

RTZ IRON & TITANIUM AMERICA

SORELMETAL[®]

A DESIGN ENGINEER'S DIGEST OF

DUCTILE IRON

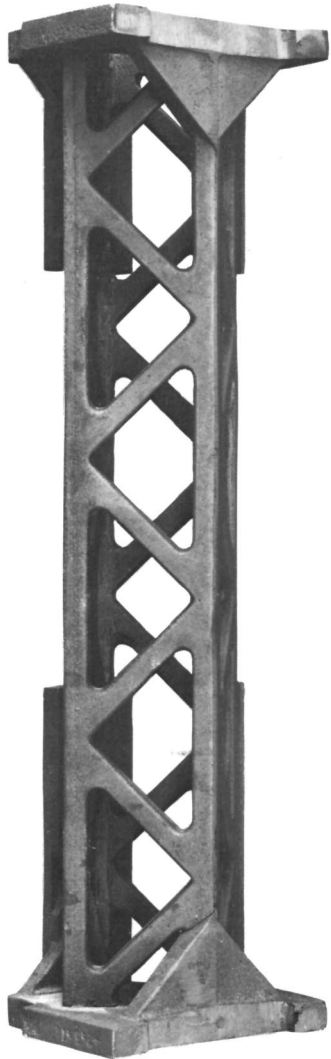
THE CAST ALLOY OF THE

- PAST
- PRESENT
- FUTURE

Eighth Edition

A DESIGN ENGINEER'S DIGEST OF

DUCTILE IRON



INTRODUCTION

During recent years, producers and users of Ductile Iron castings have observed that many potential users of Ductile Iron castings are not aware of the wide range of properties offered by the family of Ductile Iron alloys.

Since their commercial introduction in 1948, Ductile Iron castings have proven to be a cost effective alternative to malleable iron castings, steel castings, forgings, and fabrications. This is for a multitude of reasons, some of which are explained in the following pages.

Ductile Iron castings are found in every field of engineering and in every geographic area of the world. Ductile Iron is known under different names, such as S.G. Iron or Nodular Iron. This booklet uses the term Ductile Iron, which is the most commonly referred to name in North America.

Throughout this booklet are many examples of Ductile Iron castings. A good portion of these castings have been converted to Ductile Iron from other materials and manufacturing processes.

After reading the information contained in this booklet, it is hoped the design engineer will be sufficiently informed and encouraged to take advantage of the performance potential of Ductile Iron as a cost effective engineering material. Ask your Ductile Iron foundry for more information and assistance.

**PRECISION INSTRUMENT
CONNECTING FRAME**
Courtesy: IBM, W. Germany

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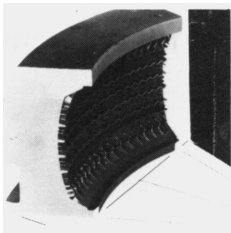
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DUCTILE IRONS – WHEN AND WHY

Characteristic	Ductile Iron	Malleable Iron	Grey Iron	0.3%C Cast Steel	White Iron
Castability					
Ease of Machining					NA
Vibration Damping					
Surface Hardenability					NA
Modulus of Elasticity					NA
Impact Resistance					NA
Corrosion Resistance					
Strength/Weight					NA
Wear Resistance					
Cost of Manufacture					



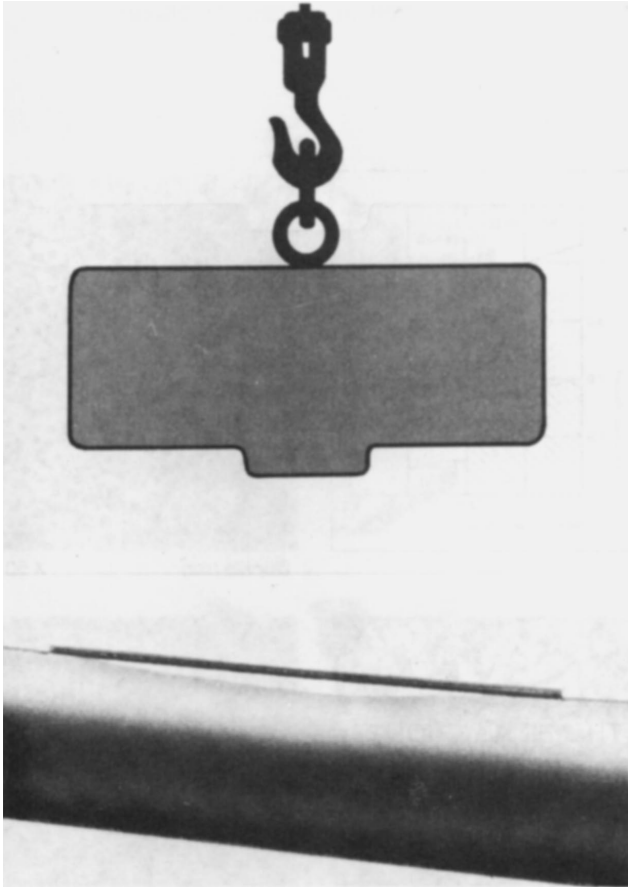
RADIAL TIRE MOULD.

Courtesy: Morris Bean & Co., Yellow Springs, Ohio, U.S.A.

THE PLACE of Ductile Iron among engineering materials is as difficult to define precisely as it is for example for wood, plastic or aluminum. No materials can be better than all the others. Nevertheless, thousands of examples prove, that Ductile Iron castings can replace other materials and manufacturing processes with either an improvement in performance or lower production cost, or both.

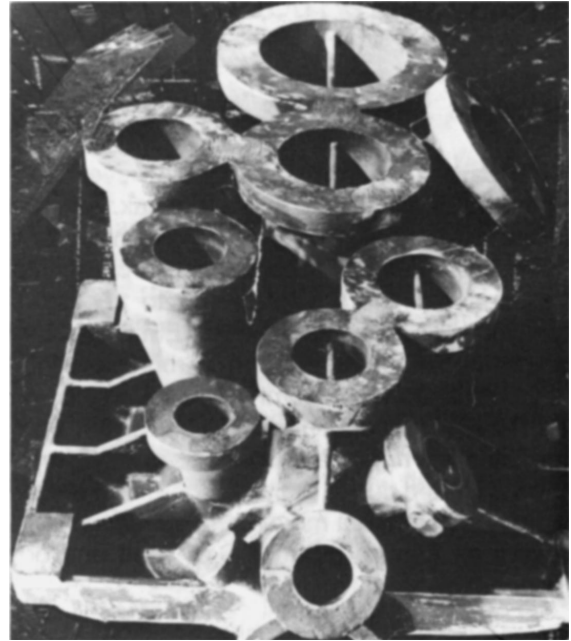
THE DESIGNER is advised to become acquainted with this family of cast alloys, with the production of castings and with general foundry operations. For instance, while not all foundries produce Ductile Iron grades, virtually all castings or cast shapes can be made from an appropriate grade of Ductile Iron. Ductile Iron will always have ductility. It is at least as strong as cast mild steel, but can be specified at much higher yield strength. Material selection depends not necessarily on strength. Within the limits of the space available, this booklet attempts to acquaint you with a variety of Ductile Iron properties.

THE FINAL CHOICE may or may not be Ductile Iron. The purpose of this booklet is to point out the unique combination of properties available with this material thereby helping the designer make a safe and economical choice. This choice is made much easier due to the existence of many foundries, capable of producing Ductile Irons of reliable quality.



Courtesy: Cast Iron Pipe Research Association, USA

Dropping a 2-ton weight from a height of 9 meters caused a slight dent in this Ductile Iron pipe but did not reduce its serviceability.



HOUSING

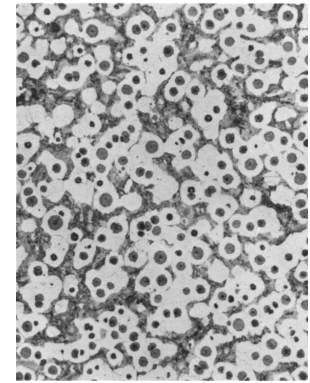
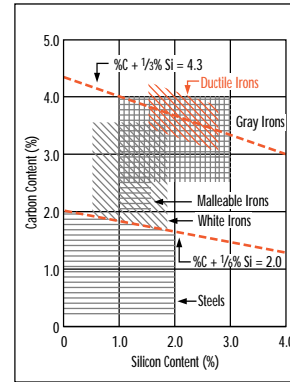
Courtesy: Vulcan Iron Works, USA

THE EXAMPLES in this digest highlight the freedom Ductile Iron offers to the designer, while providing internal integrity. The five-stage turbo-compressor housing shown above must be pressure tight at very high testing pressures. This was accomplished, even though the shape of the housing is exceptionally complex.

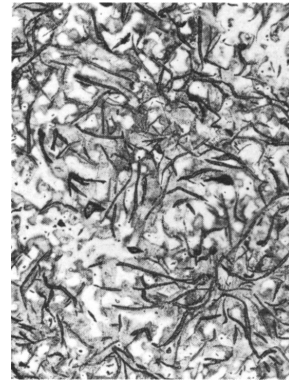
FIRST A WORD...

PURE, carbon-free iron is practically never used as a cast metal because it is soft and weak. As carbon content increases, so does hardness and strength. The beneficial effect of carbon, although creating production problems, is advantageous to about 0.9% carbon. These alloys are called **STEELS**. Additional problems are encountered with carbon contents to about 2.0%, and these “semi-steels” are seldom used. **WHITE IRONS**, containing 2 to about 3.3% carbon, can be used for highly abrasive service, but the application is limited due to the brittle nature of the alloy. It is a true cast iron, but most of the contained carbon is present as iron carbide Fe_3C , a hard and brittle compound.

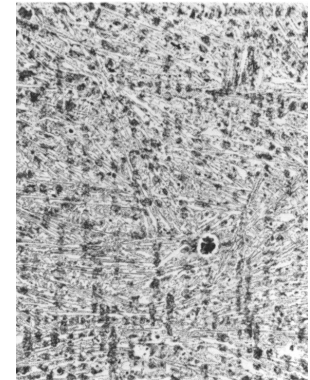
The carbon contents of white and **MALLEABLE** irons overlap. Indeed, malleable iron must solidify as white iron. (Hence, its production is limited to relatively thin castings.) A lengthy heat treatment of the white iron castings decomposes the Fe_3C into iron and nodules of graphite. In this condition, malleable iron exhibits strength/elongation combinations from 40,000 p.s.i. (280 mPa) with 18% elongation to 116,000 p.s.i. (800 mPa) with about 2% elongation.



Ductile Iron X50

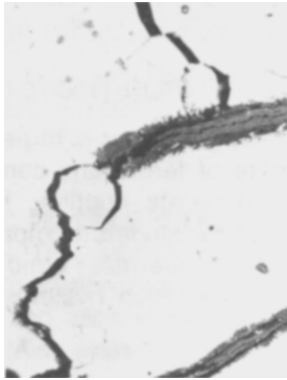


Gray Iron X50



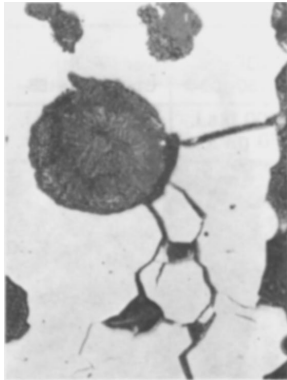
White Iron X50

...ABOUT STEEL AND IRON



A

← In gray and Ductile Irons, carbon in excess of its solubility in solid iron is present as finely dispersed graphite shapes, rather than as Fe_3C (cementite, iron carbide). In **GRAY CAST IRONS** the graphite flakes act as stress raisers and under stress help crack propagation (See illustration A). As a result, gray cast irons are weak, with ultimate tensile strength is the order of 20,000 to 58,000 p.s.i. (150 to 400 mPa) and with practically no elongation. The size of graphite flakes varies with production conditions and, also, with casting thickness. Normally flake lengths are from 0.1 to 1.0 mm.



