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INVESTMENT CASTING TRENDS

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IN THIS ISSUE

Comments From The President . . .

This is our first issue of "Investment Casting Trends." It is specifically designed to keep you current with the latest technical advances and applications in the Investment Casting Industry. We are confident you will find this and future issues informative, thought provoking, and helpful in your work.

The Investment Casting Institute is made up of independent member foundries and the principal suppliers of our raw materials. By working together we have:

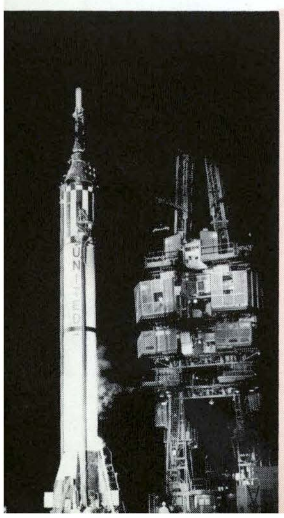
- — established design, alloy and tolerance standards
- — provided a forum to exchange technical information
- — promoted the use of our product
- — been the responsible spokesman for our industry.

The member foundries sponsoring this publication are your reliable vendors of quality Investment Castings. It is their business to furnish you with unusual cast shapes in a wide assortment of ferrous, non-ferrous, and special purpose alloys. These cast parts may dramatically reduce your cost of machining and fabrication. Improved quality is possible by applying our design freedom and wide choice of alloys to provide for improved strength and function. Any member foundry will be pleased to consult with you at your request.

Cordially yours,

R. E. Gray

RICHARD E. GRAY
PRESIDENT
INVESTMENT CASTING INSTITUTE



ABOUT THE COVER

The performance of this space vehicle depends in part on the reliability of certain critical investment castings to perform effectively under extreme heat and pressure. Full details in story at right.

Under Extreme Pressures and Temperatures

INVESTMENT CASTINGS RIDE INTO SPACE

THE PART: an investment-cast adapter (pictured above) used in the igniter of the rocket engine of a space vehicle.

THE PROBLEM: greater reliability and optimum performance under extreme pressure and temperature conditions.

THE USER: Thiokol Chemical Corporation's Redstone Division, Huntsville, Alabama.

The adapter, which looks something like the top of a fire hydrant with a pair of tubular orifices projecting from the top, is bolted to the head-end of the rocket motor case. It weighs approximately 4½ lbs., and is produced from 4340 high-strength structural steel.

The part was formerly made from bar stock or produced as a sand casting. However, it did not meet the specified exacting requirements.

The original print called for 160,000 to 180,000 yield strength, with 7% minimum elongation However, as an investment casting, the part typically gives 195,000 psi tensile strength, 180,000 yield strength, and 10% elongation. It is subject to Class 1A, 100% x-ray inspection.

How To Design Investment Castings

Industry's thinking about investment casting has been pretty much like a pendulum — it has swung from one extreme to another. In the early days, over-enthusiastic boosters of the process made exaggerated claims and many were "burned" when the claims were not fulfilled. More recently, many who could profitably employ the process have avoided it because of the misconception that it is limited to a narrow range of special applications.

As usual, the truth is somewhere in the middle — and defining the "middle" design-wise is the purpose of this article.

BASIC ADVANTAGES Investment castings offer several basic engineering advantages to designers, engineers, and manufacturers. These include close dimensional tolerances, within the practical range of ±.003 to ±.005 in./in. Such tolerances permit production of castings which require only minimum machining in critical areas. Often, parts need no machining and may be used as cast. As-cast surface finish on castings is good, ranging from 40 to 125 microinches root mean square. With secondary finishing operations, a surface finish of 32 microinches rms can be obtained.

