International Journal of Engineering & Technology, 7 (4.26) (2018) 322-325

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

The Effect of Slurry Erosion Wear on Boronized Ductile Iron

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Abstract

In this study, the effects of boronizing on slurry erosion wear properties of ductile iron were investigated. Specimens were boronized at temperatures of 850ºC, 900ºC and 950ºC for 8 hours and self-cooled in the furnace until reached the room temperature. Boronizing paste were used as a medium in this process. The specimens were analyzed using optical microscope (IMAPS Software) and Vickers Microhardness tester to find thickness and microhardness of boride layer respectively. Slurry erosion wear test were performed to define the weight loss. As a result, the hardness of boride layers was measured in the range of 454 $HV_{0.10}$ – 1023 $HV_{0.10}$. Furthermore, the wear resistance of boronized temperature at 950ºC is higher than the samples at temperature 900ºC, 850ºC and untreated sample. It can be concluded that the higher the heating temperature will result in higher wear resistance of boronized ductile iron.

Keywords: *Ductile Iron, Boronizing, Slurry Wear Behaviour*

1. Introduction

Ductile cast iron is broadly utilized in various industrial applications, for example, aviation material, agriculture machinery, automotive engine, heavy machinery parts, nuclear and compartments of waste [1]. Besides having excellent functionality and castability, it also has better durability, malleability as well as strength than gray cast iron. Ductile iron is cheaper compared to malleable iron in terms of processing cost [2]. Boronizing is a thermochemical surface treatment that can be applied to ferrous metals and non-ferrous metals [3]. Boronizing can be accomplished in all conditions of thermochemical surface treatments by different procedures such as in forms of powders and pastes [4]. Boronizing of ferrous materials is generally performed at temperatures ranging from 840ºC to 1050ºC [5]. The process can be carried out in solid, liquid and also gaseous medium. Boronized steels and cast irons are known for their great surface hardness and wear resistance. Boronizing ferrous materials at temperatures between 800ºC - 1000ºC for periods ranging from 1 hour to 8 hours' forms (Fe_2B + FeB) or Fe_2B iron boride phases. Additionally, the process produces a borides layer which having hardness up to 2000 HV and thickness in the range of 40-270 µm [6]. Tooth-shaped structure is a distinguishing property of boride layer. The concentration of alloying elements as well as the period and temperature of treatment determine the toothing degree between the layer and the substrate [7]. As the thickness increases, the boronizing layer becomes more fragile [8]. Mechanical action which removes material from a solid surface is known as wear. Normal load applied, hardness, shape abrasive size grit or hardness, sliding speed and material fracture toughness are important wear mechanisms. Abrasive wear can possibly be reduced by a number of approaches including the development of various materials, heat and surface treatment as well as application of composite materials. Wear is the greatest contribution to the failure of machine parts [9].

This study aims to investigate the effect of slurry erosion wear on boronized ductile iron. The different temperatures and constant soaking time was applied in the surface treatment process. Microstructure observation, hardness and slurry wear behaviour of boronized and as cast specimens were investigated.

2. Experimental procedure

2.1. Substrate materials and boronizing

The ductile iron materials were molded in standard Y-block casting. Ferritic matrix, few pearlite and good graphite nodularity are the characteristics of as cast ductile iron microstructure. The bulk composition of this ductile cast iron was obtained by spectrometer test which is provided in Table 1. Boronizing were conducted on paste medium for a constant 8 hours of holding time at temperature of 850 ºC, 900℃ and 950º C using Carbolite High Temperature Furnace. Samples were first coated with boron paste before it was heated in an air tight steel box.

Table 1: Chemical Composition of Ductile Cast Iron Samples

C	Si	Mn	Pb	S	Cr	Ni	Cu	Ti	Nb	V	Fe
3.4	2.28	0.412	0.0074	0.01	0.16	0.66	0.449	0.017	0.079	0.019	92.4

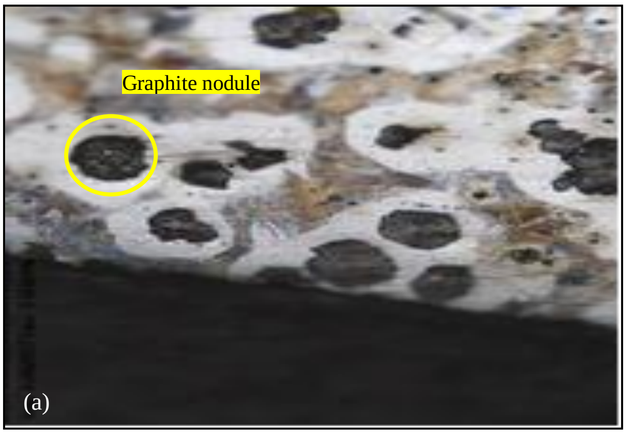
2.2. Microstructure, boride layer thickness, microhardness and slurry erosion wear