B

← **CAST IRON WITH SPHEROIDAL GRAPHITE** (i.e. Ductile Iron) became an industrial reality in 1948. A suitable treatment of the molten iron causes the graphite to precipitate as spheroids, rather than flakes. The nearly spherical shape of the graphite removes the “crack” effect and, in fact, the graphite spheroids act as “crack-arresters”, as shown impressively on the page (See illustration B).

THE FAMILY OF DUCTILE IRONS

The majority of Ductile Iron castings are produced in one of the following three types, all of which can be produced in the as-cast condition without the need for heat treatment.

• FERRITIC DUCTILE IRON (60-40-18)

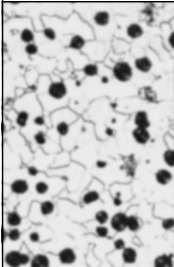
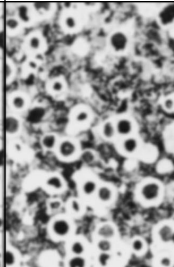
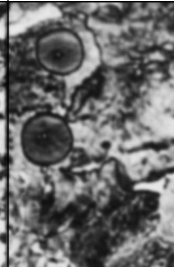
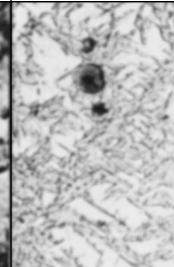
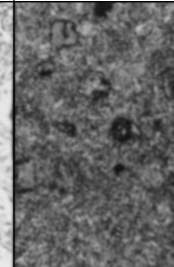

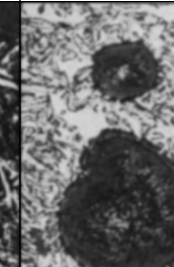
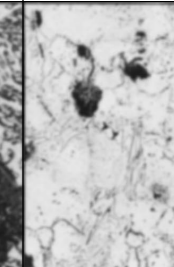
Graphite spheroids in a matrix of ferrite which is basically pure iron. High impact resistance. Relatively good thermal conductivity. High magnetic permeability. Low hysteresis loss. In some exposures, good corrosion resistance. Good machinability.

• PEARLITIC-FERRITIC DUCTILE IRON (80-55-06)

Graphite spheroids in a mixed matrix of ferrite and pearlite. This is the most common grade of Ductile Iron. Properties are between those with “fully ferritic” or “fully pearlitic” structures. Good machinability. Usually the least expensive Ductile Iron.

• PEARLITIC DUCTILE IRON (100-70-03)

Graphite spheroids in a matrix of pearlite. Pearlite is a fine aggregate of ferrite and cementite (Fe_3C). Relatively hard. Moderate ductility. High strength. Good wear resistance. Moderate impact resistance. Somewhat reduced thermal conductivity. Low magnetic permeability. High hysteresis loss. Good machinability.

MATRIX							
Ferritic Grade 60-40-18	Ferritic-pearlitic Grade 80-55-06	Pearlitic Grade 100-70-03	Martensitic (With retained austenite)	Tempered Martensitic	ADI Grade 150-100-70	ADI Grade 230-185-	Austenitic
60,000 p.s.i. (414 mPa)	80,000 p.s.i. (552 mPa)	100,000 p.s.i. (690 mPa)	N.A. *	115,000 p.s.i. (793 mPa)	150,000 p.s.i. (1050 mPa)	230,000 p.s.i. (1600 mPa)	45,000 p.s.i. (310 mPa)
							

*Approximate ultimate tensile strength 87,000 p.s.i. (600 mPa) Hard, Brittle

(Note that magnifications are different.)

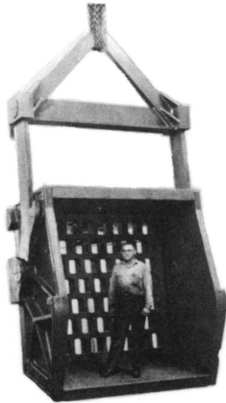
Occasionally, the designer will encounter special situations, and consider the special grades of the Ductile Iron alloys.

• MARTENSITIC DUCTILE IRON (Q&T)

In the “as-cast” condition the alloy is hard and brittle, and seldom used. However, **TEMPERED MARTENSITE** has very high strength and wear resistance. A 930°F (500°C) tempering results in 300 HB, a 1110°F (600°C) tempering in 250 HB hardness.

• AUSTENITIC DUCTILE IRON

They are never chosen for strength alone. The outstanding features are good corrosion and oxidation resistance, magnetic properties, strength and dimensional stability at elevated temperatures. (Also known as Ductile Ni-Resist).

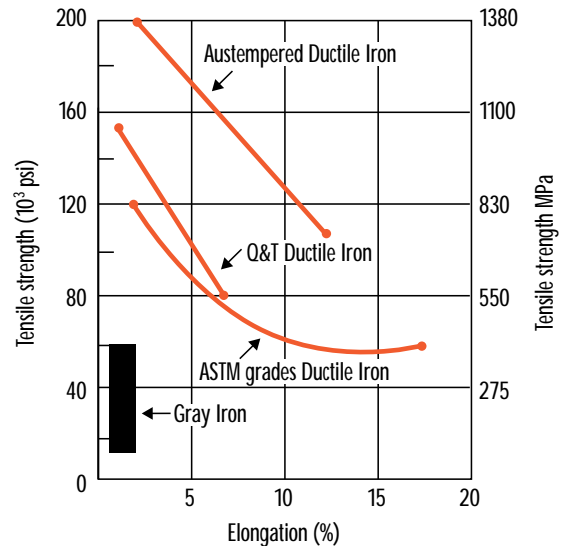


*Crop Box from Steel Weldment
Black Clawson Foundry, Watertown, NY*

• AUSTEMPERED DUCTILE IRON (ADI)

This is the most recent addition to the Ductile Iron family and represents a new group of Ductile Irons offering the design engineer a remarkable combination of strength, toughness and wear resistance.

ADI is almost twice as strong as the regular ASTM grades of Ductile Iron whilst still retaining high elongation and toughness characteristics. In addition, ADI offers exceptional wear resistance and fatigue strength, thus enabling designers to reduce component weight and costs for equivalent or improved performance.



Note: The orange sheet in the back of this book gives more information on specifications and properties.

The remarkable properties of ADI are developed by a closely controlled heat treatment operation (austempering) which develops a unique matrix structure of bainitic ferrite (60%) and retained (high carbon) austenite.

The retained (H.C.) austenite is thermally stable to extremely low temperatures but is work hardenable and will locally transform to martensite under suitable conditions of stress. Advantage of this feature of ADI is taken by allowing the service loading stresses to work harden the load bearing services. Alternatively, surface stresses can be deliberately imposed prior to service, e.g. by shot peening of gears or fillet rolling of crankshafts in order to achieve significant improvements in wear resistance and fatigue life.

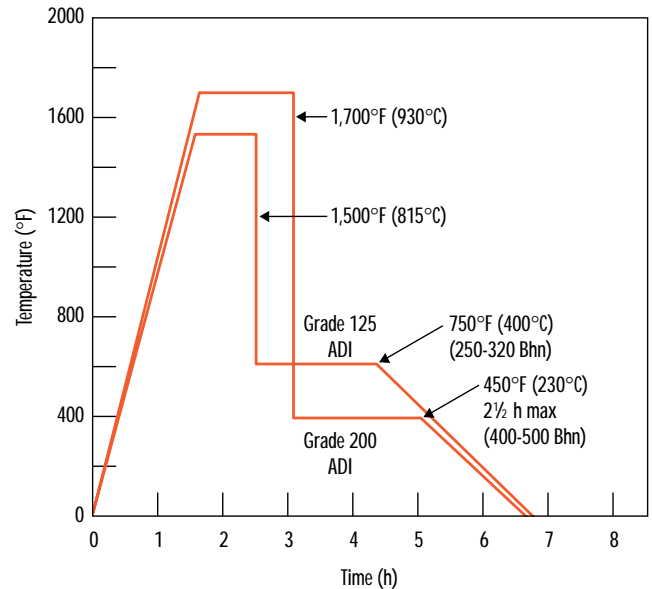
Presently there are no accepted standard specifications for ADI, but proposals for five grades of ADI have been made which form the basis for discussion and material selection between designers and foundrymen.

**Current ASTM A897
ADA Specifications**

Tensile Strength		Yield Strength		Percent Elongation	Charpy (unnotched) (ft. lb.) (J)	BHN Hardness Range*	
(KSI)	(MPa)	(KSI)	(MPa)				
125	850	80	550	10	75	100	269 - 321
150	1050	100	700	7	60	80	302 - 363
175	1200	125	850	4	45	60	341 - 444
200	1400	155	1100	1	25	35	388 - 477
230	1600	185	1300	-	-	-	444 - 555

*not part of specification

The heat treatment necessary to produce ADI is essentially a two-stage operation:



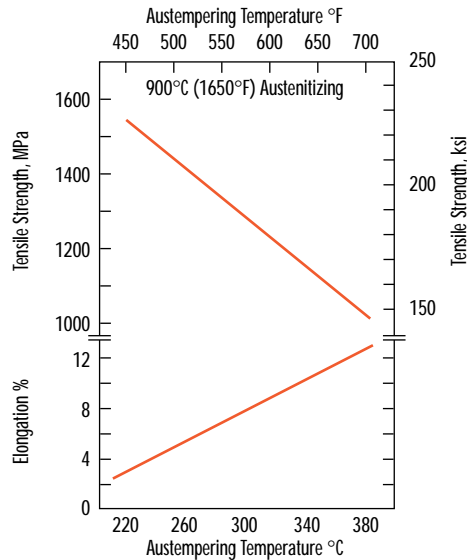
Typical Austenitizing & Austempering Cycles

Stage 1

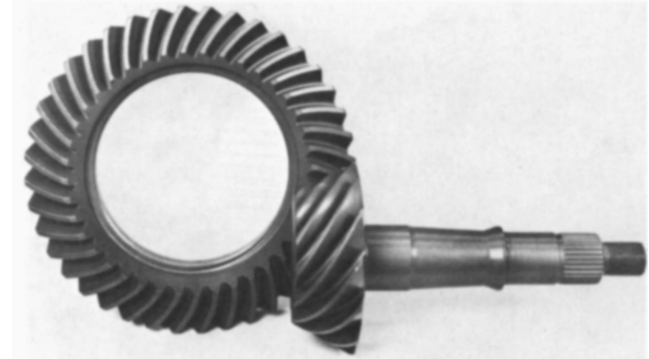
Austenitizing in the range 1500-1700°F (815-920°C). The specific austenitizing temperature selected is related to the subsequent austempering temperature and the grade of ADI required. Once selected, the austenitizing temperature must be closely controlled ($\pm 10^\circ\text{F}$).

Stage 2

Rapid transfer of the castings to the austempering furnace (usually a salt bath) where the castings are held isothermally at the selected austempering temperature. Austempering temperatures are in the range 450-750°F (230-400°C) according to the properties required in the castings (ADI grade). Close control over temperature and time of austempering is essential.

