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THE INFLUENCE OF ALLOYING ELEMENTS ON MICROSTRUCTURE AND HARDNESS OFGRAY CAST IRON

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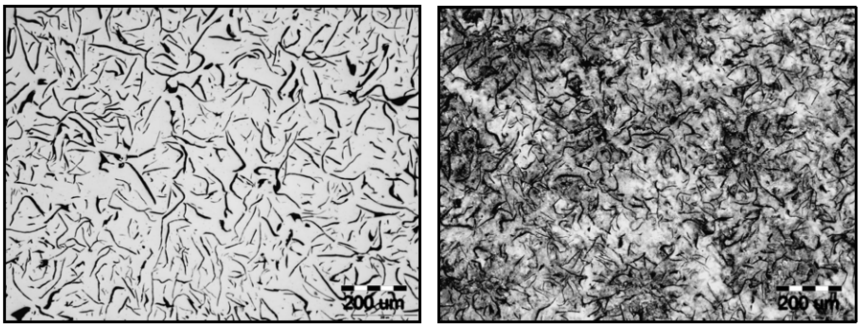
ABSTRACT
The chemical composition of casting is an important factor affecting the shape of graphite and the mechanical properties and microstructure of the metal base. Different elements have different influence to casting properties. All elements that affect the microstructure development during casting solidification have significant influence on mechanical properties of the castings. In the practical part of this paper influence of molybdenum and chromium on the change in hardness and pearlite content in the microstructure is presented. The results show that with the addition of pearlitizing elements (Cr and Mo), the content of pearlite in the microstructure of the metallic matrix and hardness of the castings increase.

1. INTRODUCTION

Gray castironbelongstothefamily of iron castings in which carbonisexpressed as graphite, Figure 1.Due to the lamellar structure of graphite, gray cast iron has low tensile strength, hardness, toughness, elongation and modulus of elasticity and increased sensitivity to wall thickness, outstanding moldability and compressive strength. The mechanical and physical properties of gray cast iron depend directly on the chemical composition and microstructure. The typical microstructure of gray cast iron consists of a perlite-ferrite metal base and graphite lamellae. Because graphite phase interrupt the continuity of the metal base, that is, they act as notches in the metal base, the mechanical properties of gray cast iron largely depend on the amount, shape, size and distribution of graphite[1.4.5].



a) after polishing *b) etched by nital*

Figure 1. Microstructure of a typical gray cast iron microstructure, 100x[1]

Typical applications of gray cast iron are: mechanical engineering (stands and parts of machinery, housings, etc.), furnace and stove castings, structures, fittings for water supply systems, process and power engineering, motor vehicle industry (cylinders, piston rings, blocks and engine heads, brake discs, flywheels, various gears, assembly housings, etc.), decorative castings (decorative poles, lighting poles, etc.), and many other areas[1.4].

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

Chemical composition is an important factor affecting the shape of graphite and the microstructure of the metal base. In the usual qualities of gray cast iron, the carbon content ranges from 2.9% to 3.8%. Increasing carbon content increases the volume fraction of the graphite phase, resulting in a decrease of mechanical properties of the castings. Increasing carbon content increases the castability of the melt and reduces the shrinkage tendency and possibilities for creating cavities and porosity during solidification process[2.5].

Silicon reduces the solubility of carbon in the solid and liquid phases, increases the diffusion of carbon at all temperatures, and acts as a graphitizer, reducing tendency for carbides formation. Like other graphitizers, it segregates into a solid phase during solidification and raises the solidification temperatures of stable eutectic (Fe-C) and lowers the solidification temperatures of metastable eutectic ($Fe\text{-}Fe_3C$) (Figure 2). Carbide forming elements (eg chromium, vanadium, etc.) do the opposite [2.5].

