Microstructural stability of gray iron thin section castings for enameling

Mikrostrukturna stabilnost sive litine z lamelnim grafitom v tankih stenah za emajliranje

Snježana Zeljko[1], Zoran Glavaš[2,*], Katarina Terzić[2], Faruk Unkić[2]

[1]Plamen International, d. o. o., Njemačka ulica 36, p. p. 209, 34000, Pozega, Croatia
[2]University of Zagreb, Faculty of Metallurgy, Aleja narodnih heroja 3, 44103 Sisak, Croatia

*Corresponding author. E-mail: glavaszo@simet.hr

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Abstract: The influences of chromium on the stabilization of pearlite in the microstructure of gray iron thin section castings and distortion of castings during enameling were analyzed in this paper. Chromium content varied from the mass fractions 0.08 % to 0.37 %. It is found that the distortion of castings with or without the addition of chromium in the as-cast condition was in the acceptable range. The microstructure of castings in as-cast condition was consisted of pearlitic metal matrix and graphite flakes dispersed throughout. The results showed that the distortion of castings containing the mass fractions 0.08 % and 0.17 % of chromium was outside the acceptable range after enameling, due to decomposition of pearlite and transformation to austenite during enameling. After enameling, distortion of castings containing 0.37 % chromium was acceptable. Decomposition of pearlite was considerably lower than in castings containing 0.08 % and 0.17 % chromium. The obtained results confirmed the beneficial effect of chromium on the stabilization of iron carbide and prevention of decomposition of pearlite at elevated temperatures.

Izvleček: V delu je narejena analiza vpliva kroma na stabilnost perlita v mikrostrukturi sive litine z lamelnim grafitom v tankih stenah ter deformacije ulitkov med procesom emajliranja. Masni delež kroma se spreminja med 0,08 % in 0,37 %. Ugotovljeno je bilo, da je deformacija ulitkov z dodatka kroma ali brez njega v litem stanju v

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zadovoljivih mejah. Mikrostruktura ulitkov v litem stanju sestoji iz perlitne matrice in grafitnih lamel v njej. Rezultati analiz kažejo, da je deformacija ulitkov, ki vsebujejo med 0,08 % in 0,17 % kroma, zunaj dovoljenega območja po izvedenem emajliranju. Vzrok za to je razpad perlita in transformacija avstenita med emajliranjem. Po izvedenem emajliranju je za ulitke, ki vsebujejo masni delež Cr 0,37 %, ugotovljeno, da je deformacija v sprejemljivih mejah. Razpad perlita je značilno manjši v tem primeru kot v litinah, ki imajo masni delež Cr 0,08 in 0,17 %. Dobljeni rezultati potrjujejo ugoden učinek kroma na stabilizacijo železovih karbidov in preprečujejo razpad perlita pri delovnih temperaturah.

Key words: gray iron, microstructure, enameling
Ključne besede: siva litina z lamelnim grafitom, mikrostruktura, emajliranje

INTRODUCTION

Gray iron refers to a broad class of ferrous casting alloys normally characterized by a microstructure of flake graphite in a ferrous metal matrix which is usually a fully pearlitic.[1, 2] They are relatively inexpensive and easy to produce. They have high thermal conductivity and damping capacity, low modulus of elasticity and an ability to withstand thermal shock.[3] This make them suitable for castings subjected to local or repeated thermal stressing, such as components of ovens and stoves.[3]

The components of ovens and stoves are in many cases enameled in order to improve corrosion resistance, thermal stability, appearance and many other features.[4] Enamels are inorganic vitreous coatings applied to products or parts made of cast iron to improve appearance and to protect the metal surface. They may be applied to the surface of components by either the wet process or the dry process. After that, they are fused to the casting surface at temperatures 780–800 °C during the firing process.[4]

During enameling, distortion of castings may occur due to high firing temperatures.[4] Distortion of castings results from low metal strength at the firing temperature, thermal stresses due to non-uniform heating and cooling, decomposition of pearlite and transformation to austenite.[4] Changes in design of the components and firing practice alleviate the first two causes, and properly alloying minimizes decomposition of pearlite and transformation to austenite. Moreover, dimensional stability of gray iron castings at elevated temperatures is affected by factors such as growth, scaling, and creep rate.[5–9] To prevent these processes, alloying elements must be added to stabilize pearlite.[5–10]

The objective of this paper was to determine the influence of various additions of chromium on the stabilization of pearlite and distortion of castings during enameling.