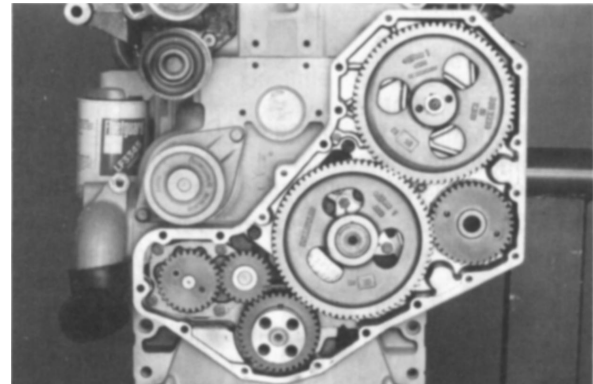


ADI is well established as a gear material replacing forged steel with major production cost savings, quieter operation and reduced weight. By machining the gears before the austempering heat treatment, major savings in machining costs are achieved.

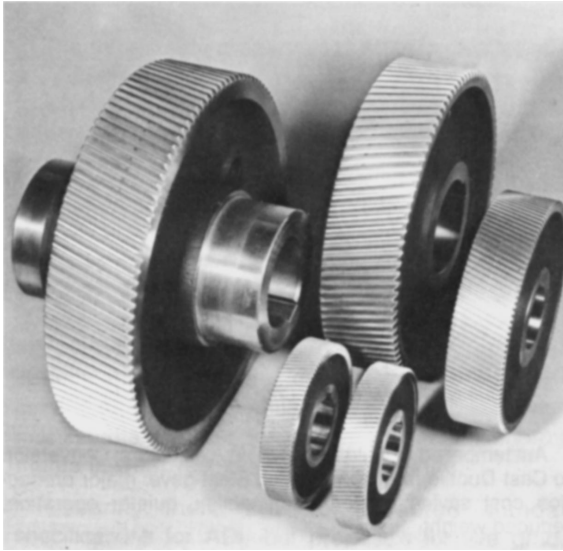


Courtesy: General Motors Corp., Central Foundry Division, Saginaw, Michigan, USA

Austempered Ductile Iron Hypoid Axle Gears: Conversion to Cast Ductile Iron from Forged Steel gave major production cost saving, better machinability, quieter operation, reduced weight.



ADI Timing Gears for Cummins B-Series diesel engines. Replaced forged and case carburised 1022 steel with 30% cost saving.



Courtesy: Hogfors Industries Ltd., Finland

Austempered Ductile Iron gears to patented specifications K9805.

Other examples of the use of ADI castings include truck spring supports, railroad axle-box spring adaptors, crankshafts, connecting rods, agricultural plough shares, etc.



ADI Crankshaft for Ford turbo-charged engine—ADI capable of meeting fatigue strength requirements at much lower cost than forged steel.

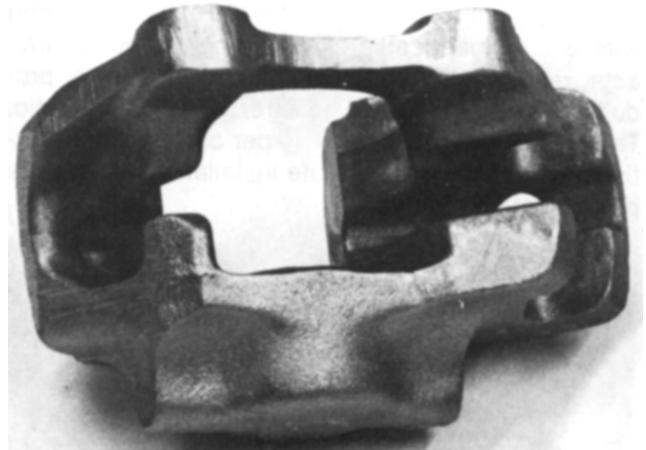
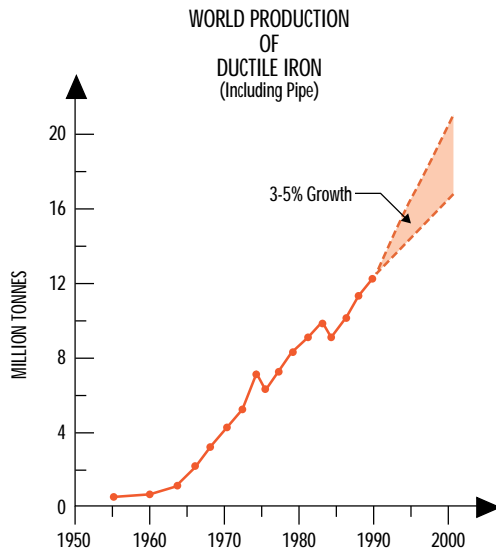
Success in consistently achieving the optimum properties and performance of ADI requires high quality, careful selection and control over the base Ductile Iron, and heat treatment parameters. This necessitates material of high nodule count which is free from carbides, inclusions and shrinkage and of a composition which minimizes the dangers of alloy segregation.

This brief summary about the **DUCTILE IRON FAMILY** is based on metallurgy, rather than on standard specifications. A chart showing the properties of most of the Ductile Iron grades is enclosed on the inside back cover of this publication. All properties are primarily determined by chemical composition, cooling (solidification and solid cooling rate) and matrix structure.

DUCTILE IRON—“MORE STRENGTH FOR LESS EXPENSE”

Ductile Iron appears to have been invented (1948) with the designer in mind. The tensile strength, proof stress, and elongation combinations obtainable in Ductile Iron exceed those for ANY OTHER cast ferrous alloy, including steel and malleable iron.

Since its introduction, the growth of Ductile Iron applications has exceeded all expectations. World-wide production is approximately 12 million tons and is expected to reach 20 million tons by the turn of the century. The application of Ductile Iron is a notable engineering achievement of our age.

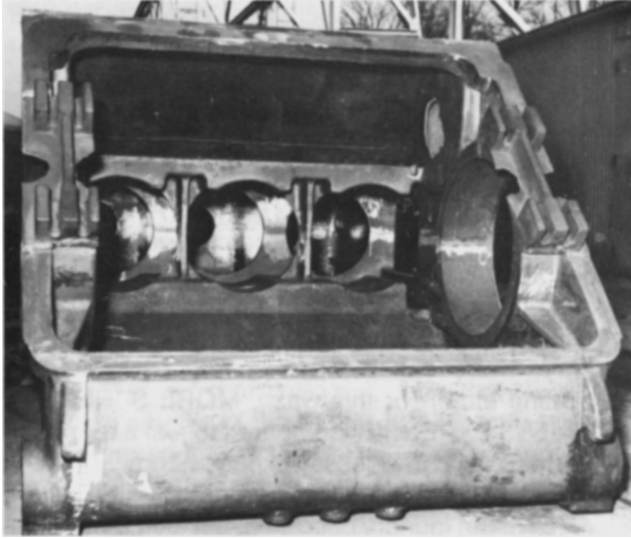


DISK BREAK CALIPER

Whether in an automobile component, as shown above, a water pipe, plow, or a “robbery-proof” parking meter box, Ductile Iron has made major inroads to the casting market in every industrially developed country. There can be little doubt, that the major motivating factor for this was **“MORE STRENGTH FOR LESS EXPENSE”** compared to just about every other cast alloy. The lesser expense comes not only from the readily available raw materials and the efficiencies of the foundry operation, but also from reduced cleaning and machining costs of Ductile Iron castings.

The following pages present a variety of Ductile Iron case histories from around the world. Many more examples could have been added. The Ductile Iron alloys are versatile and appear to find unlimited applications.

The original design of the 1,000 H.P. pump frame was a steel fabrication. Converting to Ductile Iron achieved more uniform stress distribution, lower production cost and improved strength-to-weight ratio. The weight was reduced by 46 percent, which is particularly important for remote installations where the parts must be airlifted.



Courtesy: Gardner Denver Co., USA

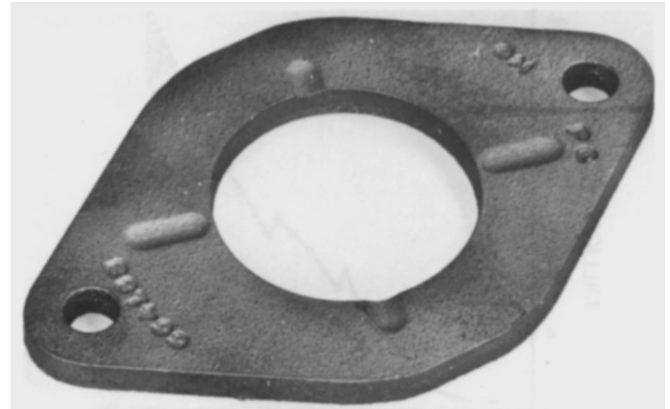
A camshaft thrust plate is exposed to severe abrasive wear. The reason for selecting Ductile Iron was to combine wear resistance with machinability.

For break-in, this casting is phosphate-coated.



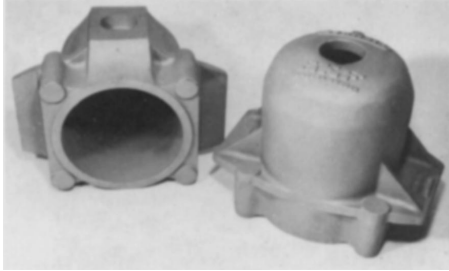
Courtesy: Fichtel & Sachs, Germany

Ductile Iron can readily be surface hardened to 55 Rc, which provides for the superior performance of this catch-sleeve.



Courtesy: Dana Corp., USA

In the design of bearing housings, compressive strength is an important factor. Ductile Iron, as shown in the photographs, compares favorably with steel. Additional advantages are better machinability and vibration damping.

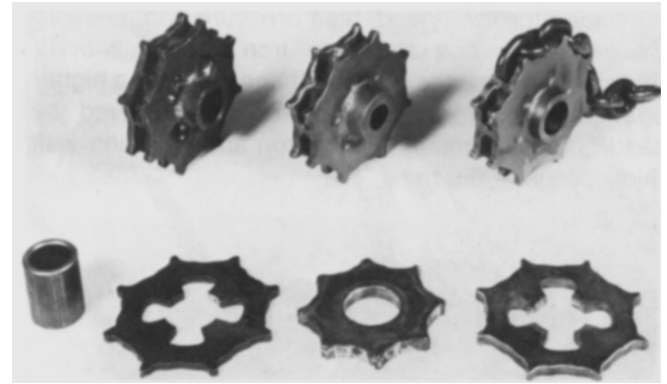


Courtesy: S.K.F., Katrineholm, Sweden



Courtesy: Metallgesellschaft, A.G. Germany

The scaffold fittings shown above, with 2 to 5 mm wall thickness, illustrate the excellent castability of Ductile Iron.

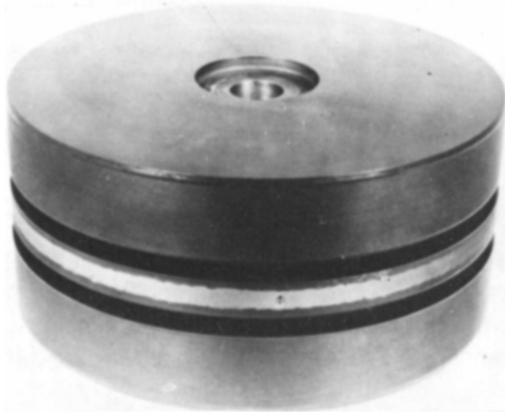


Courtesy: Ausherman Manufacturing Co., Inc., USA

This 5-1/2 lbs. (2-1/2 kg.) idler chain sprocket is from a large jack used for straightening automobile and truck frames. Designed by Kansas Jack, Inc., McPherson, Kansas, USA and cast by Ausherman Manufacturing Co., Inc., this part is made of Ductile Iron to USA specifications ASTM A 536 - 65-45-12 and is used in the as-cast condition.

