Enhancing the wear resistance of AISI 1025 Steel by Pack Boronizing Process

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Abstract- Boronizing Is One Of The Most Promising Surface Hardening Practices In Order To Improve The Wear Performance Of Steel. Boronizing Process Is Conducted In Boronizing Media At A Temperature Of 950 ºc For Sufficiently Long Duration To Form Hard Boride Needles On The1025 Steel By Thermo-Chemical Reactions. For Instance, It Is Possible To Achieve High Vicker's Hardness Of About 1880 Hv By Producing Boride Layer Having A Thickness Of 132 µm In Three-Hour Duration. The Present Work Aims At Understanding The Effect Of Pack Boronizing On The Wear Resistance Of Aisi 1025 Steel. The Microstructural Characteristic Of Boride Coating Was Investigated By Optical Microscopy And X-Ray Diffraction Is Used For Phase Analysis. A Pin-On-Disc Tribometer Was Utilized To Evaluate The Wear Resistance Of Boronized And Unboronized Specimens. Experimental Data Revealed That Wear Resistance Of Boronized Aisi 1025 Specimen Is Enhanced By About 60% As Compared To That Of The Unboronized Aisi 1025 Specimen.

Keywords: AISI 1025 steels, surface hardening, boriding or boronizing, microstructure, microhardness and wear test.

1 Introduction

Surface characteristics of steels are usually improved by thermal and thermochemical processes. Boronizing is an alternate surface hardening procedure, which involves diffusion of boron atoms into the alloy's surface at high temperature [1]. Some properties of metal's surfaces like hardness, wear resistance and corrosion resistance can be improved through boronizing process [2]. Major benefits reported of this process are improvement in high hardness, abrasion resistance and enhanced oxidation resistance as compared to other surface hardening treatments, hence this treatment which also improves its reliability [3, 4, 5]. Boronizing typically improves durability of the treated parts compared to other hardening process like nitriding, carburizing, nitrocarburizing and carbonitriding [6]. Boronizing treatment is normally done by pack, paste, molten salts, gas, laser, and electrolytic means. Among these processes, solid pack process is considered as an economical one [2-6].

The pack boronizing medium consists of boron source like B_4C, filler material like SiC and an activator like KBF_4. The boronizing media which is placed around the substrate material supplies active

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boron by the thermochemical reaction in a conventional muffle furnace at boronizing temperature [7, 8]. The boronizing temperature of the ferrous alloys ranges from 1073 K to 1273 K. Two hard metallic layers namely Fe_2B and FeB are formed due to the thermochemical reactions in the boriding mixture. However, Fe_2B is favored as compared to FeB, since Fe_2B has less brittleness and its thermal coefficient of expansion matches with that of steel. FeB and Fe_2B together, results in lateral cracks in boronized layer due to their high difference in thermal co-efficient of expansion [9, 10]. The layers obtained by boronizing at three different time durations at 950ºC were tested in a pin-on-disc tribometer as attempted for other alloys [11]. This study as a whole is aimed to examine microhardness, microstructure and wear characters of borided AISI 1025 steel specimens and they are compared with untreated specimens.

2 Materials And Methods

The material chosen for this study is AISI 1025 steel, which is extensively utilized for constructions of mechanical products. The composition of specimens used in this study is given in Table 1**.** A rod of 25mm diameter and 200mm length was annealed at 750°C for an hour to mitigate internal residual stresses. Then it was cut and machined to dimension of 10 x 10 x 10 mm3 specimens for micro-hardness and microstructural characterization. The specimens were then ground, cleaned and desiccated at room temperature before proceeding to the boronizing process [12]. A cylindrical specimen having 10mm diameter and 35mm length were prepared for pin-on-disc wear testing.

Table 1: Chemical composition of AISI 1025 steel

C	**S**i	**M**n	**M**g	**N**i	**C**r	**P**	**M**o	**A**l	**C**u	**F**e
0.24	0.222	0.432	0.007	0.086	0.138	0.168	0.018	0.047	0.176	98.3

The primary step in boriding is the preparation of boronizing mixture. The following mixture was used in our experiments.

