THE INFLUENCE OF ALLOYING ELEMENTS TO CAST IRON MICROSTRUCTURE

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Keywords: alloying, cast irons, microstructure, molybdenum, chromium, copper

ABSTRACT

Gray cast iron belongs to the group of iron casts that contain graphite particles in the microstructure. Graphite particles in gray cast iron have the shape of lamellae and are connected to each other. The specific combination of properties of gray cast iron, which is satisfactory for many applications, and simple and cheap production are the main reasons for its very wide application. For many years, gray cast iron has been the most used material for making metal castings. In this paper, there are microstructure tests for different variations of alloying gray cast iron with chromium, molybdenum, and copper. The assumption is that these elements influence the formation of pearlite in the microstructure, in different combinations.

1. INTRODUCTION

The quality and properties of gray cast iron depend on the shape, distribution, and size of the separated graphite lamellas and the microstructure of the metal matrix. The chemical composition is an important factor that affects the shape of the graphite and the microstructure of the metal matrix [1].

Cast iron with lamellar graphite (gray cast iron) includes a class of iron-based materials characterized by a microstructure with the presence of graphite separated in the form of lamellae in the metal matrix. In order to fully understand the issues of production and properties of this group of castings, the influence of the chemical composition is easiest to observe if the influence of individual elements is discussed according to the groups as follows:

1. Basic elements
2. Accompanying elements
3. Alloying elements and trace elements

Alloying elements and elements present in traces are elements that affect the properties of cast iron. Sometimes these elements are deliberately added with the aim of increasing their influence on the desired properties of the casting (addition of copper or tin with the aim of obtaining a pearlite microstructure of the metal matrix), and they can also be found in the melt as unwanted elements that have a negative effect on the properties of the casting (lead, bismuth, nitrogen, etc.) [2,3].

2. INFLUENCE OF CHEMICAL COMPOSITION ON MICROSTRUCTURE OF GRAY IRON CASTINGS

Copper is a graphitizer and promotes the formation of pearlite, and also increases the strength of the formed pearlite. It is expected that in ferrite or ferrite and pearlite cast iron base, copper has a stronger effect [4]. During hardening, graphite/austenite separates at the boundary and thus represents a diffusion barrier for carbon in the casting cooling process. Taking into account this fact, it is clear that in the process of transformation in the solid state, the formation of pearlite is promoted, while it is not a carbide promoter. Unlike manganese, there is no danger of carbide formation, and copper is a stronger promoter of pearlite. Amounts recommended as alloying additions range up to 1,55% copper. Research has shown that the addition of 0,82% copper has the same effect on achieving a pearlite microstructure as 1,74% manganese. The difference in the microstructures is that in the case of alloying with copper, a microstructure was obtained without the presence of carbides, in contrast to alloying with manganese, where a larger amount of separated carbides was observed. The combination of the addition of copper and silicon in the casting increases the security of the formation of microstructure without the presence of whitening, that is, the sensitivity of the casting to different wall thicknesses per cross-section is reduced and the possibility of metastable hardening in thinner sections is reduced. Silicon reduces the solubility of carbon in the solid and liquid phase, increases the diffusion of carbon at all temperatures, and acts as a graphitizer, reducing the tendency to form carbides. As other graphitizes, it separates into a solid phase during solidification and raises the solidification temperatures of the stable eutectic (Fe-C), and lowers the solidification temperatures of the metastable eutectic (Fe-Fe_3C). Carbide-forming elements (chromium, vanadium, etc.) do the opposite. The negative effect of copper comes to the fore in the case of efforts to obtain a ferrite microstructure, where a casting with a maximum of 0.03% copper must be provided to avoid the appearance of pearlite in the microstructure of the casting. It should be emphasized that only the addition of a highly pure copper alloy from a well-known manufacturer in foundries gives the desired effect [2,3]. Copper promotes the formation of graphite and it is a pearlite stabilizing element. It can have a grain refining effect [5].