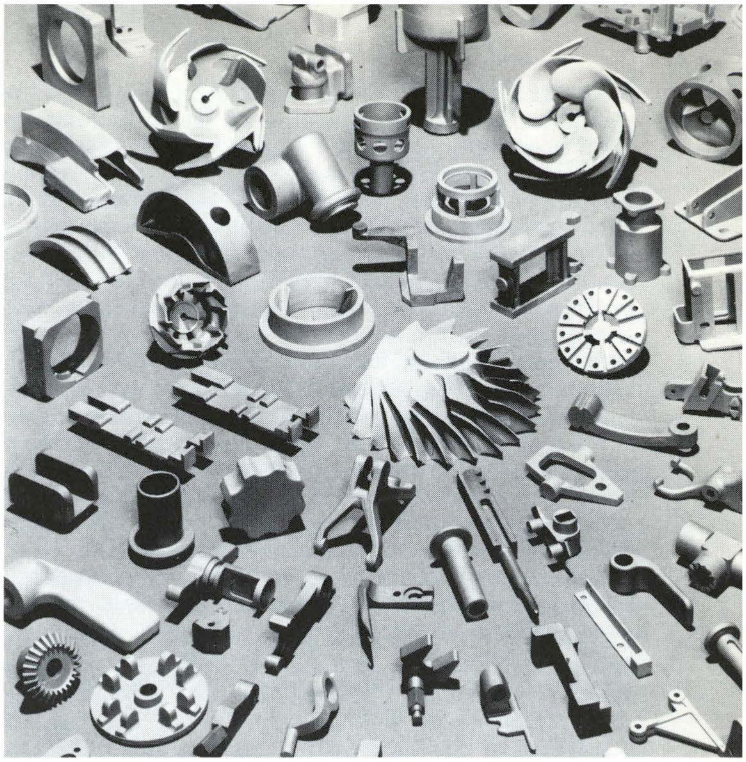
Perhaps the most outstanding advantage of the investment casting process is the flexibility which can be allowed in the shape of parts cast. It is actually hard to imagine a shape which can not be cast by this method.

The illustration (right) shows only a few of the shapes which have been investment cast. Undercuts, blind holes, both open and closed angular passages and many other shapes impossible to machine and which can not be cast accurately enough in sand are made by this process.

DESIGN IS IMPORTANT If you design your part for function and for the process, you will reap the maximum benefits from investment casting.

If you decide the part on your drawing board is suitable for investment casting we recommend consulting with an Investment Casting Institute member. He can tell you not only whether investment casting is practical but also what specific tolerances should be used for best function and maximum economy. And you'll often find this advice invaluable in helping you to avoid the unnecessary expense associated with over-specifying tolerances.

SUGGESTIONS FOR DESIGNING AND SPECIFYING SURFACE FINISH Attainable finishes will vary somewhat, depending on the type of metal from which the casting is made.* The degree of smoothness of a surface is measured in microinches root mean square (generally abbreviated to rms), the lower rms values designating the smoother surface. The following table shows rms values obtainable with alloys commonly used for investment castings. Any given production lot of castings generally would fall within the ranges listed. Additional alloys not appearing in this list usually can be identified closely with one of the metals listed and the same rms value used.



It is suggested that the designer specify the maximum rms value acceptable for a given casting and consider smoother surfaces acceptable. That will assure acceptable castings and place less restriction on the foundry.

*May we suggest reference to the Investment Casting Institute Handbook "How To Design And Buy Investment Castings" for a comprehensive listing of the most widely cast materials.

Metal	Average rms Value As-cast	Average rms Value Finished*
Aluminum alloy	60-100	40-100
AMS — 4640 bronze	60-100	60-100
Beryllium copper	60-100	40-100
400 series stainless steel	100-125	60-125
300 series stainless steel	90-125	60-125
Cobalt chrome alloy	80-100	50-100
Carbon steel	90-125	60-125

* Surface finishes as smooth as 32 rms can be attained by special finishing and polishing techniques. It should be recognized, however, that such operations add to the cost of a part and should not be specified unless absolutely necessary.

FINISHED AND GENERAL DIMENSIONAL TOLERANCES Tolerances on finished castings (sand blasted finish) will vary somewhat from part to part, depending on factors of metal, size, and configuration. A general rule of thumb, however, can be applied with reasonable accuracy, particularly in the smaller sizes. This general rule is expressed in the following table.

To meet special requirements, tolerances of ±.003 in. for dimensions of .250 in. and under can be held, with a tolerance of ±.004 in. for dimensions from .251 to .500 in. Such tolerances should not be specified, however, unless absolutely necessary. Exceptionally close tolerances add to the production cost of castings.

