Cast Iron Fundamentals: Types Properties and Applications

An Online Continuing Education Course for Engineers

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Cast Iron Fundamentals – Types, Properties and Applications

Introduction

The term "*cast iron*" designates an entire family of metals with a wide variety of properties. It is a generic term like steel which also designates a family of metals. Steels and cast irons are both primarily iron with carbon (C) as the main alloying element. Steels contain less than 2% and usually less than 1% C, while cast irons contain more than 2% C.

There are many ways to classify cast irons. For this course, the four basic types of cast iron are:

- Gray iron
- While iron
- Malleable iron
- Ductile iron

Grey cast iron is characterized by its graphitic microstructure, which causes fractures of the material to have a grey appearance. It is the most commonly used cast iron and the most widely used cast material based on weight. In grey iron, the free graphite forms as thin flakes which run through the ferrite/perlite matrix. These flakes give excellent heat transfer characteristics particularly with repeated heating and cooling cycles. However, because the flakes end in sharp points which act as stress raisers and crack propagation sites, flake graphite iron is a brittle material, excellent under compression but of limited use in tension or under shock loading.

White cast iron is named after its white surface when fractured, due to its carbide impurities which allow cracks to pass straight through. White iron is too brittle for use in many structural components, but with good hardness and abrasion resistance and relatively low cost, it finds use in such applications as the wear surfaces in industrial equipment. This course will focus on high alloy white irons, containing at least 4% alloys by weight.

Malleable iron starts as a white iron casting that is then heat treated at about 900 °C (1,650 °F), causing carbon to agglomerate into small roughly spherical aggregates of graphite. Like other similar irons with the carbon formed into spherical or nodular shapes, malleable iron exhibits good ductility. Malleable iron is a good choice for small castings or castings with thin cross sections. Other nodular irons produced with graphite in the spherical shape can be difficult to produce in this applications due to the formation of carbides from the rapid cooling.

In *ductile iron*, the graphite is in the form of spherical nodules rather than flakes (as in grey iron), thus inhibiting the creation of cracks and providing the enhanced ductility that gives the alloy its name. The formation of nodules is achieved by addition of nodulizing elements, most commonly magnesium. The properties of ductile iron are like malleable iron, but ductile iron parts can be cast with larger sections. The focus of this course will be on Austempered Ductile Iron (ADI). In ADI, the metallurgical structure is manipulated through a sophisticated heat-treating process, which delivers yield strength, toughness and impact resistance comparable to many cast/forged steels.

Vermicular graphite iron (VG), also known as compacted graphite iron (CGI), is a form of cast iron that doesn't fit neatly into any of the basic types listed above. VG mixes some of the beneficial properties of both grey iron and ductile iron to produce a material with excellent heat transfer properties coupled with good mechanical strength in compression and tension. In VG, the graphite forms a flake with rounded ends which look "worm like" under a microscope. This achieves two things. Firstly, it removes the sharp stress and crack propagation points of the normal graphite flake leading to a ductile rather than a brittle material and secondly, because there is still a lattice like structure of graphite running through the matrix, it retains heat transfer properties like a grey iron.

Weldability is an important consideration in many manufacturing processes. This course concludes with an overview of welding processes that are typically used for cast irons. The brittleness of gray iron makes it very difficult to weld without special precautions. But, the more ductile cast irons exhibit good weldability.

Gray Iron

Cast irons are alloys of iron, carbon, and silicon in which more carbon is present than can be retained in solid solution in austenite at the eutectic temperature. In gray cast iron, the carbon that exceeds the solubility in austenite precipitates as flake graphite.

Gray irons usually contain 2.5 to 4% **C**, 1 to 3% **Si**, and additions of manganese, depending on the desired microstructure (as low as 0.1% **Mn** in ferritic gray irons and as high as 1.2% in pearlitics). Sulphur and phosphorus are also present in small amounts as residual impurities.

The composition of gray iron must be selected in such a way to satisfy three basic structural requirements:

- The required graphite shape and distribution
- The carbide-free (chill-free) structure
- The required matrix

For common cast iron, the main elements of the chemical composition are carbon and silicon. High carbon content increases the amount of graphite or Fe3C. High carbon and silicon contents increase the graphitization potential of the iron as well as its castability.

The combined influence of carbon and silicon on the structure is usually considered by the carbon equivalent (**CE**):

CE = %C + 0.3x(%Si) + 0.33x(%P) - 0.027x(%Mn) + 0.4x(%S)

Although increasing the carbon and silicon contents improves the graphitization potential and therefore decreases the chilling tendency, the strength is adversely affected. This is due to ferrite promotion and the coarsening of pearlite.

The manganese content varies as a function of the desired matrix. Typically, it can be as low as 0.1% for ferritic irons and as high as 1.2% for pearlitic irons, because manganese is a strong pearlite promoter.

The effect of sulfur must be balanced by the effect of manganese. Without manganese in the iron, undesired iron sulfide (FeS) will form at grain boundaries. If the sulfur content is balanced by manganese, manganese sulfide (MnS) will form, which is harmless because it is distributed within the grains. The optimum ratio between manganese and sulfur for a FeS-free structure and maximum amount of ferrite is:

%Mn = 1.7x(%S) + 0.15

Other minor elements, such as aluminum, antimony, arsenic, bismuth, lead, magnesium, cerium, and calcium, can significantly alter both the graphite morphology and the microstructure of the matrix.

In general, alloying elements can be classified into three categories. Silicon and aluminum increase the graphitization potential for both the eutectic and eutectoid transformations and increase the number of graphite particles. They form colloid solutions in the matrix. Because they increase the ferrite/pearlite ratio, they lower strength and hardness.