Kansas Jack's on-the-shelf cost, ready to use in assembly is 63% less for the Ductile Iron casting, than it was for the weldment.

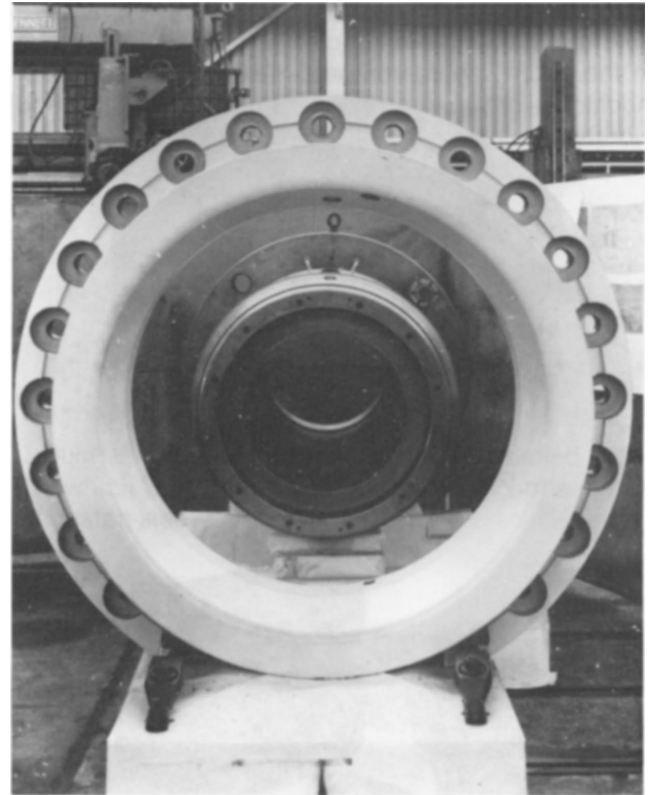
Pistons for low speed, high pressure compressors were originally one-piece gray iron castings with 19 mm walls. As speeds increased, the need for a higher strength, lighter weight piston was achieved by casting the pistons in Ductile Iron and reducing wall thicknesses to 5-6 mm.



Courtesy: Gardner Denver Co., USA

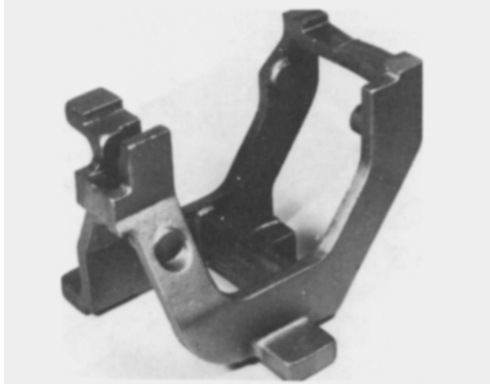
Also, a design change to a two-piece welded assembly simplified casting procedures and permitted further weight reduction. This saving in weight reduced inertia of the piston.

The mating surfaces and weld bevels of the piston halves are machined, then bolted together on an arbor and furnace heated to 1,050°F (565°C). The preheated assembly is welded using a shielded metal arc with nickel-iron electrodes (ENiFeC1). The weld is made in three passes and the assembly heat treated to the specified 201-260 BHN.



Courtesy: C.A. Parsons & Co., Ltd., England

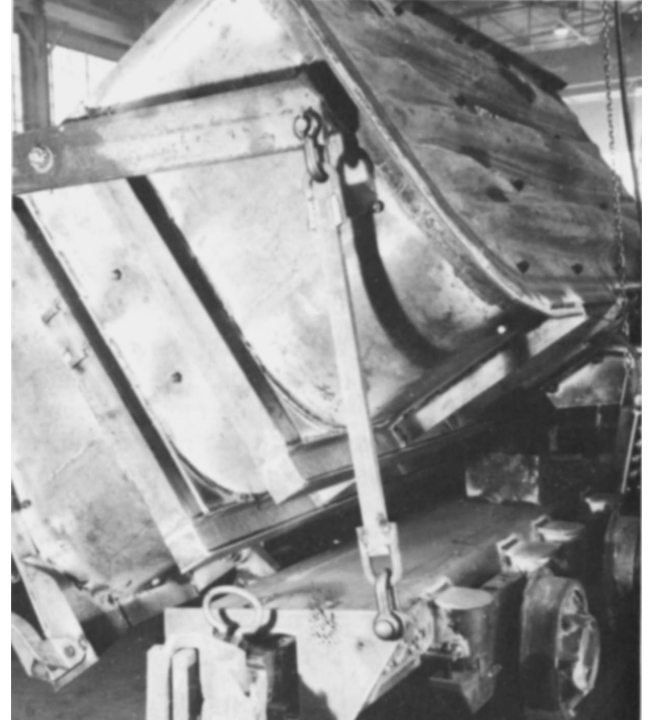
The seating ring is part of an advanced design marine sterngear unit. Beside the need for high strength, good corrosion resistance in a saline environment is required. The choice: austenitic Ductile Iron to British Standard BS3468-AUS 202A.



Courtesy: The H.P. Deuschel Co., USA

This frame, for a 4,000 volt primary “lighting” arrester and overload switch gear, was originally cast in steel. Inadequate strength often resulted in warpage, which caused the failure of the whole assembly.

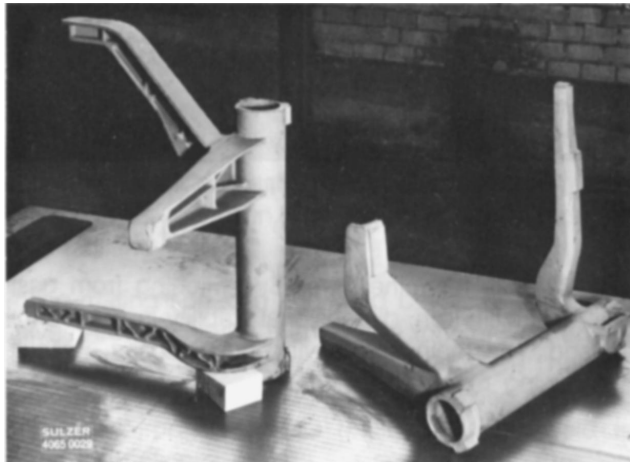
Switching to medium-strength Ductile Iron provided adequate strength and impact loading resistance. The part cost was also reduced.



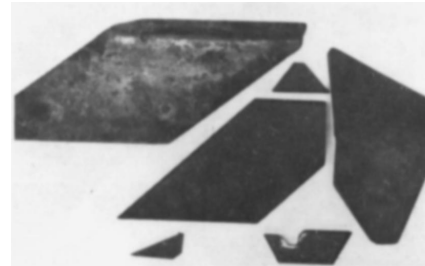
Courtesy: Dorr Oliver Long, Ltd., Canada

Axle trucks for mine cars. By switching from cast steel to Ductile Iron, dimensional stability in service increased. The main cost saving occurred as a result of reducing machining.

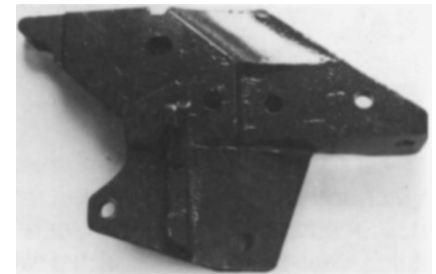
The bracket shown below must have precise dimensions and carry heavy loads. The alternative material—cast steel—would be more expensive because of alloying, machining, and heat treatment costs. Ductile Iron is also superior in its dimensional accuracy. The casting is used in the as cast condition.



Courtesy: Sulzer Bros., Ltd., Winterthur, Switzerland



Before
fabricated
(assembly)

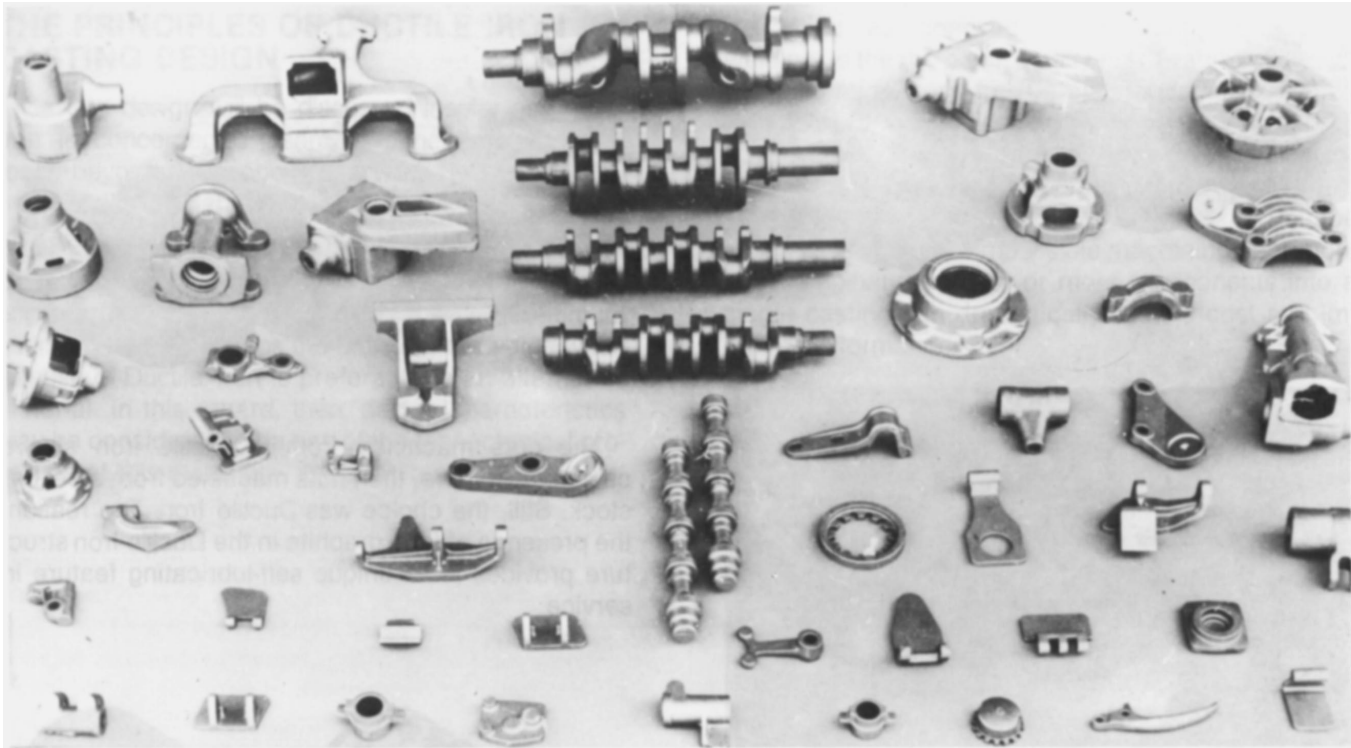


After one
piece D.I.
casting

Courtesy: Ferrovorm, Republic of South Africa

Mounting bracket on a mold board plow produced by Fedmech Holdings Limited. The reason for switching to a grade 72,500 p.s.i. (500 mPa) Ductile Iron casting was the many field failures of the heavily welded steel part. Repeated attempts to improve the fabricated design resulted in too many components which led to warping and dimensional accuracy problems during welding. There was also a high reject level during fabrication of the part.

Since switching to a Ductile Iron casting there have been no field failures.

