The effect of inoculants on hardness and machinability of grey cast iron with flak graphite

Vpliv cepljenja sive litine z lamelnim grafitom na trdoto in obdelovalnost

Marica Prijanovič Tonkovič[1], Vranjković Jovo[2], Mihoković Igor[2]

[1]Višja strokovna strojna šola, ŠC Novo mesto, Slovenia
[2]Livar, d. d., Ivančna Gorica, Slovenia

*Corresponding author. E-mail: marica.prijanovic-tonkovic@guest.arnes.si

Received: July 6, 2009 **Accepted:** September 3, 2009

Abstract: Grey cast iron with flak graphite precipitates carbon in the form of graphite or cementite during the solidification process. If the cementite appears in the microstructure in the form of ledeburit, the mechanical machining of castings becomes impaired. In this research paper we described the conditions that contribute to forming of ledeburitic cementite in thin wall castings casted by the process of automatic casting. We produced workpieces with the help of two inoculants differentiated by their content of barium, calcium and aluminium. During the test we observed the quality of inoculation by using chemical and metalographic research and stepped as well as wedge samples. We also studied the machinability. The results of these tests showed that the occurance of precipitation of cementite and machinability depends on the amount and on the type of added inoculants. Thus the difference in hardness in various wall thicknesses is smaller in the case of using inoculant which contained less barium and no aluminium.

Izvleček: Pri sivi litini z lamelastim grafitom se med strjevanjem izloča ogljik v obliki grafita ali cementita. Če se cementit pojavi v mikrostrukturi v obliki ledeburita, se poslabša mehanska obdelava ulitkov. V raziskovalni nalogi smo preiskovali pogoje, kdaj pride do tvorbe ledeburitnega cementita v tankostenskih ulitkih, ulitih po postopku avtomatskega litja. Izdelali smo preizkušance z uporabo

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dveh različnih cepiv, ki sta se razlikovali po vsebnosti barija, kalcija in aluminija. Med preizkusom smo spremljali kakovost cepljenja s kemičnimi in mikroskopskimi preiskavami ter s stopničastimi in klinastimi vzorci. Hkrati smo spremljali tudi obdelovalnost. Rezultati preiskav so pokazali, da je pojav izločenega cementita in s tem tudi obdelovalnost odvisna od količine in vrste dodanega cepiva. Tako je razlika v trdoti pri različnih debelinah stene manjša v primeru uporabe cepiva, ki je vsebovalo nižji odstotek barija in ni bilo legirano z aluminijem.

Key words: grey cast iron, inoculation, ledeburitic cementite, machinability

Ključne besede: siva litina, cepljenje, ledeburitni cementit, obdelovalnost

Introduction

Grey cast iron with flak graphite precipitates carbon in the form of cementite and graphite during the process of solidification. The form of precipitated carbon has an effect on mechanical properties of grey cast iron out of which the most important are tensile strength and hardness. If cementite is present in perlite, we talk about perlitic grey cast iron. It is undesirable for cementite to be precipitated in the »free« form. The occurance of free precipitated cementite (This is cementite into ledeburite.) increases the hardness to a great extent and cast iron with this kind of microstructure is hard to be machined.[1]

There are many factors[2] that influence precipitation of the ledeburitic cementite in the grey cast iron with flake graphite, such as input raw materials, chemical composition of the produced cast iron, furnaces for manufacturing the grey cast iron, the pouring temperature of casting, wall thickness, amount of inoculants,… The cooling speed is essential. Different speed in cooling can in spite of the same chemical composition of the cast iron cause differently formed graphite and the microstructure of base.[3] If the cooling is carried out too fast or if the inoculation is carried out incorrectly, ledeburitic cementite can occur. The result is white solidification – solidification into ledeburite. Thin walled castings[4] are very susceptible to precipitation of cementite from ledeburite. Solidification into ledeburite can be avoided if the grey cast iron is added different modificators known as inoculants. These are alloys of FeSi75Al 0.3, CaSi, FeSiMn… We know different types of inoculants,[2] out of which mostly used nowadays are complex inoculants that besides silicon also contain barium, zirconium, strontium and rare earths.[5, 6] The type of inoculants have an effect on formation of nucleation and dendrites of austenite. The increased number of austenitic dendrites causes a bigger number of eutectic cells. Thus a primary solidified austenite has an effect on nucleation.[7] Manganese and sulphur also have an effect on nucleation because it has been proven that graphite can start growing on particles of MnS.[8] As shown above, the right amount of crystal nucleus can be achieved with the right chemical composition of the base melt, the right choice of inoculants and optimal addition of inoculants. Thus we prevent the occurance of hard spots and excesive hardness especially in thin walled castings because of reduced undercooling during the solidification process. This ensures that the graphites flakes grow evenly in the metal base. The precipitated graphite is in this case of type A. With increased undercooling the microstructure shows undesired forms of graphite and it can lead to precipitation of ledeburitic cementite.

