

Microstructure and mechanical properties of Fe–Cr–C–Nb white cast irons

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ABSTRACT

The microstructure and properties of 17 wt.% Cr–2.9 wt.% C cast irons with up to 3.17 wt.% Nb additions, in both as-cast and heat treated state, have been studied. Also the influence of titanium and cerium on the structure and properties of 17 wt.% Cr–2.9 wt.% C–2 wt.% Nb alloys are examined. NbC carbides present in the structure of tested alloys, due to their characteristic morphology, show higher wear resistance and toughness than M_7C_3 carbides. Increasing amount of this type of carbides, caused by the increase of niobium in Fe–Cr–C–Nb alloys, contributes to the improvement of wear resistance and dynamic fracture toughness. The alloy containing approximately 3% Nb gives the best compromise between wear resistance and fracture toughness. This alloy shows about 30% greater dynamic fracture toughness and about 30% greater abrasion wear resistance than the basic Fe–Cr–C alloy. Titanium and cerium affect the crystallisation process of Fe–Cr–C–Nb alloys and the transformation of austenite during the cooling after solidification. The addition of 0.26% Ti results in a substantial change in the morphology and distribution of NbC carbides. The secondary carbides which precipitate in the matrix regions of the tested 17 wt.% Cr–2.9 wt.% C–2 wt.% Nb white iron containing titanium has an impact on the abrasion behaviour and fracture toughness. The alloy containing 0.28% Ti and 0.19% Ce has pearlite–austenitic matrix microstructure in as-cast condition. The pearlite, due to its high microhardness, improves the wear resistance under low-stress abrasion conditions, but drastically reduces the toughness of tested alloy.

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1. Introduction

High chromium white cast irons are an important class of wear resistance materials currently used in a variety of applications where stability in an aggressive environment is a principal requirement, including the mining and mineral processing, cement production, slurry pumping and pulp and paper manufacturing industries.

In the case of high chromium white cast irons, important microstructural parameters for wear resistance include the volume fraction, hardness, orientation and morphology of carbides [1–4] and the type of matrix [1,2,5–7]. These factors also influence the hardness and fracture toughness of the material [1,6].

Extensive industrial applications of high-chromium white cast irons have attracted researchers to try different carbide-forming elements such as tungsten [8,9], vanadium [8,10–13], niobium [8,10,14–20], titanium [10,16,21–25] and boron [26] to further improve this type of material. The addition of an alloying element which confines carbon in the form of a carbide different from cementite, with a greater hardness and more favorable morphology, and which reduces the carbon content of the matrix,

allows the simultaneous improvement of both toughness and abrasion resistance. By controlling the morphology of the carbide phase and the matrix structure in these materials, significant improvement of toughness and service life may be achieved.

The introduction of niobium to these alloys resulted in the preferential formation of NbC which is appreciably harder than other carbides present and which forms efficiently since niobium is partitioned fully to these phases [14–16,19]. Subsequently, niobium improve the hardness and wear resistance [10,17,18]. However, there is little information [18] available concerning the influence of niobium on the fracture toughness or how much of this element should be combined with high chromium white iron to obtain optimal fracture toughness and abrasive wear resistance.

The solubility of titanium to molten cast iron is so small that fine titanium carbides precipitate at higher temperature even in the low titanium-bearing melts, and they likely affect the following solidification [21,24].

Titanium and niobium can refine the microstructure of high chromium white cast irons [10,23,25].

Cerium affects the microstructural characteristics [27,28] and mechanical properties [29,30] of hypoeutectic high chromium white irons. The optimum content of cerium in Fe–Cr–C alloys is in the range 0.13–0.26% [30].

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In this study the influence of niobium on the microstructural characteristics and properties of hypoeutectic high chromium white iron containing 17 wt.% Cr was examined in both as-cast and heat-treated conditions. Also, the effect of titanium and cerium on the properties relevant to the service performance of Fe–Cr–C–Nb alloys, namely the abrasion resistance and fracture toughness, was examined.

2. Materials and methods

The chemical composition of tested alloys is listed in Table 1. Induction furnace was used for melting, and 200 mm long and 30 mm in diameter bars were cast in sand moulds. Samples for structural analysis, hardness, wear, and fracture toughness tests were cut from the cast bars.

Samples were heat treated in an electric furnace at 950 °C for 1 h and then were air cooled to room temperature.

The microstructure was examined using conventional optical microscopy (OM) and transmission electron microscopy (TEM). Samples for optical microscope examination were prepared using standard metallographic techniques (etched with picric acid solution (1 g) in methanol (100 ml) by adding 5 ml of hydrochloric acid). The volume fraction of the carbides present in the structure was determined using an image analyzer. Discs for TEM examinations were prepared by using a twinjet electropolisher. These samples were examined at 200 kV in a JEOL-2000FX transmission electron microscope. The chemical composition of the matrix was determined using energy dispersive X-ray spectroscopy (EDS).

The hardness of tested Fe–Cr–C–Nb alloys was examined by the Vickers method at 294 N load.

Abrasive wear resistance was evaluated according to the ASTM: G65 standard. The volume loss, ΔV , was then calculated by dividing mass loss by the alloy density. The reciprocal value of the volume loss, ΔV , due to wear is called wear resistance, Δ^{-1} .