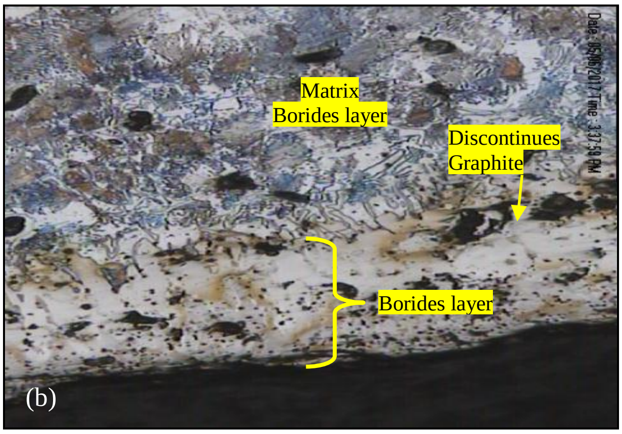
Microstructure and the depth of coating layers were measured by using an optical micrometre attached to an Olympus optical microscope. Microhardness of boride layers were measured using a Vickers microhardness tester with loads of 1000 HV. Slurry erosion wear test were carried out using DUCOM Slurry erosion tester machine. The specimens were made to obtain the dimensions of 76 mm x 25 mm x 6 mm with the 8.5 mm diameter hole at the centre of it. The size of sand was set at 1.18 mm and was filled into a slurry container. The test was running for 5 intervals at a speed of 180 RPM for 4 hours per each interval. The weight losses of the specimens of each interval were computed by using the electronic digital balance.

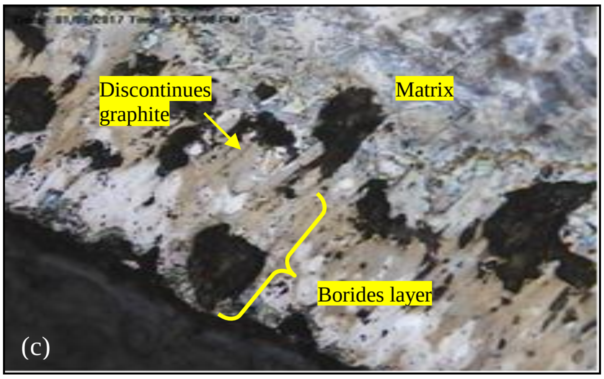
3. Results and Discussions

3.1 Microstructure observation and boride layer thickness

Figure 1 (a) to (d), shows the optical micrographs of the cross-sectioned ductile cast iron samples which were boronized at 850ºC, 900ºC, 950ºC for 8 hours soaking time. The boronizing temperature process started from 850^0C to 950^0C was mainly considered the presence of austenite. The presence of austenite can increase the hardness of the ductile cast iron.







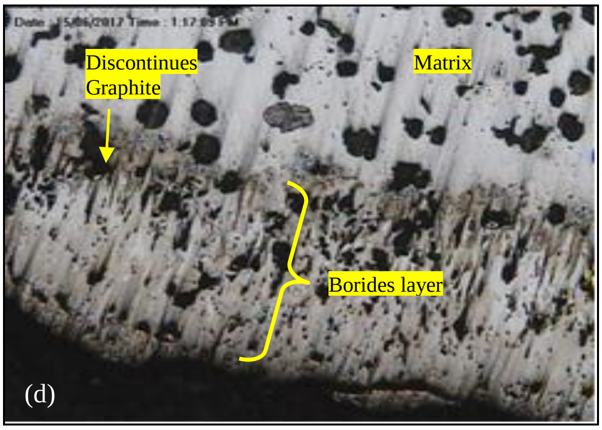


Fig. 1 (a)-(d): The cross-sectioned ductile cast iron samples boronized at (a) untreated (b) 850ºC (c) 900ºC (d) 950ºC through optical microscopy

Saw tooth shaped morphology of borides layer is shown in Fig. 1(c) and (d). There are three different phases found in the surface regions of cross sectional boronized materials which are i) FeB and Fe2B borides layer, ii) a ferrite zone formed between boride teeth and substrate together with discontinuous graphite zones and iii) substrates of ductile iron matrix. The globular graphite within the coating layer and the substrate has remained in place during the diffusion process. The change of boronizing temperature were affected to the depth of borides layer as shown in Fig. 2. When the temperature increased, the thickness of borides layer was increased. From the observations show in Fig. 2, the boride layers' thickness is change accordingly to the temperature. The thickness increased around 47 % when temperature increased from 850ºC to 950ºC.

