Innovative Wax Design to Meet the Challenges Within the Investment Casting Industry

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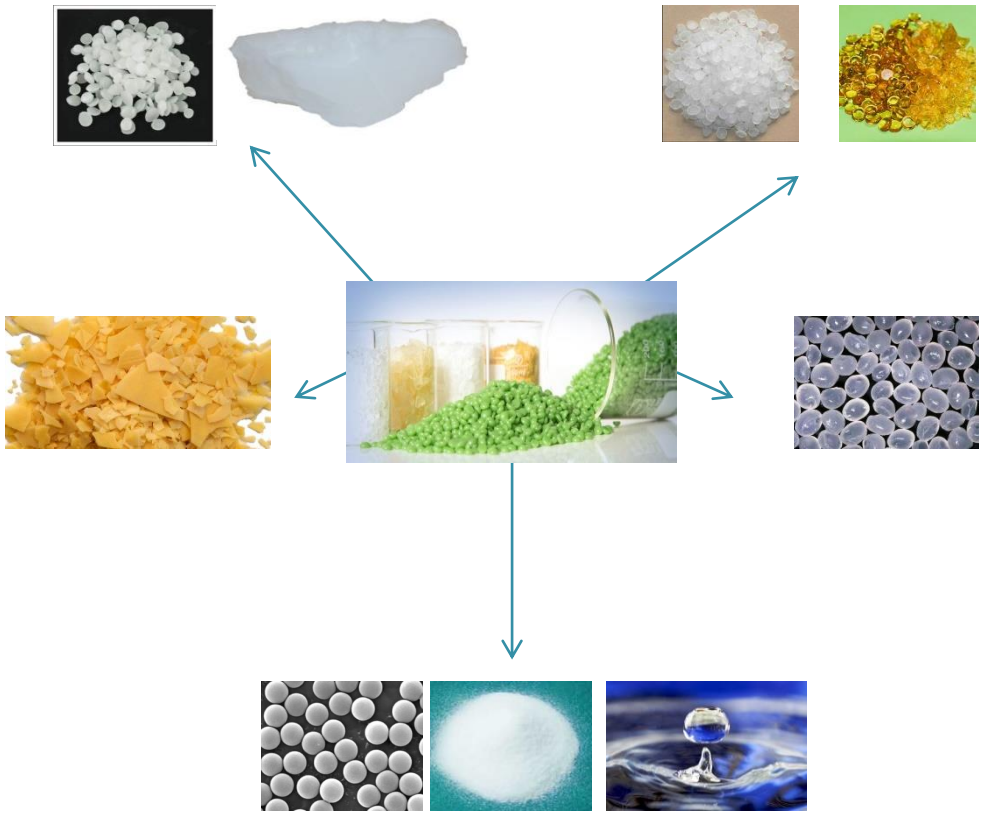
ICI 65th Technical Conference and Expo
Kansas City – October 2018

Blayson

Agenda

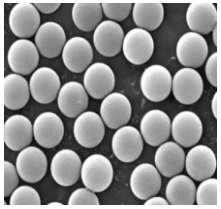
- Wax Composition
- Dimensional Variability – Designing a dimensionally repeatable material
- Dewax Aspects – Designing a gating wax from first principles
- New Generation Materials – Designing wax for tomorrow
- Further Research
- Summary

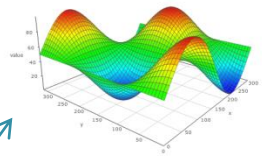
Wax Composition

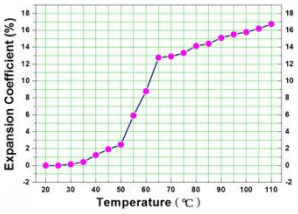


- Paraffin Wax
- Microcrystalline Wax
- Resins
- Polymers
- Hard Wax
- Fillers
- Other Materials
- Formulations can be complex with many elements

The Effect of Raw Materials



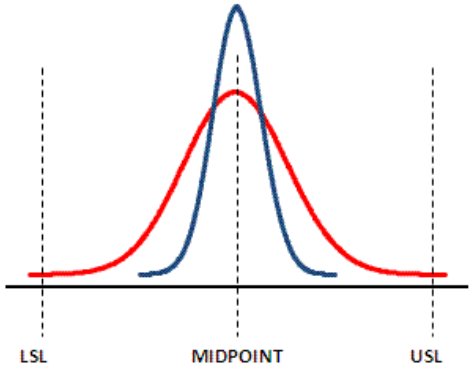




Raw materials have profound effects for example just two possible materials – Resin and Fillers can affect the following

