THE MORPHOLOGY CHANGE OF IRON DIBORIDE IN THE Fe-B ALLOY DURING DEFORMATION

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This research work studies the effect of deformation and destabilization heat treatment on morphology of the iron diborides of Fe-B cast alloy. The results show, that iron diborides change the morphology from continuous network to discontinuous, if the deformation is used. Relatively homogenous distribution of iron diborides is achieved, if the deformation is combined with destabilisation heat treatment at elevated temperatures. Obtained results show that Fe-B alloys can be advantageously used as a substitute material for Fe-Cr-C cast iron in wear applications due to their better toughness.

Keywords
Iron Diboride, Metal Matrix Composite, Microstructure, Hardness

1. Introduction

The use of Metal Matrix Composites (MMCs) is an excellent combination for hard ceramic reinforcements and ductile metallic matrix, which makes them a promising material for wear-resistance applications [Acosta 1996]. Conventional production routes, such as powder metallurgy, often involves the addition of reinforcing phases into the metal matrix directly, which leads to poor wetting behaviour between ceramic phase and metal matrix and segregation of reinforcements. The commonly used elements for ceramics phase in iron based MMCs are Ti, Nb, Mo, W, V and C, B [Chotěborský 2009a, Chotěborský 2009b, Zhang 2007]. Ceramic phase could also be created by crystallization or by precipitation in supersaturated solid solution. Each of the elements which are added to iron alloy changes the alloy enthalpy [Kootsookos 2008]. This way moves to innovation of white iron with elements for secondary precipitation [Karantzalis 2009]. It has been found that toughness of the white iron depends on its structure which can be affected by a casting technology. Plastic deformation is unfeasible as is probably unreal. It is commonly known that toughness of white cast iron is low with or without secondary precipitation particles. One of the possible ways to increase white iron toughness is a destabilization heat treatment [Kootsookos 2008].

Generally, the binary Fe-B system is used to develop the metal matrix composites (Fig. 1) [Liu 2009]. Boron being an alloy element in iron is known for its hardenability with steel which increases with the addition of boron. However, the limit of solubility of boron in iron is very low, either in austenite or in ferrite, and more addition could induce the formation of boride. Borides have a higher hardness than carbides when combined with the same element, which replaces the carbides in the white cast iron with borides. Moreover, carbon is almost dissolved in boride, thus the properties of matrix can be adjusted by carbon content. This offers a unique possibility to increase hardness of reinforcement in MMC by using borides and at the same time adjust the properties of the matrix by levelling the carbon content. The development of high boron iron based alloy is to modify the white cast iron with boron, and the design idea is to use boride to replace carbide in white cast iron, and to use low or medium carbon matrix to replace high carbon matrix [Liu 2009]. This is the way to increase the toughness metal matrix composites with iron based system. According to Fe-B binary system, a limit of solubility of boron in solid solution at room temperature is less than 0.02 wt. %, Fig.1. The system with higher amount of boron will result in eutectics structure with Fe_2B. It was demonstrated that solubility of boron in iron can be affected by alloying of specific elements. Gou [Gou 2003] found that solubility of boron in iron can be changed with the addition of other elements such as Cr, Mo and V. Also [Ma 2010] found that adding the element Cr changed significantly the toughness of boride particles $(Fe, Cr)_2B$ in the system as well as mechanical properties of the matrix [Liu 2008a]. The effect of chromium has clearly shown in abrasive resistance and higher toughness significantly changes wear resistance [Zhang 2012]. Ozdemir's results [Ozdemir 2009] show that high chromium and nickel contents result in precipitation of CrB and Ni_2B respectively. High chromium content does not only leads to new phases but changes corrosion resistance in liquid metal [Ma 2010]. Derivation of the Fe-B system moves to ideal metal matrix composite with titanium boride particles embedded in the tough metal matrix. Titanium, when added to binary system Fe-B leads to formation of TiB_2 phase. One of the first experiments resulted in innovation of the high modulus strength steel which has been reinforced by titanium diborides [Tanaka 1998].

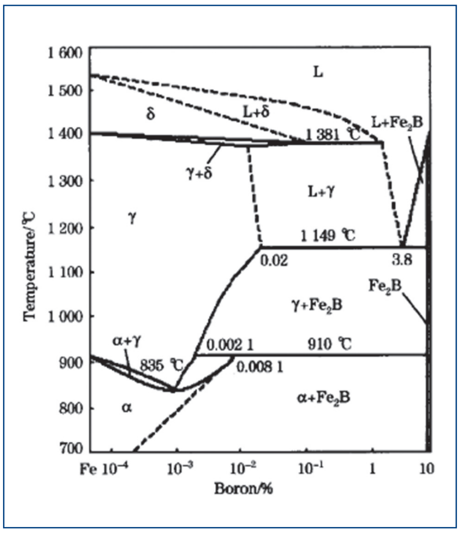


Figure 1. *Fe-B binary diagram*

General studies [Dang 2010, Fu 2007, He 2012, Ma 2012, Xiang 2010, Zhang 2007] deal with heat treatment of Fe-B alloys. If the heat treatment is applied, the matrix of high boron cast steel transforms according to Fe-C system. But short time of heat treatment does not affect the shape of the borides. A long time destabilization heat treatment has to be applied to change the morphology of borides and to inftigated.hness were not the araoluence secondary precipitation mechanism in matrix. High boron content in steel leads to innovation of the coating technology because eutectic borides cause decrease in toughness. On the contrary, large primary borides increase wear resistance. [Dabara 2006, Du 2008a, Du 2008b, Ozdemir 2006].