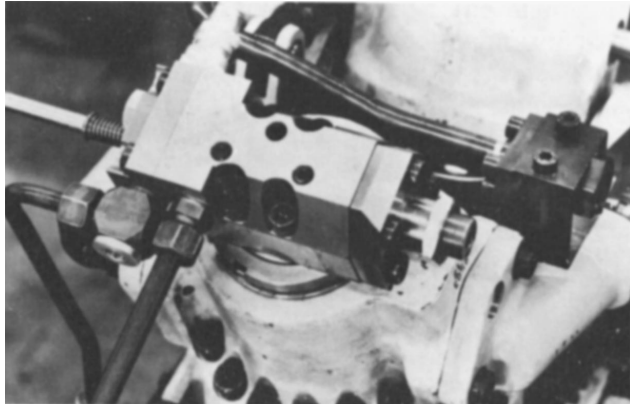
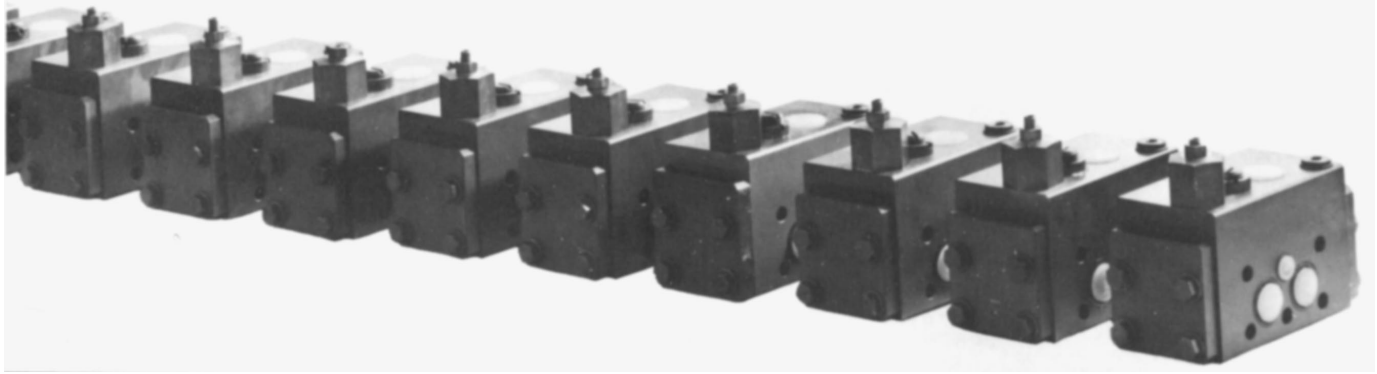


SOME OF THE DUCTILE IRON CASTINGS USED IN A JAPANESE AUTOMOBILE.

Courtesy: Toyota Motors Corporation, Japan

AUTOMOBILES USE MANY DUCTILE IRON CASTINGS. While this booklet is too short to describe all the reasons for the material selection, the major ones are castability, ease of machining, reliability in service, vibration damping, surface hardenability, wide range of strength to choose from, etc.

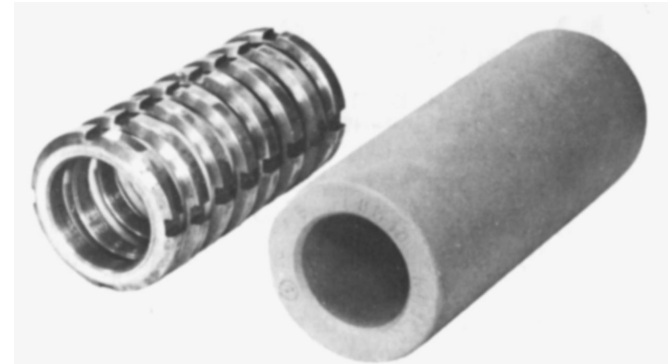
In addition, since the modulus of elasticity of Ductile Iron is somewhat lower than that of steel, the stresses due to unavoidable misalignment are lower. Crankshafts are a good example of the utilization of this property.



Courtesy: Von Roll, A.G., Klus, Switzerland

Housings for hydraulic control devices used mainly on heavy machine tools. These housings, machined from grade DIN 1693; GGG 60 (German Standard), (continuously cast Ductile Iron) must withstand up to 500 atmospheres (7,000 psi) internal pressure.

The nuts machined from a Ductile Iron sleeve casting cost more than nuts machined from steel bar stock. Still, the choice was Ductile Iron. The reason: the presence of face graphite in the Ductile Iron structure provides for a unique self-lubricating feature in service.



Courtesy: Metalgesellschaft, A.G. Germany

THE PRINCIPLES OF DUCTILE IRON CASTING DESIGN

Casting design will be discussed insofar as Ductile Iron is concerned. Presenting general rules would reach beyond the scope of this work. There are reference books available that deal with Casting Design.

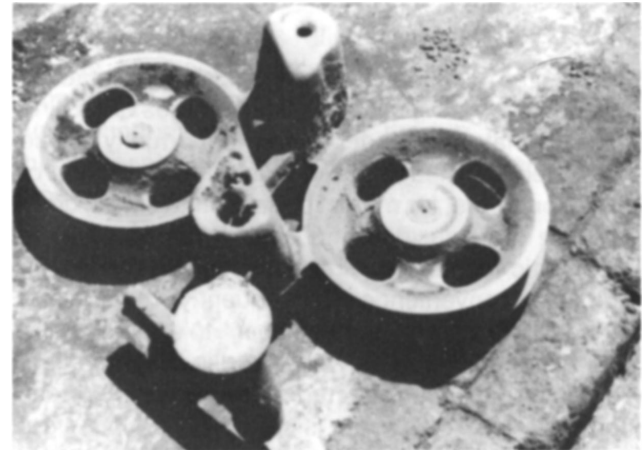
Familiarizing oneself with the advantages of designing with Ductile Iron helps not only to achieve engineering elegance (uniform stress-flow, optimum economy) but also helps the designer to decide when the use of Ductile Iron is preferable to an alternative material. In this regard, then, design characteristics may be considered to be one of the technological properties of this material.

Principle No. 1—

Utilize the Freedom Offered by the Casting Process.

The purpose of design is to achieve functional performance of a part at minimum cost in materials and manufacture. An individual design is usually a compromise between an engineering concept to satisfy specific service requirements and a form suitable for high quality, low cost production.

Casting as opposed to stamping, forging or welding, is the most universally practicable method of metal forming and offers great freedom in creating the shape of the part to be designed. Complex curves and ribs or bosses may be combined with little process restriction. The ability, for instance to cast pump and turbine casing involutes to their desired shape eliminates an almost impossible machining operation. The combination of two or more components into a single casting can dramatically reduce cost and improve performance.



Courtesy: TMF, Republic of South Africa

↑ Ductile Iron tram wheels for underground mining operations, shown “as-shaken-out”. Machining time was reduced to 1/8 that of the previous material, cast steel, while safety in service increased.

In spite of design freedom, difficulties are sometimes encountered when transforming the engineering concept into a useful casting especially when the part was originally designed as a forging, stamping or fabrication.

Since the designer is concerned with a wide range of products, he is seldom wholly conversant with the casting process and so the part is designed without regard for a multitude of foundry variables. This is not to suggest the designer should obtain a comprehensive understanding of the casting process but rather that he should understand the fundamentals and refer additional queries to the founder who is a specialist in the casting process.

Ideally, the designer and founder should establish close contact during the preliminary stages of casting design so that the founder has an opportunity to use his detailed knowledge of the foundry industry and of his own products, for mutual benefit. In this way, comments on draft designs and pattern construction to suit specific foundry requirements, can be made with the least inconvenience. Consequently, major (late) changes in shape, dimensional tolerances and material specification may never arise. All these factors will probably be reflected in lower casting prices since the price of a casting is not simply a function of its weight but rather of the complexity of its shape and how this affects the cost of patterns, cores, molds, cleaning and casting yield.

The process of deciding to design and produce castings may be summarized as follows:

Preliminary

- decision to use a casting
- detailed design
- inquiry, quotation, order

Production

- pattern manufacture
- sample/prototype casting production
- bulk casting production

Very often only superficial contact is established between designer and founder until sample or prototype castings are produced. Occasionally, significant changes are requested at this stage by the designer, or the founder. The designer may have the impression he did not quite receive what he ordered and the founder may realize that a few relatively minor changes to the casting shape may make the casting much simpler and therefore cheaper to produce without affecting performance of the casting. For whatever reason, changes at this stage may mean lengthy, costly delays.

It is therefore essential to involve the founder from the beginning in the technical aspects of detailed design and minimize the occurrence of costly delays during the production stages.

Principle No. 2–

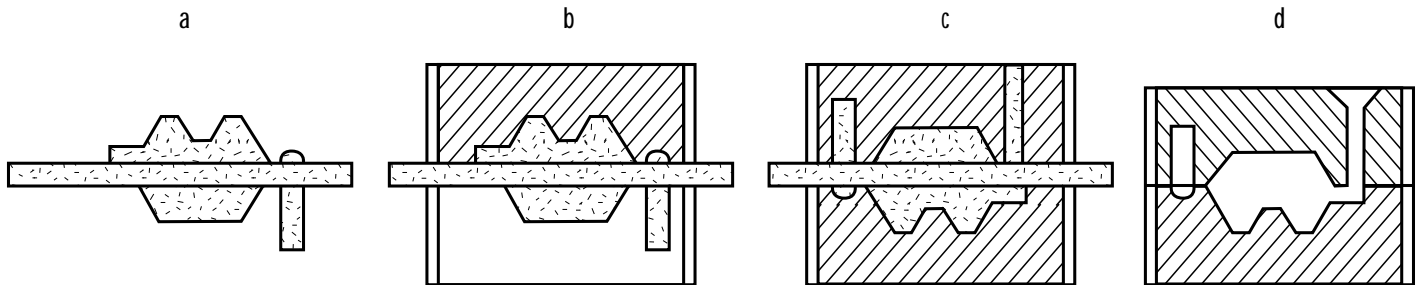
Understanding the Fundamentals of the Casting Process

Most modifications to the “ideal” casting shape, aimed at optimum production economy, arise from the understanding of the casting process. This required knowledge may be summarized as follows:

The first step in the casting process is to produce the pattern, a nearly exact reproduction of the whole casting, usually in wood or metal. The pattern is then sectioned (a) usually in one or more parallel planes. The sections, one after the other, are placed into molding boxes or flasks and the box is tightly filled with bonded, firm sand (b) (c). The pattern creates a cavity after withdrawal (d). This cavity will be filled later with liquid iron to form the casting.

Cavities in the mold other than that of the casting cavity are needed for two purposes; 1, to deliver the liquid iron from the top of the assembled mold to the casting cavity, 2, to replace the volume lost due to the shrinkage of the liquid iron from the pouring temperature to the freezing temperature. The first set of cavities or channels is called the gating system while the “feeding” cavities are called risers. As a rule, both the gating system and the risers are integral parts of the pattern.

The liquid iron first passes through the gating system, then, through one or more openings (gates) into the mold cavity, and finally, the entire mold cavity including the risers fills with liquid iron. While passing through all the channels and filling the mold, the temperature of the liquid iron decreases. The thinner the casting walls, the greater the temperature loss. This increases markedly the danger of defects due to improper fusion.



Internal cavities in the casting must be produced by placing properly shaped inserts, called cores, usually made from bonded sand, into the mold cavity. The core materials must be subsequently removed and, therefore, the internal cavity must communicate with the outside of the casting. The core also must be well-supported and anchored by the mold to avoid flotation or deformation during mold filling due to the difference between the density of the core and that of the liquid iron. One anchor point is the theoretical minimum. Normally at least two anchor points (core prints) are required.