- Overall material dimensions and repeatability
- Viscosity / Fluidity
- Expansion
- Mechanical characteristics
- Design is both skilled and potentially time consuming

Dimensional Variation



- Wax dimensional aspects as we know are affected by injection parameters in particular the following

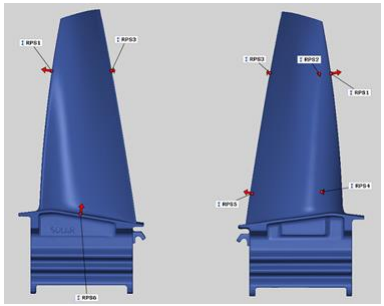
- Control of temperature

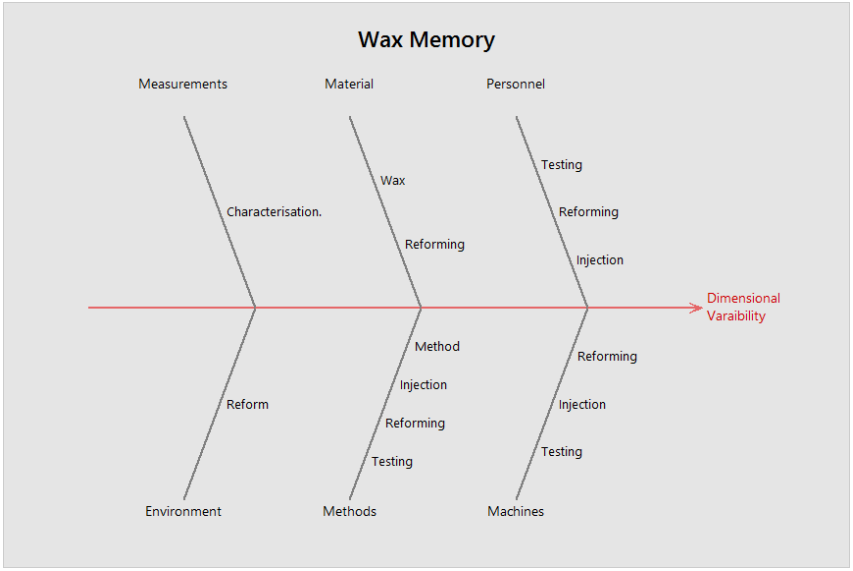
- Injection time

- Also aspects such as deformation on removal from the die

- But also post injection “creep” which is commonly known as “memory”

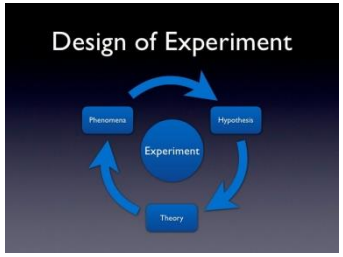
Understanding Wax Memory



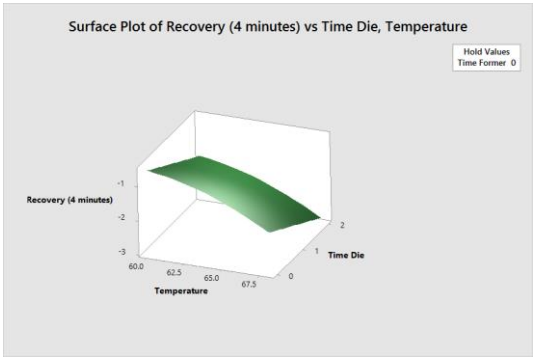


- An important aspect of problem solving is understanding it in detail
- Wax memory was known to be shape driven but little else was understood
- Various techniques existed to compensate, but the overall problem was variability
- It was not known if the problem was material or process related

The Challenges



- Injection variables
- Reforming variables
- Different wax

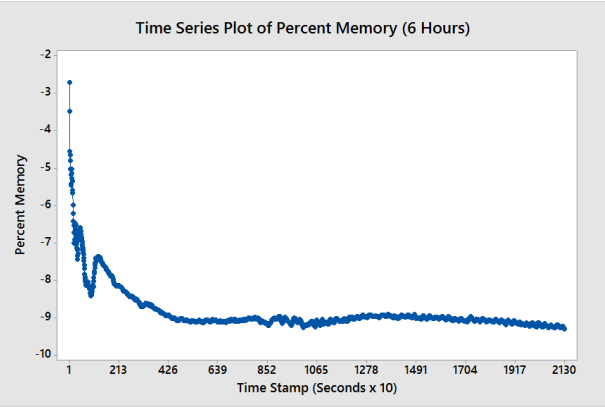


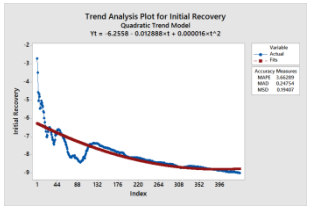
Reforming Process – Key Variable ⟷ **Injection Process – Key Variable**