3.2 Microhardness of boride layer

The initial hardness value at the tip of boride layer surface of the sample of 850°C is 1003 HV whereas the initial hardness for 900°C is 1035 HV and for 950°C is 1098 HV (as indicated in Figure 3). Microhardness were measured from the outer into the interior surface along a line. It is considered as a high hardness value and be classified as FeB phase since hardness value of FeB is in the range for more than 1000 HV [10] . Double phase borides layer which are FeB and Fe_2B can be produced through 8 hours boronizing time. The development of double or single phase of boride layer were depending on the boron availability. Referring to figure 3, the presence of borides layer FeB and Fe_2B lead to a greater hardness compared to the substrate. Furthermore, the hardness of each phase are different [11]. It can be concluded that, the greater temperature of boronizing, caused the boride layer thickness increased. In addition, the process of boron atoms diffusion is initiated from the outer surface towards into the matrix, therefore boron diffusion becomes more difficult and the boron concentration at the surface increases [12]. This leads to the start of the formation of FeB phase. The FeB phase content in the duplex layer decreased when boronizing temperature increased [6]. However, when the boronizing temperature is higher, the boron concentration is become lower. Thus, when boron atoms away from the borides layer surfaces, the FeB will transform into Fe_2B [13]. As a result, the hardness of substrate is lower compared to the hardness of borides layer. According to figure 3, the formation of the harder FeB phase as well as higher hardness are the effects from the higher boronizing temperatures. Hence, when structural defects such as porosity and cracks are present, hardness values and types of the boride layers will be different.