Nickel, copper, and tin increase the graphitization potential during the eutectic transformation, but decrease it during the eutectoid transformation, thus raising the pearlite/ferrite ratio. This second effect is due to the retardation of carbon diffusion. These elements form solid solution in the matrix. Since they increase the amount of pearlite, they raise strength and hardness.

Chromium, molybdenum, tungsten, and vanadium decrease the graphitization potential at both stages. Thus, they increase the amount of carbides and pearlite. They concentrate in principal in the carbides, forming $(FeX)_nC$-type carbides, but also alloy the aFe solid solution. If carbide formation does not occur, these elements increase strength and hardness. Above a certain level, any of these elements will determine the solidification of a structure with Fe_3C (mottled structure), which will have lower strength but higher hardness.

Generally, it can be assumed that the following properties of gray cast irons increase with increasing tensile strength from class 20 to class 60:

- All strengths, including strength at elevated temperature
- Ability to be machined to a fine finish
- Modulus of elasticity
- Wear resistance.

On the other hand, the following properties decrease with increasing tensile strength, so that low-strength irons often perform better than high-strength irons when these properties are important:

- Machinability
- Resistance to thermal shock
- Damping capacity
- Ability to be cast in thin sections.

Successful production of a gray iron casting depends on the fluidity of the molten metal and on the cooling rate, which is influenced by the minimum section thickness and on section thickness variations.

Casting design is often described in terms of section sensitivity. This is an attempt to correlate properties in critical sections of the casting with the combined effects of composition and cooling rate. All these factors are interrelated and may be condensed into a single term, castability, which for gray iron may be defined as the minimum section thickness that can be produced in a mold, cavity with given volume/area ratio and mechanical properties consistent with the type of iron being poured.

Scrap losses resulting from misruns, cold shuts, and round corners are often attributed to the lack of fluidity of the metal being poured.

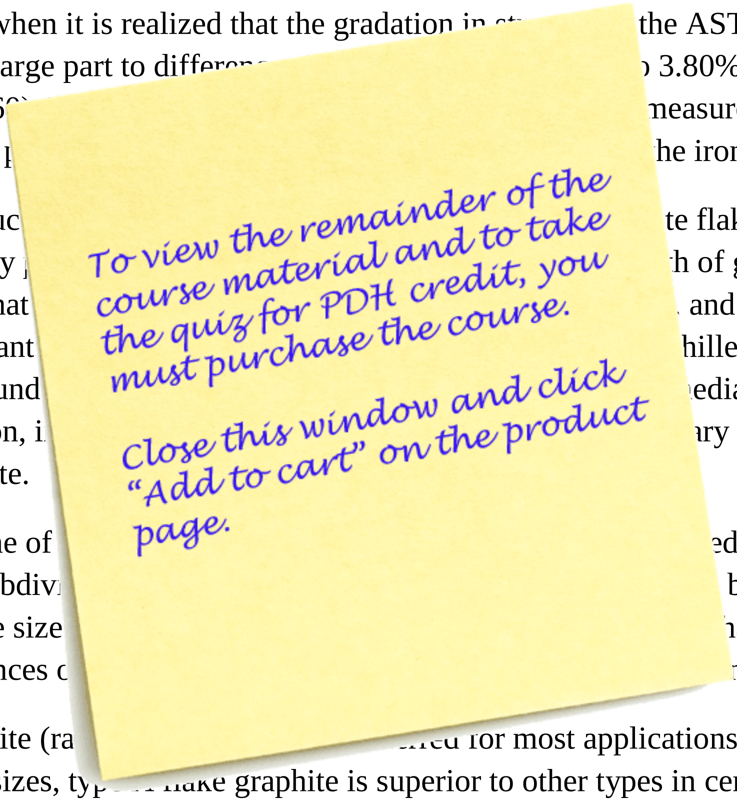
Mold conditions, pouring rate, and other process variables being equal, the fluidity of commercial gray irons depends primarily on the amount of superheat above the freezing temperature (liquidus). As the total carbon content decreases, the liquidus temperature increases, and the fluidity at a given pouring temperature therefore decreases. Fluidity is commonly measured as the length of flow into a spiral-type fluidity test mold.

The significance of the relationships between fluidity, carbon content, and pouring temperature
becomes apparent when it is realized that the gradation in the ASTM classification of
gray iron is due in large part to differe 3.80% for class 20; ~2.70
to 2.95% for class 6 measure of the practical
limits of maximum p he iron being poured.

The usual microstruc te flakes dispersed
throughout. Foundry h of graphite flakes
occur in a pattern that and distribution of
graphite are important hilled iron, in which the
excess carbon is found ediate rates can
produce mottled iron, i ry cementite (iron
carbide) and graphite.

Flake graphite is one of ed in ASTM A 247.
Flake graphite is subdivi by the letters A
through E. Graphite size hart, which shows
the typical appearances n.

Type A flake graphite (ra red for most applications. In the
intermediate flake sizes, ty flake graphite is superior to other types in certain wear
applications such as the cylinders of internal combustion engines.



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Type B flake graphite (rosette pattern) is typical of rapid cooling, such as is common with moderately thin sections (about 10 mm) and along the surfaces of thicker sections, and sometimes results from poor inoculation.

The large flakes of type C flake graphite are formed in hypereutectic irons. These large flakes enhance resistance to thermal shock by increasing thermal conductivity and decreasing elastic modulus. On the other hand, large flakes are not conducive to good surface finishes on machined parts or to high strength or good impact resistance.

The small, randomly oriented interdendritic flakes in type D flake graphite promote a fine machined finish by minimizing surface pitting, but it is difficult to obtain a pearlitic matrix with