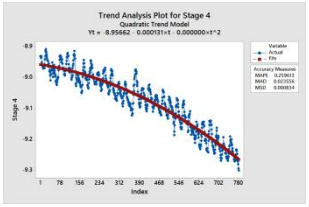
There were a number of challenges we faced before we could understand the problem in detail

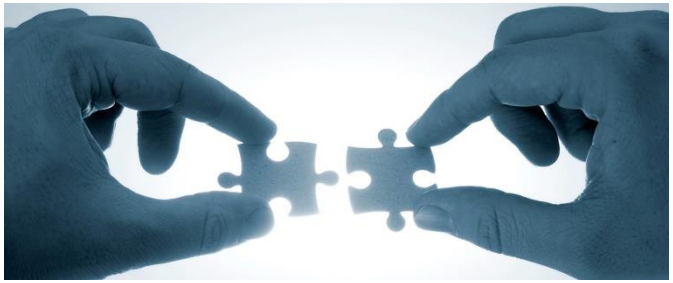
- The effect of contact measurement
- Modelling an industrial process under laboratory conditions
- Suitable test piece
- Having proven these we were able to start identifying key variables

Raw Material Evaluation



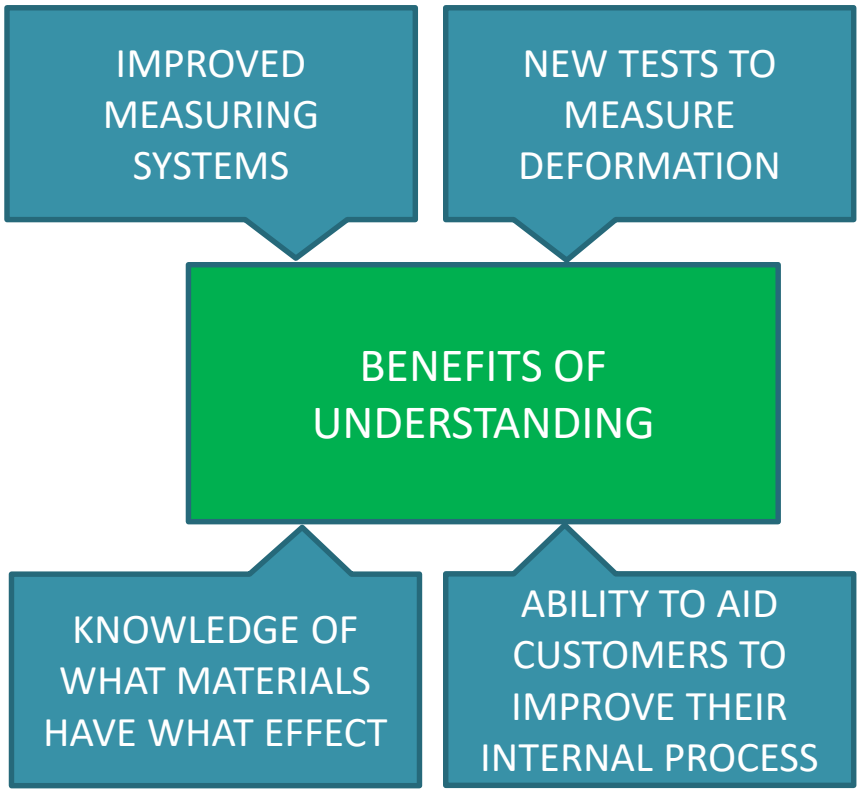






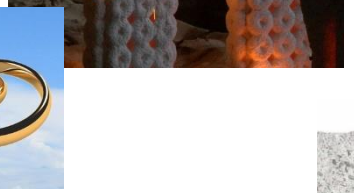
- To identify key ingredients by means of elimination would have been time consuming and costly with up to 10 raw materials
- DOE reduced a potential 100 mixes to 3 and identified the materials which had profound influence on memory enabling formulations to be developed to reduce the wax memory effect
- We are now at the stage where partners are working to develop this wax in their process

