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A STUDY OF THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF CONTINUOUSLY CAST IRON PRODUCTS

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The horizontal continuous casting has a lot of advantages in comparison with traditional casting methods. But it has a few disadvantages and unsolved problems. The objective of this research was the experimental investigation of the effect of chemical composition of cast iron and the casting conditions on the microstructure and properties of continuously cast ingots. As a result, tensile strength, Brinell hardness, and pearlite content increased with increasing Cr, Cu, and Sb additions and decreasing carbon equivalent. As for microstructure of graphite, higher silicon to carbon ratio and lower solidification rate decreased a zone of interdendritic graphite. Nomograph of continuously cast iron structure was made.

Key words: *continuous casting, cast iron, mechanical properties, microstructure*

Studij mikrostrukture i mehaničkih svojstava kontinuirano lijevanih željeznih proizvoda. Horizontalno kontinuirano lijevanje ima brojne prednosti u usporedbi s tradicionalnim načinima lijevanja. Ali ono ima i nekoliko nedostataka i neriješenih problema. Cilj ovog istraživanja je bio ekspereminentalno utvrđivanje ujecaja kemijskog sastava lijevanog željeza i uvjeta lijevanja na mikrostrukturu i svojstva kontinuirano lijevanih ingota. Kao rezultat istraživanja utvrđeno je da vlačna čvrstoća, tvrdoća (HB) i sadržaj perlita rastu s porastom dodatka Cr, Cu i Sb, te smanjenjem ekvivalenta ugljika. S obzirom na mikrostrukturu grafita, viši odnos silicija i ugljika, te niža brzina skrućivanja smanjuju zonu interdendritnog grafita. Izrađenje i strukturni nomogram kontinuirano lijevanog željeza.

Ključne riječi: *kontinuirano lijevanje, lijevano željezo, mehanička svojstva, mikrostruktura*

INTRODUCTION

The rapid progress of technology requires improve the mechanical and operational properties of the main casting alloy - cast iron. In this respect continuous casting iron is in exceptional position by its properties [1]. Continuous casting has its peculiarities, which, first of all predetermine grey cast iron microstructure and properties [2]. It is well known that the quality and properties of cast products are strongly related to the microstructure developed during solidification. This especially can be seen in the cross-sections of the cast iron ingots, where anomalous, intermediate and normal structural zones can be obtained. This is the result of specific ingot cooling and solidification conditions [3, 4]. Therefore, it is important to investigate the effect of the cooling rate on the microstructure of metal in order to regulate properties of ingots. Investigations of the continuously cast iron microstructure are important, because, by change of casting parameters it is possible to obtain necessary ingots properties in these parts of cross-section, where damaging effect of operational factors is most strong. It is well known that the quality and properties of cast products are strongly related to the chemical composition of cast iron too. However, only limited information is available in the literature about the effect of chemical composition on continuously cast iron ingots properties. Consequently, the aim of the present paper was to investigate the effects of the solidification rate and various chemical elements on the microstructure and mechanical properties of continuously cast products.

EXPERIMENTAL PROCEDURES

Cast iron was melted in the standard line frequency induction furnace of capacity the 10 t. The iron charge contained steel scrap, cast iron returns, ferrosilicon (FeSi75), ferromanganese (FeMn75), ferrochrome (FeCr65), pure copper and antimony. The average chemical composition of cast irons aimed at 3,4 - 3,6 % C, 2,0 - 2,1 % Si, 0,4 - 0,5 % Mn, 0,15 - 0,6 % Cr, 0,03 - 0,04 % S and 0,08 - 0,09 % P. The industrial continuous casting machine was

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used. The capacity of the not heated metal receiver of the machine was 2 tons. The cylindrical and rectangular specimens were cast by continuous casting.

Effect of chemical composition on continuous casting ingots initial microstructure was investigated on various composition cast iron (eutectic Se = 0,8 - 1,0, ratio of silicon to carbon Si/C = 0,5 - 0,9).

A microstructural analysis was made by optical microscopy. The graphite flake type, form, and size were defined by procedure described in the European Standard “Cast iron - Designation of microstructure of graphite” (EN ISO 945-1994). The procedure of quantitative metalography was carried out in accordance with Russian Standard “Iron castings with different form of graphite. Evaluation of structure“ (GOST 3443-87). The microstructures observed were identified from the corresponding reference diagrams included in this standard. The tensile test was been determined on the machined test pieces prepared from samples cut from the continuously cast ingots in accordance with EN 1561. The test piece diameter was 16 mm. The hardness was been determined as Brinell hardness from the samples cut from a casting, according to standard EN 10003-1.

