



ANALYSIS OF THE CHEMICAL COMPOSITION AND MICROSTRUCTURE OF WHITE CAST IRON

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ABSTRACT

Low and medium alloy cast irons were considered. Those cast irons, silicon was the main alloying element, although others in small quantities were considered. However, in this chapter, cast irons with more than 10% in alloying elements will be presented, having as objective improving abrasion, corrosion and heat resistances in cast irons, as specific purposes.

KEYWORDS: *white cast iron, alloyed, composition, abrasion-resistant, machine, chromium, corrosion-resistant, eutectic carbide, microstructure, material, silicon, graphite, structure, austenite, cementite, ledeburite.*

INTRODUCTION

High-alloy white cast irons are an important group of materials whose production must be considered separately from that of ordinary types of cast irons. In these cast iron alloys, the alloy content is well above 4%, and consequently they cannot be produced by ladle additions to irons of otherwise standard compositions. They are usually produced in foundries specially equipped to produce highly alloyed irons [1].

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foundries specially equipped to produce highly alloyed irons.

The high-alloy white irons are primarily used for abrasion-resistant applications and are readily cast into the parts needed in machinery for crushing, grinding, and handling of abrasive materials. The chromium content of high-alloy white irons also enhances their corrosion-resistant properties. The large volume fraction of primary and eutectic carbides in their microstructures provides the high hardness needed for crushing and grinding other materials. The metallic matrix supporting the carbide phase in these irons can be adjusted by alloy content and heat treatment to develop the proper balance between the resistance to abrasion and the toughness needed to withstand repeated impact.



High-alloy cast irons

The requirement of an alloying element – silicon – with the purpose of manufacturing grey cast irons was presented. The necessity of adjusting carbon and silicon contents to the different applications of lamellar graphite cast irons was also considered. Some aspects about composition of malleable (nodular) and spheroidal graphite cast irons were also indicated. The researcher has available some criteria for being able to establish relationships between composition, structure, properties and applications. In this way, for instance (see Table 1), diminishing the equivalent carbon content seems logical when mechanical strength and tightness are

pursued in lamellar graphite cast irons. A good castability requires high equivalent carbon contents. Silicon content should be increased if the parts are thin. It is also convenient a certain phosphorus content for achieving good wear resistance. However, in all these considerations, the sum of weight percentages of the different elements – excepting carbon because this element is always present in cast irons – is lower than 10%. Nevertheless, cast irons with an alloying percentage higher than 10% will be considered. These cast irons are known as high-alloy cast irons. High-alloy cast irons are used when looking for other additional properties such as *abrasion, corrosion and heat resistances* [2].

Table 1. Composition of some cast iron parts of common uses [3]

Type of part		Composition (wt%)				
		C	Si	P	S	Mn
High resistance		2.75	2.25	0.10	0.10	0.80
Ornamental		3.50	2.50	1.00	0.10	0.50
Machine equipment	Small thickness	3.25	2.25	0.25	0.10	0.50
	Average thickness	3.25	1.75	0.25	0.10	0.50
	High thickness	3.25	1.25	0.25	0.10	0.50
Ingot moulds		3.50	1.50	0.25	0.07	0.90
Mine waggon wheels		3.35	0.65	0.35	0.12	0.60
White heart malleable cast iron		3.00	0.75	<0.15	<0.20	0.50
Blackheart malleable cast iron		2.75	1.00	<0.15	<0.20	0.50
Ductile cast iron		3.50	2.50	<0.04	0.01	0.03–0.05 Mg

It seems logical to question about the advantages of employing these high-alloy cast irons (more expensive than the cast irons previously studied) instead of unalloyed or low-alloy cast irons. In relation to low and medium alloy grey cast irons, it was said that they have a good corrosion resistance. Moreover, it was also mentioned that cast irons with martensitic matrix are used when a good wear resistance is pursued.

However, it should be considered that all above mentioned is referred to some ferrous materials whose primary requirements are the general properties of grey cast irons, and that secondarily it would be interesting that they have another property of the three previously listed. On the contrary, in the case of high-alloy cast irons, the required properties – abrasive wear resistance, corrosion resistance to the chemical attack or inalterability at high temperature –

are pursued no matter they have grey or white structures.

On another note, the same high – alloy cast iron usually behaves satisfactorily faced to more than one of the requirements previously mentioned. In this way, high chromium alloy cast iron is almost always used because of its good abrasive wear resistance in the presence of very hard minerals (for instance, quartz), although has a good corrosion and heat resistances as well [4]. High silicon alloy cast iron has good corrosion resistance but also has good wear resistance. High nickel alloy cast iron is stable to heat and behaves well in front of corrosive conditions. As it will be seen, chromium, silicon and nickel are usually present – one or more than one of them – in high proportion in all high – alloy cast irons.