Previous studies have been focused on medium and high content of the boron in cast iron, content of boron in experimental plain cast steel being higher than 1.2 wt. %. It has been observed that all experimental procedures of tested experimental alloys focused on kinetics and size of hard phases with primary aim to increase hardness and wear resistance. Other mechanical properties such as toughness were not investigated [Hrabe 2010, Liu 2008b, Zhang 2012]. The Fe-B alloys can be used as low cost variance to expensive Fe-Cr-C wear resistance alloys.

The research work is focused on Fe-B not alloyed cast steel with boron content lower than 1 wt. %. A goal of the paper is to verify the possibility to change continuous eutectic areas to dispersed separated particles as a result of plastic deformation.

2. Material and Methods

The alloys used for this investigation were melted in a vacuum medium-frequency induction furnace of capacity 100 g. The alloys were poured at 1,650 °C into graphite mould which was preheated up to 600 °C. The chemical compositions of the alloys are listed in Table 1. Samples were heated at 950 °C for 0.5 h, followed by forging in power hammer, cross section reduction was 4. Subsequently, the samples were tempered at 950 °C for 2 h with cooling on air.

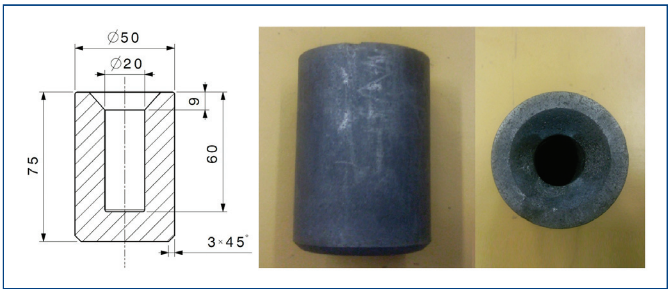


Figure 2. *The graphite mould for cast samples, preheated up to 600 °C*

Alloy	C	B	Si	Mn	Cr	Ni	Fe
1	0.27	0.68	0.15	0.28	0.08	0.25	Bal.
2	0.27	0.81	0.29	0.3	0.1	0.28	Bal.

Table 1. *Chemical composition of experimental alloys (wt. %)*

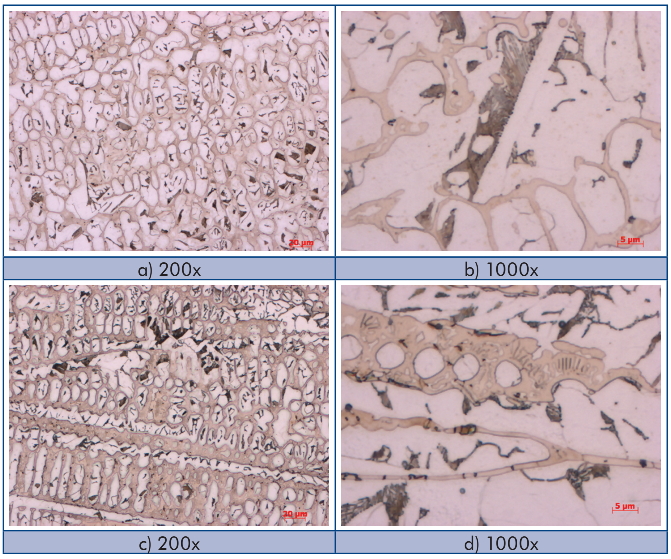
The hardness was measured on metallographic samples by Vickers hardness tester using a 30-kg load. Samples for metallography were prepared using conventional metallographic techniques. Once polished, samples were etched with 4 vol. % nital solution.

3. Results and Discussion

The as-cast microstructures of the investigated alloys are shown in Fig. 3. The microstructure of the alloys consists of matrix and eutectic boride, shown as white and black and grey areas in the micrographs, respectively. According to equilibrium binary diagram, the boride of eutectic structure is identified as Fe_2B (grey). The metallic matrix is composed of ferrite (white) and pearlite (dark). Moreover, netlike distribution of Fe_2B has been observed as shown in Fig. 3. It seems that different concentration of boron leads to different eutectic continuous network into structure (Fig. 3b and Fig. 3d).

