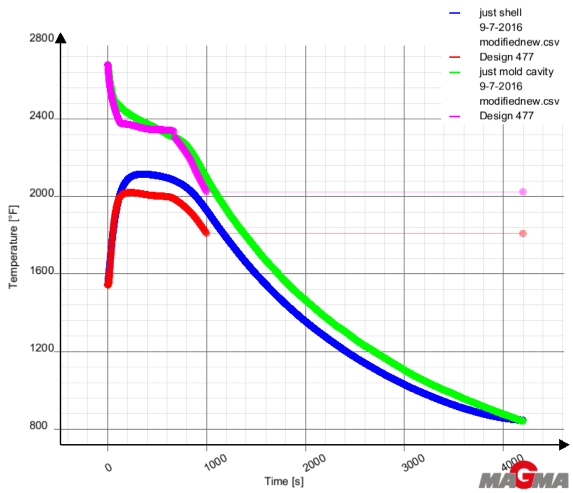
Fig. 1. *Test block with thermocouple placement in mold*

In order to accurately and securely place the thermocouple in the mold, a glass tube for containing the thermocouple in the center of the casting was molded into the wax test block as shown in figure 2.

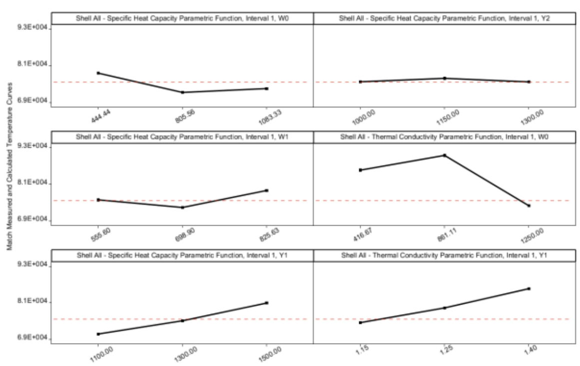
After de-wax the outside of the glass tube was exposed so that the probe could be inserted. For the thermocouple on the outside of the shell a thermocouple was placed at a depth of eighty thousandths of an inch into the shell. To maintain a consistent shell composition the same binder and sand was used to backfill the hole as was used for the final dip. Insulation was wrapped around the mold to minimize the impact of the air temperature. The shell was placed in the oven to cure and be preheated for pouring. By running the thermocouple wire out of the oven, data collection could begin before the shell is out of the oven, which allows for seeing the temperature drop from the oven to the pouring tray. Once the mold is on the pouring tray, the thermocouple probe is inserted into the glass tube and temperature readings are from inside the casting recorded.

EXAMPLE 1 – INVERSE OPTIMIZATION

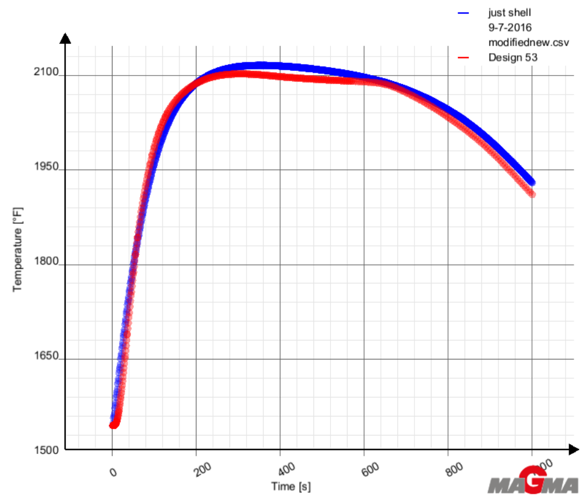
Inverse Optimization is a methodology used to match measured and simulated data. Virtual thermocouples are placed in the same locations in the simulated mold, as in the real mold. Using measured temperature data from the foundry and output temperature data from simulations, the software changes variables with the intent of reducing the area between the curves and eliminating the difference in slopes between them as well. If the measured and simulated cooling curves match, the simulation accurately predicts the heat flow passing through the shell, which will have an impact on all simulation results. Two variables of the shell data were evaluated: 1) the temperature dependent specific heat capacity and 2) the temperature dependent thermal conductivity. The software varied both in an effort to match the simulated with the measured cooling curves in the center of the casting and on the surface of the shell. Theoretically, there would have been 553,350 possible combinations to be evaluated. However, as the software approaches this so-called design space in a very efficient manner by essentially learning “on the go” about what changes in the variables have the most impact on making the curves match, only 640 simulations were actually run. The best one is shown in graph 1. The curves for the casting match very well, while the ones for the shell can be improved. Through reviewing of the main effect charts (Graph 2) it was determined to focus on modifying a certain temperature