We usually use of the alloy that has the chemical composition mentioned below:

3:5%C-2:5%Si-0:5%Mn-0:1%P-0:12%S

First, the equivalent carbon should be calculated:

$$EC = C + \frac{Si}{3} + \frac{P}{3} = 3.5 + \frac{2.5}{3} + \frac{0.1}{3} = 4.37\% > 4.25 = EC_{\text{Grayiron}} \quad (1)$$

EC = 4.37%, so, this cast iron is hypereutectic. As applications, it is possible to mention low resistance ornamental parts (sculptures, lampposts, manhole covers, etc.) because of the low solidification interval and excellent castability. In ornamental applications, eutectic grey irons are

usually employed because of the nearly zero solidification interval. With the same finality, hypereutectic grey irons are used in ornamental parts because the hypereutectic graphite does not impair the castability and increases the thermal conductivity [5].

We choose chemical compositions for manufacturing grey cast irons with applications in thin parts with tensile strength, ingot moulds and elements with resistance to wear and thermal growth:

(A) 3.8% C-1.5% Si-0.9% Mn-0.2% P-0.07% S

(B) 2.75% C-2.25% Si-0.9% Mn-0.1% P-0.07% S

(C) 1% C-16% Si-0.4% Mn-0.1% P-0.012% S

The equivalent carbon of the cast irons is calculated:

$$EC^A = C + \frac{Si}{3} + \frac{P}{3} = 3.8 + \frac{1.5}{3} + \frac{0.2}{3} = 4.37\% \quad (2)$$

$$EC^B = C + \frac{Si}{3} + \frac{P}{3} = 2.75 + \frac{2.25}{3} + \frac{0.1}{3} = 3.53\% \quad (3)$$

$$EC^C = C + \frac{Si}{3} + \frac{P}{3} = 1 + \frac{16}{3} + \frac{0.1}{3} = 6.3\% \quad (4)$$

The manufacture of *elements with growth and wear resistances* requires a grey iron with high silicon content. For that reason, *Cast Iron C* has the suitable chemical composition. This cast iron is commercially known as Duriron. The high silicon percentage (16%) impedes the growth that cementite suffers when splits into iron and graphite at temperatures higher than 450 °C, and also improves the scaling resistance as a consequence of that reduces the propensity of ferrite to oxidation. Duriron is a grey cast iron of matrix thoroughly ferritic (stable cooling). Moreover, this cast iron has wear resistance due to the hardness conferred by the silicon.

The manufacture of *ingot moulds* requires a grey iron with high carbon content because the graphite is a good heat conductor. The main feature of the ingot moulds is its ability for heat dissipation, which is achieved by means of graphite, especially lamellar graphite. For that reason, *Cast Iron A* has the suitable chemical composition.

The manufacture of *thin parts with tensile strength* requires cast irons of low carbon content, because the lower the carbon contents, the lower the graphite presence. In this way, the notch effect is reduced, and the resistant cross section is increased (higher toughness), and consequently the tensile strength is improved. That is to say, low carbon

content is required. *Cast Iron B* has the suitable chemical composition.

Non-alloyed White Cast Irons

Except for the former reference to the metastable solidification, it was not mentioned in previous sections neither the structure of white cast irons *nor their most typical property, the abrasive wear resistance*. Before talking about the categories of high-alloy cast irons whose abrasion resistance is the main feature, it is noteworthy to refer to non-alloyed white cast irons. Non-alloyed white cast irons are cheap materials with an excellent abrasion resistance and with a better wear resistance in comparison with grey irons and steels. On the contrary, white cast irons have a worse toughness. Even though the components of the alloy are essentially iron and carbon, their excellent wear resistance comes from the microstructure inherited from the metastable solidification [6].

For instance, it should be considered the evolution from the molten state down to the room temperature of a sand-moulded binary hypoeutectic white cast iron of 3% C balance iron. Its solidification begins at the temperature T_1 of around 1280 °C. The primary constituent that solidifies (between T_1 and 1148 °C) is austenite. In equilibrium cooling conditions, the solidification ends at 1148 °C. The structure is constituted by primary austenite

(2.11% C), and the ledeburitic eutectic matrix (52 wt% austenite (2.11% C) and, 48 wt% cementite, called ledeburite, where cementite is, in turn, the matrix constituent of this ledeburite).