Dynamic fracture toughness was measured at room temperature using an impact test machine equipped with an instrumented Charpy tub. The testing methodology selected was based on the three-point bending tests. The specimens of 10 mm × 10 mm × 55 mm in size, were notched and precracked by fatigue following ASTM: E399 standard. The dynamic stress intensity factor, K_{Id} , was determined using the following equation [31,32]:

$$K_{Id} = \left(\frac{P_{\max} S}{BW^{3/2}} \right) f \left(\frac{a}{W} \right) \quad (1)$$

where P_{\max} is the maximum load, S is the span, B is the specimen thickness, W is the specimen width, a is the initial crack length and $f(a/W)$ is a geometry factor.

Table 1
Chemical composition of tested alloys (wt.%).

Alloy	C	Cr	Mn	Cu	Ni	Mo	Si	Nb	Ti	Ce
1	2.93	16.93	0.85	0.83	0.73	0.92	0.55	0.001	–	–
2	2.96	17.02	0.88	0.81	0.68	0.89	0.56	0.62	–	–
3	2.94	16.97	0.84	0.87	0.71	0.91	0.59	1.00	–	–
4	2.96	17.01	0.86	0.82	0.74	0.88	0.57	1.63	–	–
5	2.95	16.94	0.82	0.86	0.75	0.92	0.58	2.08	–	–
6	2.93	16.98	0.88	0.84	0.73	0.93	0.62	2.62	–	–
7	2.97	16.93	0.80	0.89	0.71	0.87	0.57	3.17	–	–
5-1	2.94	16.91	0.88	0.82	0.69	0.89	0.61	2.06	0.11	–
5-2	2.97	16.95	0.85	0.89	0.71	0.88	0.57	2.09	0.26	–
5-3	2.96	16.92	0.86	0.85	0.72	0.91	0.59	2.07	0.28	0.19

3. Results

3.1. Microstructure of tested alloys

The as-cast microstructure of hypoeutectic Fe–Cr–C–Nb white irons with different niobium content (alloys 1–7, Table 1), and with addition of titanium (alloys 5–1 and 5–2, Table 1) and cerium (alloy 5–3, Table 1) consists of primary austenite dendrites and eutectic colonies composed of M_7C_3 carbide and austenite (Figs. 1–3). These alloys also contained various amounts of NbC carbide (Figs. 1b–3).

Morphology of NbC carbide changes with increasing content of niobium in alloy (Fig. 2). Petal-like NbC carbides were observed to form in alloys that contained up to 1.0% Nb (Fig. 2b). A further increase in the niobium content resulted in the formation of the compact form of these carbides appeared as the nodular or hexagonal disc carbides (Figs. 2c and 3a). In the Fe–Cr–C–Nb alloys containing over 2.5% Nb, apart from nodular or hexagonal disc carbides, NbC dendrites were noted, often grouped in series (Fig. 2d).

The addition of 0.11% Ti in Fe–Cr–C–Nb–Ti white iron containing 2.06% Nb does not change the morphology of NbC carbides (see Fig. 3a and b), whereas the addition of 0.26% Ti results in a substantial change in the morphology and distribution of NbC carbides (see Fig. 3a and c). It is evident that there is a tendency for the NbC to change from a needle shape to a dendritic and petal-like shape as the titanium content is increased from 0.11% to 0.26%.

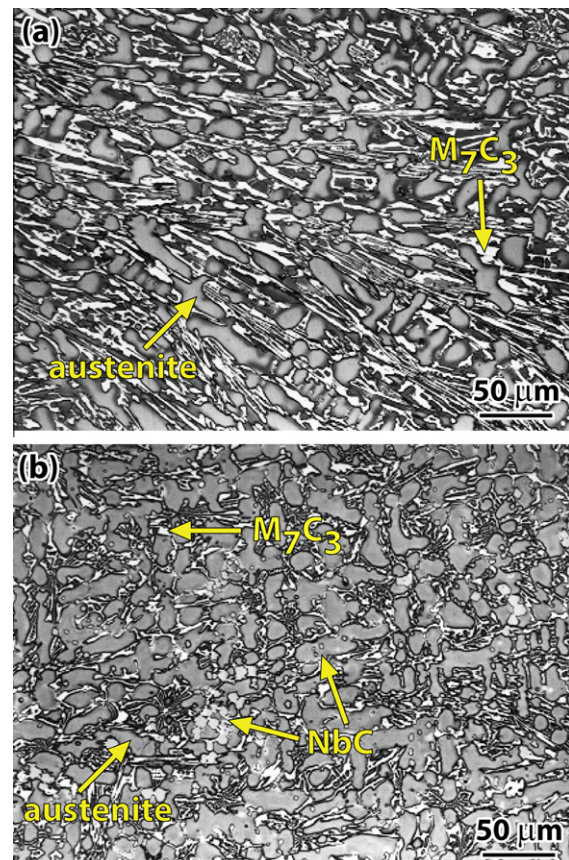


Fig. 1. As-cast microstructures of the basic Fe–Cr–C alloy (a) and Fe–Cr–C–Nb alloy containing 3.17% Nb (b).