Materials and methods

The gray iron melts were produced in two mains frequency coreless induction furnaces from a charges consisting of pig iron, steel scrap, gray iron returns, ferrophosphorus, silicon carbide and recarburizer. To obtain desired chromium content in the melts, granulated ferrochromium containing the mass fraction 65,0 % of chromium was added. During charging, heating and melting the induction furnaces followed the same power-time program as a means to keep the thermal history of the melts as controlled as possible in the "furnace" phase.

Gray iron melts from induction furnaces were tapped and then poured at 1400–1420 °C into vertically-parted green sand molds produced in vertically parted molding machine. The dimensions of the molds were: 800 mm × 1000 mm × 250 mm. Pouring was performed by automatic pouring system (pressurized pouring furnace). Late (stream) inoculation was performed with 0.1 % of calcium/aluminum/strontium containing ferrosilicon. Poured castings were used as components of stoves.

After shakeout and blasting, castings were inspected for defects and distor-

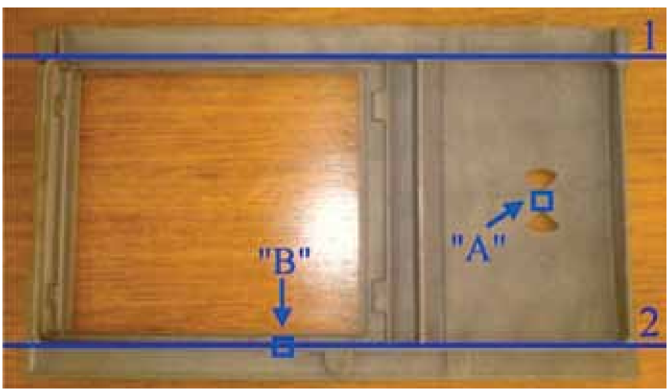

Figure 1. Casting after shakeout and blasting. Distortion was measured along the marked lines (1 and 2). Samples for metallographic examinations were cut from areas marked with the letters "A" and "B"

tion. Distortion, i.e. concavity of castings was measured along the ribs 1 and 2 according to figure 1. Maximum acceptable distortion was 1.0 mm.

Enamel was applied to both sides of the castings by wet process (spraying). Fusing of the enamel coating to the castings surface was done in a continuous furnace. Coated castings were fired at 780 °C. Firing time was 10 min. After enameling, distortion of the enameled castings was measured on the previously described manner. The maximum allowable distortion of the castings after enameling was 1.0 mm.

Hardness of the castings before and after enameling was measured by Brinell tester. Metallographic examinations of the castings in as-cast condition and enameled castings were performed by a light metallographic microscope with a digital camera and the image analysis system. Samples were cut from two places as shown in Figure 1: between openings ("A" sample) and from the rib ("B" sample), due to different section thickness (4.0 mm and 6.0 mm). Kinetics of phase transformations in the castings containing 0.08 % and 0.37 % chromium was analyzed by differential scanning calorimetry. The conditions were the same as in the enameling process. Samples were heated at 780 °C and then held at that temperature for 10 min. Heating rate was 40 K/min. The cooling rate after holding at 780 °C was 30 K/min.

RESULTS AND DISCUSSION

The chemical compositions of examined gray iron heats are given in table 1.

Table 1. Chemical composition of examined gray iron heats in mass fractions, *w*/%

Gray iron heat	Chemical composition, *w*/%							
	C	Si	Mn	P	S	Cr	Cu	CE
1	3.55	2.44	0.43	0.370	0.064	0.08	0.09	4.49
2	3.56	2.54	0.44	0.360	0.066	0.17	0.10	4.53
3	3.55	2.47	0.42	0.370	0.071	0.37	0.09	4.50

Table 2. Distortion of castings before and after the enameling

Gray iron heat	The number of castings	Distortion of castings. mm			
		Along the rib 1 (see figure 1)		Along the rib 2 (see figure 1)	
		Before enameling	After enameling	Before enameling	After enameling
1	20	0.15–0.25	1.70–1.90	0–0.20	1.85–1.95
2	50	0.20–0.25	1.20–1.30	0.25	1.20–1.30
3	40	0.10–0.20	0.35–0.50	0.35–0.50	0.30–0.50