Raw Material Evaluation

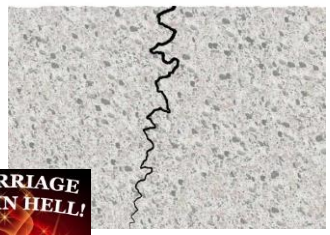


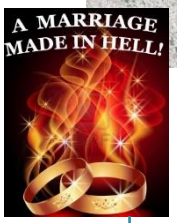
- The research and development associated with dimensional understanding has yielded a number of benefits both to ourselves and our customers
- Development of the first reduced memory range of wax materials
- Improved process based measurement systems
- A deep understanding of how customer process and use of the wax affect dimensional repeatability

The Theory of Dewax



Wax melts and flows through permeable shell – No cracking





Pressure of wax expansion is too great on brittle shell – Cracking

- Perfect scenario – The shell and wax work in harmony, the wax is able to melt and flow into the shell before any failure occurs
- Alternate scenario – The brittle shell does not have sufficient strength to withstand forces exerted by wax as it expands during melt process
- Determining root cause is often difficult

Considerations When Designing Runner Wax

Wax Melting Variables
Difference in Melting Points
Wax Expansion
Energy Demands – DSC Criteria
Energy Demands – Specific Heat Capacity
Flow Properties Post Melting
Mechanical Aspects

- Its not possible to engineer a wax for a poor or variable shell
- Its not possible to engineer a wax for poor equipment, systems or human failure
- When engineering a runner wax a number of aspects need to be considered

The Effect of Additives

	Micro	Paraffin
Melt Point °C	67	70
SHC J g-1/ °C-1	7.131	15.341
Ductility (mm)	10	2

- Typical additives to help reduce melting points of gating wax might be paraffin or microcrystalline wax
- However despite having similar raw material feedstock their properties are very different
- If for example we compared a paraffin and microcrystalline wax with similar congealing points
- The microcrystalline wax would appear to be the best option but would make the runner wax more ductile

The Effect of Additives – Further Analysis

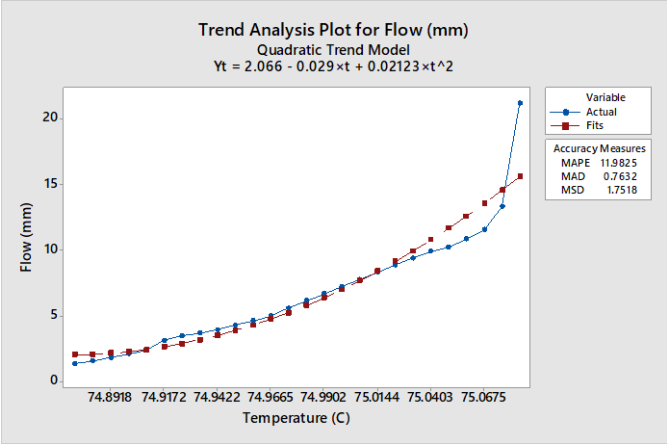
- Looking at the TMA / DSC analysis of the two materials up to the melting point
- Rate of expansion and amount of expansion are similar
- But analysis suggests that the microcrystalline wax begins to expand earlier and set later

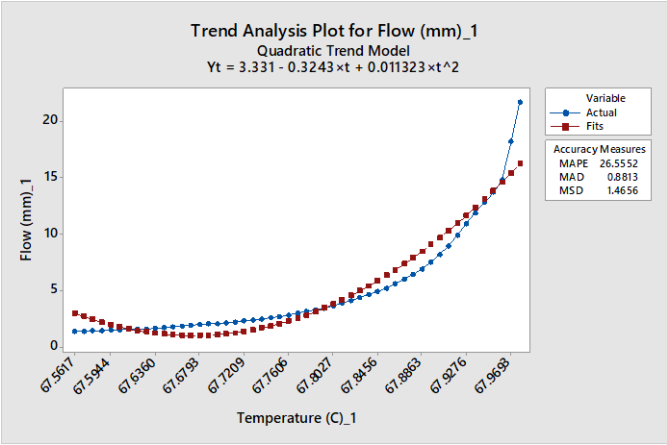
Flow of the Material Post Melt

- Research suggests that a key variable is the ability of the material to flow through the prime coat post melting. The theory is that the material must flow through the shell material fast enough to reduce pressure exerted during expansion
- TMA and DSC give us an indication of how a material might absorb energy during the melt process and what it might do with that energy, but what about flow?