Graph 1. *Measure vs. Simulated Temperatures*



Graph 2. *Main Effect Charts*



Graph 3. *Best mold temperature match*

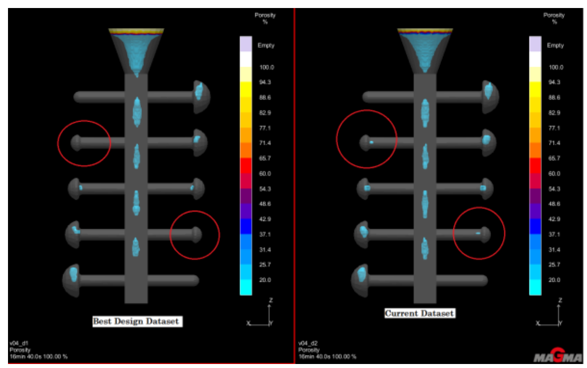


Fig. 3. *Impact of dataset change on porosity prediction*

segment of the thermal conductivity curve, as this showed the biggest impact on moving the simulated temperature curve closer to the measured one. This time only 80 of the 341 possible designs needed to be run.

The best match between the measured and simulated shell temperature is shown in graph 3, while figure 3 shows what impact the changes made in the thermophysical property dataset of the shell material actually have on the prediction of porosity results. The results now show that the alloy feeds better than previously simulated. This behavior matches the real world experience of AFG much better than the original setup.

EXAMPLE 2 – PROCESS WINDOW EVALUATION

Form3d Foundry in Portland, OR wanted to evaluate the proposed gating system and process parameter configuration for the casting of a sculpture regarding its ability to fill the casting without misruns or cold shots and avoid surface or internal defects. The initial filling and solidification simulation showed satisfactory results for the filling behavior and temperature distribution during and after the filling process (Figures 4, 5 and 6).

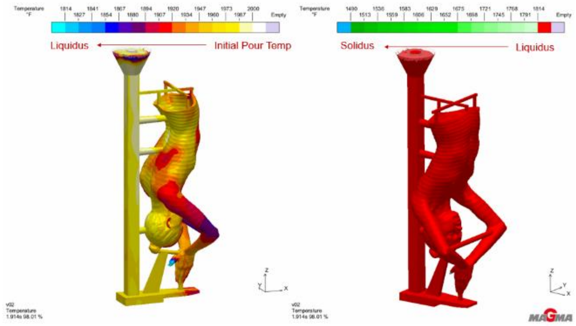


Fig. 4. *Melt temperatures stay above Liquidus until melt rests in its final location*

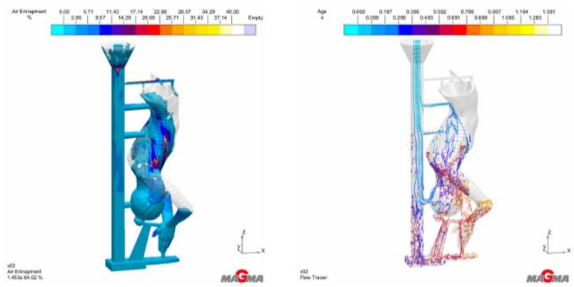


Fig. 5. *Filling process results show only a minor potential for air entrapment and inclusion potentially leading to surface defects*