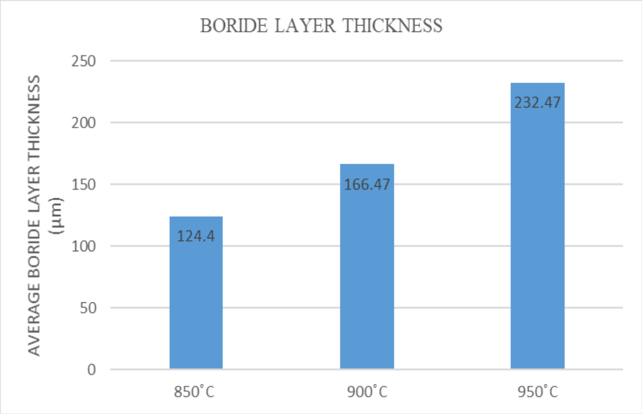


Fig .2: The average thickness of boride layers

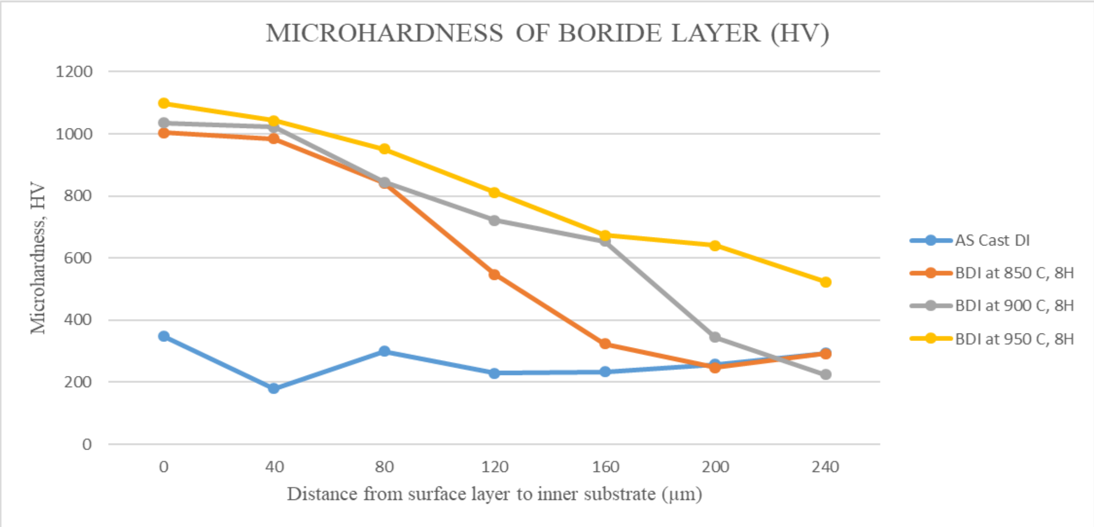


Fig 3: Microhardness of boride layer

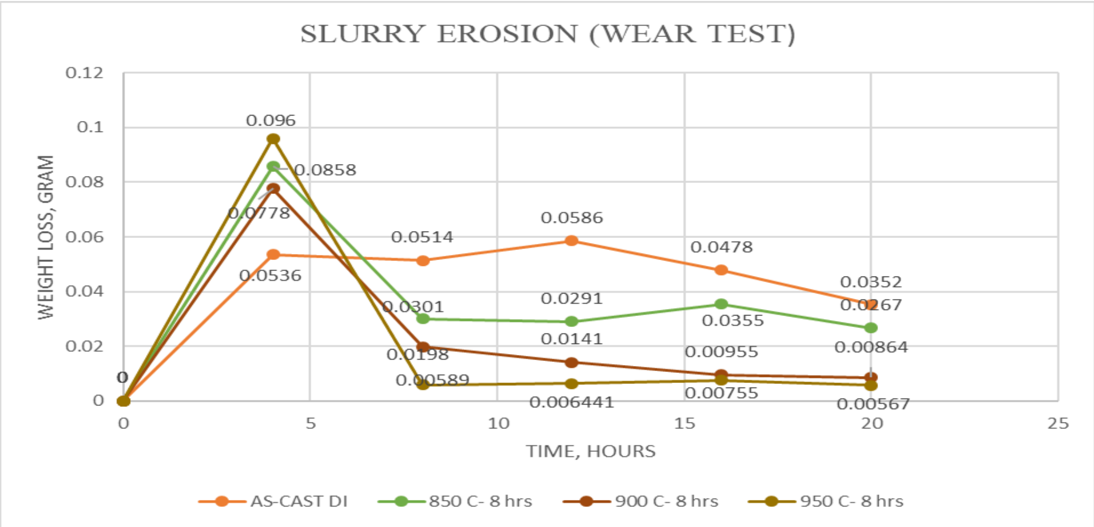


Fig 4: Slurry erosion wear test

3.3 Slurry erosion wear

The weight loss of as cast ductile iron and boronized ductile iron at 800°C, 900°C and 950°C for 8 hours were exhibit in figure 4. The weight loss of boronized specimens is lower than unboronized material. Though, the boron paste residues that attached to the external surface of material caused the weight loss of boronized higher than as cast at first interval (first 4 hours). Therefore, the process of removing the residual pastes happened at the first interval. For the second until fifth interval, it shows the weight losses value of boronized ductile iron is fewer than the sample of as-cast ductile iron. At these stage, the hardness of the borides layer surfaces played an important role as the wear resistance of the material. From this study, the hardness of boronized ductile iron is greater than the as cast sample. In conclusion, hardness is proportionally related to wear resistance. Higher hardness will causd the wear resistance to increase. From figure 3, the surface hardness of boronized ductile iron is harder than sample of 850°C. FeB layer phase has a higher internal stress. Therefore, the Fe_2B layer phase is the highest wear resistance compared to FeB phase [14]. This condition is due to more boron dispersion to form the borides layer that contain of two layers which are FeB as a protective layer and Fe_2B as a dispersion layer. The functions of these two layers are to protect the materials from suffering the greater weight loss and produced the higher wear resistance compared to unboronized materials [15].

4. Conclusion

i) Toothing structures of borides layer (FeB and Fe_2B) were formed at boronized ductile iron surfaces. The layer thickness increased about 46 % when the temperature increased from 850ºC to 950ºC. The FeB and Fe_2B phases in boride layers were found in the surface of boronized materials. The changes of different temperature do not affect the graphite morphology in the boride layers.
ii) The hardness value of boride layer is increased about 8.6% when the temperature increased from 850ºC to 950ºC. It can be concluded that, increasing the boronizing temperatures resulted the higher hardness. This phenomenon is due to the formation of harder FeB phase.
iii) The hardness and wear resistance were increased when the boronizing temperature were increased. Borides layer contain of two layers which are FeB as a protective layer and Fe2B as a dispersion layer. These two layers were act as the protection of the materials from getting the greater weight loss and produced the higher wear resistance.

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