Flow of the Material Post Melt

- The challenge here is that no test existed to characterise how a wax flowed post melting
- Certainly viscosity would play a part but the viscosity will change as the material temperature increases
- Initial trials involved use of a viscosity cup held at a fixed temperature and measuring weight loss versus wax temperature
- This initial test gave way to a mechanised version using flow measured using a camera

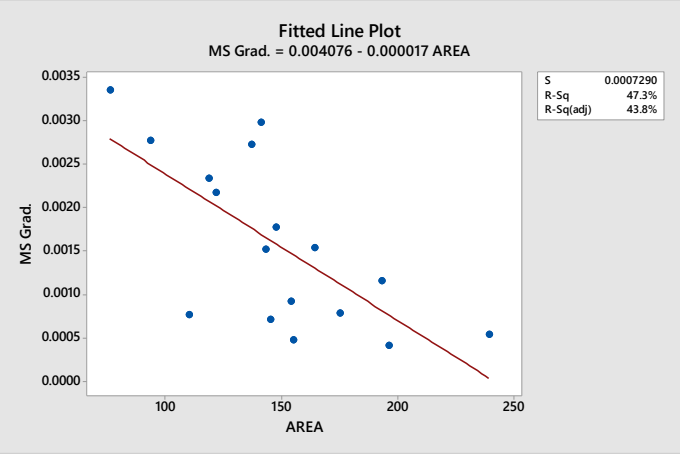


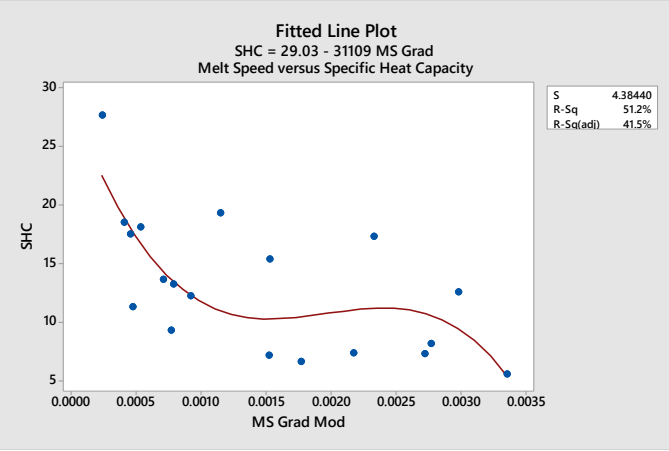


Flow of the Material Post Melt – Raw Material

Taking this approach further allowed us to evaluate how raw materials behaved. An understanding of this would allow design improvements.

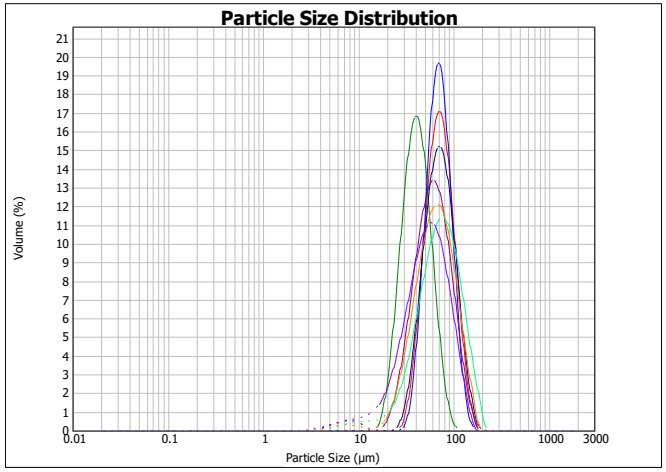
Material	% Expansion	Rate Expansion E-6	AREA	ONSET	END	PEAK	MS Start Time_1	MS Grad._1	SHC
A0116	9.09	1136	145.3	108.2	117.7	115	750	0.000711	13.659
A0120	11.27	1409	110.1	55.3	75.2	68.1	270	0.000767	9.314
A0160	10.16	1270	76.22	34.3	68.9	57.7	210	0.00335	5.525
B0210	12.84	1605	143.1	33.2	74.6	50.6	510	0.00152	7.131