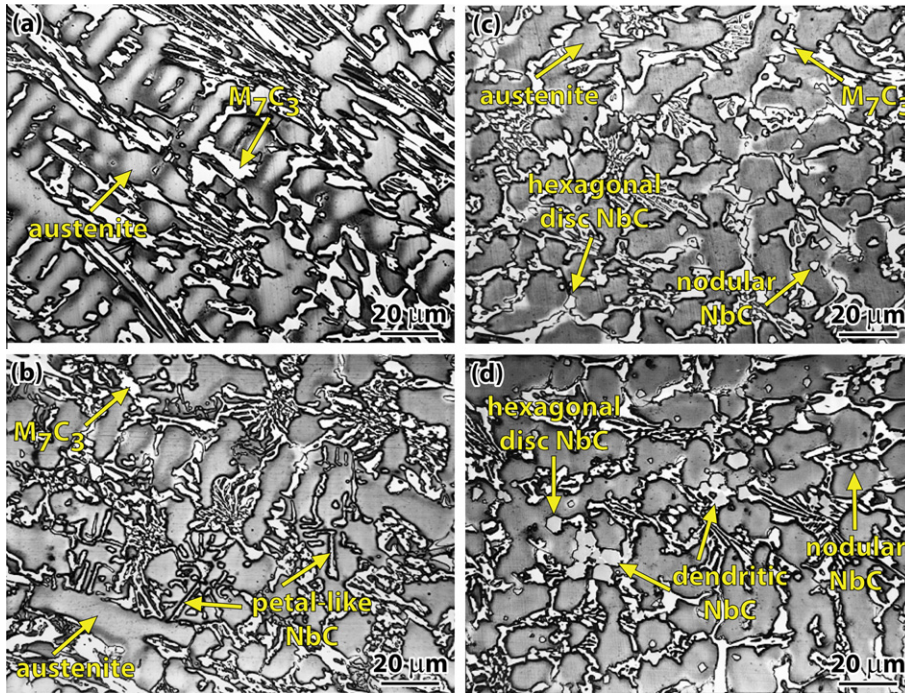


Fig. 2. As-cast microstructure of tested Fe-Cr-C-Nb alloys containing: (a) without Nb, (b) 1.00% Nb, (c) 1.63% Nb, and (d) 3.17% Nb.

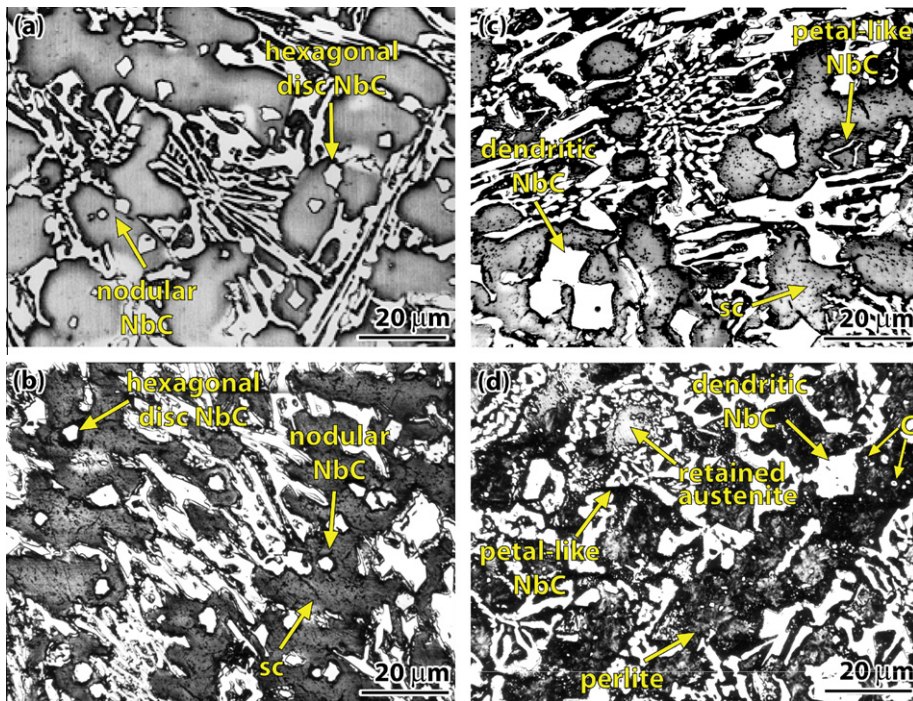


Fig. 3. As-cast microstructure of tested Fe-Cr-C-Nb alloys containing: (a) 2.08% Nb, (b) 2.06% Nb and 0.11% Ti, (c) 2.09% Nb and 0.26% Ti, and (d) 2.07% Nb, 0.28% Ti and 0.19% Ce.

The addition of 0.19% Ce in tested Fe-Cr-C-Nb-Ti alloy containing 2.07% Nb and 0.28% Ti, does not affect the morphology of NbC carbides (see Fig. 3c and d).