During solid-state cooling, carbon solubility in austenite diminishes both in the primary austenite and in the austenite of the ledeburite. The carbon excess, which was rejected from the austenite cells, precipitates as cementite in either the boundaries of the dendrites or inside of the austenite.

When the temperature of 727 °C is reached, the carbon content in the austenite is 0.77% C. At this temperature, 0.77% C austenite transforms into

pearlite (a lamellar eutectoid made of ferrite and cementite). This transformation affects the primary austenite and the eutectic austenite as well.

In Fig.1, it is possible to see the morphology of the disperse constituent, which was austenite formed before reaching 1148 °C and that has already been transformed into pearlite. It is also possible to see the eutectic matrix that is formed by cementite (white constituent) and dark points that belong to the eutectic austenite, which has also been transformed into pearlite. The same considerations can be made in the case of the hypereutectic white cast irons (Fig.2), but as distinct to

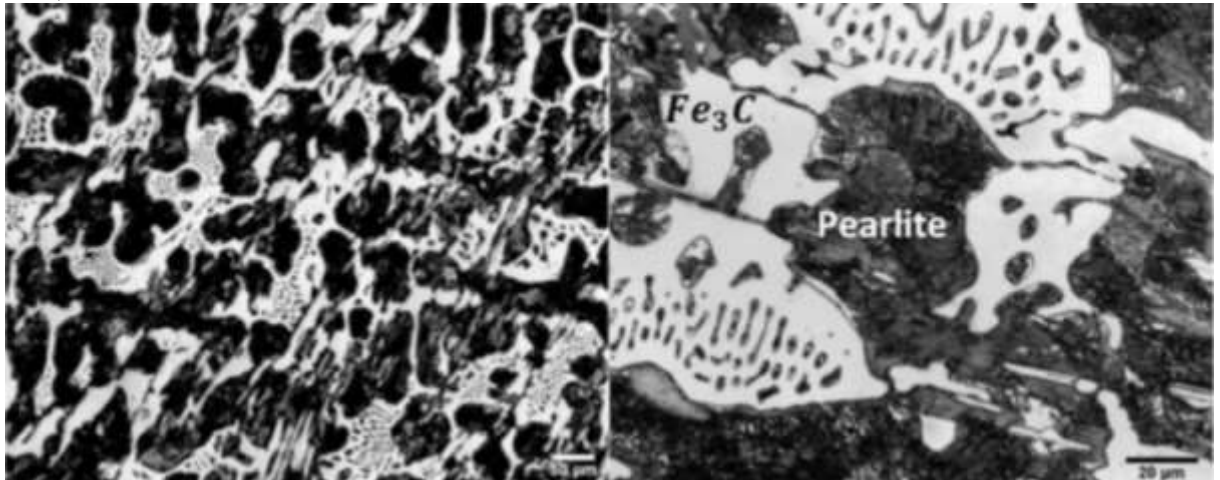


Fig. 1. Hypoeutectic white cast iron. The matrix constituent is ledeburite (ledeburitic austenite - and also primary austenite - is transformed into pearlite)

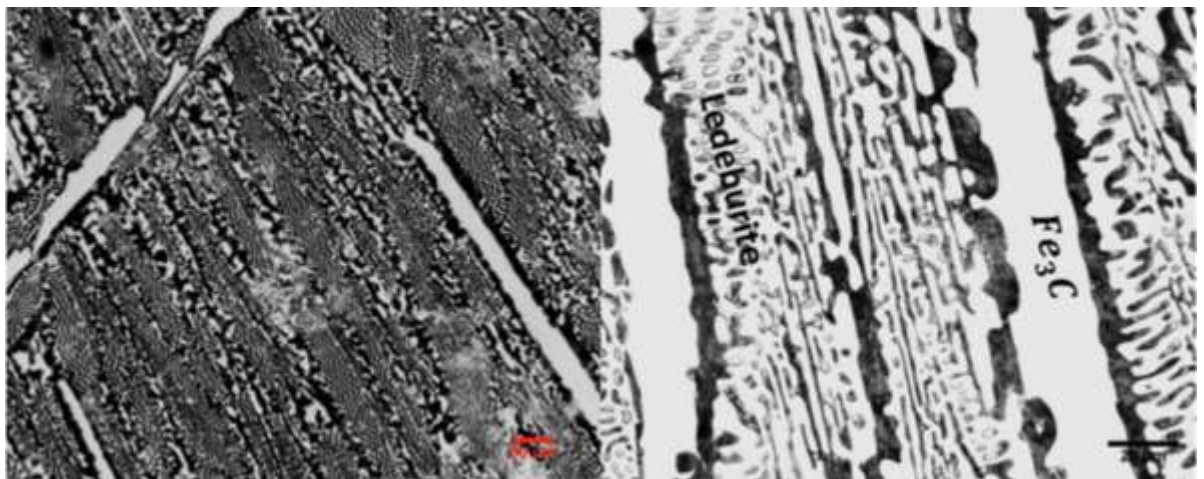


Fig. 2. Hypereutectic white cast iron [7]