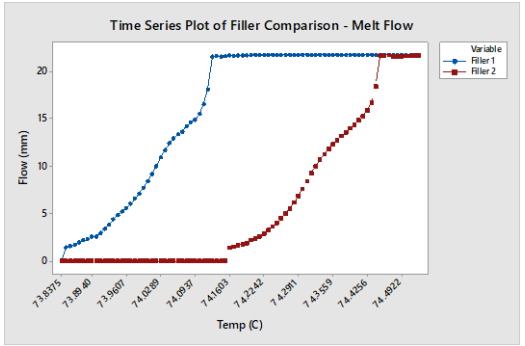


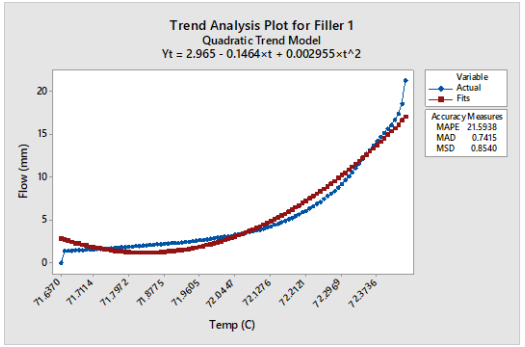


Flow of the Material Post Melt – Fillers

- This approach also allows the development of alternative material sources and suppliers
- Fillers are supplied to a particular particle distribution, the challenge is understanding how this variability might affect areas such as dewax and in particular flow during dewax
- Customer trials have shown that filler particle distribution can be used to design materials to help a customer reduce shell cracking







Summary

- **Development of tests to evaluate the full range of wax melting properties**
- **The impact of raw materials on these properties**
- **The ability to use this knowledge in the design of -**

- **Virgin wax materials**
- **Reconstituted runner wax to virgin repeatability**
- **Reclaim runner wax**

New Generation Pattern Wax Materials

IMPROVED DIMENSIONAL REPEATABILTY

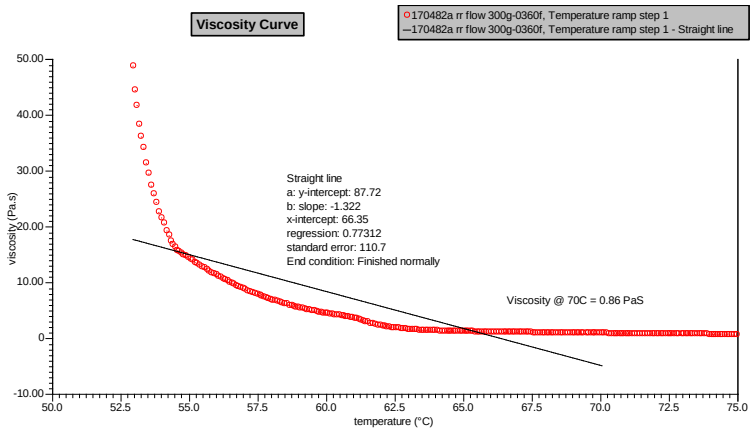
GOOD FLOW CHARACTERISTICS

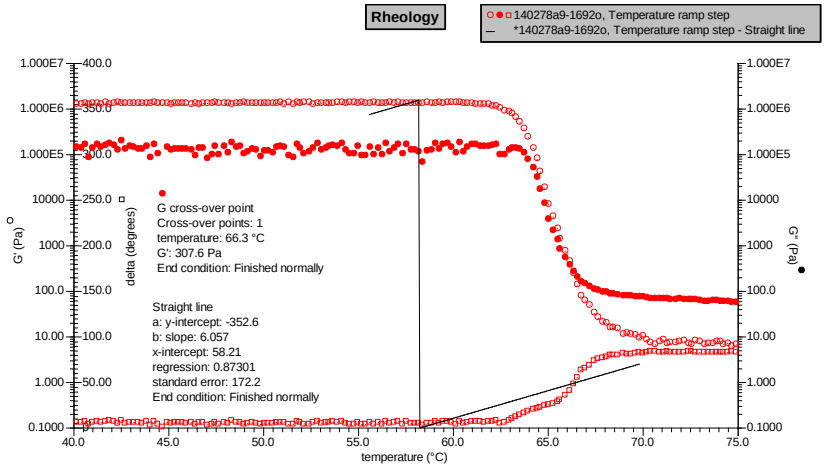
FAST SET RATES

LASER MEASUREMENT

The request from a customer was for a material with improved fluidity characteristics to overcome non fill issues