RESULTS AND DISCUSSION

Investigation of the microstructure of the continuously cast 100 × 50 mm cross-section ingots showed that there was point graphite in surface of the ingots edges. It was situated in between dendrites. At about 10 mm distance from the surface the point graphite became substantially bigger but it was located among dendrites yet. Additionally, dendrites arms were substantially bigger than they were in the ingots surface. In 20 mm thickness layer from the surface almost all graphite was flaky. In the more deeply located layers the flakes fattened.

There was only 6 percent of a pearlite in the ingots surface layer. Such little amount of pearlite results from cooling rate. High cooling rate raises the number of nucleation sites and reduces the coagulative and coalescentive processes. As a result, it reduces the carbon diffusion path during the eutectoid transformation and increases the amount of ferrite in the structure. On the other hand, there is not time enough for the growing of the nucleuses to take place, and finally there are many point graphite in the cast iron structure.

The effect of these two factors on continuously cast ingots was investigated on various composition cast iron (eutectic Se = 0,8 - 1,0; ratio of silicon to carbon Si/C = 0,5 - 0,9). Results of the tests are generalized in the structural nomograph shown in the Figure 1. The difference of presented nomograph from analogical nomographs is that zone with interdendritic graphite is included and the critical values of solidification rates are fixed; when approaching to these values, graphite formation way becomes different. Investigation of the effect of ratio Si/C on cast iron microstructure showed that, when Si/C = 0,5 - 0,6 one form of the graphite transforms to another in the narrow solidification rate interval. In the cast irons with ratio Si/C = 0,7 - 0,9 interdendritic graphite forms up at higher solidification rates. Thus, for continuous casting the cast iron with higher silicon to carbon ratio should be used for two reasons: to decrease occurrence of hard spots in a cast iron and to decrease zone of interdendritic graphite. Besides, grey cast iron with higher silicon to carbon ratio and lower degree of eutectic is stronger and resistant to cracking.

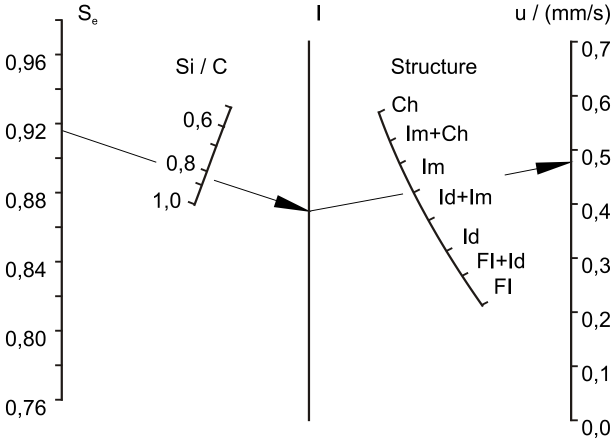

Figure 1. **Structural nomograph of the continuously cast iron: Se is eutectic; Si/C is silicon to carbon ratio; *u* is solidification rate; *I* - scale; *Ch* - chilled casting; *Im* - interme-diate; *Id* - cast iron with interdendritic graphite; *Fl* is cast iron with flaky graphite**

Slika 1. **Strukturni nomograf kontinuirano lijevanog željeza: Se - eutektik, Si/C - odnos sadržaja silicija i ugljika, *u* - brzina skrućivanja, *I* - skala, *Ch* - kokilni lijev, *Im* - međuprijelazno stanje, *Id* - lijevano željezo s međudendritnim grafitom, *Fl* - lijevano željezo s listićavim grafitom**

The effect of carbon equivalent (CE) on the tensile strength in the 50 × 50 mm cross-section billet is given in Figure 2. As this Figure shows, the tensile strength decrease significantly with an increase in CE, as a result of increase in ferrite content.

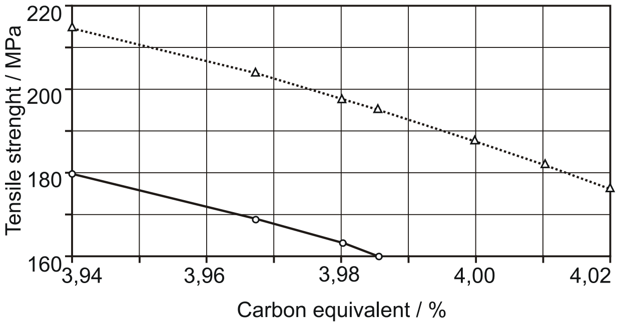

Figure 2. **Effect of carbon equivalent on the tensile strength of the 50 × 50 mm cross-section continuously cast billet**

Slika 2. **Utjecaj ekvivalenta ugljika na vlačnu čvrstoću kontinuirano lijevane gredice poprečnog presjeka 50 × 50 mm**

Well known pearlitization improving elements such like chrome, tin, manganese, and copper not only help to form up pearlitic structure, but also make it fine. Figure 3. shows the influence of manganese on the pearlite content in the continuously cast billet.