General tolerances applied to nonfunctional areas should be as generous as possible to insure economical production of the casting. Desirable tolerances are as follows:

FINISHED TOLERANCE

Dimension	Tolerance
Up to 1 in.	±.005 in.
Over 1 in.	±.005 in./in.

GENERAL TOLERANCE

Dimension	Tolerance
Under 2 in.	±1/64 in.
2 in.-4 in.	±1/32 in.
4 in.-6 in.	±3/64 in.
Over 6 in.	±1/16 in.

RADIUSES Tolerances set forth here represent the minimum achievable. Because of the difficulty encountered in inspecting radiuses accurately on a production basis, it is suggested that a minimum tolerance span of $\pm 1/64$ in. be established for all small radiuses. For larger radiuses, the tolerance is based on $\pm 1/64$ in. for each 2 in. of radius or fraction thereof, with a minimum tolerance of $\pm 1/64$ in. In rare instances where a smaller tolerance span is required, ±.005 in. can be held. For all radiuses over 1 in., the spans will be based on the $\pm 1/64$ in. tolerance previously noted. All tolerances can be considered as applying to internal and external radiuses.

Radiuses should be measured with standard radius gages. Toolmaker microscopes, comparators, or other special devices which are not standard inspection equipment should not be used. The application of minimum tolerances for radiuses adds to the production cost of castings. Consequently, tolerances should be as liberal as possible.

STRAIGHTNESS Limits on straightness primarily are a function of mechanical straightening and can vary to almost any degree desired. However, incorporation of gussets and ribs often can control distortion of the part during casting and minimize or eliminate subsequent straightening operations. Tolerance ranges set forth in the accompanying table represent the practical production limits of a typical casting. Within the size range of most investment-cast parts, length is the determining factor in straightness with diameter having little effect.

Length	Full Indicator Reading As-cast	Full Indicator Reading Finished
Up to 2 in.	.020 in.	.010 in.
2 in.-4 in.	.030 in.	.020 in.
4 in.-6 in.	.040 in.	.020 in.
Over 6 in.	.060 in.	.030 in.

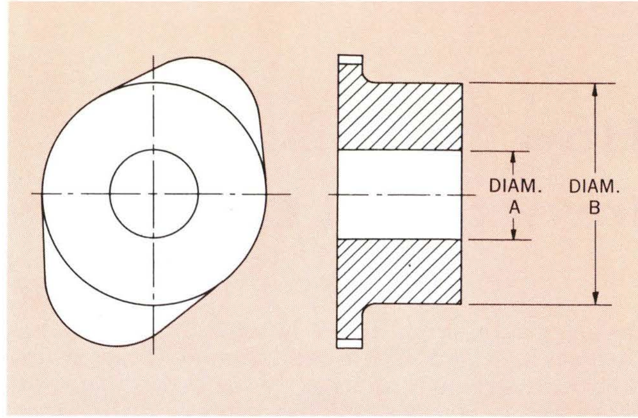
FLATNESS As in the case of straightness, flatness limits largely are a result of mechanical straightening of the part. Also, length is the determining factor in flatness rather than width or thickness. Incorporation of ribs can help control distortion and minimize straightening operation. Although data in the accompanying table are based on a typical rectangular piece, the tolerance span would apply to any flat piece no matter how irregular in configuration. Dimensions are to be checked with a straight edge and feeler gage. Tolerances deal with bow only and must not be confused with local surface irregularities.

Length	1 in.	2 in.	4 in.	6 in.
As-cast	±.008 in.	±.016 in.	±.025 in.	±.030 in.
Finished	±.004 in.	±.006 in.	±.010 in.	±.015 in.

CONCENTRICITY The concentric relationship of an outside diameter to an inside diameter can be controlled mechanically only where the wall thickness of the part is sufficiently thin to allow movement of the metal during the straightening operation. As can be seen from the accompanying chart, parts having small diameters with a heavy wall are difficult, if not impossible, to straighten. However, as the outside diameter increases, the part becomes more workable even with a heavy wall.