Molybdenum is an alloying element that has mild carbide-forming properties. In the case of alloying with molybdenum over 0.3%, separated carbides rich in molybdenum are noticeable at the grain boundaries, where the effect is much more pronounced in thicker sections of the casting due to the occurrence of segregation. The important role of molybdenum is that it improves the hardenability of the casting during the heat treatment process, especially in combination with copper and nickel. In addition to improving hardenability, molybdenum affects the fragmentation of the graphite phase, affecting the increase in the number of eutectic cells, while reducing the effect of the variation of properties across the cross-section of the casting in the case of different wall thicknesses in the casting. The negative side of the presence of molybdenum as an alloying element is if you want to get a pearlite microstructure, and therefore it is mostly recommended to add molybdenum together with some of the elements that will prevent the formation of certain amounts of ferrite in the microstructure. Most often, these are combinations of molybdenum + chromium, molybdenum + copper, molybdenum + tin, or combinations with several alloying elements, such as molybdenum + copper + nickel and similar combinations. Taking into account the above facts, it can be said that molybdenum is one of the most versatile alloying elements used in iron-based castings [2]. Molybdenum hardens ferrite and strongly increases the hardenability of austenite. It is a carbide stabilizer (not as strong as chromium) and when in high enough concentrations, it can form carbides [6].

Chromium prevents graphitization and stabilizes primary, eutectic, and eutectoid carbides [7]. Chromium is one of the alloying elements that has the strongest potential for carbide formation. In the hardening process, like other carbide formers, it lowers the temperature of the stable eutectic and raises the temperature of the metastable eutectic. Since it lowers the hardening interval, it increases the tendency toward the formation of spalling in the microstructure of the casting. The maximum amount of chromium that is allowed (to achieve a cast structure without the presence of carbides) is 0.05%, although, in the case of a larger amount of manganese, this value is even lower due to the effect of manganese on the formation of carbides. Chromium carbides are highly resistant to heat treatment even after several hours of annealing. The tendency of chromium to form carbides affects the increase in the mechanical properties of the casting. The negative side is that these carbides mostly segregate along the grain boundaries [2].

3. EXPERIMENTAL PART

In the practical part of the work, the results of testing gray cast iron samples are presented in order to explain the influence of alloying elements on the microstructure of the tested samples. Four melts of gray cast iron were prepared, one melt from regular production and one with each of the alloying elements: copper, molybdenum, and chromium.

3.1 Chemical composition of the melts

Table 1 shows the chemical composition of sample 1, a sample from regular production.

Table 1.Chemical compositions for sample 1, sample from regular production

/	Chemical composition, wt. %							
	C	Si	Mn	Cr	Mo	Cu	P	S
Sample 1	3,585	1,945	0,717	0,104	0,012	0,195	0,057	0,077

Table 2 shows the chemical composition of sample 2, alloyed with copper.

Table 2. Chemical compositions for sample 2, alloyed with copper

/	Chemical composition, wt. %							
	C	Si	Mn	Cr	Mo	Cu	P	S
Sample 2	3,545	2,049	0,641	0,103	0,016	1,046	0,042	0,051

Table 3 shows the chemical composition of sample 3, alloyed with molybdenum.

Table 3. Chemical compositions for sample 3, alloyed with molybdenum

/	Chemical composition, wt. %							
	C	Si	Mn	Cr	Mo	Cu	P	S
Sample 3	3,623	1,926	0,689	0,115	0,830	0,200	0,046	0,089

Table 4 shows the chemical composition of sample 4, alloyed with chromium.

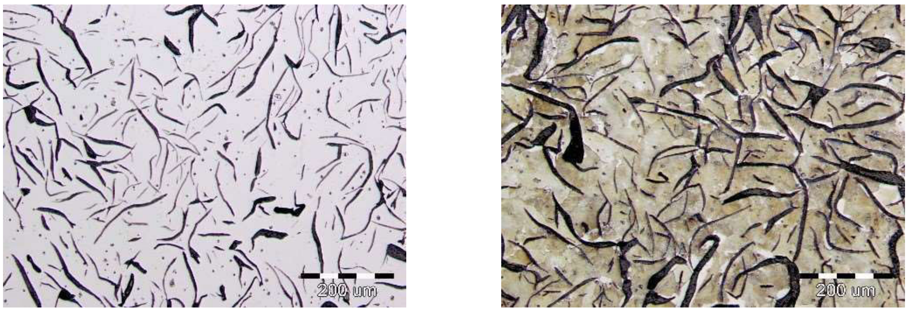
Table 4. Chemical compositions for sample 4, alloyed with chromium

/	Chemical composition, wt. %							
	C	Si	Mn	Cr	Mo	Cu	P	S
Sample 4	3,499	1,862	0,759	0,587	0,015	0,200	0,035	0,076