The hypoeutectic white cast irons, they have as primary constituent needles of Fe₃C that were formed previously to the eutectic solidification.

The microstructure of non-alloyed white cast irons, whose disperse constituent is pearlite, justifies their typical properties: all of them, both hypoeutectic and hypereutectic white cast irons, have *ledeburite as matrix constituent (and the matrix of the ledeburite is cementite)*.

According to the microstructure, a good model to explain the white irons' behaviour could be the *sponge of cementite* with hollows filled in by pearlite. These unalloyed white cast irons are ceramic matrix composites. Strictly speaking about hollows is not adequate because there are no void areas in white cast irons. In white cast irons, a coherency between the primary constituent and the ledeburitic matrix, which is obtained at the end of the solidification (just like between the eutectic cementite and the pearlite),



exists. Apart from the above comment, the *sponge's model* is suitable for explaining white cast irons origin: discloses the history of the non-alloyed white cast iron since the liquid state and explains its excellent *abrasion resistance*, at least against abrasive materials, whose hardness in the Mohs scale is lower than the pearlite hardness. The *sponge of cementite* will suffer the most part of the fretting, although the pearlite that fills the hollows results also affected, and because of that pearlite has lower hardness than cementite, it will suffer, in comparison, more wear.

The hardness of an abrasive material has marked influence in the abrasion speed of the material that frets with it. In any case, with the aim of calculating the superiority of one material with respect to other, both materials should be subjected to the same kind of abrasive effort. And their behaviour also depends on the way by which the abrasion is produced and the mode of application of this abrasion as well: wet, dry, by erosion, with grinding wheel, with gouge, etc.

The degree of abrasion resistance of a white cast iron can also change for the same composition depending on the solidification technology that was used. In this way, for instance, a *white iron chill moulded*, or in a graphite mould, which is better heat transfer, usually results in *more resistant to wear than the same cast iron sand moulded*. Chill moulding confers columnar structure, a finer eutectic, and because of the non-equilibrium solidification, a major proportion of ledeburite [8].

If the white cast iron had 6.67% C, and therefore cementite was its only constituent, without pearlite, the cast iron would have a higher abrasion resistance in comparison with the hypereutectic white cast irons and, obviously, than all hypoeutectic white cast irons. On the contrary, toughness would be very low. Because of the low toughness of white cast irons, logically the higher the carbon content, the lower the toughness, explains that the hypereutectic white cast irons are hardly used.

The *sponge* model also justifies the lack of elongation in these cast irons during the tensile test: the cementite matrix breaks without elongation, as corresponds to the ceramic nature of the Fe₃C intermetallic compound.

The compromise between abrasion resistance, which grows with the carbon content, and toughness, which diminishes with the carbon content, advises the use of hypoeutectic white cast irons, and also justifies - as it will be seen afterwards - the utility of high - alloy cast irons. However, unalloyed white cast irons have limitations that make necessary the use of high-alloy cast irons. This happens, for example, when the abrasive mineral has hardness higher than that one of the pearlites [9].

With all that, because of the large number of mining uses, such as mill balls, jaws, wearing plates, etc., unalloyed, or lowly alloyed white cast irons

offer their possibilities in the abrasion resistance field [10]. Behaviour of white cast irons that, as can be easily justified if we compare their microstructures, is better than in hypereutectoid steels and in grey cast irons. Reciprocally, due to the excellent abrasion resistance, white cast irons cannot be machined with common tools.

CONCLUSION

White cast iron is mainly composed of ledeburite structure. Ledeburite is a mechanical mixture of fine grains of austenite and primary cementite, consisting mainly of 4.3% C. It is mainly austenite 52% and cementite 48%. The structure of ledeburite is in the form of rough graphite, which is hard and brittle, and can cause various cracks and internal stresses in the pressure-working shale. Therefore, for the use of white cast iron in machinery, it is recommended to work mainly with alloying elements.

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