The full indicator reading (FIR) should not be less than the high-low limit on the inside or outside diameters. That is, the total span of the plus-minus tolerance.

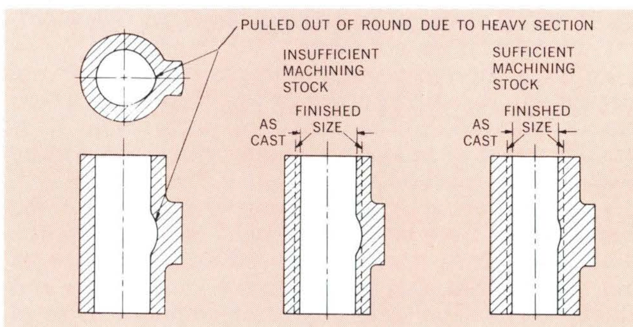
Outside Diam.	Inside Diam.	Full Indicator Reading As-cast	Full Indicator Reading Finished
$3/4$ in.	$1/4$ in.	±.004 in.	±.004 in.
1 in.	$1/2$ in.	±.005 in.	±.005 in.
$1\frac{1}{2}$ in.	$3/4$ in.	±.008 in.	±.005 in.
2 in.	1 in.	±.010 in.	±.008 in.



ROUNDNESS With regard to solid bars, roundness is a function of the normal shrinkage variations in the metal. Data in the accompanying table show that as the shrinkage variation increases with the diameter, the tolerance required increases nearly proportionally. The general rule of thumb tolerance of ±.005 in./in. can be applied to diametrical tolerances, although smaller ranges are possible.

Diameter	$1/2$"	1"	$1\frac{1}{2}$"	2"
Roundness tolerance (full indicator reading)	.010 in.	.016 in.	.024 in.	.030 in.

It should be noted that these tolerances are not based on outside diameter grinding operations, since such operations are not part of standard investment foundry process. Therefore, the as-cast measurements of the part must be considered as the minimum tolerances achievable.



In the case of hollow tubing of larger diameters, corrective action through straightening is possible. Because of this factor, generally closer tolerances can be held on tubes than on solid bars, particularly in the larger sizes. Again it should be noted that wall thickness is a controlling factor in such straightening and the table below is predicated on a wall thickness and material which will allow straightening.

Outside Diameter	Full Indicator Reading Roundness, As-cast	Full Indicator Reading Roundness, Finished
$1/2$ in.	.010 in.	.005 in.
1 in.	.020 in.	.006 in.
$1\frac{1}{2}$ in.	.024 in.	.008 in.
2 in.	.030 in.	.010 in.

With regard to inside diameter tolerance for roundness, tolerances for holes generally can be set up, using the following general scale. These tolerances do not apply to tubing where the roundness of the inside diameter becomes a function of straightening. Holes may be cast out-of-round or "egg shaped." Some of the factors that affect the roundness of a hole are gate area, type of metal, length, and an unusual distribution of mass around the hole as shown above.

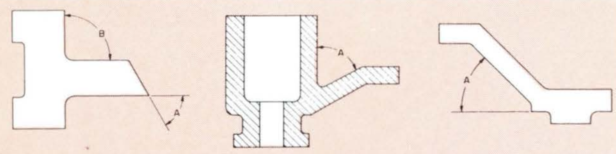
Inside Diameter	Full Indicator Reading Roundness Within:
.092- .250 in.	.012 in.
.251- .500 in.	.016 in.
.501-1.000 in.	.020 in.
Over 1.000 in.	.020 in./in.

ANGLES Tolerances for angles vary, depending on their location in the cast part. Three drawings are included here to illustrate variances in tolerances for typical situations involving angles.

Angle A in the illustration below can not be changed from the as-cast condition by any means other than grinding or machining to bring it into tolerance. Angle B can not be machined, and, therefore, the as-cast and finished values are the same.

Because of the unsupported position of the angular flange in the part illustration below, inherent distortion would be expected in the as-cast condition. However, straightening may be applied in this case, resulting in a much closer finished tolerance for angle A.