In this paper we described the results of the research of castings that were claimed back because there was ledeburitic cementite in the microstructure. Although there was not much of it, these castings could not be turned on the automatic CNC machine. Our tests were started by first searching for reasons of this fault and how to react in the production process to ensure that the produced castings would be of good quality. The type of inoculation[9] and type of inoculants have a major effect on precipitation of cementite. This means that it was necessary to determine which inoculant is the most appropriate for the production in our foundry and determine the minimum amount of inoculant that has to be added to the casting to ensure that the microstructure will contain no ledeburitic cementite.

Experimental work

Because of claiming back the castings due to not good machinability we analyzed these pieces. Chemical analysis did not show any deviations from the standard requirements of customers. But it was a different case with hardness and microstructure. It showed that on the edge ledeburitic cementite was occured.

To improve the manufacturing process of the claimed back castings, we produced specimens and observed the occurance of cementite. Because the distance from the casting system (place of casting) also has an effect on precipitation of cementite from ledeburite, we first checked the occurance of cementite on different spots of casting and then also on the different castings of the match plate. We realized that solidification into ledeburite occured on all the castings regardless of where they were positioned on the match plate.

We prepared different specimens which all had the same starting chemical composition and we only varied the quantity and type of inoculant. Table 1 shows the chemical composition of non inoculated cast iron.

Table 2 shows the number of produced specimens and type as well as quantity of added inoculants.

Table 3 shows chemical composition of the inoculant used.

We made four different specimens for the test. Table 1 shows the chemical composition of the base cast iron. The temperature of casting the base cast iron was 1421 °C. We casted specimen 1 with the base cast iron. The time of casting these samples was from 12 s to 13 s. To produce specimen 2 we added 0.06 % of inoculant from producer 1 to the base cast iron. Specimen 3 contained 0.09 % of the inoculant from the

Table 1. Chemical composition of the non inoculated cast iron

Alloy type	Chemical composition (mass fraction, *w*/%)									
	C	Si	Mn	S	Cr	P	Cu	Sn	Ni	Mo
Base grey cast iron	3.48	1.99	0.53	0.06	0.12	0.10	0.4	0.01	0.09	0.02

Table 2. Specimens type

Number	Specimen type	Quantity of the inoculant
1	Specimen 1	Without inoculant (base cast iron), *w*/%
2	Specimen 2	0.06 % of inoculant − producer 1
3	Specimen 3	0,09 % of inoculant − producer 1
4	Specimen 4	0.09 % of inoculant − producer 2

Table 3. Chemical composition of the inoculants

Type of inoculant	Chemical composition (*w*/%)			
	Si	Al	Ca	Ba
Producer 1	60–65		2.2–2.7	2–2.5
Producer 2	69.4	1.82	1.7	6.09

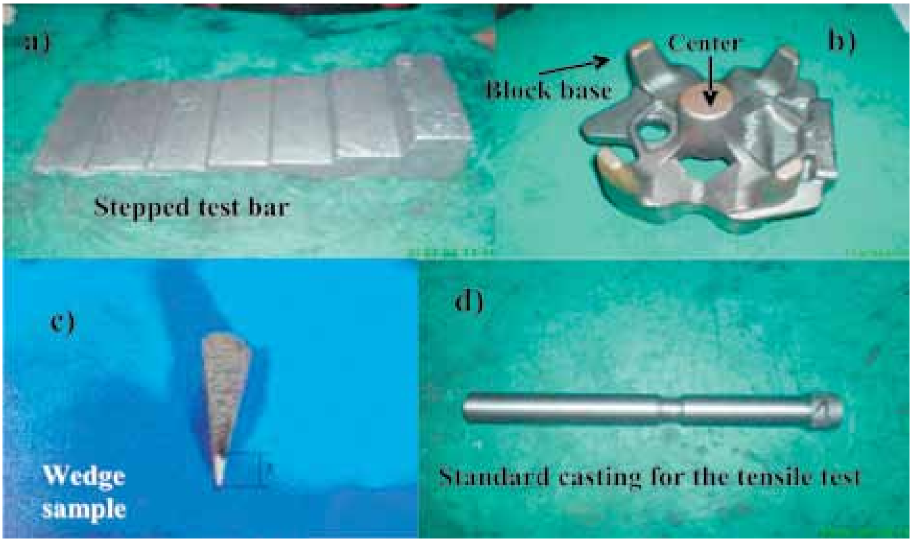

Figure 1. Presentation of samples for testing the quality of grey cast iron

same producer, while specimen 4 contained 0.09 % of the inoculant from producer 2. This means that specimen 4 was different from specimen 3 because we changed the producer of the inoculant while the added quantity of the inoculant stayed the same. We added the inoculant into the form.