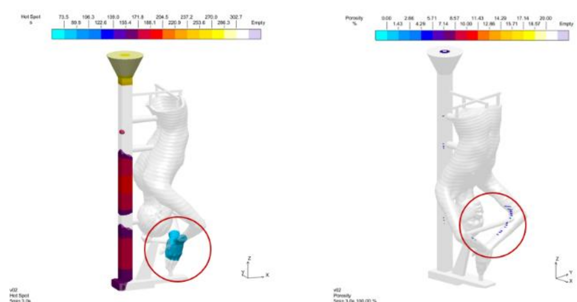
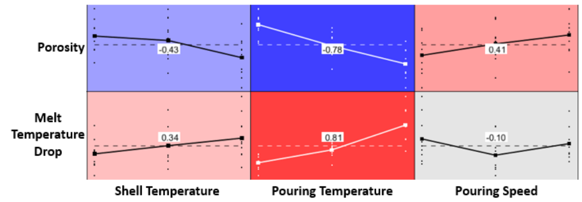


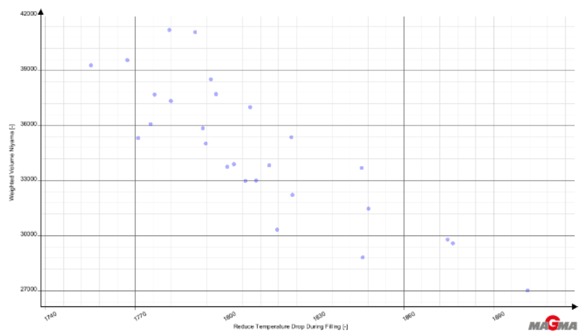
Fig. 6. *Only a minor potential for surface shrinkage defects were detected*

The question was posed if this single simulation of one process point is representative of the production process, which experiences potential variations in process parameters. Predominant ones are the shell temperature, the pouring temperature and the pouring speed. Traditionally a simulation engineer now would have to set up several separate simulations with each process parameter combination. Fortunately the simulation tool used simplifies that process, as it allows the engineer to set up all desired process parameter variations in one setup. The program then runs all parameter combinations of this Design of Experiment (DoE) and at the end provides statistical information to the engineer. In this case the main effect diagrams showed that the shell temperature and the pouring speed has a smaller impact on the temperature loss during the filling process than the pouring temperature (Graph 4).



Graph 4. *Impact of shell and pouring temperature, as well as pouring speed on temperature drop and porosity defects*

However, they also show that the pouring speed produces more shrinkage defects. Interestingly a higher final temperature at the end of the filling process also creates less porosity, which is confirmed by the scatter chart where each dot represents one simulation run (Graph 5).



Graph 5. *Impact of higher pouring temperature on porosity defects*

Overall, the DoE showed that a slower pouring speed at a higher temperature is beneficial no matter at what shell temperature. It also showed that no parameter combination in the process window produces non-acceptable castings, so the gating system is robust for the given process window.

EXAMPLE 3 – RISER OPTIMIZATION

West Supply in Chicago/IL was collaborating with MAGMA on designing a gating system for an art casting. The gating system should lead to good castings in combination with the lowest cost. Some of the biggest cost factors are the amount of material used and the labor involved to remove gates and risers. The basic geometry is shown in figure 7.

