Boriding of high carbon high chromium cold work tool steel

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Abstract. High-carbon high-chromium cold work tool steels are widely used for blanking and cold forming of punches and dies. It is always advantageous to obtain an increased wear resistant surface to improve life and performance of these steels. In this connection boriding of a high-carbon high-chromium cold work die steel, D3, was conducted in a mixture of 30% B4C, 70% borax at 950 °C for two, four and six hours. Case depth of the borided layer obtained was between 40 to 80 µm. After boriding, the surface hardness achieved was between 1430 to 1544 HV depending upon the process time. X-ray diffraction studies confirmed the formation of a duplex compound layer consisting of FeB and Fe2B. It is generally considered that FeB is undesirable because of its inherent brittleness. Post boriding treatment (homogenization) transformed the compound layer into single-phase layer of Fe2B, while surface hardness decreased to 1345-1430 HV. Pin-on-disc wear test showed that wear resistance of the borided samples was superior as compared to non-borided material and increased with boriding time.

1. Introduction

The surfaces of tools, dies and majority of the machine parts are commonly subjected to higher stresses, wear and corrosive damages. In such working conditions, surface properties are often most important for reliable and long economic service life. In order to reduce this loss, properties of the surfaces should be improved. The diffusion of atoms of different elements into the surface of the materials is a commonly used technique to improve surface properties of tools and mechanical parts. Among these surface hardening treatments, boriding is highly effective method for increasing surface hardness, wear resistance, corrosion resistance and high temperature oxidation resistance [1-3].

Boriding is a thermochemical surface treatment that involves diffusion of boron into a substrate at elevated temperatures. Diffusion of boron into the surface of metals and alloys by means of gaseous, liquid or solid substances forms intermetallic borides [4]. Other techniques include plasma boriding and fluidized bed boriding [5]. Boriding can be applied to a wide range of steels including carbon steel, low alloy steel, tool steel and stainless steel. In addition, materials like nickel base alloys, cobalt base alloys, tungsten and niobium can also be borided to obtain very high hardness and wear resistance surface [1-8]. During boriding of ferrous alloys, generally, a boron-compound layer develops which consists of a surface-adjacent FeB layer and a Fe2B underlying layer. If the concentration of boron id kept around 9%, the Fe2B phase grows. On the other hand, if the concentration of boron rises to 16%, FeB forms and grows on the top of Fe2B [2,4]. Other factors that influence the formation of single or duplex layers are potential of the medium, process temperature, time and chemical composition of the substrate material [4, 8-10]. The process temperature is in the range of 700-1000 °C [1-4, 8, 10].

In industry, the high carbon high-chromium cold work tool steels (D type) are the most commonly used cold-work tool steels. They offers high hardenability, low distortion after quenching, high resistance to softening and good wear resistance. They are commonly used for various types of cold
work dies, rolls and punches. The use of appropriate hard coatings on these steels can further improve their wear resistance. Surface treatments provide improved tribological performance [3].

The object of present work is to investigate some physical and mechanical properties of borided high carbon high chromium cold work tool steel, D3. The boriding is performed by molten salt bath technique. Three different boriding durations are selected and a post boriding heat treatment is carried out in an attempt to obtain single phase layer. Metallography, X-ray diffraction (XRD), microhardness, Scanning Electron Microscopy (SEM) and wear test measurements were performed to describe the effect of boriding time on the boride layer morphology, phases, surface hardness and wear properties.

2. Experimental Techniques:
The material used in this study was tool steel (D3) bar. The chemical composition of the material is (wt. pct.) 2.18C, 0.39Mn, 0.21Si, 12.05Cr, 0.35 Ni, 0.55V and 0.008S. The hardness of the as received material was 243 HV. Cylindrical samples, Ø10 mm and 15 mm length were machined from the bar and were cleaned ultrasonically. Thermoreactive diffusion boriding was conducted in molten bath at 950 °C for 2, 4 and 6 hours. The composition of the bath was 30%B4C and 70% borax. After boriding treatment, the samples were quenched in hot water. Post boriding heat treatment was carried out at 800°C for 6 hours in inert gas atmosphere.