The angular configuration of the part illustrated below also would result in distortion of the part during production. The part can be straightened, however, reducing the finished tolerance considerably. In similar parts, a gusset or rib between the base and the angular arm would minimize distortion of angle A.



Tolerance, Angles A or B — As-cast ±1/2 degree; Finished ±1/2 degree
Tolerance, Angle A — As-cast ±1 1/2 degrees; Finished ± 1/2 degree
Tolerance, Angle A — As-cast ±2 degrees; Finished ±1 degree

LENGTH Tolerance ranges covering length of cast parts or segments of parts generally fall under the ±.005 in./in. rule. It is advisable, however, for the designer to consult a reputable investment casting engineer for discussion of length tolerances on any particular part. Many factors such as configuration, cored sections, and other considerations can affect the shrinkage factor of a given part. These factors must be considered in determining tolerance ranges.

BLIND AND THROUGH HOLES Incorporation of holes in a casting often is a matter of importance to the design engineer. Holes are formed by the ceramic mold investment or by preformed ceramic cores, and certain limitations must apply. Hole diameter, position, parallelism of the walls, mass surrounding the hole, and the relationship of hole length to diameter are factors which must be considered in determining whether or not a hole can be cast into a part. Draft generally is not required on cores for forming small diameter holes except when an extremely long draw is required. It is preferred, however, that cores for holes of 1 1/4 in. in diameter have a 15 minute draft.

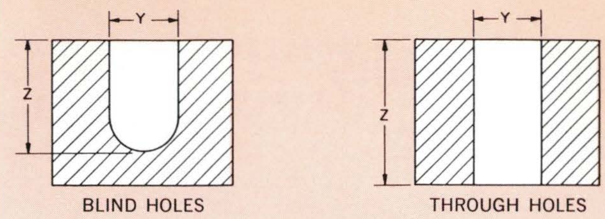
In the accompanying tables, Y represents the general minimum diameter in relation to length Z. Since the diameter to length relationship differs between ferrous and nonferrous castings, values are given for both.

FERROUS CASTINGS

Blind Holes Length, Z	Blind Holes Diam., Y	Through Holes Length, Z	Through Holes Diam., Y
1/4 in.	3/16 in.	1/4 in.	3/32 in.
1/2 in.	1/4 in.	1/2 in.	1/8 in.
3/4 in.	1/2 in.	3/4 in.	3/16 in.
1 in.	5/8 in.	1 in.	1/4 in.
1 1/4 in.	3/4 in.	1 1/4 in.	5/16 in.
1 1/2 in.	3/4 in.	1 1/2 in.	3/8 in.
2 in.	1 in.	2 in.	7/16 in.
2 1/2 in.	1 in.	2 1/2 in.	1/2 in.

NONFERROUS CASTINGS

Blind Holes Length, Z	Blind Holes Diam., Y	Through Holes Length, Z	Through Holes Diam., Y
1/8 in.	1/8 in.	1/8 in.	1/32 in.
1/4 in.	3/16 in.	1/4 in.	3/64 in.
1/2 in.	1/4 in.	1/2 in.	3/32 in.
3/4 in.	7/32 in.	3/4 in.	5/32 in.
1 in.	3/8 in.	1 in.	7/32 in.
1 1/4 in.	7/16 in.	1 1/4 in.	1/4 in.
1 1/2 in.	1/2 in.	1 1/2 in.	5/16 in.
2 in.	9/16 in.	2 in.	3/8 in.
2 1/2 in.	5/8 in.	2 1/2 in.	1/2 in.



These tables indicate that blind holes must have larger diameters in relation to length than through holes. Because cores forming blind holes are supported at only one end, they must be thicker for greater strength. Such cores must not break when subjected to the pressure and thermal shock of molten metal.

It should be understood that the use of special, preformed cores can result in a reduction of minimum diameter on both blind and through holes. The use of preformed cores adds to the cost of casting. Therefore, their use is suggested only in special instances where configuration or other factors in certain castings require it.