We studied the quality of the inoculation by using:

- stepped test bar (figure 1 a),
- wedge samples (figure 1 c),
- standard specimens (trial bar) for the tensile test (figure 1 d) and
- castings (compressor block, figure 1 b).

Results and discussion

Hardness of stepped test bars are in Table 4. Figure 2 shows that hardness increases with reducing the wall thickness. Hardness measurements also show that optimally inoculated sample has the smallest difference in hardness between 50.8 mm and 3.2 mm thick wall in specimen 3 and it accounts for only $HB = 44$.

Hardnesses of castings are in table 5. The measurements showed that the hardness is lower in the center of the casting than on the base. The difference in hardness is large, if the casting is not well inoculated. This is confirmed by measurements of hardness in specimens 1 and 2.

Table 4. Hardness of the stepped test bar

Step thickness (mm)	Hardness (*HB*)			
	Specimen 1	Specimen 2	Specimen 3	Specimen 4
3,2	297	278	229	231
6,3	241	229	222	222
12,7	224	222	219	217
25,4	211	209	209	211
38,1	195	197	193	195
50,8	189	189	185	187

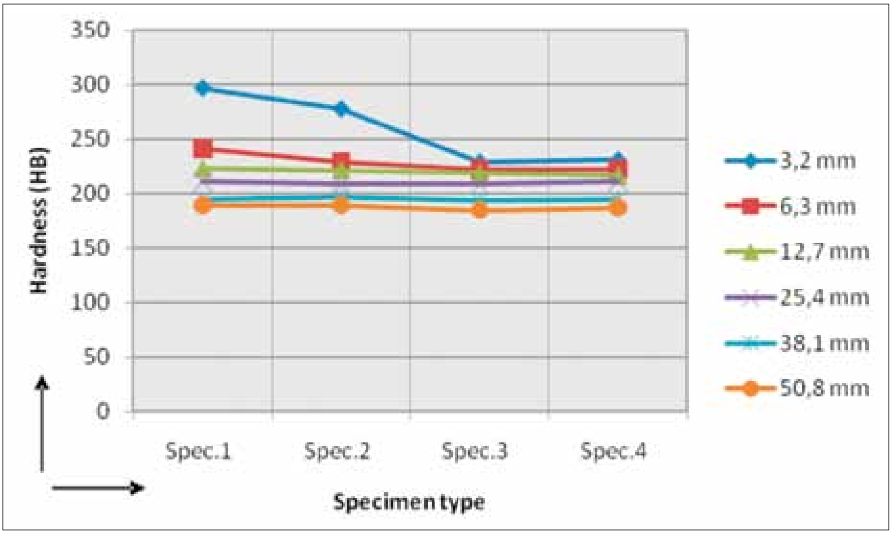

Figure 2. The influence of the type and quantity of the inoculant on hardness at different wall thickness of the castings

As visible from table 5 and figure 3, the quality of inoculant also plays a part on the difference in hardness between the center of the castings and its base because specimens 3 and 4 have the same inoculants but of different producers. This can also be seen in qualitative profile of hardnesses where the smallest difference between the hardness of the center and of the base is *HB* =17 which means that the quality of the inoculant in specimen 3 is the best.

Table 5. Hardness on the castings

Specimen type	Hardness of castings (*HB*)		Difference (*HB*)
	Center	Base	
Specimen 1	215	301	86
Specimen 2	213	285	72
Specimen 3	209	226	17
Specimen 4	207	229	22