Measuring Fluidity





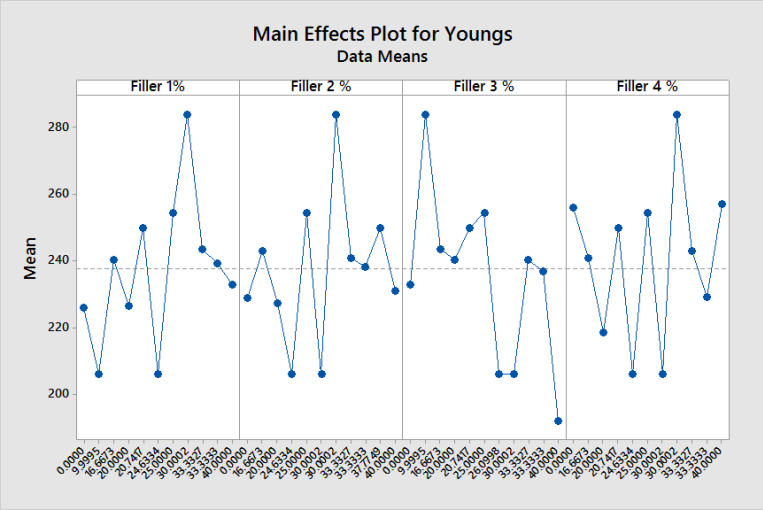
- Traditional methods rely on viscosity but this is dependent upon test equipment and conditions
- Rheology gives a more detailed picture but requires skill to interpret
- A spiral injection test is a simple process based procedure

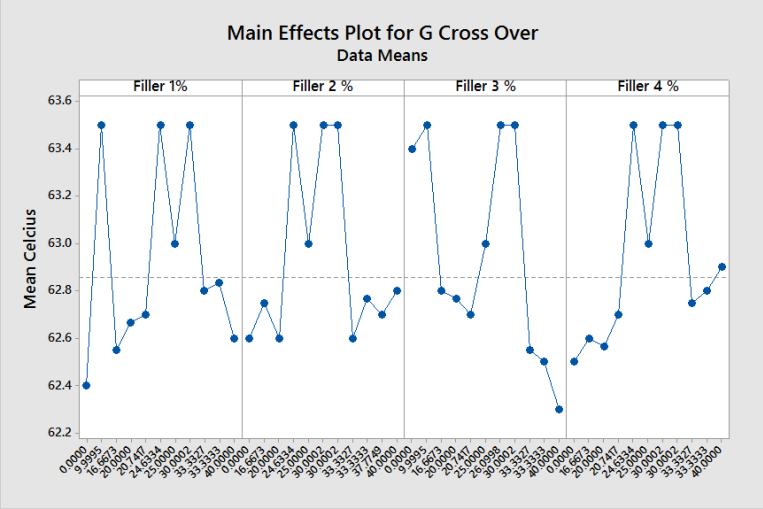
The Effect of Fillers

Filler 1%	Filler 2 %	Filler 3 %	Filler 4 %	FLC@64	FLC STD	Fluidity (cm)
10.0	30.0	30.0	30.0	0.74	0.05	44.4
24.6	24.6	26.1	24.6	0.76	0.02	43.4
16.7	33.3	33.3	16.7	0.75	0.04	45
25.0	25.0	25.0	25.0	0.78	0.04	45.2
30.0	30.0	10.0	30.0	0.83	0.07	54.5
16.7	16.7	33.3	33.3	0.75	0.02	54.6
25.0	25.0	25.0	25.0	0.78	0.04	61.3
20.7	37.8	20.7	20.7	0.76	0.03	59.3
33.3	16.7	16.7	33.3	0.79	0.06	56.4
33.3	33.3	33.3	0.0	0.76	0.04	48.4
20.0	20.0	20.0	40.0	0.8	0.02	47.8
40.0	20.0	20.0	20.0	0.78	0.05	46
33.3	0.0	33.3	33.3	0.79	0.04	49.8
0.0	33.3	33.3	33.3	0.76	0.04	48.3
33.3	33.3	16.7	16.7	0.78	0.04	48.1
20.0	40.0	20.0	20.0	0.77	0.03	46.1
33.3	33.3	0.0	33.3	0.86	0.02	50.1
20.0	20.0	40.0	20.0	0.71	0.02	44.5

- The results are based on a 30% filled wax recorded under the same injection conditions
- Research work suggested that by manipulation of type and percentage of filler we could affect both fluidity and dimensional repeatability

The Effect of Fillers





- Using this approach also allowed us to gain some insight into the effect of filler combinations on other areas of interest
- Mechanical
- Dewax properties
- Fluidity aspects