The primary austenite in tested Fe-Cr-C-Nb alloys with different niobium content in as-cast condition is mainly stable at cooling down to room temperature (Fig. 2). In the region of primary and

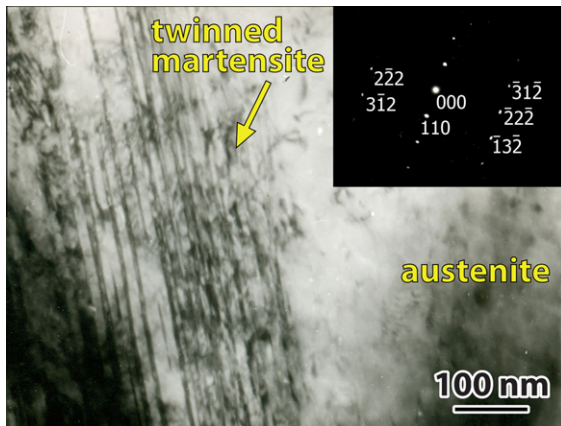


Fig. 4. TEM micrograph of tested alloy containing 2.08% Nb showing region of dendrite near to a eutectic carbide and selected-area diffraction pattern (in the corner) from the region in this micrograph showing a [112] zone axis.

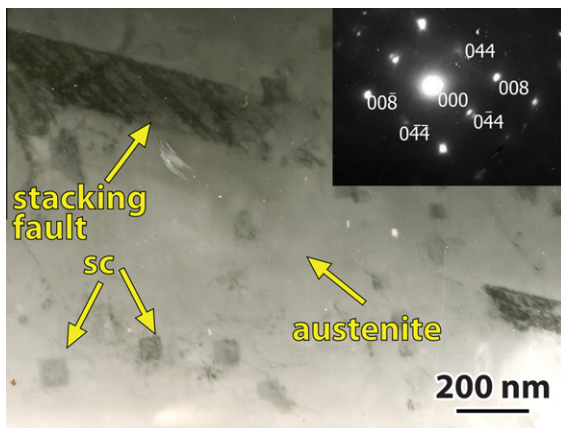


Fig. 5. TEM micrograph of tested alloy containing 2.09% Nb and 0.26% Ti showing secondary carbides and selected-area diffraction pattern (in the corner) from the region in this micrograph showing a [100] zone axis.

Table 2

Chemical composition of the matrix in tested alloys (wt.%).

Alloy	Cr	Mn	Cu	Mo	Si
1	11.01	1.17	0.97	0.28	0.64
4	11.56	1.08	0.99	0.29	0.57
5	11.74	1.13	0.95	0.24	0.55
7	12.23	1.18	0.92	0.27	0.68

eutectic austenite, around the eutectic carbides, twinned martensite detected (Fig. 4).

The very fine dark particles are observed in the primary austenite dendrites of Fe–Cr–C–Nb–Ti alloys with different titanium content (Fig. 3b and c). Particles in the matrix (Fig. 3b and c) were identified as $M_{23}C_6$ type carbide (Fig. 5).

The as-cast matrix microstructure of tested alloys containing 0.19% Ce was significantly different compared to all other tested alloys, and showed classical features of eutectoid transformation producing pearlitic-based products (Fig. 3d).

Results obtained by EDS analysis of the as-cast matrix in tested Fe–Cr–C–Nb alloys are given in Table 2. These results (Table 2) indicate that with increasing niobium content the concentration of chromium increases in austenite.

The influence of niobium on the volume fraction of M_7C_3 and NbC carbides is shown in Fig. 6. The volume fraction of M_7C_3

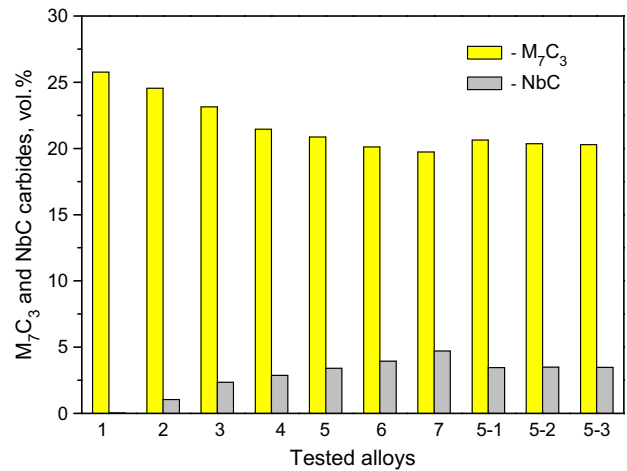


Fig. 6. Volume fraction of M_7C_3 and NbC carbides in tested alloys.

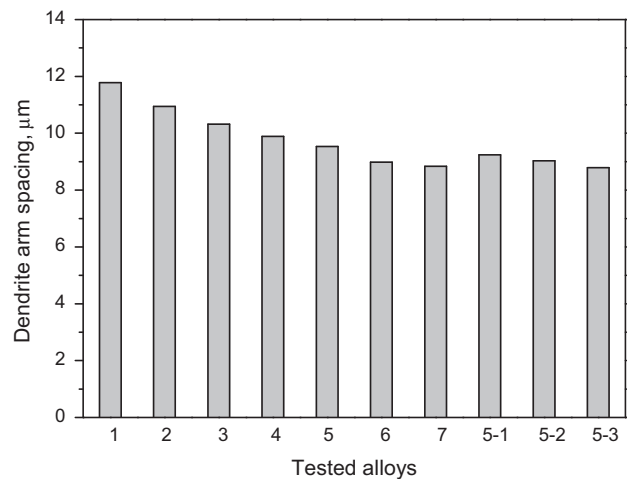


Fig. 7. Dendrite arm spacing in tested alloys.

carbides is decreased, whereas the amount of NbC carbides is increased with increasing the niobium content (Fig. 6).