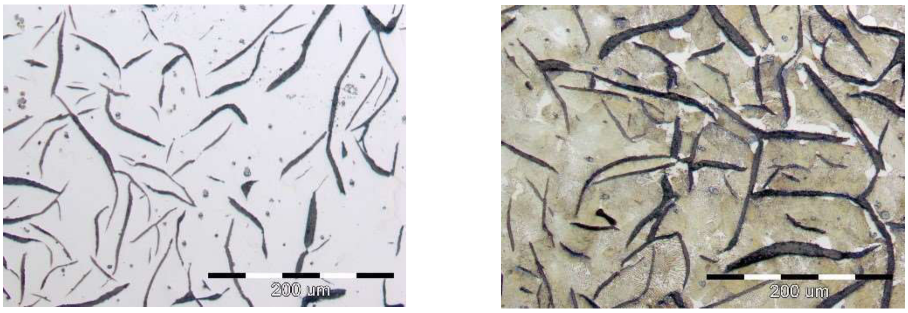
4. RESULTS

Metallographic samples were prepared for the microstructure analysis (optical microscopy) for three types of cast iron and one for samples from regular production. According to the photographs of the microstructure shown in the etched state, it was shown that the mentioned alloying elements are pearlitizers, that is, we confirmed the pearlite microstructure on each sample (figures of all samples etched by nital 2%, magnification 100x, and 200x).

Figure 1 shows the microstructure of sample 1, gray cast iron from regular production.



a) after polishing, magnification 100x *b) etched by nital 2%, magnification 100x*

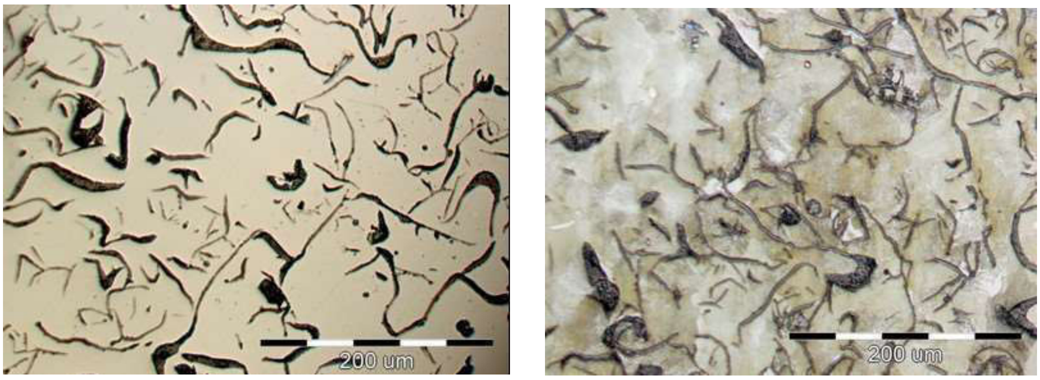


c) *after polishing, magnification 200x* *d) etched by nital 2%, magnification 200x*

Figure 1. Microstructure of sample 1, gray cast iron from regular production

Figure 2 shows the microstructure of sample 2, gray cast iron alloyed with copper (1,046 wt %).

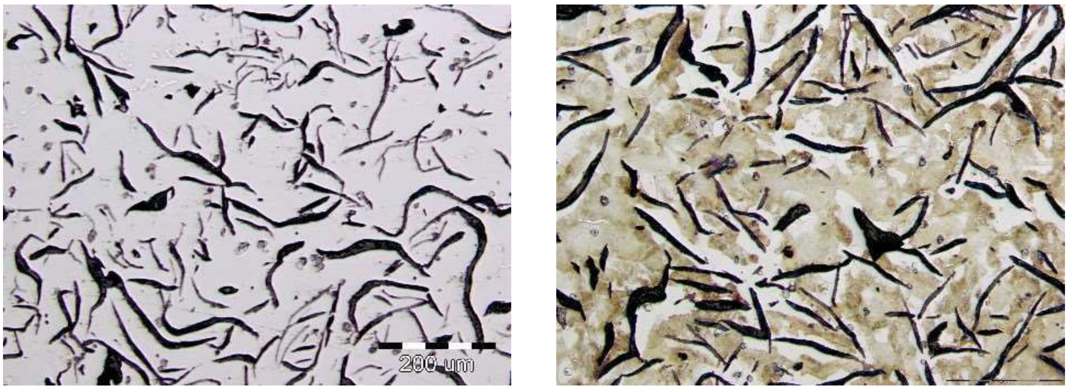
a) after polishing, magnification 100x *b) etched by nital 2%, magnification 100x*