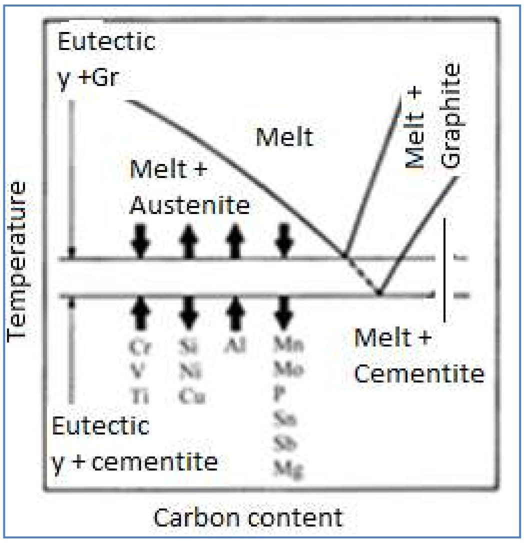


Figure 2: Effect of chemical composition on solidification temperature of stable and metastable eutectic.[4]

Manganese promotes the formation of perlite and carbides. Unlike silicon, manganese lowers the solidification temperature of stable (Fe-C) but also metastable eutectics (Fe-Fe_3C) (Figure 2) [3].

Nickel raises the solidification temperature of stable eutectic (Fe-C) and lowers the solidification temperature of metastable eutectic (Fe-Fe_3C)[3.5].

Chromium belongs to the group of elements with a very high tendency for carbides formation because it lowers the solidification temperature of stable eutectic (Fe-C) and increases the solidification temperature of metastable eutectic (Fe-Fe_3C) (Figure 2.). Chromium is twice as effective as nickel and copper in increasing the tensile strength of gray cast iron.To maintain the graphitization potential of the melt, 1.5 to 5 times the amount of chromium amount of nickel should be added. Chromium has proven to be the most effective element for improving the heat resistance of gray cast iron, especially in combination with molybdenum[3.5].

Molybdenum is one of the most versatile alloying elements for improving the mechanical properties of gray cast iron, due to the hardening of the metal base and the crushing of graphite phase. The addition of molybdenum reduces the variation of mechanical properties between thin and thick walls. Since molybdenum significantly more strongly suppresses the pearlite reaction to lower temperatures than ferrite, the formation of free ferrite is possible. Therefore, if added alone, molybdenum can provide more time for carbon diffusion and ferrite formation, which means, it can increase the proportion of ferrite in thick walls[3.5].

3. EXPERIMENTAL PART

The practical part of this paper presents the results of testing of a gray cast iron samples in order to explain the influence of alloying elements on the change in hardness and content of pearlite in the microstructure of the samples tested.

Two gray cast iron melts were prepared. Melt 1 (Sample SL) is from regular production and standard chemical composition for gray cast iron. Melt 2 (SL-CrMo sample) is a melt of gray cast iron alloyed with chromium and molybdenum.

3.1. Chemical composition of the melts

Table 1 shows the prescribed(by technology preparation in the foundry) chemical compositions of tested melts (SL and SL-CrMo samples).

Table 1. Prescribed chemical compositions for SL and SL-CrMo samples

/	Chemical composition, wt. %							
	C	Si	Mn	Cr	Mo	Cu	P	S
Sample SL	3.48-3.62	1.8-2.1	0.6-0.8	/	/	/	max 0.2	max 0.2
Sample SL-CrMo	3.53-3.6	1.8-1.9	0.68-0.82	0.3-0.35	0.3-0.35	0.62-0.82	max 0.2	max 0.2

Table 2 shows the chemical compositions of the tested grey cast iron samples (SL and SL-CrMo samples).

Table 2 Chemical compositions of grey cast iron for SL and SL-CrMo samples

/	Chemical composition, wt. %							
	C	Si	Mn	Cr	Mo	Cu	P	S
Sample SL	3.51	1.9	0.68	/	/	/	0.082	0.060
Sample SL-CrMo	3.57	1.88	0.73	0.33	0.31	0.64	0.082	0.059

According to data presented in Tables 1 and 2 it can be seen that the chemical compositions of the grey cast iron for the SL and SL-CrMo samples are within the prescribed limits.