- 5% - Boron Carbide (B_4C)
- 5% - Potassium flouroborate (KBF_4)
- 90% - Silicon carbide (SiC)

Initially silicon carbide (filler material) and potassium fluoroborate (activator) were mixed to get a uniform mixture without lumps. Then, boron carbide was added to this mixture and mixed thoroughly to have a homogeneous mixture. Next, the clean steel samples to be borided were placed in three different stainless-steel containers and packed on all sides by the boronizing mixture. The thickness of the powder is at least 15mm on each side. The top lids were filled and covered with proper proportions of sand, refractory clay and sodium silicate gel and dried to avoid entry and exit of gases during boronizing. The packed containers were clamped using a specially fabricated C-clamp (Figure 1) and then placed within a crucible and kept inside the muffle furnace and heated to 950°C. Out of the three containers, one was taken out after one hour and allowed to cool in the atmospheric. After two hours another box was removed and after three hours the third box was removed and cooled [13].

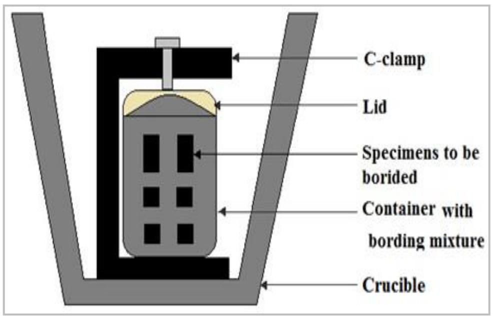


Figure 1: Boronizing-samples at 950°C in the muffle furnace

To observe the microstructure of boronized layer, a sample was selected, sectioned and mounted in an acrylic cold mounting material. Then slow grinding was done in several stages [14]. The samples can be ground with emery papers with grit size 120, 320, 1000, 1500 and 2000. Final polishing was done on billiard cloth using diamond paste. Samples were washed and dried using an air blower, and etched with 3% Nital and 3% Picral solution [12, 14, and 15].

A schematic diagram of pin-on-disc tribometer is depicted in Figure 2**.** The pins were mounted vertically to facilitate the circular flat surface to press against the abrasive paper fixed on a rotating disc [16-18]. The parameters selected for wear testing were, (1) Applied load, (2) Sliding Speed, and (3) Sliding distance. In the current experimental work three varying loads were used. They are 4N, 3N and 2N.