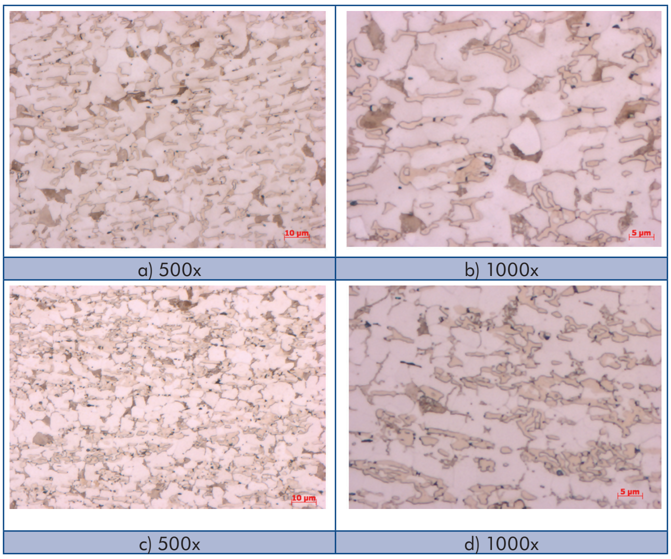
Fig. 4 shows the microstructures of high boron cast steel forged from 950 °C and cooled in air. Plastic deformation breaks up the boride network and the metallic matric becomes continuous phase. Netlike boride becomes strips after forging. At the same time, secondary precipitates were not found. Under the increasing amount of boron, boride particles are uniformly distributed in the metallic matrix (compare Fig. 4b and Fig. 4d).

Fig. 5 show the deformed microstructures of high boron cast steel after annealing at 950 °C for 2 hours and cooled in air. In each case, the metallic matrix transforms into ferrite-pearlite structure. It seems



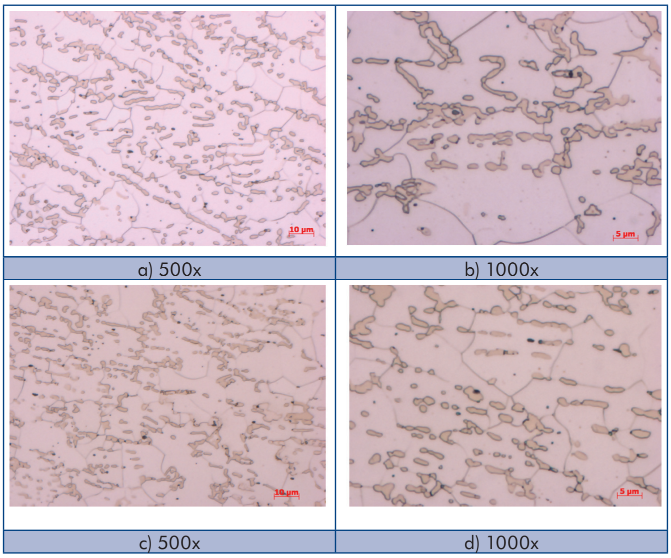
a) 200x | b) 1000x | c) 200x | d) 1000x

Figure 3. *Microstructure of the experimental samples 1 (a, b) and 2 (c, d)as cast*



a) 500x | b) 1000x | c) 500x | d) 1000x

Figure 4. *Microstructure of the experimental samples 1 (a, b) and 2 (c, d) after forging*



a) 500x | b) 1000x | c) 500x | d) 1000x

Figure 5. *Microstructure of the experimental samples 1 (a, b) and 2 (c, d) after forging and annealing*

Sample	Cast	Deformed	Deformed and annealed
1	242±1.2	227±1	174±3
2	276±7	250±3	192±2

Table 2. *Hardness (HV30) of the experimental samples*

that annealing after plastic deformation, higher Boron amount in steel is necessary for homogenous distribution of boride particles in metallic matrix (compare Fig. 4d and Fig. 5d).

The hardness of high boron cast steel is listed in Tab. 2. Compared with not deformed samples with different boron content, higher amount of boron leads to increasing hardness of the high boron cast steel. Deformed samples, deformed and annealed samples show decreasing trend of the hardness of high boron cast steel. It seems that the hardness dereferences between both experimental high boron steels are the same for deformed, deformed and annealed samples. Compared with 27MnB annealed steel (ferrite-pearlite microstructure) with 130 HV30, the benefits of the boride particles on hardness is obvious. The changes of the iron diboride morphology in the high boron steel can affect toughness and wear resistance directly. High importance of the morphology changes lead us to the idea that toughness of the high boron steel after forging can be higher than without forging. The effect of iron diboride microstructure changes can influence the wear resistance behaviour but we believe that three body abrasive wear resistance will be affected positively.

4. Conclusions

Microstructure of high boron steel after solidification consists of eutectic boride and metallic matrix. The eutectic borides are Fe_2B and metallic matrix is composed of ferrite and pearlite.

Plastic deformation breaks up boride network and promotes boride particles. After deforming or deforming and annealing, the morphology of boride in the deformed high boron steel changes into a spheroidized structure. Compared with the not deformed samples, the hardness of the deformed samples or deformed and annealed samples decreased.

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