With a carbon content in the gray iron melts in the range from 3.55 % to 3.56 %, silicon content in the range from 2.44 % to 2.54 % and a phosphorus content in the range from 0.36 % to 0.37 % carbon equivalents in the range from 4,49 to 4,53 were achieved. This corresponds to slightly hypereutectic compositions. Total carbon and silicon contents were in the target range. If both are low, the iron tends to be brittle and to blister during enameling. If both are high, the iron is soft and warps easily when reheated for enameling. Phosphorus was added intentionally to increase the fluidity of the gray iron melts. Within this range (0.36 % to 0.37 %), phosphorus has a negligible effect on the strength of the gray iron castings at enameling firing temperatures. However, these contents of phosphorus may result in the formation of phosphide eutectic (steadite). The sulfur content was balanced with manganese to promote the formation of manganese sulfides. They were distributed through the structure and acted as nuclei for eutectic graphite. Chromium was added intentionally in gray iron melts number 2 and 3 to stabilize pearlite in the microstructure of castings. Copper promotes pearlite formation, but its content was low in all melts.

The results of measuring distortion (concavity) of castings before and after enameling are given in table 2.

It can be observed from table 2 that in all cases distortion of castings before enameling was in the acceptable range. After enameling distortion of casting containing 0.08 % and 0.17 % chromium was exceeded the maximum allowed value, while the distortion of castings containing 0.37 % chromium was acceptable.

The results of metallographic examinations show that the chromium has pronounced effects on microstructural stability of gray iron castings at firing temperatures (Figures 2 to 4).

It can be observed from figures 2 to 4 that all castings in as-cast condition were fully pearlitic. Types B, C and D graphite flakes were found in thinner "A" samples. In thicker "B" samples, types B and C graphite flakes were present. A large volume fraction of coarse type C graphite flakes was obtained due to hypereutectic compositions. This type of graphite flakes is desirable in applications requiring a high degree heat transfer and high resistance to thermal shock, such as components of stoves. Types B and D graphite flakes are undercooled forms which form when solidification occurs at a large undercooling. Undercooling was occurred due to inadequate nucleation of graphite for a given high cooling rates. The increase of the undercooling during the solidification results in increasing of volume fraction of type D flake