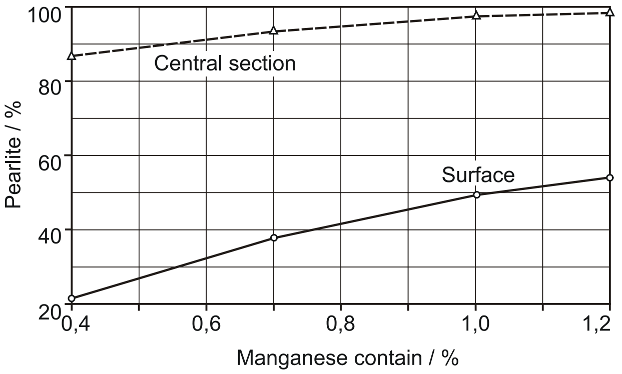

Figure 3. **Effect of manganese on the formation of pearlite formed in the matrix of 50 50 mm cross-section billet**

Slika 3. **Utjecaj sadržaja mangana na nastajanje perlita u matrici gredice poprečnog presjeka 50 × 50 mm**

Inoculation with manganese increases the hardness of billets, too. The hardness increases up to 180 - 207 HB in the central section of a casting (Figure 4.). The increase of hardness is explained by a sudden decrease of ferrite content in the structure. When Mn > 1,0 percent, the increase of hardness relates to pearlite, becoming more and more fine, and to the increase of tied carbon content. This is proved by the decrease of graphite content in the entire cross-section. White structure, appearing due to greater manganese content in castings, is avoided successfully by a graphitizing inoculation.

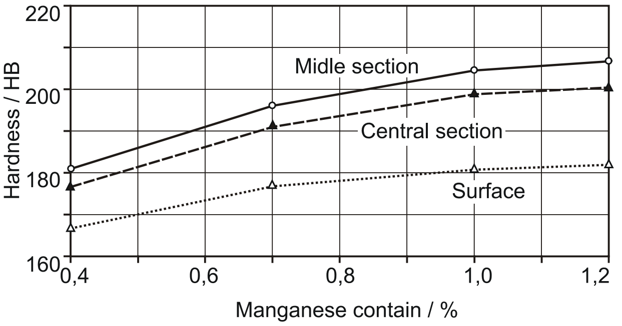

Figure 4. **The effect of the content of manganese on the hardness of the continuous casting 50 50 mm cross-section billet**

Slika 4. **Utjecaj sadržaja mangana na tvrdoću kontinuirano lijevane gredice poprečnog presjeka 50 × 50 mm**

Investigating the effect of inoculation with chromium on the microstructure in the central section of 50 × 50 mm cross-section billet, it was found that inoculation with chromium decreases ferrite content a little. When chromium content in a metal increases from 0,15 to 0,25 percent, pearlite content in the central section of a billet increases from 87 to 96 percent, and in some specimens even to 100 percent. Pearlite content in the surface layer of billets increased almost twice - from 22 to 40 percent (Figure 5.). Chromium had no effect on the size of graphite insertions.

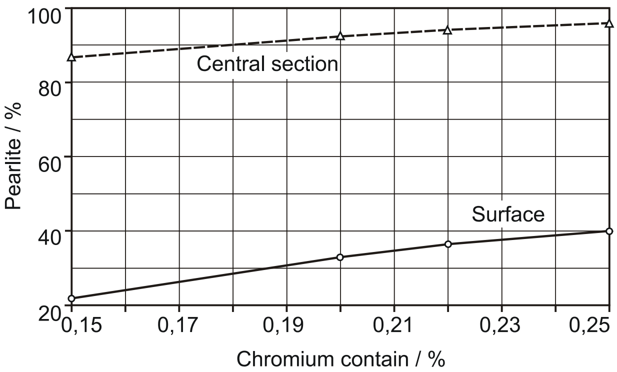

Figure 5. **The effect of chromium content in cast iron on pearlite content in the quadratic cross-section (50 × 50 mm) casting**