Cores are also required when, due to configuration, the pattern cannot be withdrawn from the mold. Such cores can be readily made, but they add considerably to the cost of production. For this reason, the designer should be aware that undercuts prevent pattern withdrawal. Small cores exhibit relatively low strength especially at the temperature of liquid iron. For this reason, if holes of small cross section are required in the casting, it may be less expensive to machine the holes than to form them by the use of small (weak) cores. Channels of small cross section may be cast integrally by placing appropriately shaped steel tubing in the mold cavity in a core-like fashion. A portion of the steel tubing wall will fuse with the liquid Ductile Iron.

The volume changes that occur during the cooling and solidification of Ductile Iron are unlike those in any other alloy. The volume of the liquid decreases

with decreasing temperature until slightly above the solidification temperature. Upon further cooling, the contraction stops and a definite volumetric expansion starts. Unfortunately, the expansion phase prevails through only part, but not all of the solidification process. The expansion gives way to another contraction phase, "secondary shrinkage", which continues until all of the liquid is transformed to solid.

It is the craft of the foundryman to use the above-described pattern of volume changes to obtain sound castings. The temperature of the liquid iron should be high enough to provide for complete fusion of the separate streams and to avoid the entrapment of small gas bubbles. Each section thickness has its optimum pouring temperature range within which perfectly sound castings can be made. Ductile Iron castings with 3 mm thick walls may need to be poured as hot as 2,640°F (1,450°C), while 100 mm thick castings can be poured at between 2,300-2,400°F (1,260-1,320°C). Difficulties may arise when large differences in section thickness exist in one casting. Such castings can be made sound, with considerable extra effort. The foundry will be pleased to explain.

It is in the best interest of both casting producer and user to design with as little difference in wall thicknesses as possible. It may be more economical to mechanically assemble two or more castings than to produce a one-piece casting with widely varying section thicknesses.

Principle No. 3–

Design for Optimum Economy

The price of a casting quoted by the foundry is relatively unimportant both to the ultimate user and to the designer. Instead, the contribution of the casting cost to the total cost should be considered. This incorporates items such as machining, shipping costs, ease of repair, service life, and others.

Every step in the manufacturing process affects total production economy and each of these is influenced by the designer. A complete review here is neither necessary nor possible. Instead, four major factors influencing economy will be discussed. One additional factor, dimensional tolerance, will be discussed later.

Factor #1 Strength required

The grade of Ductile Iron selected will have a considerable effect on economy. With reference to the classification on the insert, grade 65-45-12 is the least expensive especially if machining costs are of some consideration. Grade 80-55-06 costs approximately the same to cast but is somewhat less easy to machine. Grade 100-70-03 is still relatively inexpensive and should be selected where its high strength and good wear resistance are utilized. Grades 60-40-18 and 120-90-02 are the most expensive to cast, but either may be the most economical choice if the particular material characteristics are of value in service. The evaluation of the very expensive austenitic grades of Ductile Iron must be

considered individually on the basis of their excellent corrosion, erosion and oxidation resistance, performance at elevated temperatures, magnetic properties, low thermal expansivity and other unique features.

Factor #2 Machining cost

Machining costs are frequently of major importance from the point of view of economy. Strength, weight, service life, and other considerations may be overruled on occasion to minimize machining cost. The grades easiest to machine are 3 and 4, followed by 5, then 2. Grade 1 is the least machinable although its machinability is superior to steels with the same hardness. The machinability of austenitic Ductile Irons is generally superior to that of stainless steels.

Factor #3 Cooling rate

It will be shown how cooling rate (section thickness) affects the properties of Ductile Iron. Rapid cooling promotes a hard and brittle structure which is difficult-to-machine. In terms of wall thickness, 6 mm or heavier sections are relatively easy to produce without any embrittlement or undue high hardness. Thinner walls are increasingly more difficult to produce without such deterioration in the as-cast condition. The brittleness and high hardness can be eliminated through heat treatment, but such treatment is expensive and also results in distortion to various degrees. Whenever practical, cast wall thickness should be at least 6 mm to facilitate as-cast delivery. Heat treatment increases casting cost by 10 to 30%.

Factor #4 Design Simplicity

It is well known that the simplest design is the best design. It is also the most economical. A healthy compromise between contour simplicity and uniform stress distribution usually requires less expensive pattern equipment and few or no cores. The construction and maintenance of pattern and core boxes and core-making itself all contribute to product cost. Again, talk to the foundry.

The effect of large differences in section size on casting soundness was briefly discussed earlier. Heavy bosses or walls adjoining thin sections require special treatment on the part of the foundry (risers, chills). This means additional cost and is detrimental to casting yield. The impact of casting yield on foundry production economy is the most important of all variables including the material selected and heat treatment. The freezing pattern and feeding requirements are also influenced by the geometry of the design. More on this later.



SCAFFOLD FITTING

One advantage of using castings is the clear marking of names, direction of rotation, etc. Even the date, or heat, or production hour can be easily marked on the surface.

*Courtesy: Metallgesellschaft,
A.G. Germany*

Principle No. 4-

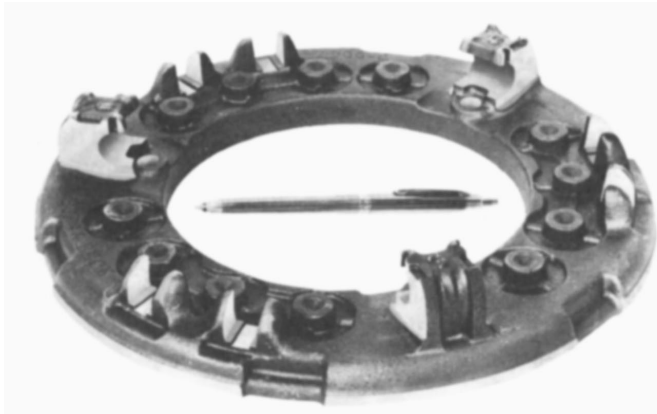
Design for Casting Soundness

Thanks to the volumetric expansion which occurs during part of the solidification process, a sound, pressure tight casting is easier to produce from Ductile Iron than from any other metal or alloy except ordinary gray cast iron. Still, feeding requirements vary with casting shape and size—variables under the control of the designer. Unlike steel, brass and most other alloys, the designer and foundry processes for Ductile Iron should aim at simultaneous solidification of the whole casting. This requirement is opposite to the desire for directional solidification which applies to steel.

Design aimed at simultaneous solidification minimizes and sometimes eliminates the need for risers with corresponding improvement of casting yield. Conversely, parts of a Ductile Iron casting which cool much slower than the rest may become defective unless the foundryman provides extra (and expensive) feeding. Some examples of such isolated “hot spots” are as follows:

- Cast-on heavy bosses
- Cast-on heavy test coupons
- Sharp internal corners
- Joints between equally thick walls
- Multiple joints (2 is better than 3, 3 is better than 4, etc.)
- Joints at acute angles (90° is best)
- Isolated heavy sections.

Which could be lightened without reducing load carrying capacity.



Courtesy: Hitachi Ltd., Katsura, Japan

Automobile clutch pressure plate. High strength, reliability, and ease of machining led to the selection of Ductile Iron for the part shown. It is exposed to heavy alternating loads.

One simple qualitative method for evaluating the degree of success toward a uniform solidification pattern is to inscribe circles into selected sections of the design. If the diameters of the circles are all the same, as they would be in a straight wall, optimum conditions prevail. Sudden increases in the circle size (to twice or more of the diameter in an adjoining section) require special attention by the foundry.

Principle No. 5–

Specify No More Dimensional Accuracy than Needed

Due to the nature of the casting process, the dimensional accuracy of raw castings is more difficult to control than, for example, machining to size.

Principal dimensional inaccuracies in Ductile Iron arise from the following sources:

- a. Inherent inaccuracies in the machined dimensions of the pattern and core box.
- b. Deformation of core(s) in liquid iron.
- c. Inaccuracies due to the presence of parting line(s).
- d. Relief of cast-in stresses, if and when castings are heat treated.

With the exception of source a. the inaccuracies are dependent on the physical size of the casting. The larger the casting the more inaccuracy expected. Dimensional inaccuracies from mold deformation during pattern withdrawal are minimized through proper tapering of the pattern (draft). A minimum draft of 1:100 suffices only for very shallow patterns. Deep patterns may need to be drafted as much as 5:100 for maximum accuracy.

The following is presented as an approximate guide to the dimensional accuracies to be expected in Ductile Iron castings.

Approximate Dimensional Tolerances on Ductile Iron Castings in Green Sand

Specified Dimension in Millimeters	Tolerance \pm in Millimeters
0- 25	1.0
25- 125	2.0
125- 250	2.5
250- 500	4.0
500-1,000	6.0
1,000-2,500	8.0

Additional points to be considered:

- The values given refer to 80-to-90 mold hardness range (green sand). Softer molds yield lower dimensional accuracy.
- Accuracy can be increased at additional cost through the use of very hard molds such as dry sand, chemically bonded sand, etc. Even more accurate castings can be produced in semi-precision and precision molds. The investment casting process provides about the utmost accuracy obtainable with approximate tolerances of $\pm 0.003 \times$ specified dimension. Production costs increase with increased demand for accuracy.
- Accuracy can be improved by a factor of approximately two if the (large) number of castings to be produced permits an experimental production run followed by reworking of the pattern equipment.

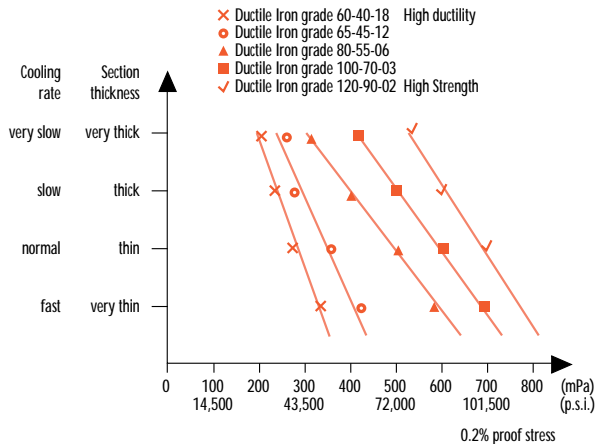
Principle No. 6-

The Effect of Section Size on Mechanical Properties

Data included in this work, like most published data on Ductile Iron properties, are valid for approximately 20 to 50 mm thick castings. Standard specifications are normally set for 25 mm keel block or Y-block test castings. Some standard specifications recognize the effect of section size (cooling rate) by lowering minimum required values, usually for elongation, with larger test castings or for samples cut from the casting.

The effect of section size on properties is the result of changes in microscopic structure as the latter is influenced by cooling rate. Three prominent effects of cooling rate on microscopic structure are:

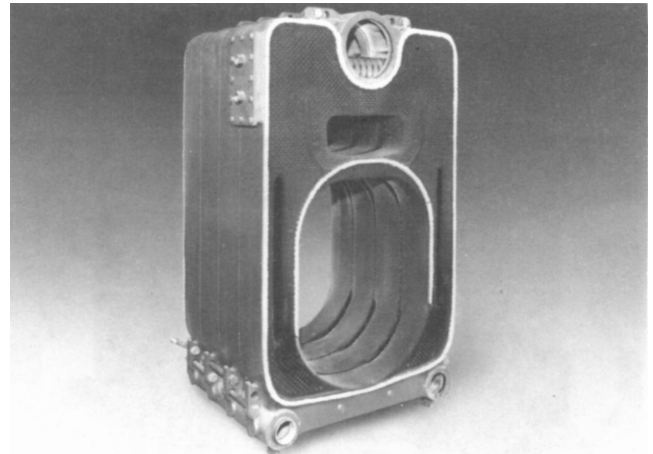
- Very high cooling rates do not permit all the insoluble carbon to precipitate in the form of spheroidal graphite. Instead, various amounts of a hard and brittle component, iron carbide (Fe_3C) will form.
- Very slow cooling results in large diameter, irregularly-shaped spheroids of graphite up to 1.5 mm in diameter.
- Varying the cooling rate in the 1560-480°F (850-250°C) temperature range from very fast to very slow produces different structures from martensite (very fast cooling) through pearlite, pearlite-ferrite to all ferrite (slow cooling).