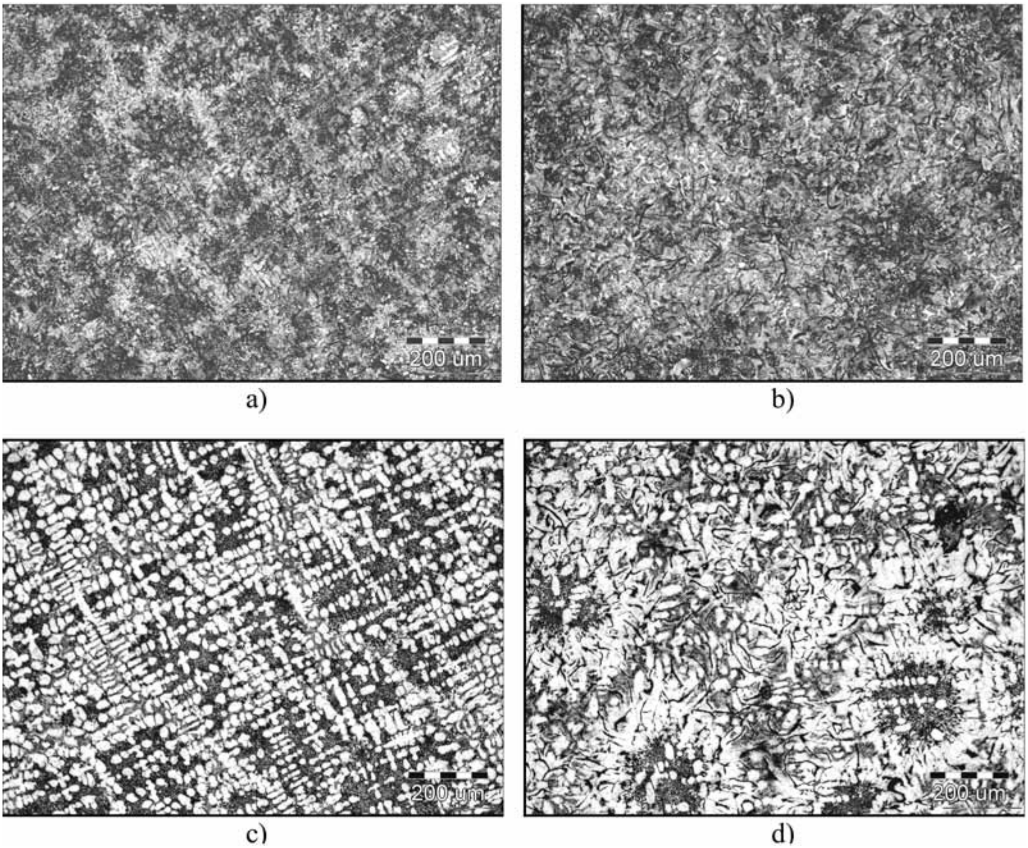

Figure 2. Optical micrographs of the microstructure of gray iron casting containing 0.08 % chromium: a) "A" sample before enameling (as-cast condition), b) "B" sample before enameling (as-cast condition), c) "A" sample after enameling, d) "B" sample after enameling

graphite. High phosphorus contents were resulted in the formation of another microstructural constituent, steadite. Due to the high cooling rates and chromium addition, a small amount of carbides was also found (especially in the microstructure of castings containing 0.37 % chromium).

The results of examinations show that enameling was altered the metal matrix, but no effect on size and shape of graphite achieved during solidification (figures 2 to 4). The pearlite content in the metal matrix decreases after enameling. However, decomposition of the pearlite to ferrite and graphite and transformation to austenite in microstructure of castings containing 0.37 % chromium was considerably lower than in castings containing 0.08 % and 0.17 % chromium. Due to

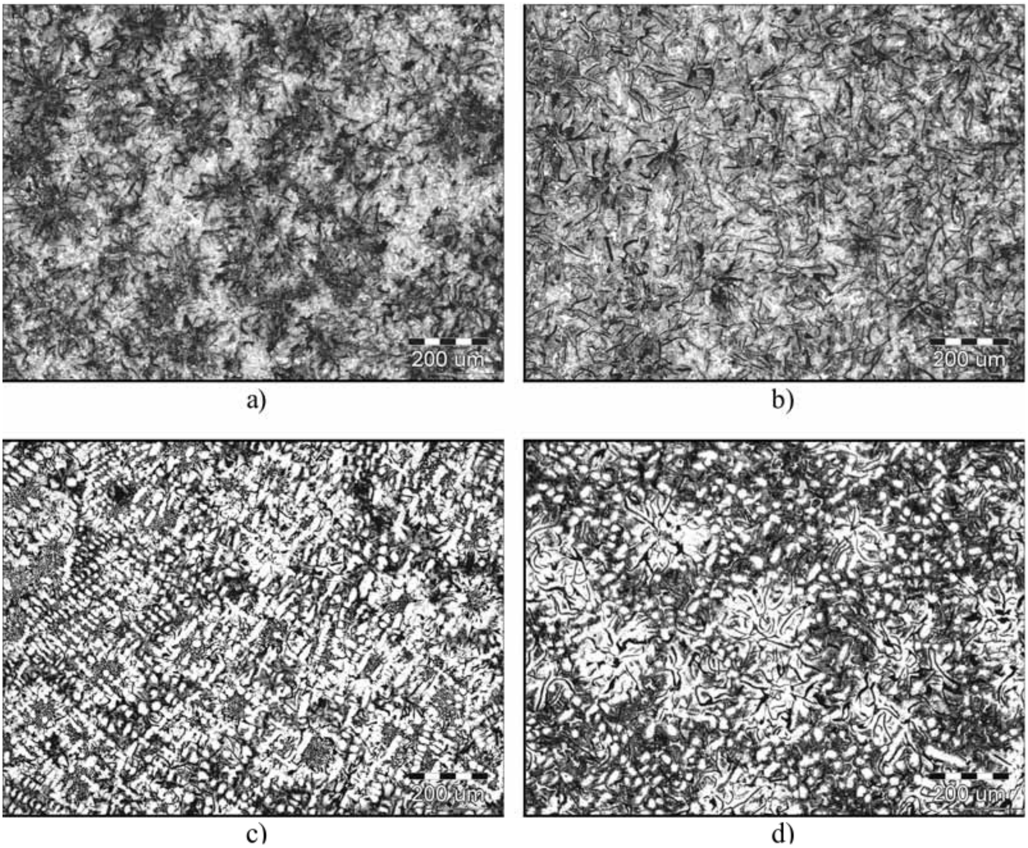

Figure 3. Optical micrographs of the microstructure of gray iron casting containing 0.17 % chromium: a) “A” sample before enameling (as-cast condition), b) “B” sample before enameling (as-cast condition), c) “A” sample after enameling, d) “B” sample after enameling

that, distortion of castings containing 0.37 % after enameling was acceptable. It is obviously that chromium stabilizes iron carbide and therefore prevents the breakdown of pearlite at the firing temperature. This improves the dimensional stability of gray iron castings during enameling.