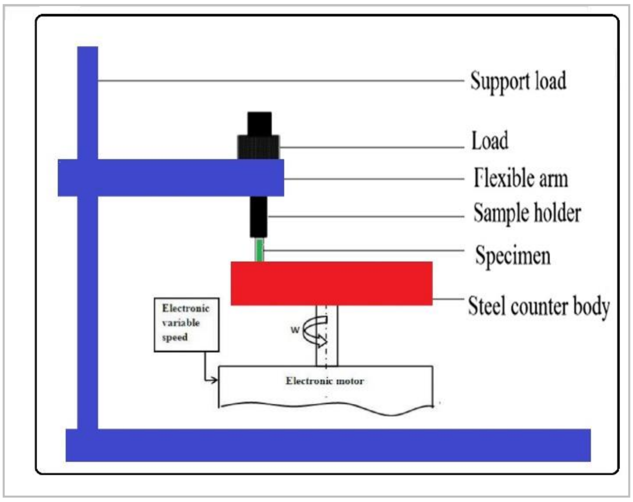
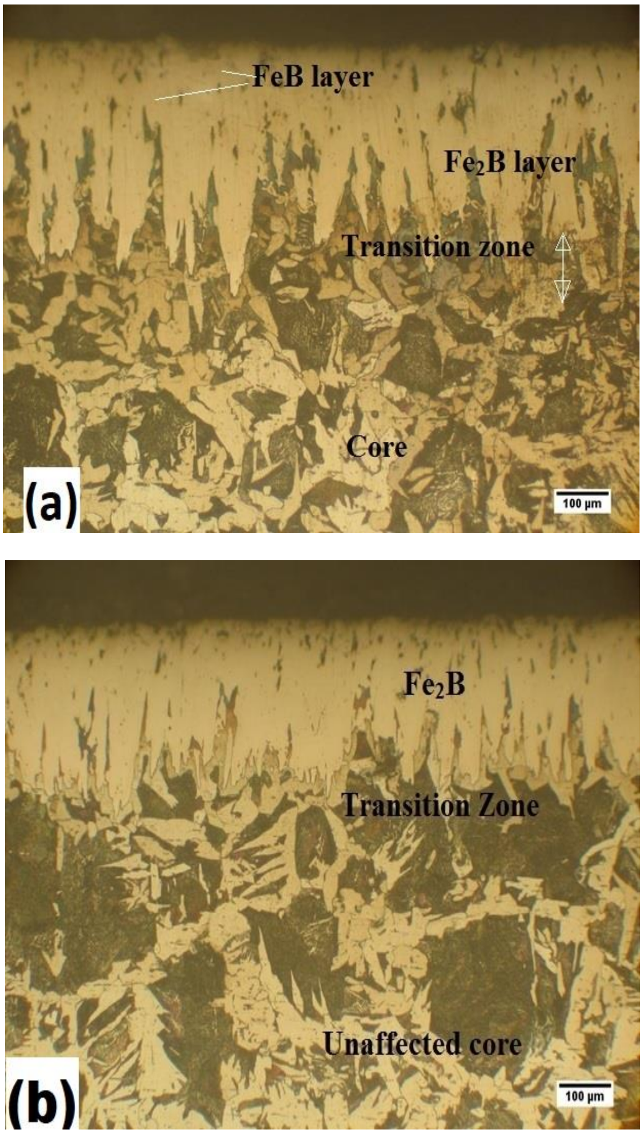


Figure 2: Shematic diagram of Pin-on-disc trobometer.

3 Results And Discussion

The etched specimens were characterized using Carl-Zeiss optical microscope and the images are shown in Figure 3. The microstructure shows the borided region, transition zone and core regions. The acicular needles of borides are seen. The diffused layer thickness was measured at many locations and an average layer thickness was estimated. The boride layer thickness was measured to be 51-110 µm for one hour borided sample, 66 to 122 µm for two hours and up to 132 µm for three hours borided specimen.



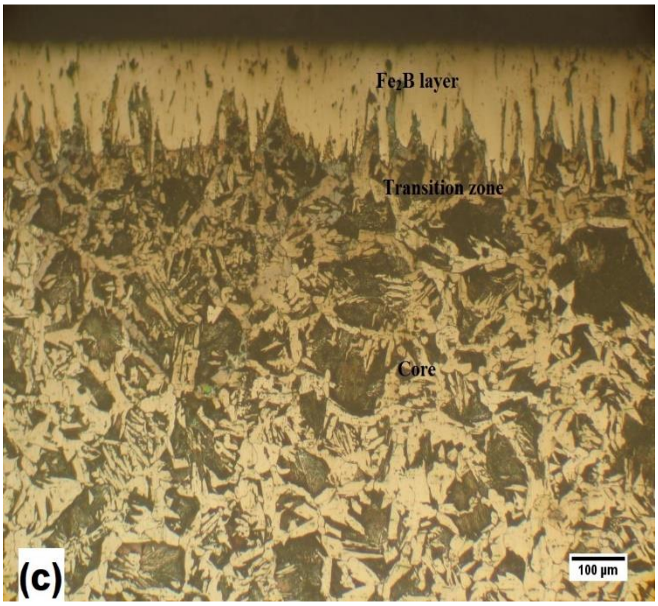


Figure 3: Optical micrographs of the boronized specimen (a) 3hour - 200X, (b) 2hour-200X, (c) 1hour-200X

Microhardness value was measured using Vickers microhardness tester. The load chosen was 50g and dwell time given was 15 seconds. The microhardness achieved for the borided steel at 950°C for one hour, two hours and three hours were measured and the values were plotted against the boronizing duration as shown in Figure 4.(a). The microhardness of borided 1025 steel ranges from 1650 HV to 1880 HV. This value is very high as compared to untreated specimen whose hardness is only 280HV. Figure 4(b) also shows the distribution of microhardness from surface toward the core.