Further Challenges

- Two challenges we faced were

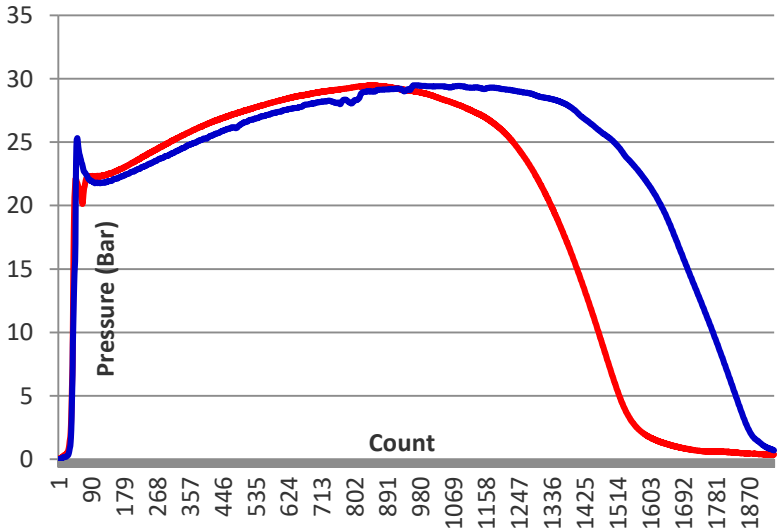
- How to measure the effects of the action of removing a part from a die

- How to give a reflection of wax set rate during injection

Comparison Standard vs New Generation Wax

Description of Test	Standard Wax	New Generation Wax
Congealing Point (°C)	62	66
Melting Point (°C)	77.3	71.2
Ash (%)	0.028	0.012
Penetration (dmm)	10	10
Viscosity@70°C (Pa · s)	0.344	0.75
Filler (%)	28.80	36.00
Mechanical Analysis		
Maximum Load (N)	312	375
Ductility (mm)	1.11	1.21
Young's Modulus MPa	250	282
Toughness MPa	0.021	0.028
Injection Profiling@68°C		
Free Linear Contraction	1.04	1.02
Fluidity (cm)	45	71
% Distortion	2.22	2.60

Summary



- The work outlined led to the development of

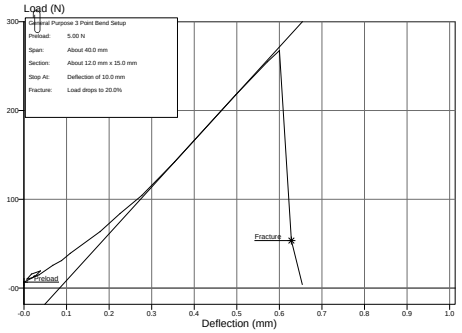
- Wax materials for turbo wheel and aerospace blade manufacture which are

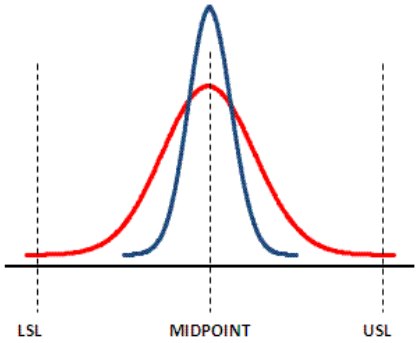
- High filled for dimensional repeatability

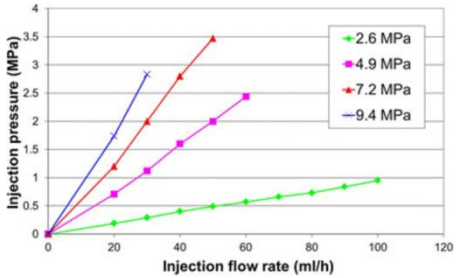
- Very fluid

- Improved set rates for productivity gains

Further Research







- Further research taking place includes looking at the relationship between forces exerted during the injection process, dimensional repeatability and injection parameters
- The aim being to understand in particular forces exerted on cores both during and after injection

Summary

- In design and selection of a wax material there are many competing factors which need to be taken into account
- This paper has attempted to provide a small insight into the challenges and some unique solutions that were adopted to overcome these challenges
- The design of any material is a two way process involving not just the manufacturer but critical feedback from the customer
- Essential that foundries and suppliers work together to ensure the best possible wax performance to overcome the challenges of today and tomorrow

Thank You

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ICI 65th Technical Conference and Expo
Kansas City – October 2018

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