Although the size and type of the graphite flakes was unaffected by firing process, the size and type had a marked influence on the carbon kinetics during firing process. In castings with a high volume fraction of fine type D graphite flakes, the carbon diffusion paths were shorter, which facilitates the decomposition of pearlite. If pearlite was not stabilized, shorter carbon diffusion paths resulted in higher ferrite volume fraction in the metal matrix after enameling.

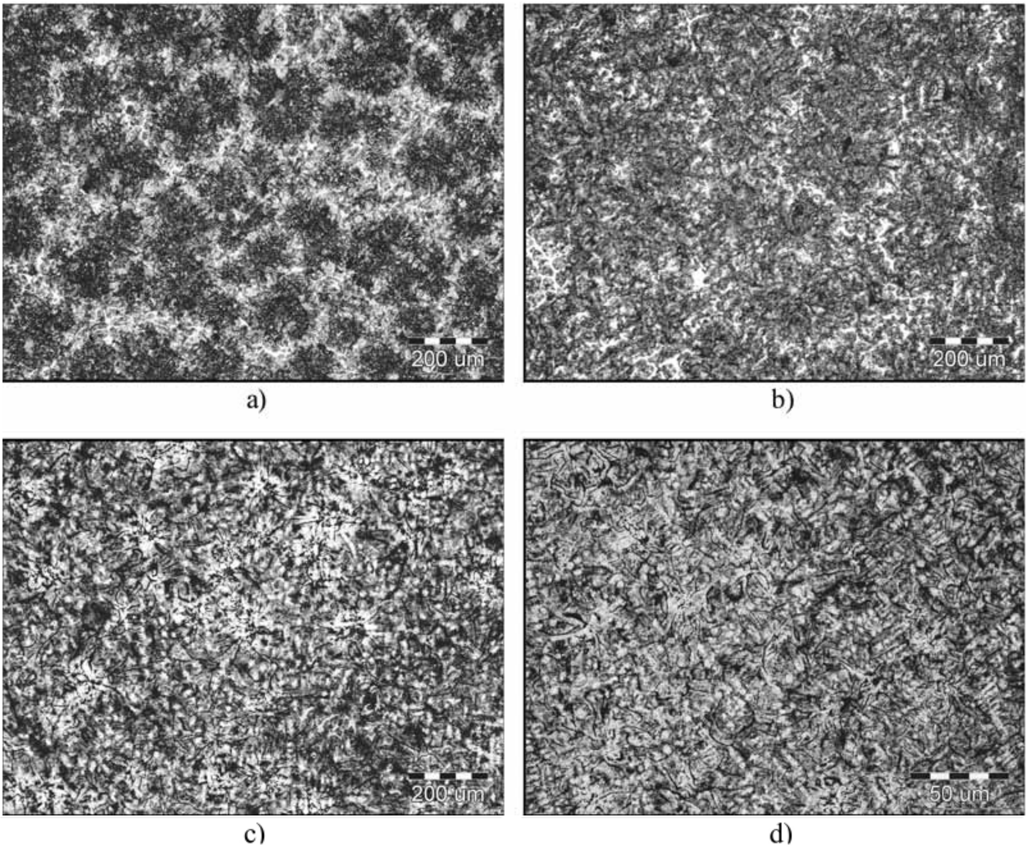

Figure 4. Optical micrographs of the microstructure of gray iron casting containing 0.37 % chromium: a) "A" sample before enameling (as-cast condition), b) "B" sample before enameling (as-cast condition), c) "A" sample after enameling, d) "B" sample after enameling

DSC analysis (figure 5) confirmed the results of metallographic examinations. Heating curve of the sample containing 0.08 % chromium shows that a significant decomposition of pearlite occurred already at ≈350 °C. Decomposition of pearlite progressed very intensively with a further increase in temperature. The maximum was reached at ≈620 °C. Decomposition of the pearlite to ferrite and graphite occurred due to instability at elevated temperatures. Growth, residual stresses and dimensional instability of the casting are the results of the breakdown of the pearlite and transformation to austenite, which occurred at ≈742 °C.