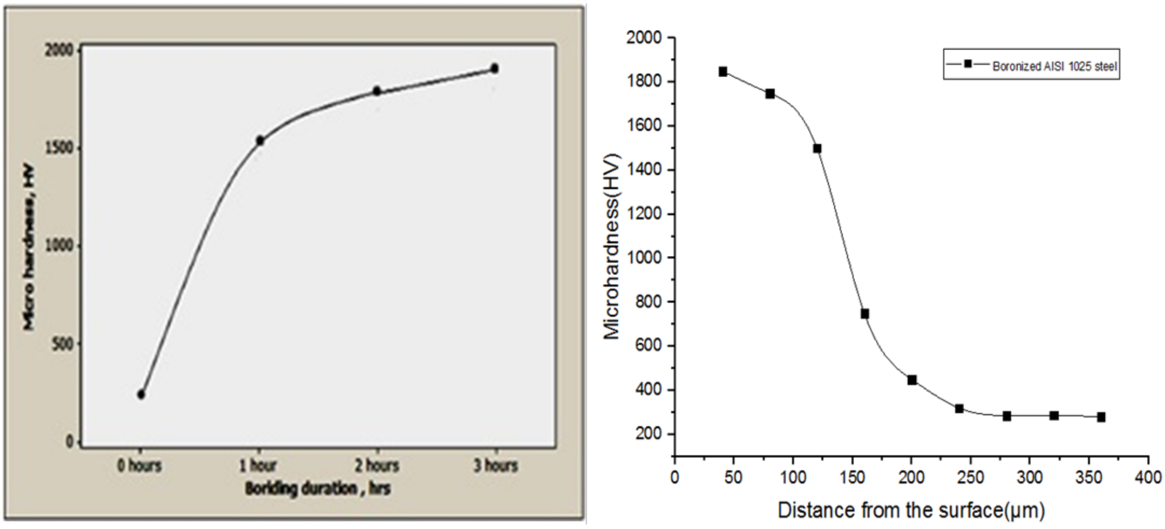


Figure 4: Hardness data of the boronized steel specimen (a) Hardness as a function of boronizing time and (b) Hardness profile of boronized specimen as a function of case depth

The phases present in the boronized layers was analyzed using XRD (Bruker-D8) using CuKα radiation with λ=1.54A. A step of 0.02° was used to scan 2θ from 20° to 90°. The matrixes of the structures were indexed with several planes. In addition to the XRD steel patterns, numerous peaks were observed in the Figure 5. The XRD shows FeB and Fe2B phases.