The borided samples were cut and the cross section was mounted, polished and etched in 2% nital to measure the depth of the borided layer with the help of optical microscope fitted with a digital camera. The hardness profiles were taken on the polished cross sections from surface to bulk with the help of a microhardness tester. X-ray diffraction studies were carried out to identify the phases in the layer. Pin-on-disc wear tests were performed to study the worn surface and weight loss in non-borided, borided and borided & homogenized samples. The wear machine consisted of two discs. One disc was fitted with 320 grit size SiC carbide paper and acted as a rotor. The second disc was used as sample holder and remained fixed. The sample holding disc was attached to a hydraulic system for applying a load normal to the contact surface. Two sets of samples of each condition were tested. Each sample was tested individually under the same conditions of load and time. A new abrasive paper was used each time. Worn surfaces were examined using SEM and weight loss was calculated to compare the relative wear resistance of non-borided, borided and borided & homogenized samples.

3. Results and Discussion:
The depth of the boride layer was dependent on boriding time as shown in figure1. The average case depth of boride layer after 2, 4 and 6 hours of boriding was about 40, 52 and 90 µm. The boride layer contained 10 to 35 µm deep layer of FeB.

![Figure 1. The boride layer after 2,4 and 6 hours of treatment](image-url)
The hardness profile, figure 2, shows that plateaus of higher hardness bend down after some depth and finally reaches the uniform hardness of the matrix. The maximum surface hardness of boride layer after 2, 4 and 6 hours of boriding was 1430, 1505 and 1544 HV.

![Figure 2](image1.png)

**Figure 2.** Hardness profile with depth of borided and borided&homogenized samples after a) 2; b) 4 and c) 6 hours

X-ray diffraction studies, figure 3, showed an almost single-phase layer of Fe$_2$B after homogenization, figure1b. However, small-scattered traces of FeB were found in outer most layer of the samples borided for six hours. The surface hardness was decreased from 1431, 1505 and 1544 to 1345, 1413 and 1430 HV after homogenization and the same is presented in figure 2. No significant change in case depth was observed after the post boriding treatment.

![Figure 3](image2.png)

**Figure 3.** X-ray diffraction patterns of borided and borided&homogenized samples
The samples tested on pin-on-disc machine were analyzed under scanning electron microscope. SEM study showed grooved features on worn surfaces confirming an abrasive wear condition. SEM study of worn samples borided for 2 hours showed a complete removal of the boride layer along with the substrate. The reasons were less case depth and the presence of isolated patches of hard FeB phase. These patches after detachment from the layer remained trapped between the sample and the abrasive surface resulting in increased weight loss, figure 4(a). In the sample borided for 4 hours, the borided layer was partially removed because the hard FeB was present as a continuous layer very close to the outer edge. This layer resisted the wear for some time and when detached, enhanced the severity of wear mechanism to some extent, figure 4(b). In the samples borided for 6 hours the compound layer was completely removed along with the substrate. In this case, hard FeB layer was continuous but slightly deeper than in the samples treated for 4 hours. During the wear test this layer resisted the wear but once it worn off, the severity of the wear mechanism increased many times due to the trapped FeB particles, causing wear of the substrate, figure 4(c).

The 2 hours samples, which contained no FeB after homogenization, did not show this accelerated wear. The case depth of these samples were almost the same as that of the unhomogenized samples, but the resistance to wear was better, figure 5(a). Similarly, 4-hours borided & homogenized samples showed the same trend. Due to greater case depth, figure 5(b), the boride layer remained even after the test. The 6-hour borided & homogenized samples should have shown the same trend. But the layer was removed upto the substrate, figure 5(c). This was due to the presence of some retained FeB. The FeB particles after detachment increased the wear.

This is supported by the XRD plot for the same sample. Wear resistance of the borided & homogenized samples was superior to the borided samples. The weight loss data is presented in figure 6. The plot further shows that best wear resistance was achieved in samples treated for 4 hours. The reason has already been discussed in preceding paragraphs. The wear mechanism observed was abrasive wear.
4. Conclusions

- Surface hardness was improved from 243 to 1430 HV, after boriding and homogenization.
- Case depth was found sensitive to boriding time while the surface hardness was not significantly changed.
- Homogenized 4-hours samples showed the best wear properties in a pin-on disk rig.
- Borided samples showed better wear resistance than un-borided samples in a pin-on disk rig.

5. References

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