The addition of Ti up to 0.3% and 0.2% Ce in Fe–Cr–C–Nb alloys containing about 2% Nb did not have a significant effect on the volume fraction of M_7C_3 and NbC carbides (Fig. 6).

Niobium influenced the refinement of the structure of high chromium white cast iron (see Figs. 1 and 7). Also, the addition of titanium and cerium reduced the austenite dendrite arm spacing (Fig. 7).

After heat treatment at temperature 950 °C for 1 h, matrix microstructure of all tested alloys is predominantly composed of precipitated secondary carbides and martensite (Fig. 8). Precipitation of secondary carbides during austenitizing resulted in depletion of austenite of carbon and during quenching austenite partially transformed to martensite.

Optical observations revealed that less austenite was retained in specimen with higher niobium content than in specimen with the lower niobium content of tested Fe–Cr–C–Nb alloys (Fig. 8a and b).

3.2. Mechanical properties of tested alloys

The results obtained by examination of hardness, wear resistance and dynamic fracture toughness of tested Fe–Cr–C–Nb alloys in both as-cast and heat treated conditions are presented in Figs. 9–11, respectively. With increasing niobium content the hardness

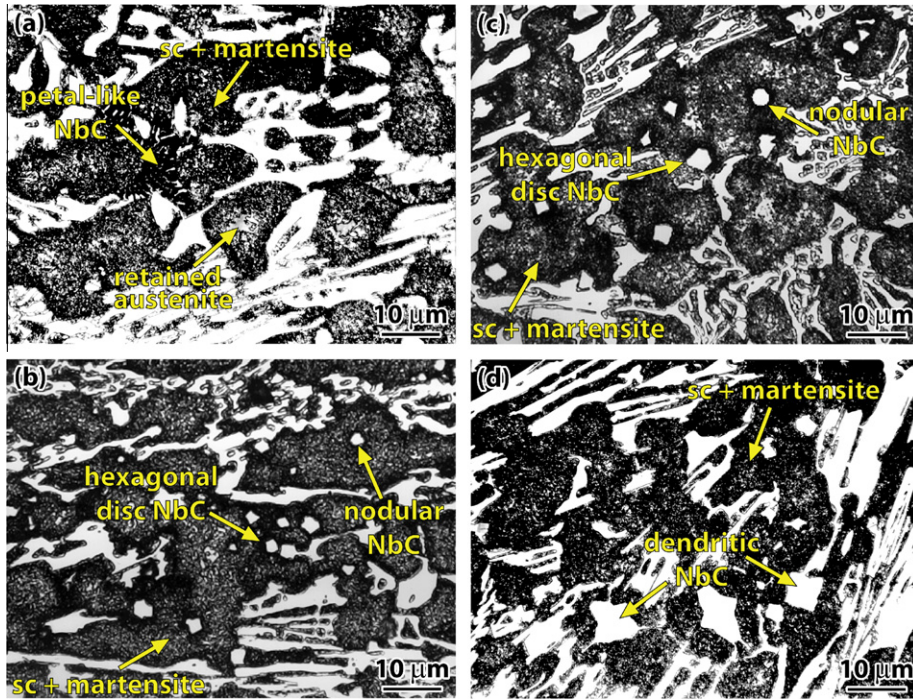


Fig. 8. Microstructures of tested Fe–Cr–C–Nb alloys in heat treated condition at 950 °C/1 h: (a) 0.62% Nb, (b) 2.62% Nb, (c) 2.06% Nb and 0.11% Ti, and (d) 2.07% Nb, 0.28% Ti and 0.19% Ce.

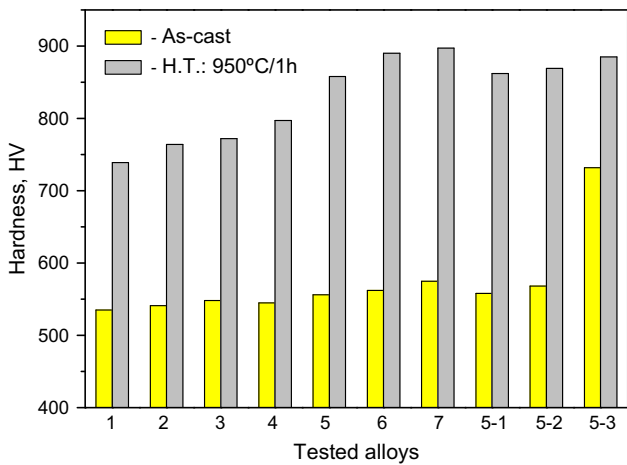


Fig. 9. Hardness in tested alloys.

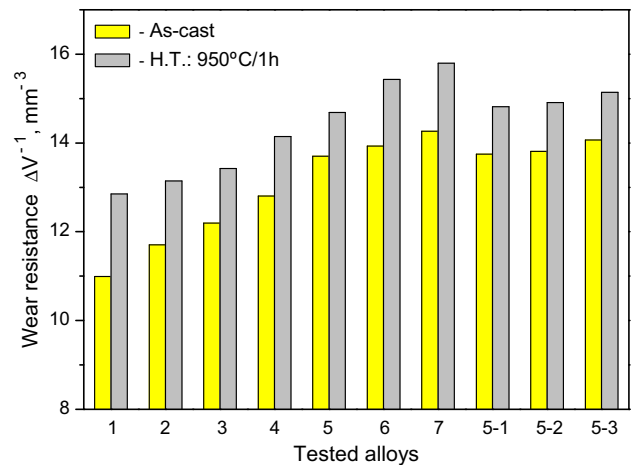


Fig. 10. Wear resistance in tested alloys.

and wear resistance was found to increase (Figs. 9 and 10). The toughness also increased with increasing niobium content in as-cast condition (Fig. 11). However, in heat-treated Fe–Cr–C–Nb alloys with varying contents of niobium, lower K_{Ic} values were obtained, compared with as-cast alloys (Fig. 11).