The presence or absence of carbides and the type of matrix obtained in any given section can be controlled by alloying or heat treatment. They need not be discussed here as long as the effects are recognized by the designer. The size of the spheroidal graphite, on the other hand, can be influenced by, amongst other things, the cooling rate of the casting which in turn can be determined by the shape or design of the casting. These effects should be considered in design calculations.

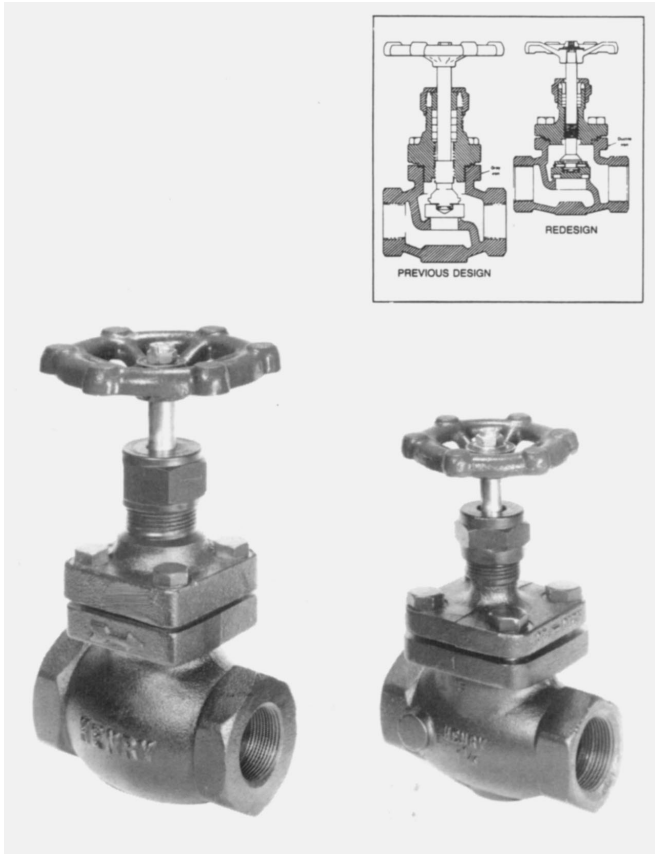
Providing the shape of the graphite is approximately spheroidal, there is negligible deterioration of chemical, physical and technological properties. However, published data vary over a very wide range. Some tentative information on the mechanical properties to expect in carbide-free Ductile Iron of different section sizes is given above. If more precise knowledge of these or other properties is essential

for design calculations, the designer must request the foundry to produce test castings which will cool at approximately the same rate as the product casting. Mechanical tests on these test castings will yield the most accurate prediction of the properties in the product casting.



Courtesy: Cleaver-Brooks Company, Division of Aqua-Chem, Inc., USA

This manufacturer specified Ductile Iron pressure vessel sections over gray iron for its new line of cast iron boilers. Ductile Iron to ASTM specification A 395-80 (60-40-18) was selected for its superior tensile, yield and thermal fatigue strengths. For boiler applications these properties are important since they provide improved resistance to pressure vessel failures caused by thermal shock or other stresses. Ductile Iron's excellent corrosion and wear resistance was another factor in Cleaver-Brooks material selection.



The need to redesign an ammonia valve line gave Henry Valve Co. of Illinois the opportunity to make the conversion from gray iron to Ductile Iron as shown. Size (thinner valve walls) and weight reductions (45% reduction) were achieved without sacrificing performance.

Principle No. 7-

Design with Adequate Safety

Both automobile steering knuckles and plowshares are made in Ductile Iron. It is obvious these castings have different safety requirements. Safety requirements vary within wide limits, with the above two examples representing extremes.

The designer is in command of all controls necessary to achieve whatever degree of safety is needed. These controls, however, need to be applied judiciously, because increasing part safety invariably increases cost. The controls available are:

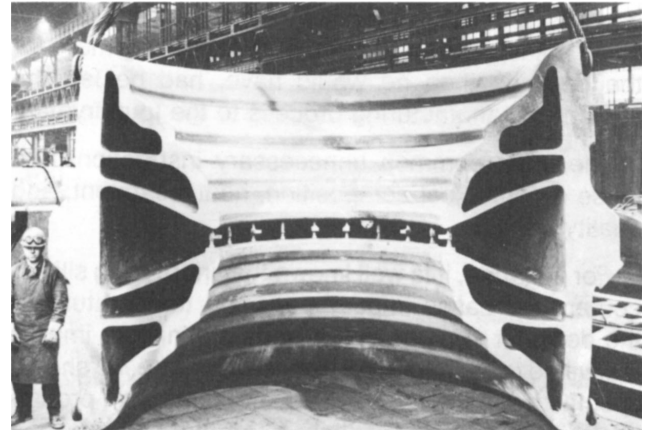
- a. Approximating the ultimate load carrying capacity of the material to various predetermined degrees. Under static loads the maximum permissible stress equals the yield strength. Usual design stresses vary from 50 to 75% of the yield strength (0.2% offset proof stress). Parts exposed to frequently varying loads should be designed on the basis of the endurance limit. Design stresses of 50 to 100% of the endurance limit are customary, corresponding to a very high, and low margin of safety, respectively.
- b. Estimating the effect of potential emergency overloads involves the determination of the most likely failure mechanism. Emergency operating conditions can seldom be foreseen. Nevertheless, the occurrence of such conditions should be considered. Excessive static or dynamic loads may cause failure either through deformation of the

part beyond utility or by fracture. Depending on the type of service, one failure mechanism will prove to be safer than the other. For example, in a pressure-tight container an unexpected major increase in the internal pressure may burst the casting or it may permanently deform it. A permanent deformation will probably be the safer failure mechanism. This is one example of relatively few applications where ductility is the desired design property. Another example is that of a gear. A sudden unexpected load may break or bend one or more teeth. In this case, breakage will probably be safer since the structure will be able to continue operating, albeit poorly, until replacement is effected.

The indiscriminate use of the high ductility grade (Grade 60-40-18) cannot be upheld even from the point of view of safety. Grade 80-55-06 can withstand 70 to 80% higher loads; Grade 120-90-02 can withstand two-and-a-half times more load, either static or dynamic, than Grade 60-40-18. Beyond these limits, Grades 120-90-02, 100-70-03 and 80-55-06 will fail through fracture while Grade 65-45-12 and especially Grade 60-40-18 will fail through permanent deformation under much lighter loads. If safety so dictates, the low strength, high ductility grades should be chosen but each application must be evaluated individually.

- c. Specifying destructive and non-destructive tests on a given number of castings, and the frequency and thoroughness of testing is directly proportional

to the degree of safety expected from the casting. For the so-called "safety critical" parts, 100% non-destructive testing is often required even though such extensive testing is very expensive. Radiographic, eddy current, magnetic and ultrasonic and sonic frequency methods are available for non-destructive testing.



Courtesy: Salzgitter Huttenwerk, A.G., Salzgitter, Germany

↑ Housing for low pressure section of a 300 MW turbine. Total weight: 48 tons. The success of Ductile Iron for this application is attributed to its good elevated temperature strength, and particularly, its high temperature yield strength. Castings allow the design engineer to generate internal contours, which are nearly impossible to machine.

Principle No. 8–

Trust the Foundry

Foundrymen producing Ductile Iron are well aware of choices in manufacturing processes, effects of chemical composition, the effects of heat treatment, and the in-plant controls necessary, to produce a serviceable casting.

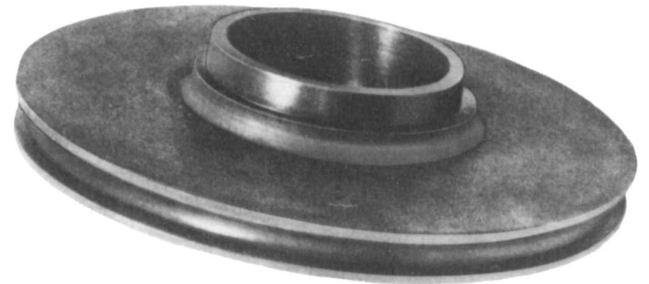
If the designer prescribes how the castings should be manufactured he obviously trespasses the foundryman's domain. The designer representing the buyer will probably succeed in this interference, but gains nothing by it and often ends up paying more for the castings than he would have, had he left the choice of manufacturing process to the foundryman.

The most common unnecessary instructions are those on chemical composition, heat treatment, and quality control.

For instance, it is well known that increasing silicon content increases impact transition temperature. If the designer decides that a certain minimum impact test value is desired at a given temperature, he should specify that, rather than the silicon content. Most properties can be obtained via heat treatment but, provided proper production controls are exercised, they can be obtained as-cast as well. It should remain the foundryman's choice to deliver castings as-cast or heat treated as long as the casting properties meet specifications.

Tight quality control needs to be exercised throughout the entire casting process, particularly when producing a high performance material like Ductile Iron.

Whether or not the specified properties have been met should not be a matter of trust. It is not only the right but also the duty of the designer to either request or to perform tests as extensive as (safety) considerations require, in order to be satisfied that the casting indeed exhibits the properties expected.



Courtesy: Parten Machinery Co., Minneapolis, MN

This one-piece ductile carriage wheel replaces four former parts. In the redesign to ductile, total cost dropped from \$251 per unit to \$75. Machining was cut from \$189 to \$38, and the number of production operations dropped from 7 to 3. The 100-70-03 Ductile Iron was specified because of its good response to Tuffride treatment.

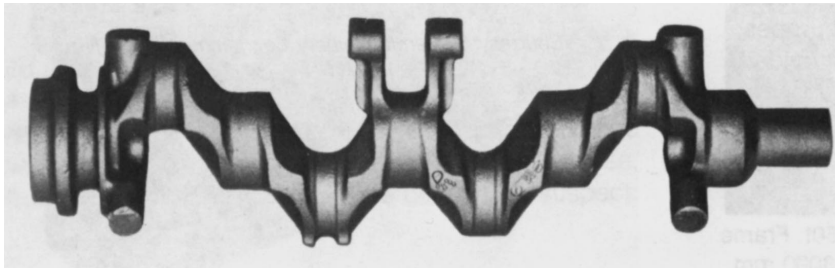
Principle No. 9–

Communicate with the Foundry

It may seem an admission of defeat to again suggest, after all the casting design principles described previously, that the designer should confer with the foundryman before finalizing his plans. However, this suggestion constitutes the last principle of designing castings in Ductile Iron.

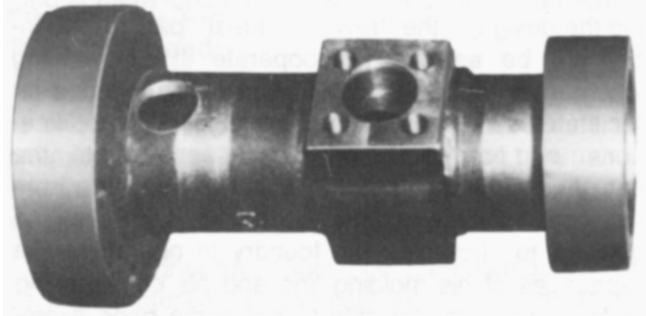
No designer will be an expert foundryman after having read the brief fundamentals of the casting process and the particulars pertaining to Ductile Iron. Following these fundamentals will hopefully assist in avoiding major design errors. Deciding on fine details of potentially large significance in economy and performance requires a more profound understanding of both the casting process and the particular foundry involved.