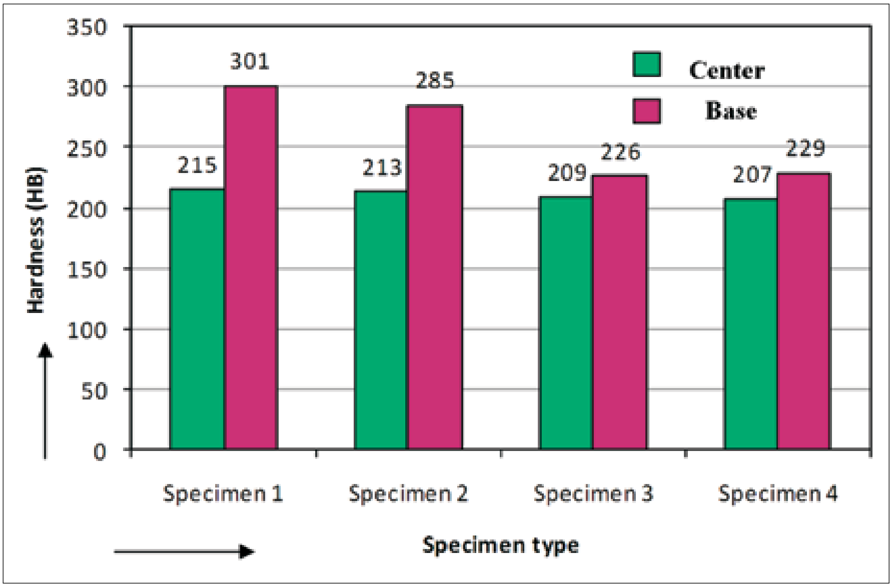

Figure 3. Hardnesses on the casting

Figure 4 shows the height of white solidification, breaking of the step at the thinnest wall spot of the step bar sample and microstructure at the critical part of the casting, i.e. on the base of the casting. It can be seen that in the microstructure of specimen 3 there is the most roughly formed perlite which means that the hardness is the lowest.

Figure 5 shows the dependence of hardness on wall thickness of the step bar sample and specimen 3. The diagram only contains the thickness of the castings for the center and the base. Step bar sample and specimen 3 were cast with the same molten metal. The picture shows that in case the casting is properly inoculated, the hardness of the

Height of solidification into ledeburite	Breaking of the step bar sample at the thickness of 3.2 mm	Microstructure of the base of the compressor