The addition of titanium in Fe–Cr–C–Nb alloys containing about 2% Nb results in slight increasing of hardness, wear resistance and fracture toughness (Figs. 9–11, respectively).

Cerium contributes to the improvement of hardness (Fig. 9) and wear resistance (Fig. 10) whereas the toughness was decreased (Fig. 11) in Fe–Cr–C–Nb alloys containing about 2% Nb and 0.28% Ti.

4. Discussions

For the present study, all the alloys were solidified at the same rate and the differences observed are attributed to the effect of alloying elements.

4.1. Effect of niobium on the microstructure

Experimental results indicate that niobium affects the solidification process in high chromium white cast irons.

Niobium in Fe–Cr–C–Nb alloys with high chromium content forms niobium carbides of the MC type [16]. The solubility of niobium in austenite (Table 2) and M_7C_3 carbide [8,10,15] is very low, so the majority of the niobium present in the alloy is in the form of MC carbide.

In Fe–Cr–C–Nb alloys containing up to 1% Nb, eutectic NbC carbides of petal-like shape were formed (Fig. 2b). According to the phase diagram presented in Fig. 12 [20], the solidification starts with formation of γ -phase in these alloys. In the course of primary γ -phase growth, the composition of the remained liquid was changing. Due to limited solubility of carbon, chromium and

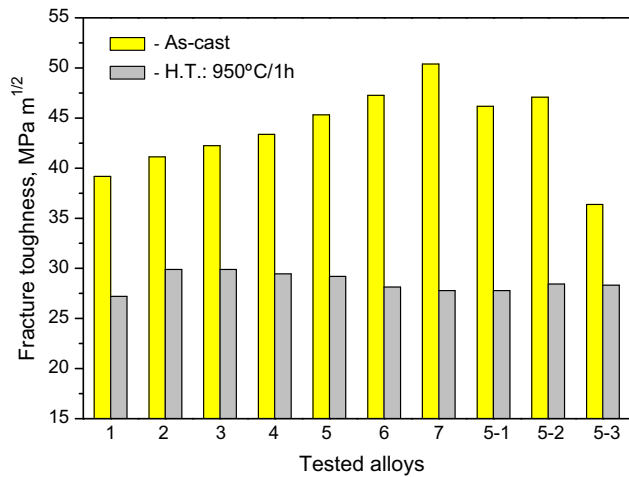


Fig. 11. Fracture toughness in tested alloys.

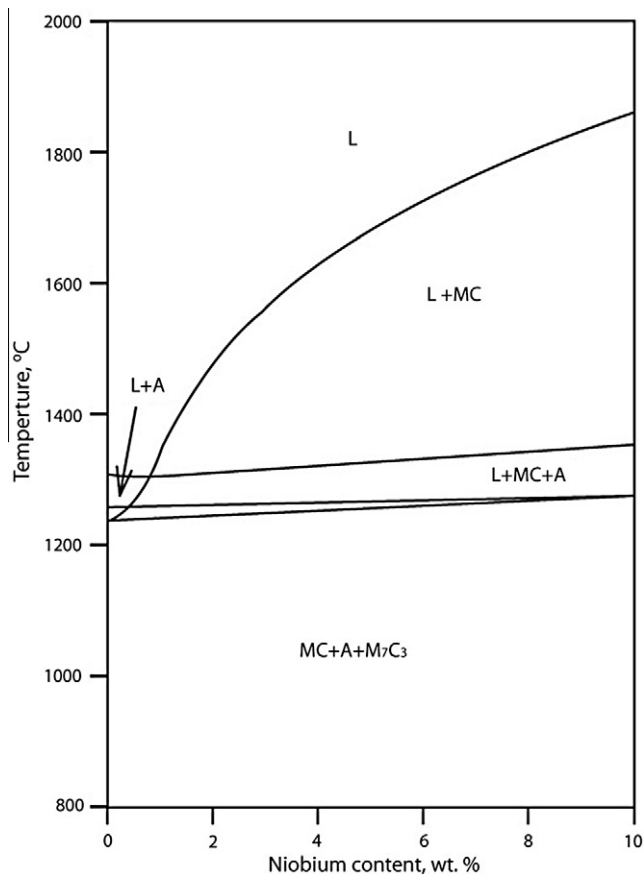


Fig. 12. Phase diagram of the Fe–Cr–C–Nb system for 15 wt.% Cr and 3 wt.% C [20].

niobium in the austenite, these elements accumulated in front of the progressing solid–liquid interface. At temperature lower than liquidus temperature during the eutectic reaction that takes place, in local areas enriched in niobium, eutectic composed of NbC and austenite was developed. Particles of NbC carbides disturb or completely block further γ -phase growth. As the temperature falls and solidification progresses, primary austenite dendrites reject solute (mainly carbon and chromium) into the remaining liquid until the eutectic composition is reached and the monovariant eutectic reaction ($L \rightarrow \gamma + M_7C_3$) takes place. From the melt remained in

interdendritic regions the coupled austenite – M_7C_3 eutectic was forming.