Minimum Wall Thickness — Wall thickness around a hole is determined by the length and cross section of the part. In addition, because of flowability factors, the type of metal required for the cast part will determine the minimum castable wall thickness. The wall thickness required to cast a 1 1/2-in.-long tube in various metals is shown here:

Metal	Minimum Wall	Metal	Minimum Wall
Magnesium alloy	.050 in.	400 series stainless	.065 in.
Aluminum alloy	.050 in.	300 series stainless	.050 in.
Beryllium copper	.040 in.	Cobalt chrome alloy	.050 in.
AMS 4640 bronze	.060 in.	Carbon steel	.060 in.

To illustrate the effect of length and cross section, the following chart covers a series of sizes in relation to the minimum wall thickness of a typical ferrous casting:

Length	Diameter	Minimum Wall	Length	Diameter	Minimum Wall
1/4 in.	1/8 in.	.030 in.	1 1/4 in.	3/4 in.	.060 in.
1/2 in.	1/4 in.	.040 in.	1 1/2 in.	1 in.	.060 in.
3/4 in.	3/8 in.	.050 in.	2 in.	1 1/2 in.	.060 in.
1 in.	1/2 in.	.060 in.	2 1/2 in.	1 3/4 in.	.060 in.

Positioning Holes and Bosses — The tolerance for determining the positioning of holes and/or bosses on a bolt circle will vary with the diameter of the circle. The governing tolerances are listed here:

BOLT CIRCLE	TOLERANCE	BOLT CIRCLE	TOLERANCE
1/2 in.	±.005 in.	2 1/2 in.	±.015 in.
1 in.	±.005 in.	5 in.	±.025 in.
1 1/2 in.	±.008 in.	8 in.	±.040 in.
2 in.	±.010 in.	10 in.	±.050 in.

SIZE OF CASTINGS Just a few years ago the size of investment castings was limited to small castings. That is, they were about one cubic inch.

Today, this has changed. The parts illustrated are far from the extremes in either largeness or smallness. Tiny parts which run hundreds to the teaspoonful are commonly made, and at the other extreme, parts weighing up to 100 lbs. have been made. Probably the average foundry would limit its upper size to under 50 lbs.

When all investment castings were made in metal flasks, the size of the parts was limited. Today, however, almost every foundry is equipped to make investment castings using one form or another of the ceramic shell technique (this should not be confused with shell molding in sand foundries). With this method, size is mostly limited by the material handling and metal melting facilities available.

Technically Speaking . . .

by: C. A. Crawford
Technical Director
Investment Casting Institute

Investment Casting is Science Plus Skill

Technical know-how among the members of the Investment Casting Institute advances steadily.

Consistent improvements add up to quick production of a larger number of reliable castings at competitive costs.

The steady developments and advances in the ceramic shell processes have established a capability for making more pieces in shorter time, meanwhile consuming smaller amounts of expensive raw materials. The user gets the benefit.

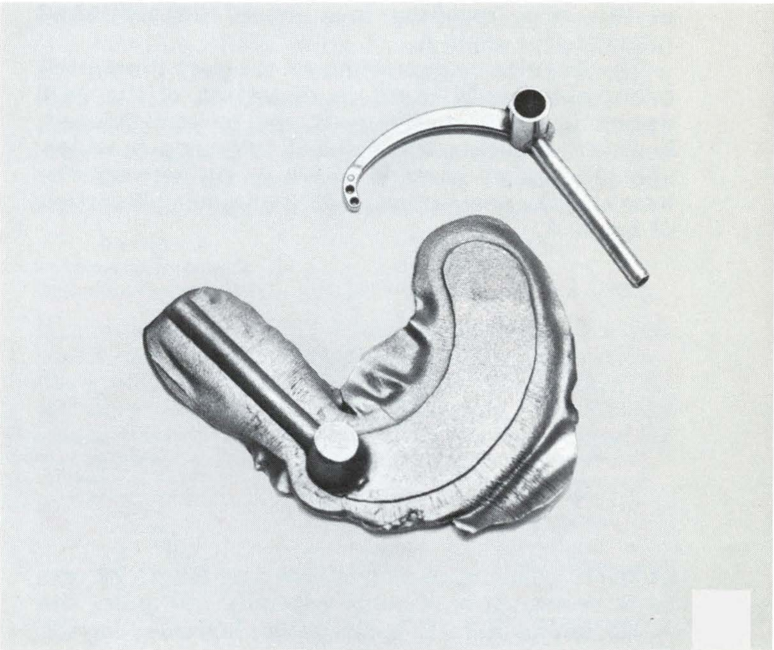
As the ceramic shell processes have been improved and perfected, certain new devices and techniques have been introduced. The use of fluidized beds for applying stucco over dip-coated patterns has made a large contribution to automation. Result: a greater number of accurately-finished castings are being produced. The user gets reliable castings more quickly — at no increase in cost.