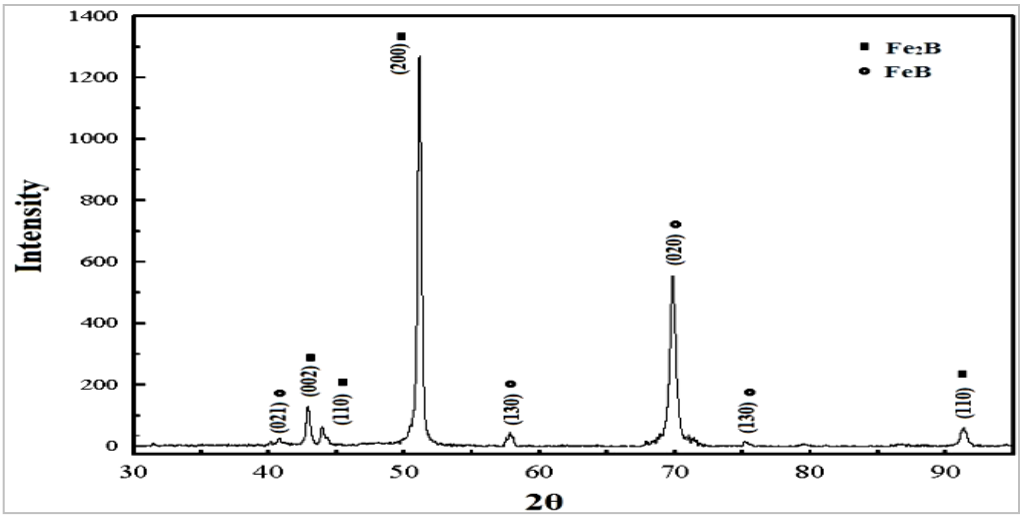


Figure 5: XRD spectrum of boronized specimen

Figure 6 shows the wear resistance of boronized specimen as a function of boriding time under different normal load conditions. The wear resistance was evaluated in accordance with wear rate equation as described below. The wear resistance of the borided specimen increased from 42.68 cm^{-2} to 58.71 cm^{-2} for the load value of 20N. Similarly, wear resistance of boronized specimen increased from 47.83 $cm^{-2}$to 62.63 cm^{-2} for the normal load of 30 N. Further, the wear resistance of boronized specimen increased from 52.84 to 66.24 cm^{-2} for 40 N load. On the other hand the wear resistance of unboronized specimens is found to be in the range of 5.33 cm^{-2} to 7.47 cm^{-2} for the normal load of 20 to 40 N. From this data, it was found that wear resistance of boronized specimen can be enhanced by approximately 60%. Further, data indicates that there is an increase in wear resistance as boriding time duration is increased and there is a decrease in wear resistance with increasing normal load.

Wear resistance was calculated based on the following equation:

Wear volume (W_v) = $\frac{WL}{\rho}$

Wear rate (W_s) = $\frac{V}{S}$

Wear Resistance (W_x) = $\frac{1}{Ws}$ cm^{-2}

Where WL is the weight loss (mg), ρ is density of steel (7.9 g/cm^2),
V refers to the wear volume and S is the sliding distance

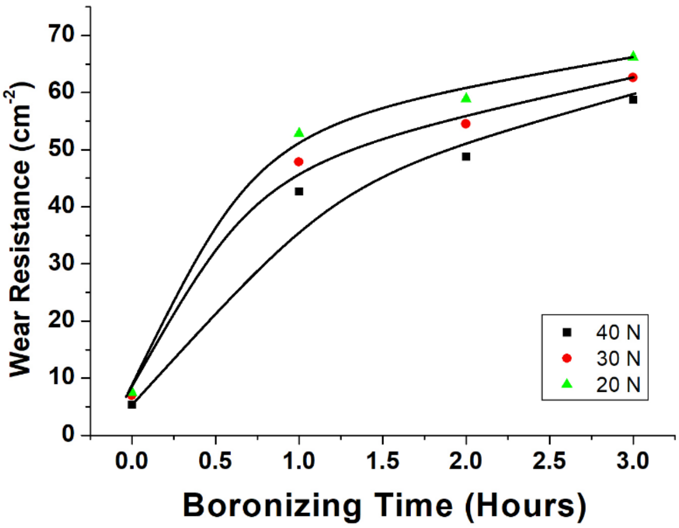


Figure 6: Wear resistance of boronized steel specimen as a function of boronizing time under different normal load condition

CONCLUSIONS

In these experiments, the AISI 1025 steel was pack-boronized conveniently at a high temperature of 950°C for up to three hours. The optical microstructure of pack boronized AISI 1025 steel shows three different regions namely (a) boronized layer (FeB and Fe_2B) (b) transition zone and (c) base material with (Ferrite and Pearlite). The XRD pattern reveals the presence of FeB and Fe_2B. Thickness of boride layer increases with boronizing time. Micro hardness of borided layer ranges between 1650 HV to 1880 HV at 50 g load. The specimen's weight loss (in wear test) is found to be much less for boronized specimens as compared to unboronized specimens. With increase in boronizing time, the wear resistance also increases. With increasing load the weight loss is found to increase.

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