The best time to meet with the foundryman is during the design of the “raw” or “ideal” part. The foundry will be anxious to cooperate in determining whether or not any modifications are needed to facilitate casting production. The suggested modifications will not necessarily be acceptable to the designer, but both sides will most certainly gain from the communication. The foundryman will also be pleased to show you his foundry in operation, the capabilities of his molding line and his core making facilities. You may be able to see some good examples of castings similar to your design.



Courtesy: Pontiac Motor Division, General Motors Corp.

Redesigned automobile crankshaft, used in the Pontiac 2.5 liter L4 engine. According to the designers, the new nodular (ductile) iron casting is 10 lbs. or 23% lighter than the one it replaced. This was accomplished without sacrificing the crankshaft's durability or integrity.

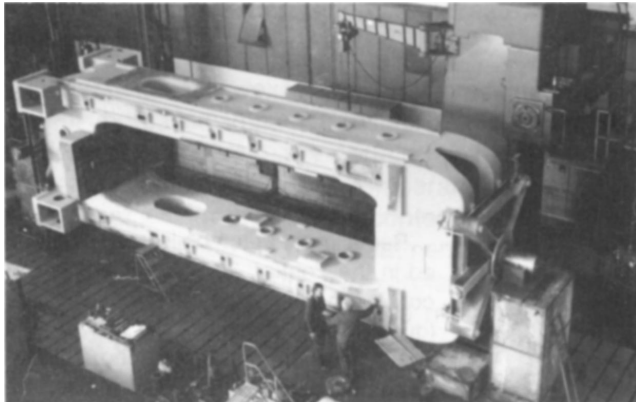


Courtesy: Daniel Industries, Inc., USA

↑ This Ductile Iron casting houses the operator for a special plug valve performing the function of two valves. The new housing was redesigned from a steel fabrication into Ductile Iron, saving Daniel Industries \$2,300,000 annually.

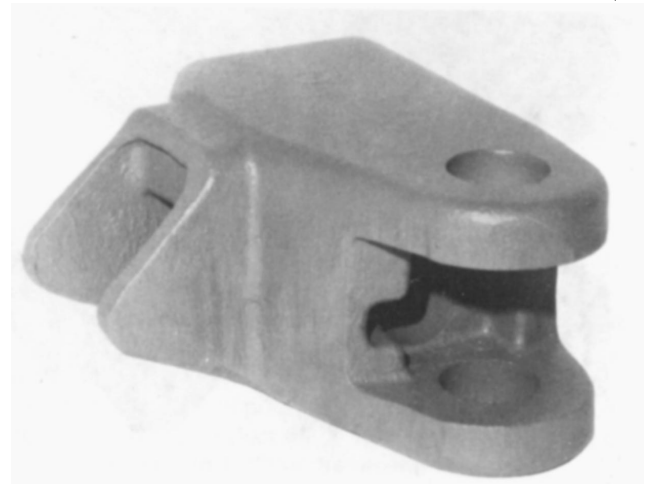
← Material and fabricating costs dropped from \$467 per unit to \$67. Another benefit of the redesign was better appearance, and reduced manufacturing problems.

This support provides vertical and horizontal safety spring attachments for a coulter blade and arm assembly, used on moldboard plows. The new Ductile Iron and steel composite design replaced a weld fabrication, reducing total cost 37%, for a first-year saving of \$167,500. Cited by the designer as additional advantages of the redesign were improved reliability and appearance. By careful attention to design, a Ductile Iron casting was conventionally welded to a sheet steel stamping. In the design, provision was made for an internal welding ear to be added to the casting in order to place the weld material in shear at the tension side of the joint.



World's heaviest Ductile Iron casting weighting 160 tons. Frame for 40MN press. Dimensions 11300 x 3800 x 3000 mm.

Courtesy: Siempelkamp Giesserei GmbH & Co.,
Krefeld, West Germany



Courtesy: John Deere Plow & Planter Works

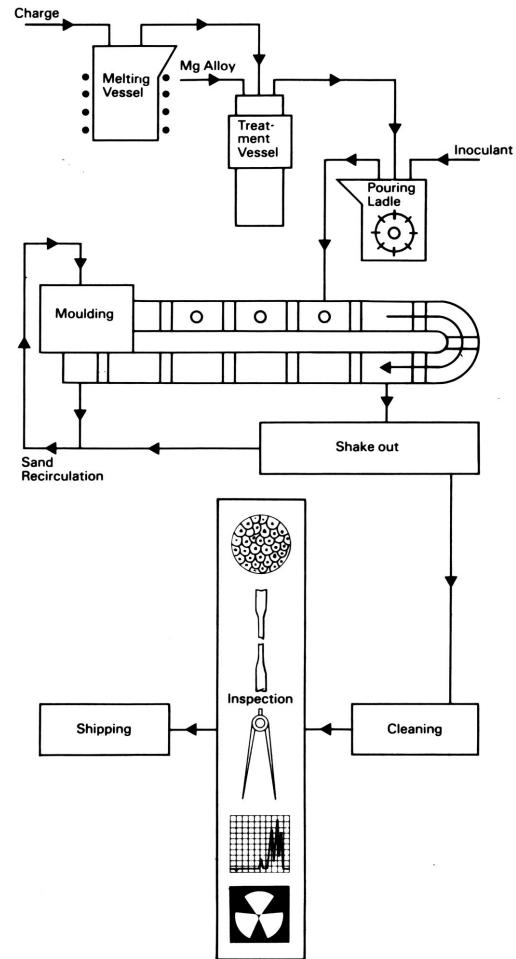
THE DUCTILE IRON FOUNDRY

The popularity of the Ductile Iron family of alloys arises from their versatility and good economy. Practical observations and adaptations by thousands of producing foundries have made the production of Ductile Iron castings, routine. Making Ductile Iron castings resembles the production of other ferrous castings—experience and craftsmanship are integral parts of founding.

A “small, but adequate” addition of magnesium is the basic step in changing graphite shape from flake to spheroidal. This treatment of the liquid iron is usually done with ferrosilicon-magnesium alloy. Equally important is the inoculation of the treated alloy by an addition of ferrosilicon when filling the pouring ladle.

The control over alloy composition involves approximately twenty elements. The determination of all is not absolutely necessary which highlights the need for reliable charge materials. Routine determination of carbon and silicon contents in the furnace is essential even in the smallest operation.

The successful foundry invariably has an established practice of careful production and quality control. As stated earlier, such control is not the designer’s responsibility. However, if the foundry is not equipped with the most basic quality control equipment, or else, fails to use it, the integrity of the castings is suspect.



Flowchart of Ductile Iron Casting Production.

INSPECTION

Inspection is principally the domain of the designer and customer. Yet, to some degree, the foundryman will get involved. First, he will inspect the castings for external appearance and dimensions. Microscopic examination will verify the spheroidization and matrix structure. Often this will suffice if the sample is taken according to the wishes of the designer. The frequency of such sampling should also be established.

Some of the routine tests which may be specified, providing these are justified by the anticipated service conditions of the casting, are listed below:

a) Mechanical Property tests:

- (i) Determination of ultimate tensile strength, yield strength (proof stress), elongation, hardness
- (ii) Determination of impact resistance
- (iii) Determination of dimensional accuracy (possibly with jigs)

Mechanical property tests can be carried out at elevated, room or sub-zero temperatures and particularly in the case of impact resistance, the test temperature should always be specified.

Additionally, the surface and sub-surface conditions of a casting may be assessed by the following:

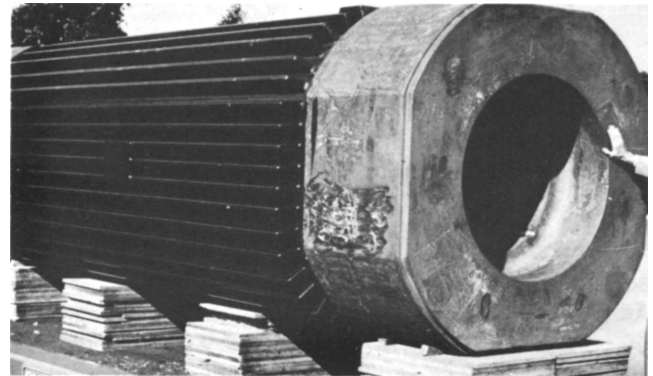
b) Methods to reveal the presence of surface defects:

- (i) Visual inspection
- (ii) Dye penetrant inspection
- (iii) Magnetic (fluorescent) particle inspection

c). Methods to reveal the presence of sub-surface defects:

- (i) X-Radiography (Gamma Radiography)
- (ii) Ultrasonic inspection

The integrity of a casting is determined by the production process parameters. Specifying any of the above tests will not improve the integrity of the casting but it will increase the delivered cost. It is reasonable to expect the foundry to exercise basic control of process quality, as previously outlined, and to monitor product quality by measuring hardness, microstructure and to visually inspect casting surface finish. When this basic control and inspection is exercised continuously, the foundryman is well disposed to produce castings which consistently meet specifications.



Courtesy: Siempelkamp, Krefeld, West Germany

Ductile Iron casting weighing 85 tons, used for the storage and transportation of spent nuclear fuel element rods. International Atomic Energy Authority (IAEA) controls apply to these castings and they were able to satisfy extremely demanding approval tests.

DUCTILE IRON—THE DESIGNER’S CHOICE

Ductile Iron castings have replaced gray iron, malleable iron and steel castings in many applications, giving better performance, often at lower cost.

Automotive and Agricultural

Axle housings	Gears and pinions
Body bolsters	Hitch brackets
Brake cylinders	Motorcycle clutch
Caliper brake	components
Camshafts	Piston rings
Clutch drums	Plowshares
Connecting rods	Steering boxes
Crankshafts	Tire molds
Cultivator	Tow bar couplings
Cylinder bushings	Wheel hubs
Exhaust manifolds	Yokes
Front wheel forks	

Other Transportation Modes

Anchors	Crawler sprockets
Bridge bearings	Elevator buckets
Bulldozer parts	Furnace skids
Cable coupler	Hoist drums
Capstans	Idlers
Car journal boxes	Pipe flanges
Charge buckets	Propellers
Chute plates	Railway wheels
Coke car plates	Rollers
Conveyor frames	Runway drains
Couplers	Track crossovers

Heavy, welded, steel fabrications up to medium size can virtually always be replaced by Ductile Iron castings. Here are just some of the current applications:

General Engineering

Actuating cams	Machine frames
Armature spiders	Mandrels
Barstock	Meter components
Bell cranks	Nuclear fuel containers
Boiler segments	Oil manifolds
Briquetting rams	Overhead switch gear
Cantilever heads	Pile driver heads
Clamp cylinders	Pipe forming dies
Coal crusher gears	Press roll bodies
Commutator drums	Pump bodies
Compressor bodies	Ratchets
Crusher hammers	Resistance grids
Damper frames	Rocker brackets
Die blocks	Rolls
Dredge sprockets	Rubber molds
Extension clamps	Sawmill beds
Forging dies	Shafts
Frames and jibs	Shear frames
Furnace grates	Spindles
Girth gears	Suspension brackets
Gyratory crushers	Tank covers
Heater coils	Thread guides
Hot forming dies	Tunnel segments
Insulator caps	Turret heads
Lawn mower frames and parts	Typewriter frames
Lightning arresters	Vise frames
	Wood augers