Improvements in die making techniques for patterns of wax or of plastic, along with use of soluble-wax cores and of preformed ceramic cores are giant steps toward pushing back the horizons for intricacy of design. Internal passageways, negative draft channels and tunnels that defy reproduction by any other method of fabrication at comparable cost are now regularly incorporated in investment castings.

Practical application of the theory of fluid flow has brought about advanced modes of gating and the use of shaped sprues and ingates. These improvements have assured reliability of sound, shrink-free castings for ordinary engineering applications, and X-ray tight parts for the most exacting demands. Melting control (the use of certified master melts and modern analytical methods) enables every member of the Investment Casting Institute to cast alloys to close compositional limits. This is the first step in meeting specified mechanical strength requirements. Combined with careful heat treatment, this advanced melting concept has brought to the user of investment castings a new confidence in reliability and reproducibility.

When SINGER Changed To Investment Castings . . .

Product Quality Went Up . . .



BEFORE (Figure 1)

Some companies redesign to improve their products. Others seek reduced manufacturing costs. Either objective is important.

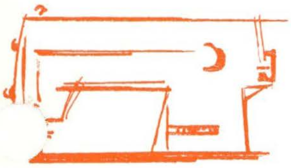
Occasionally, both objectives are realized. This is a story about a company that did achieve both — Singer Mfg. Co., maker of the famous Singer sewing machines.

The part in question: a take-up lever — used on an industrial sewing machine, also made by the company.

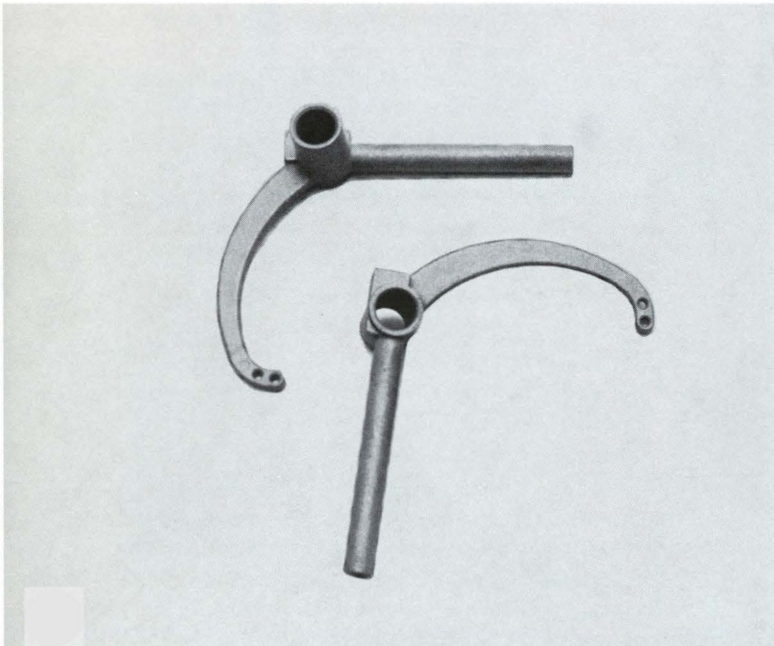
The lever used to be designed as a forging (Figure 1). In production, the rough forging was first normalized, the annealed. Next, the forging was trimmed and an arm section blanked out and coined. Then another anneal, followed by drilling and turning the hub. Two small holes were then drilled in the end of the arm and the piece carburized.

Then came still another problem.

During carburizing, the parts often warped; thus, a straightening operation on both the shank and arm had to be performed. After carburizing and straightening, the lever was hardened, then straightened again.