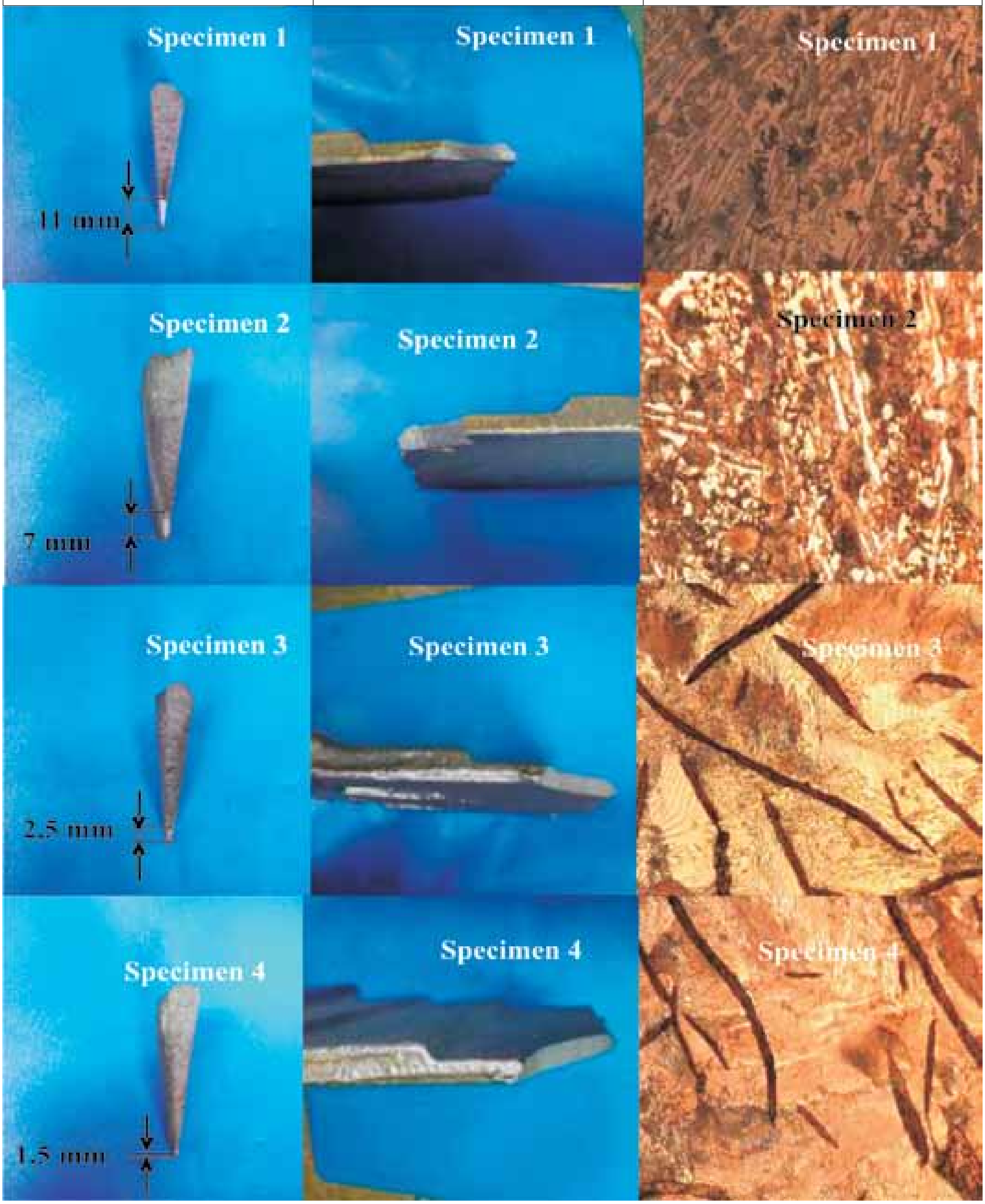

Figure 4. The influence of the type and quantity of the inoculant on the height of solidification into ledeburite, hardness and microstructure of castings (magnification 500-times)

casting and the step bar sample at the same wall thickness, don't differ. It can even be calculated by equation 1.

$$HB_{\text{of steps}} = f(\text{wall thickness}) = -0.910 \cdot f + 230.2 = HB_{\text{casting}} \qquad (1)$$

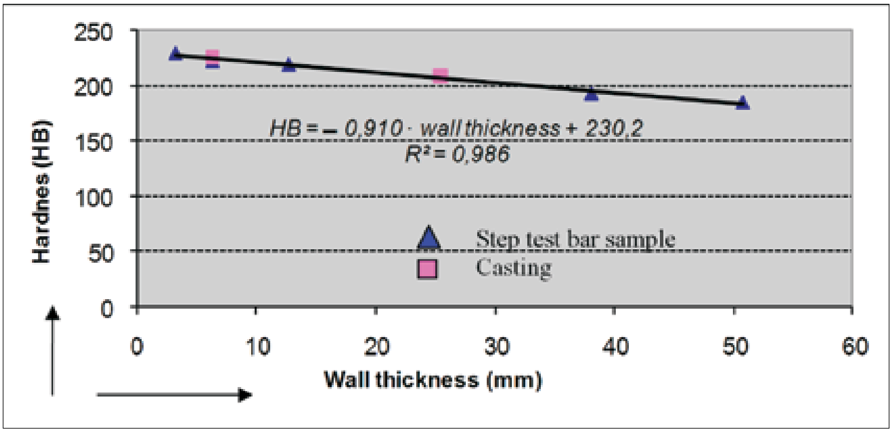

Figure 5. Interdependence of the hardness and the wall thickness

Conclusions

Because of relatively high prices of inoculants in the production process it is essential to determine the minimum quantity of the added inoculant needed for the casting to solidify without the ledeburite. We studied the effect of inoculation of the complex inoculants based on barium produced by two different suppliers. The research showed that the quantity of the added inoculant has an effect on the formation of ledeburitic cementite which impairs the mechanical machinability. Inoculants help to balance the hardness on the castings. The measurements showed that the difference in hardness of the castings at different wall thicknesses is smaller in cases, where inoculants with less barium were used and they also were alloyed with calcium and also contained no aluminium.

Summary

This paper describes the influence of ledeburitic cementite on the castings of unacceptable quality. Occurance of ledeburitic cementite is undesired because such castings cannot be machined with removing material. Thin walled castings are especially sensitive to precipitation of cementite. The observed casting had the wall thickness of 6 mm to 7 mm on the base and 25 mm in the center. This difference is big

enough to cause precipitation of ledeburitic cementite at unproperly carried out inoculation. Correct solidification in walls that thick can be regulated in the production process with a suitable type and quantity of the inoculant.

To prevent the problems in the production process, we made grey cast iron with flak graphite. We varied the quantity and type of inoculant during the test. After the test we observed solidification by studying chemical and microstructural composition of cast iron as well as step bar and wedge samples. We cast this casting with the same type of cast iron that was used for step bar and wedge samples. We measured the hardness on the test samples by Brinell. The hardness analysis shows that the hardness in step bar sample at the same thickness are comparable with the hardness of the casting. The hardness of the casting can be determined with the help of step bar sample by this equation:

$$HB_{\text{of steps}} = f\,(\text{wall thickness}) = -0.910 \cdot f + 230.2 = HB_{\text{casting}}$$

Hardness measurements and microscopic test showed that the most suitable inoculant for the chosen casting was the one that besided iron and sillicon contains also 2 % to 2.5 % of barium and 2 % to 2.7 % of calcium.

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