In tested Fe–Cr–C–Nb white cast irons containing over 1.63% Nb, NbC carbides are first to solidify from the melt (Fig. 12 [20]), and their morphology is determined by the content of niobium in the alloy (Fig. 2). The particles of NbC carbides can act as the substrates for heterogeneous nucleation of the austenite dendrites, which results in significant refinement of the final grain size (Fig. 7).

MC carbides are formed before M_7C_3 [14,19], which caused depletion of carbon in the liquid. Since carbon is the primary element that determines the amount of carbide in high chromium iron, the amount of M_7C_3 carbide should decrease as the niobium content is increased (Fig. 6). In addition to that, the niobium changes the morphology of the eutectic colonies, because their morphology is highly dependent upon the amount and shape of the austenitic dendrites formed earlier in the solidification sequence.

Furthermore, higher niobium content in the Fe–Cr–C–Nb alloys increases the degree of alloying of austenite with chromium (Table 2), thus increasing its hardenability. This is indicated by decrease in the amount of retained austenite in tested Fe–Cr–C–Nb alloys with higher niobium content after heat treatment (Fig. 8a and b).

4.2. Effect of titanium on the microstructure

Titanium preferentially partitions into TiC carbides in the Fe–Cr–C–Ti alloys and its concentration in the matrix and M_7C_3 carbides is very low [21–23].

In tested Fe–Cr–C–Nb–Ti white iron containing 0.11% Ti the morphology of NbC carbides (Fig. 3b) is same compared to the alloy without titanium (Fig. 3a). However, the addition of 0.26% Ti results in a substantial change in the morphology and distribution of NbC carbides (see Fig. 3a and c). The TiC particles are the first to solidify, and most of them serve as nuclei for the subsequent NbC carbide formation [16]. Zhi et al. [24] observed that TiC carbide particles become larger and agglomerate when the titanium content is high (over 1% Ti) in the alloy.

One might assume that in tested Fe–Cr–C–Nb–Ti alloy with 0.26% Ti inhomogeneous distribution of TiC carbide affects the inhomogeneous distribution and change in the morphology of NbC carbides. Namely, in local areas in the melt which was formed, a large number of TiC particles at higher temperatures probably come up with niobium segregation during the cooling process, since the particles of TiC carbides may act as nuclei for the NbC carbides. Due to higher concentrations of niobium in these zones of the melt, dendritic NbC carbides were formed, which is characteristic for alloys with higher content of niobium (alloy with 3.17% Nb). In local areas where a smaller number of TiC carbide particles were formed, lower concentration of niobium is expected. Thus, it leads to eutectic reaction ($L \rightarrow \gamma + NbC$) and formation of petal-like NbC carbide (this morphology of NbC carbides is characteristic of the alloy with niobium content up to about 1% Nb) in the course of solidification of austenite dendrites.

At temperatures below solidus, in the course of further cooling after solidification, the secondary carbides precipitate in austenite of tested Fe–Cr–C–Nb–Ti alloys with different titanium content (Fig. 3b and c).

4.3. Effect of cerium on the microstructure

Cerium affects the solidification process and changed the transformation characteristics of austenite in tested Fe–Cr–C–Nb–Ti–Ce alloys (Fig. 3d). Cerium, as well as niobium and titanium, has limited solubility in austenite and M_7C_3 eutectic carbide as indicated

by Bedolla-Jacuinde and Rainforth [27]. This element formed inclusions in high chromium white irons [28,30]. Qu et al. [28] found that cerium inclusions can act as heterogeneous nuclei of the primary M_7C_3 carbide and refine primary carbides in hypereutectic high chromium cast iron.

Previous studies [30] have shown that in hypoeutectic alloys, around the very fine inclusions of cerium, carbide particles rich in chromium were formed (white particles in the matrix, marked C in Fig. 3d). Carbide particles can act as the heterogeneous nuclei of austenitic dendrites to enhance nucleation or interfere with their growth and improve the refinement of primary dendrites.

Type and degree of transformation of austenite in the course of cooling after solidification in high chromium white cast irons depend on chemical composition of austenite. Changes in conditions of solidification as a result of adding cerium to Fe–Cr–C–Nb–Ti white iron influence the change in composition of austenite, which manifests itself in the form of different degrees of transformation of austenite (Fig. 3d). It can be assumed that, due to the formation of chromium-rich carbide particles, the degree of alloying of austenite with chromium will be decreased, thus reducing its hardenability. In this case, the content of Mo, Mn, Cu and Ni in tested alloy will not be sufficient to prevent the pearlitic transformation for a given cooling rate. As a result, during the cooling after solidification larger or smaller part of the austenite will transform into pearlite (Fig. 3d).

4.4. Effect of microstructure on the properties

Niobium, titanium and cerium altered the microstructure characteristics of high chromium white iron and affected its properties.

The improved hardness of the tested Fe–Cr–C–Nb alloys by increasing niobium content in the as-cast condition (Fig. 9) was the result of an increased volume fraction of the hard NbC carbide phase (Fig. 6), and structural refinement (Fig. 7).