Production Costs Went Down



AFTER (Figure 2)

Finally, the I.D. of the hub and the O.D. of the shank were ground.

All in all, 15 operations were required . . . with attendant high costs.

To eliminate these many problems, Singer engineers working with an investment casting firm (an ICI member to be sure), decided an investment casting in heat-treatable steel would give a stronger part at lower cost (Figure 2). It has proved to be so.

As an investment casting, the lever requires only three machining operations, a reduction of 80%. Fillets were easily incorporated for added strength. And scrap losses were just about eliminated.

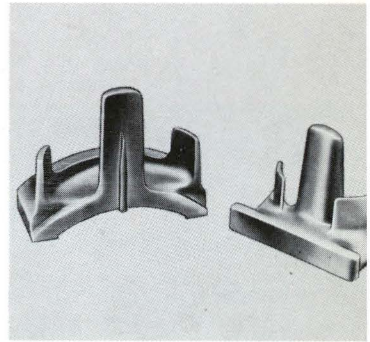
As a bonus: part identification is now cast in (this used to be still another operation). And finishing is easier and less costly (barrel finishing can be used to give the fine surface required.).

And of no small importance, manufacturing costs have been slashed 30%.

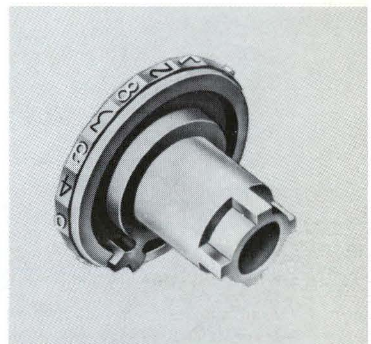
Investment Castings DIGEST

How the investment casting process has solved the problems of high cost, part failures, and excessive secondary operations.

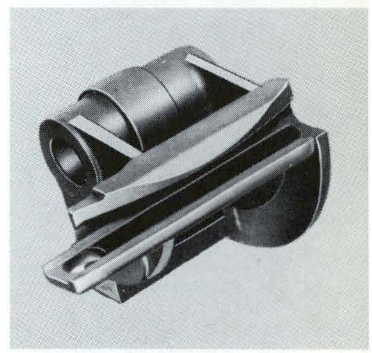
THIS COIL WINDING FORM — one of a group of such units, was formerly machined from solid stock at costs from $5.00 to $35.00 each. By using an investment casting, the parts are now used as cast except for a minor polishing operation.



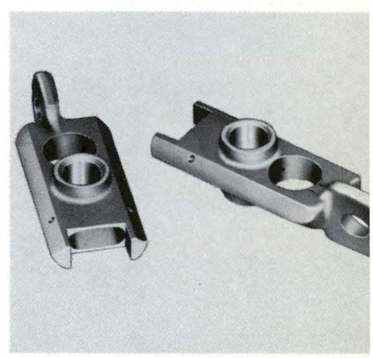
THIS NUMBERING WHEEL was originally made by brazing together seven components. Now investment cast in 4140 steel, the part is priced at less than one-half the cost of the fabricated wheel. Elimination of numerous assembly operations is a major advantage of one-piece investment casting.



THIS SHUTTLE LIFTER — used on a weaving machine, was originally fabricated from nine parts. The part was subsequently redesigned and is now cast as one piece. It weighs but ten ounces. The user company reports a reduction in costs of 86%.



THIS CROSS HEAD — for a cloth cutting machine previously hogged from the solid, is now investment cast in SAE 1020 steel to save a large number of expensive milling operations. As an indication of the extent of the machining on the original piece, more than 50 percent of the stock was lost in chips.



It's Good Business To Specify Investment Castings From Associated Members

INVESTMENT CASTING INSTITUTE

Your production requirements demand quality castings . . . delivered on schedule at minimum cost. Dependable procurement is essential to business success.

Members of the Investment Casting Institute are pledged to maintain the highest standards in the industry. All are staffed to provide expert technical assistance and practical advice. All are equipped to supply close-tolerance castings in production quantities. All are familiar with techniques to improve castings quality and to cut casting costs. It's good business to do business with associated members.

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