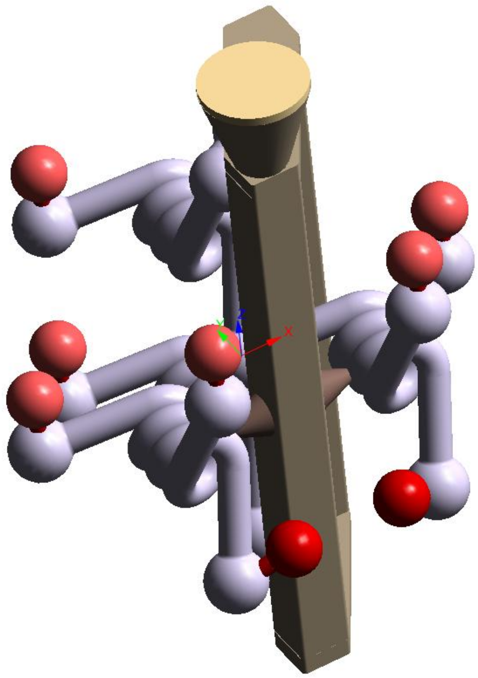


Fig. 7. *Geometry setup with castings (grey), risers (red) and tree (brown)*

The engineers working on this casting quickly agreed on the basic setup requiring risers and gates. However, finding the optimal combination of riser size, riser contact size the casting and gate contact size to the tree usually requires tedious and repetitive simulation setups with small variations in each of these geometry features. In addition, a process parameter like the varying shell temperature could have an impact on the quality of the casting. Sophisticated radiation models are required in simulation tools to accurately predict the shell surface and internal temperatures at every step of the investment casting process (Figure 8).

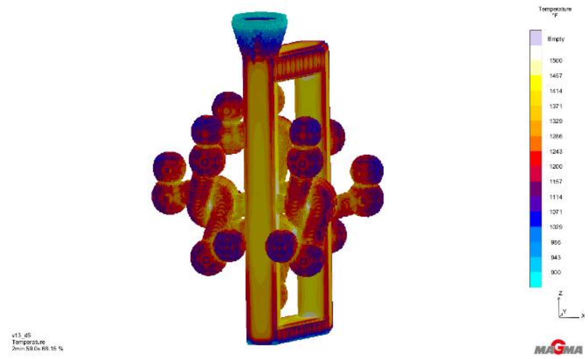
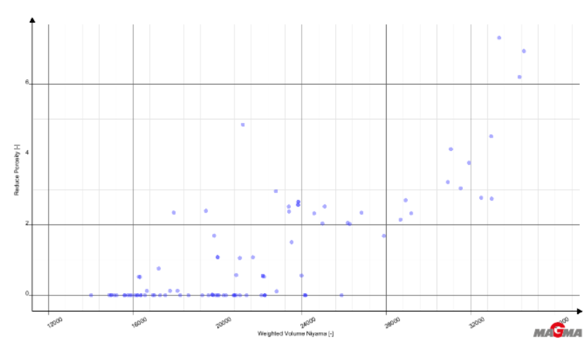


Fig. 8. *Shell temperature distribution*

Varying all these geometry features and the shell temperature and trying to simulate all potential combinations (called designs) would require an unpractical time for the simulations to run or computer resources usually not accessible to investment casting foundries. The simulation tool used eliminates the need to run all designs by taking a systematic approach of selecting a group of initial designs providing a good representation of the entire design space. Running this group of initial designs, it evaluates which ones show promise to lead to defect free, low cost castings. It finds the parameters that have the biggest beneficial impact on the desired outcome. The software then selects another set of designs based on what it learned from the first group of designs simulated. Thereby it hones in very quickly on the optimal geometry feature and process parameter combination, eliminating the need to run all potential designs. Graph 6 shows the scatter chart of all designs that were run.



Graph 6. *Comparison of all designs regarding porosity and cost. Best designs are on the lower left of this chart*

Graph 6 shows all simulations that were run autonomously (without interaction of the engineers) by the software. The best ones with the lowest porosity at the lowest cost to produce are found near the lower left hand corner of the chart, the worst ones on the upper right hand corner. Figure 9 compares the shrinkage defect prediction of the best and the worst design.