Heating curve of the sample containing 0.37 % chromium shows that the decomposition of pearlite to ferrite and graphite and transformation to austenite was considerably lower than in sample containing 0.08 % chromium. Very small decomposition of pearlite occurred up to 550 °C. Small increase in pearlite decomposition occurred in the range 550–650 °C. This confirms beneficial effect of chromium on the stabilization of iron carbide and the prevention of breakdown of pearlite during enameling. Because of that growth and residual stresses are reduced and the dimensional stability is increased.

The obtained results show that the hardness of all castings decreases after enameling, due to the decomposition of pearlite (table 3). However, castings containing 0.37 % chromium had lower decrease in hardness after enameling than castings containing 0.08 % and 0.17 % chromium, due to much more stable pearlite. The hardness of all castings in as-cast condition and after enameling did not exceed the maximum allowable 230 HB.

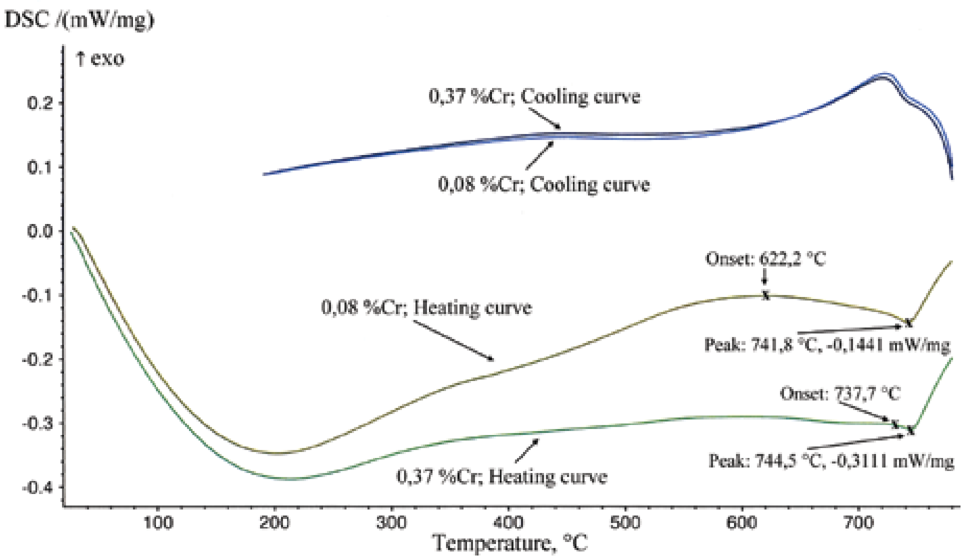

Figure 5. Simultaneous thermal analysis of gray iron samples containing 0.08 % and 0.37 % chromium by DSC method

Table 3. Hardness of castings before and after enameling

Gray iron heat	Hardness of castings, HB			
	Between openings (“A” sample, see figure 1)		On the rib (“B” sample, see figure 1)	
	Before enameling	After enameling	Before enameling	After enameling
1	206	144	214	149
2	216	163	217	166
3	217	183	229	186

CONCLUSIONS

The obtained results indicated that the chemical composition has a significant effect on the microstructure of gray iron castings after enameling. During enameling, due to high firing temperatures, decomposition of pearlite and transformation to austenite occurs if pearlite is not stabilized. Phase transformations may result in distortion and dimensional changes of castings. To prevent these processes, alloying elements must be added to stabilize pearlite.

The results of this examinations show that the chromium, when added in proper amount, stabilizes the iron carbide and therefore prevents the breakdown of pearlite during enameling process. Chromium is very effective in stabilization of pearlite, but the use of higher chromium content is limited. It is a strong chill and carbide former, and therefore, high chromium additions can be detrimental to machinability. It is obvious that the chromium content in gray iron casting for enamelling is an important process parameter and must be adapted depending on the required metal matrix structure and section thickness of castings.

Highly branched Type D graphite flakes reduce carbon diffusion distances, which facilitates the decomposition of pearlite. High cooling rates (thin sections) and low nucleation state of melt favors the formation of Type D graphite flakes and carbides. Due to that, melts must be prepared with suitable charge materials (such as pig iron) and properly inoculated.

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