In hypoeutectic Fe–Cr–C alloys increasing the volume fraction of eutectic M_7C_3 carbides up to 30% reduced volume loss caused by abrasive wear [2]. The abrasion resistance of the carbide phase was more effective than the matrix in high chromium white cast irons since, among other things, the hardness of carbides (1200–1800 HV) was greater than the hardness of the abrasive used (960 HV) [1]. Wear under low-stress abrasion conditions, and using a quartz abrasive, was apparently controlled by the rate of removal of the carbide phase the protruding carbides protected the matrix from direct attack of abrasive particles.

In tested Fe–Cr–C–Nb alloys, the volume fraction of M_7C_3 carbides decreases (Fig. 6), whereas the wear resistance increases (Fig. 10) with increasing niobium content. However, beside M_7C_3 carbides, NbC carbides are also present in the structure of these alloys. Due to their hardness and characteristic morphology, NbC carbides show higher wear resistance than M_7C_3 carbides. Increasing amount of this type of carbides, caused by the increase of niobium in Fe–Cr–C–Nb alloys, contributes to the improvement of wear resistance.

In addition to the volume fraction of carbides, the size of phases present in the structure was another microstructure variable which affected the abrasive resistance of the Fe–Cr–C–Nb alloys. The smaller size of primary austenite dendrites, i.e. the average distance between carbide particles, caused by increasing the content of niobium in the alloy (Fig. 7), protected the matrix better from direct attack by abrasive particles.

The improved wear resistance of the tested alloys after heat treatment, compared with the as-cast condition (Fig. 10) indicated that wear resistance under low-stress abrasion conditions also depended on the matrix microstructure. In addition to the fact that the matrix helped control of the penetration depth of abrasive particles, it also played an important role in preventing bodily

removal of smaller carbides and cracking of massive ones [1]. Experimental results indicate that the martensitic matrix microstructure more adequately reinforced M_7C_3 and NbC carbides to minimize cracking and removal during wear than the austenitic or pearlitic matrix (Fig. 10).

Besides, the secondary carbides which precipitate in the matrix regions of the tested Fe–Cr–C–Nb white irons containing titanium (Fig. 3b and c) also influence the abrasion behaviour (Fig. 10). By increasing the matrix strength through a dispersion hardening effect, the fine secondary carbides can increase the mechanical support of the eutectic carbides. These results agree with those of Liu et al. [33] and Wang et al. [34] who found that the precipitation of fine $M_{23}C_6$ carbides and the more homogeneous carbide distribution as a result of cryogenic treatment is responsible for the improved wear resistance of high chromium white irons.

Brittle failure involved crack initiation and propagation, the latter of which was controlled by fracture toughness. Since the crack moved easily through eutectic carbides, due to a higher content of niobium in the alloy, decreasing the volume fraction of the brittle M_7C_3 carbide phase (Fig. 6), increased fracture toughness (Fig. 11).

On the other hand, the fracture toughness increases with increasing niobium content due to increasing amount of NbC carbides (Fig. 6). These carbides, due to their characteristic morphology, have a higher toughness than M_7C_3 carbides. The Fe–Cr–C–Nb alloys containing 3.17% Nb in the as-cast condition showed greater dynamic fracture toughness (about 30%), compared to the basic Fe–Cr–C alloys without niobium (Fig. 11).

However, the results of fracture toughness tests in both as-cast and heat treated conditions (Fig. 11) show that the dynamic fracture toughness in the tested Fe–Cr–C–Nb white irons is determined mainly by the properties of the matrix. A primary role of the matrix in the fracture process in high chromium white cast irons was to prevent brittle cracks from propagating from one carbide particle to another. The matrix therefore had a crack-blunting effect, which subsequently increased the critical stress–intensity factor required to continue crack propagation [1]. Austenite was more effective in this respect than martensite or pearlite (Fig. 11).

Based on the present results, the alloy containing approximately 3% Nb gives the best compromise between wear resistance and fracture toughness. This alloy may be used to produce dents and hammers in fibrizer equipment to recover asbestos fibres and in many other applications where good abrasion resistance and toughness are necessary.

5. Conclusions

Niobium, titanium and cerium altered the microstructure characteristics of hypoeutectic high chromium white cast iron containing 17 wt.% Cr and affected its mechanical properties.

The alloy containing approximately 3% Nb gives the best compromise between wear resistance and fracture toughness. This alloy shows about 30% greater dynamic fracture toughness and about 30% greater abrasion wear resistance than the basic Fe–Cr–C alloy which does not contain niobium. Due to their characteristic morphology, NbC carbides show higher wear resistance and toughness than M_7C_3 carbides. Increasing amount of this type of carbides, caused by the increase of niobium in Fe–Cr–C–Nb alloys, contributes to the improvement of wear resistance and dynamic fracture toughness. Besides, the secondary carbides which precipitate in the matrix regions of the tested 17 wt.% Cr–2.9 wt.% C–2 wt.% Nb white iron containing titanium also influence the abrasion behaviour and fracture toughness. The alloy containing 0.28% Ti and 0.19% Ce has pearlite–austenitic matrix microstructure in as-cast condition. The pearlite, due to its high microhardness, improves the wear resistance under low-stress

abrasion conditions, but drastically reduces the toughness of tested alloy.

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