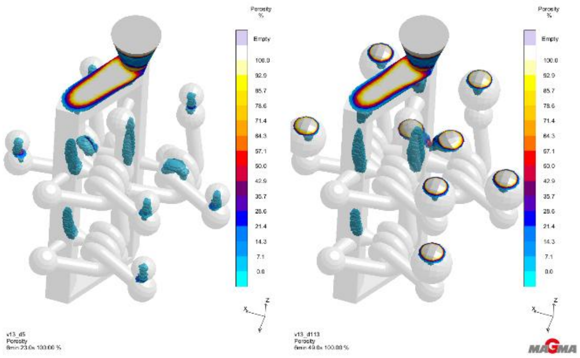
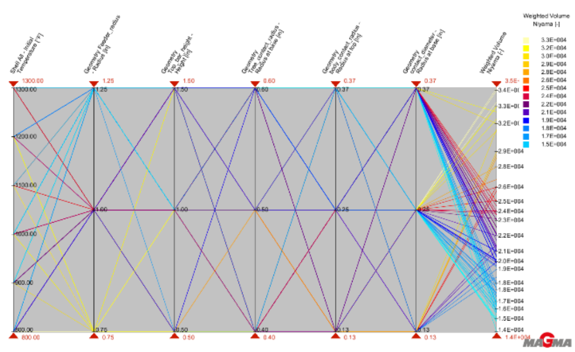


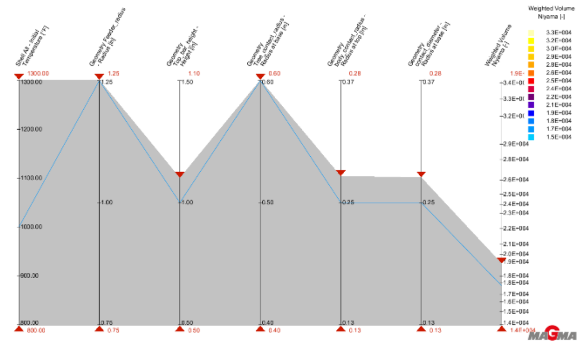
Fig. 9. *Worst (left) and best (right) design, the latter leading to a defect free casting*

Understanding of which parameter combination leads to the best casting is essential to a successful development of a casting process for a particular investment casting. In Graph 7 each line represents a specific combination of geometry features and shell temperature.



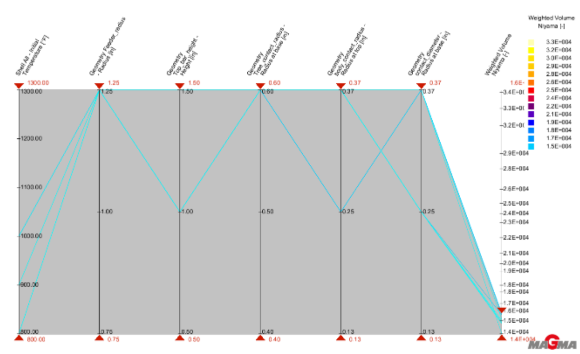
Graph 7. *Plot where each line represents one set of parameter combinations simulated*

Moving the red slider down on the right hand side leaves only the ones with acceptable shrinkage defect levels (Graph 8).



Graph 8. *Parameter combinations with acceptable shrinkage defects*

As all other parameters are the more costly the larger they are (riser diameter, contact areas, etc.), it is imperative to find a design that minimizes these values, thereby minimizing costs, in combination with acceptable casting quality. These interactive charts, provided within the simulation tool used for this work, allow engineers to choose the best compromise between lowest cost and casting quality. They can make the decision to simply choose the one with the lowest porosity. However, that might not be the most cost effective configuration. For instance the casting made in the configuration shown in Graph 9 would be slightly "cleaner" but significantly more expensive to make.



Graph 9. *Parameter combinations with acceptable shrinkage defects*

CONCLUSION

Using the capability to autonomously run virtual designs of experiments optimizations to find optimal casting process parameter and design feature combinations to make quality castings at minimal costs is the core benefit of autonomous engineering methodology integrated into the casting process simulation software

MAGMASOFT®. Three investment casting examples were used to show how the accuracy of simulation tools can be increased by using customized thermophysical property datasets for investment casting shells in combination with sophisticated radiation models. Additionally it was show how autonomous design of experiments and optimizations can prove process robustness and find the best compromise between casting quality and cost.