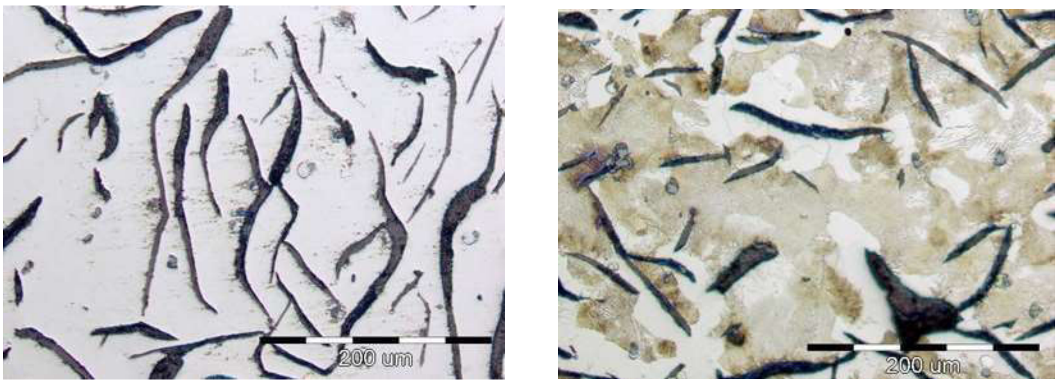
c) *after polishing, magnification 200x* *d) etched by nital 2%, magnification 200x*

Figure 2. Microstructure of sample 2,gray cast iron alloyed with copper (1,046 wt, %)

Figure 3 shows the microstructure of sample 3, gray cast iron alloyed with molybdenum, (0,83 wt, %).



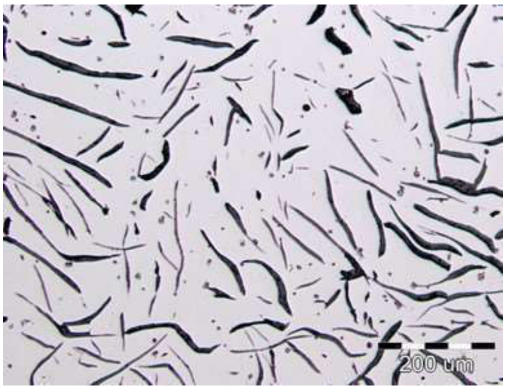
a) after polishing, magnification 100x *b) etched by nital 2%, magnification 100x*



c) *after polishing, magnification 200x* *d) etched by nital 2%, magnification 200x*

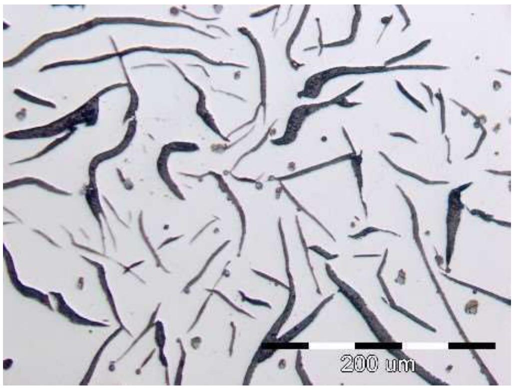
Figure 3. Microstructure of sample 3,gray cast iron alloyed with molybdenum (0,830 wt %)

Figure 4 shows the microstructure of the sample 4, gray cast iron alloyed with chromium (0,587 wt, %).



a) after polishing, magnification 100x

b) etched by nital 2%, magnification 100x



c) *after polishing, magnification 200x*

d) etched by nital 2%, magnification 200x

Figure 4. Microstructure of the sample 4, gray cast iron alloyed with chromium (0,587 wt, %)

5. CONCLUSIONS

Based on the microstructure, we can confirm that these alloying elements copper, molybdenum, and chromium are pearlitizers.

Chromium is also a carbide former, carbides mostly segregate along the grain boundaries (shown on the microstructure of sample 4, etched by nital 2%, magnification 200x).

In this case, copper is the biggest pearlitizer in combination with manganese(shown on the microstructure of sample 2, etched by nital 2%, magnification 100 x and 200x), where the least amount of ferrite is present.

Molybdenum is the mildest pearlitizer, which is why we have the most ferrite. Molybdenum creates fields (islands) of ferrite in the microstructure, creating a greater proportion of smaller graphite lamellae in the microstructure(shown on the microstructure of sample 3, etched by nital 2%, magnification 100 x and 200x). This is one of the reasons for the higher proportion of ferrite in the matrix.

6. REFERENCES

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