4. RESULTS

4.1. Hardnes testing

Hardness measurements (according to the BAS EN ISO 6506-1:2015) were performed on five samples from both types of cast irons, those from regular production and cast iron with the addition of alloying elements(Cr i Mo).

The values of the hardness for the SL and SL-CrMo samples are given in Table 3. On each of ten samples five measurments were performed and average values are presented in Table 3.

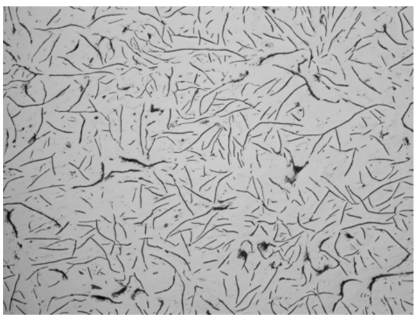
Table 3. Hardness test values for SL and SL-CrMo samples

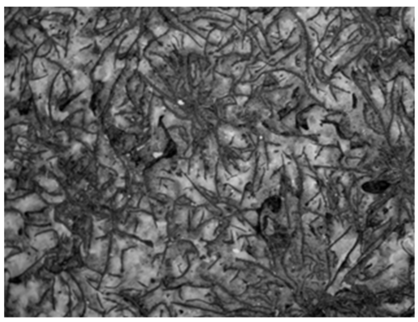
Hardness of the tested samples (HB)-average values					
Sample number					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample5
Sample SL	212	207	209	209	217
SampleSL-CrMo	229	244	241	251	249

4.2. Microstructure analysis

Metallographic samples were prepared for the microstructure analysis for both types of cast iron i.e. one for iron from regular production (sample SL) and one for alloyed cast iron (sample SL-CrMo).

Figure 3 shows the microstructure of the sample SL-gray cast iron from regular production.

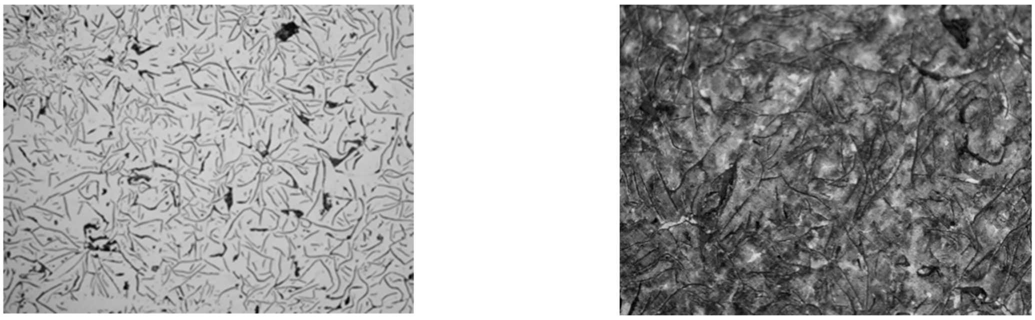




a) *after polishing* b) *etched by nital2%*

Figure 3. Microstructure of the sample SL, 100x

Figure 4 shows the microstructure of the sample SL-CrMo gray cast iron alloyed with chromium and molybdenum.