INVESTMENT CASTING INSTITUTE

Light-Weighting Using Advance Simulation & Tooling Free Investment Casting AM Process

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VIRTUAL TECHNICAL CONFERENCE & EXPO 2020

Paper № 19

Light-weighting using Advance Simulation and Tooling free Investment Casting AM (Additive Manufacturing) Process

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Abstract

Casting process simulation and ICME tools are very matured and allow accurate predictions of the residual stress & distortion; hot tear & shrinkage type defects and micro-structure & properties in most of the alloys. Tooling free castings using AM (printed wax, PMMA, PLA and SLA) offers tremendous design freedom with feature placement, orientation, and drafting. Part and feature consolidation after carefully understanding current casting higher order sub-assembly; it's form-fit and functionality can lead to a more complex one piece casting configuration, improving the final product performance at reducing cost and lead times. Author will present case studies from various research projects working with member investment foundries and manufacturing innovations institutes - America Makes and LIFT / ALMMII, demonstrating light-weighting with the application of advance simulation and AM processes.

INVESTMENT CASTING INSTITUTE

Educating The Customer

Robert Johnson – Shellcast, Inc.
Steve Sikorski – MAGMA Foundry Technologies
Russ Rosmait – Pittsburg State University
Joseph Fritz – Investment Casting Institute

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Panel Discussion No. 4

Educating the Customer

Robert Johnson
Shellcast, Inc.

Steve Sikorski
MAGMA Foundry Technologies

Russ Rosmait
Pittsburg State University

Joseph E. Fritz
Investment Casting Institute

It has long been the objective of the Investment Casting Institute to educate the industry's customer base. This responsibility cannot be addressed without the help of the Membership. This panel discussion addresses the varied ways in which our Members strive to achieve the objective of an educated customer. Topics will address approaches from casual to formal means of education as well as face to face and virtual approaches employed. The objective of this panel discussion is to encourage and support the industry in educating their customers and deriving the benefits that come from having an informed customer.

INVESTMENT CASTING INSTITUTE

Recent Developments in Hot Isostatic Pressing (HIP) for Casting Applications

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VIRTUAL TECHNICAL CONFERENCE
&
EXPO 2020

Paper № 20

Recent Developments in Hot Isostatic Pressing (HIP) for Casting Applications

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Abstract

Hot Isostatic Pressing (HIP) has been commonly used in the casting industry in high demand applications and critical components. The stringent requirements on the material properties for such components rely on HIP to remove shrinkage and gas porosity to further improve mechanical properties and fatigue resistance. Historically HIP has been used to eliminate these defects with subsequent heat treatment performed using conventional technologies to obtain the desired microstructure and mechanical performance. With advancements in HIP systems it is now possible to also achieve the desired microstructure during the HIP cycle with the aid of high-pressure gas cooling and quenching. This modern approach offers the freedom to consider a combined HIP and heat treatment cycle known as High Pressure Heat Treatment (HPHT) leading to shorten process times, cost reductions, and increase productivity while reducing scatter in material properties. This presentation will first cover the fundamentals of HPHT highlighting key technology changes enabling this approach in modern HIP equipment. Then a transition to recent studies capturing the benefits for cast materials and applications leveraging HIP and the HPHT methodology will be reviewed.
Keywords: Cast, Heat Treatment, HIP, Hot Isostatic Pressing, Mechanical Properties, Reduced Cycle Time, Lean Manufacturing, Combined HIP and Heat Treatment, HPHT, High Pressure Heat Treatment

INVESTMENT CASTING INSTITUTE

Customer Spotlight: Honeywell Aerospace

Gregory Colvin
Honeywell Aerospace

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Customer Spotlight: Honeywell Aerospace

Gregory Colvin
Honeywell Aerospace

Honeywell Aerospace is a manufacturer of aircraft engines and avionics, as well as a producer of auxiliary power units (APUs) and other aviation products. Headquartered in Phoenix, Arizona, it is a division of the Honeywell International conglomerate. It generates approximately $10 billion in annual revenue from a 50/50 mix of commercial and defense contracts.

Mr. Greg Colvin will provide a company overview, discuss investment casting configurations procured by the company and address Honeywell's expectations from its supply base.