Slika 5. **Utjecaj sadržaja kroma u lijevanom željezu na sadržaj perlita odljevka poprečnog presjeka 50 × 50 mm**

After addition of copper to cast iron, the size of graphite inclusions increases, pearlite dispersion increases, and ferrite content in all zones of a casting decreases. Cast iron with 0,7 % Cu has 10 percent of ferrite in the surface layer, and not more than 3 percent in the central section. When the concentration of copper in cast iron is greater than 1 percent, ferrite disappears in the central section completely, and it does not exceed 3 percent in the surface layer. The hardness increases quickly (about 30 units) when Cu content is about 1 percent. Tensile strength changes correspondingly. The increase of the values of mechanical properties can be explained by the increase of pearlite content, as well by the appearing surplus phase, rich in Cu.

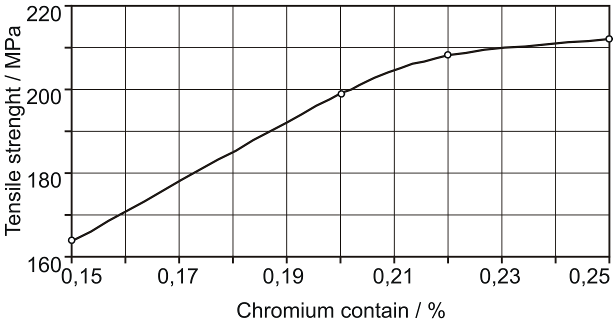

Figure 6. **The effect of chromium content in cast iron on tensile strength of the quadratic cross-section (50 × 50 mm) casting**

Slika 6. **Utjecaj sadržaja kroma u lijevanom željezu na vlačnu čvrstoću odljevka poprečnog presjeka 50 × 50 mm**

The effect of chromium content on the mechanical properties of continuously cast billets is given in Figures 6. and 7.

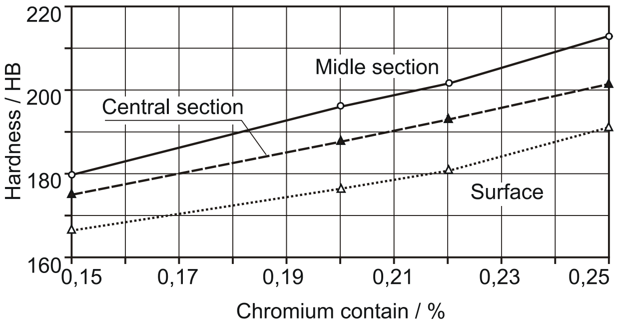

Figure 7. **The effect of chromium content in cast iron on hardness of the quadratic cross-section (50 × 50 mm) casting**

Slika 7. **Utjecaj sadržaja kroma u lijevanom željezu na tvrdoću odljevka poprečnog presjeka 50 × 50 mm**

Antimony helps to form pearlite in cast iron [5]. It is not expensive, and it is well absorbed by cast iron. Antimony stops the growth of graphite and austenite crystals, that's why crystallizing phases become more dispersed, and properties of a solidified casting become more even in the cross-section of the casting. Inoculation with antimony increases the hardness from 160 - 170 to 180 - 190 HB in the surface layer of a casting, and from 175 - 185 to 210 - 230 HB in the central section. When antimony content grows in cast iron, the hardness of a casting increases, more pearlite appear in cast iron but tensile strength increases only to a certain limit, which depends on chemical composition of cast iron and which equals approximately to 0,1 percent, and then it starts to decrease. When inoculation is made only with antimony, graphitization of cast iron decreases a little, therefore, it is better to apply a combined inoculation, i.e. antimony with a graphitizing one.

CONCLUSIONS

On the basis of presented experimental results and their discussion, the following conclusions can be drawn:

1. The zone of interdendritic graphite can be decreased with increasing silicon to carbon ratio and decreasing solidification rate.
2. Tensile strength and Brinell hardness of continuously cast ingots increased with increasing Mn, Cr, Cu, and Sb additions and decreasing carbon equivalent. However, Sb increased tensile strength only to a certain limit, which equals approximately to 0,1 percent, and then Sb started to decrease it.
3. The microstructural analyses showed that Mn, Cr, Cu, and Sb additions increased pearlite content. All these elements had stronger effect in the surface layers than in central sections. Antimony helped to unify the microstructure in the cross-section of the castings. On the other hand, pearlite content in the structure decreased with increasing carbon equivalent.

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