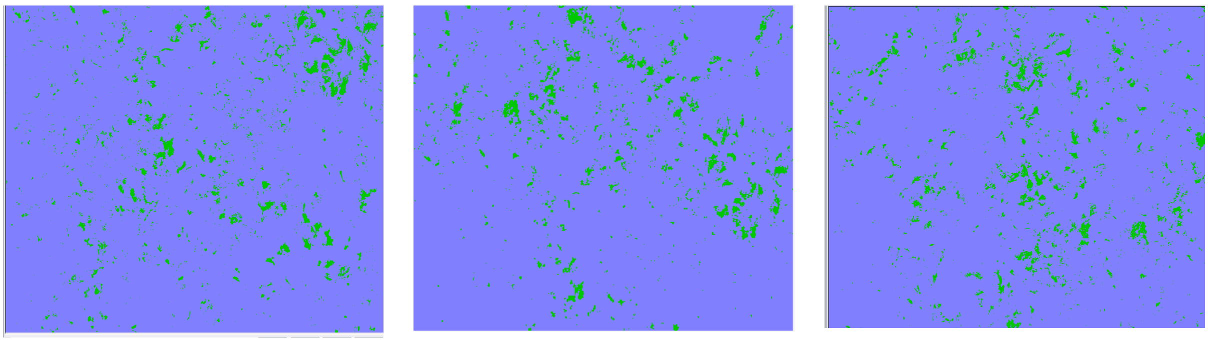
a) *after polishing* b) *etched by nital2%*

Figure 4.Microstructure of the sample SL-CrMo.

The content of perlite in the matrix was determined using a microscope with an image analyzer (Figures 5 and 6). Average values of the pearlite content after three different spots (as recommended by the sample image analysis software) analyzing were as follows:

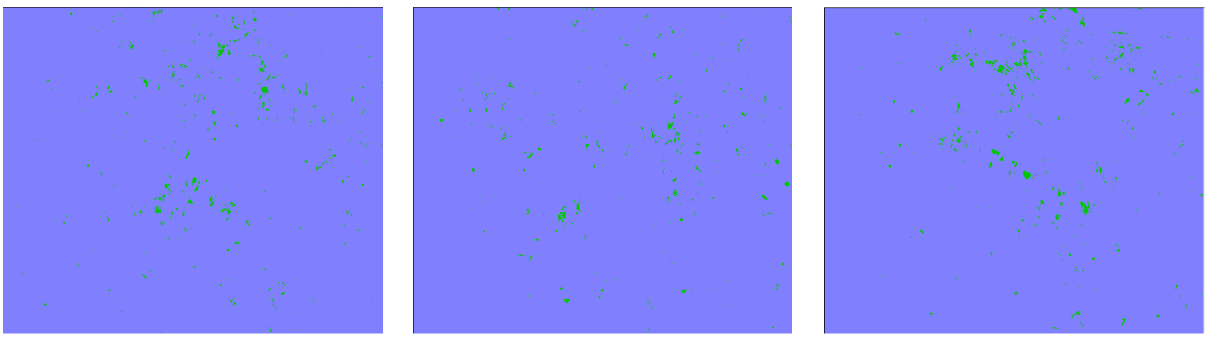
- SL sample: pearlite content – 92%,
- SL-CrMo sample: pearlite content - 97%.

Figures 5 and 6 show the ratio of two phases of the SL and SlCrMo samples. Green area represents ferrite phase and purple area represent pearlite phase. Microstructure was investigated by OLYPUS GX 51 optical microscope using color image analyze program.



a) b) c)

Figure 5. SL sample: pearlite/ferrite content, 100x



a) b) c)

Figure 6. SL-CrMo sample: pearlite/ferrite content, 100x

5. CONCLUSIONS

The aim of the presented research was to test the influence of alloying elements (Cr and Mo) in gray cast iron on hardness characteristics and pearlite content in the metallic matrix. The results show that the average hardness value of the sample SL-CrMo is higher than the hardness of the SL sample.The percentage of pearlite in the metallic matrix is higher for gray cast iron alloyed with chromium and molybdenum (sample SL-CrMo 97% perlite) compared to the proportion of perlite matrix of gray cast iron sample from regular production (sample SL 92% pearlite).From this we can confirm the expected facts: with addition of certain amount of alloying chemical elements such as chromium and molybdenum the content of perlite in the matrix and thus the values of the hardness increase.

5. REFERENCES

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