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Pack Boriding – A Low Cost Method to Improve the Wear Resistance of Steels

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ABSTRACT

A relatively new, low cost technique, pack boriding is presented for increasing the wear resistance of steels used in machine components. The borided and unborided specimens were subjected to wear tests under the same conditions and using a pin-on-disc test rig and the results are compared. Other important tests like optical microscopy, microhardness tests were carried out for a comparative study. It was found that boriding significantly improves hardness and tribological behaviour of mild steel. The wear resistance of borided steel is 40% higher than mild steel and the frictional force offered by borided specimen is 70% higher than mild steel. The optical microscope shows that one layer of borite is formed which results in improved wear resistance considering the cost and quality. Pack boriding is a low cost surface hardening process, which can be profitably employed to decrease the wear in steel components in moving parts in machinery.

Keywords: *Boriding, Friction, Wear, Tribology, Microscopy, Mild Steel*

Introduction

Considerable economic losses occur due to corrosion and wear in mechanical parts of machines and equipment during service. In order to reduce the material

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loss, the mechanical properties of the surface region of materials should be improved. One of the methods used to improve the surface hardness and wear resistance is boriding, which has been a recent and more effective surface hardening process than carburising or nitriding. The boron source may be in solid, liquid, or gaseous state. However, boronizing in solid state has technical advantages, such as ease of treatment, achieving a smooth surface, and simplicity of the required equipment. Solid state boronizing is similar to pack carburising, and it can be carried out under inert atmosphere in tightly closed containers. The boronizing agent is placed in a heat resistant box and specimens are packed in this powder. Tooth-shaped structure is a characteristic property of the boride microstructure in low carbon steels. The microstructures of the case, and the interface between the case and base material, depend on various parameters like concentration of carbon and alloying elements in base material, the treatment temperature and duration of treatment. Long slim boride needles occur in mild steels; the higher the ratio of alloying elements, the less is the degree of needle or teeth formation. The degree of bonding of the boride layer and the base metal is good because of their tooth shape.

Spence and Maklouf proposed a mechanism that describes potassium fluoborate activated pack boriding of steels and validated with thermodynamic and empirical evidence. The process occurs via three distinct steps: release of boron trifluoride gas from the potassium fluoborate activator, formation of a thin layer of iron boride on the steel's surface accompanied by the release of carbon tetrafluoride and graphite, and finally, growth of the iron boride layer by direct reaction of iron with boron carbide [1]. Martini et al. reported that the resistance to dry sliding of borided samples was better than that displayed by samples submitted to alternative surface treatments (e.g. gas nitriding) and lower that that measured for a WC–Co hard metal coating [2]. Selcuk et al. determined the friction and wear characteristics of AISI 1020 and 5115 steel surfaces improved by various thermochemical heat treatments such as carburizing, carbonitriding and boronizing. They carried out with pin-on-disc sample configurations and weight losses were determined as a function of sliding distance and applied load. The friction behaviours of tested samples were also examined. Thus, the heat treating capacity of a simple steel such as AISI 1020 was determined and compared with other treated steel samples [3]. The properties of borides formed on the AISI 1040 and AISI P20 steel substrates were investigated by Uslu et al. Boronizing was performed at 800, 875, and 950°C for 2, 4, 6, and 8 h by using Ekabor 2 powders. The hardness of borides was about 1500 HVN. The depth of boride layers ranged from 10 μm to 180 μm. Growth kinetics of the borided layer was analyzed by measuring the extent of penetration of the FeB and Fe_2B to substrates as a function of boriding time and temperature [4]. Majumdar studied the laser surface alloying with silicon of mild steel substrate using a high-power continuous wave CO_2 laser with an objective to improve wear resistance. A significant improvement in microhardness is achieved by laser surface alloying and remelting to a maximum of 800 VHN when silicon alloyed surface is melted using nitrogen shroud with carbon coating. A detailed wear study (against diamond) showed that a significant improvement in wear resistance is obtained with a maximum improvement when remelted in nitrogen atmosphere followed by carbon coating [5]. Boriding of the surface of a tool steel using boron powder and the plasma transferred arc process was investigated by Lakovou et al. It was shown that this method is an easy and effective technique in producing uniform alloyed layers with a thickness of about 1.5 mm and a hardness between 1000 and 1300 HV [6].

Literature reports many methods which are expensive to carry out. The cost of LASER coating kits and Plasma Tranferred arc machines mentioned in the literature are in the range of US$20,000 to 30,000 each; whereas the cost of the muffle furnace used in this work for pack boriding is in the range of US$ 1,000 to 5,000. Ekabor 2 powder used by Uslu et al. [4] is a commercial powder having a registered trademark. The composition of ekabor 2 powder is a trade secret and is not published in literature; but the composition of the powder mix used in this paper for pack boriding is given in the following section so that researchers and R & D establishments can freely use this mix for enhancing the surface quality of mild steel.

Induction modification of boriding had been carried out, and it is effective but more expensive in terms of equipment cost compared to the simple muffle furnace used in this work. Gaseous boriding is also expensive because it needs controlled atmosphere furnace and vacuum pump to create a non oxidising atmosphere. These are more expensive than the simple muffle furnace used in this work without any special atmosphere. Molten salt boronising creates toxic waste disposal problems. Even though boron carbide costs around US $100 per kg, we use only a small amount of it in the mix used in this work (4%). Hence, this work provides a low cost pack boriding technique which increases the wear resistance and the co-efficient of friction of mild steel.

Materials

Mild steel is the specimen used for pack boriding process as a starting step. Subsequently, other steels will be taken up for these investigations. The mixture chosen for pack boriding includes the following ingredients: Silicon Carbide, Boron Carbide and Potassium Fluoborate. After a careful study, the following composition was identified for good results: 90% SiC, 4% BC, 6% Potassium Fluoborate. The three ingredients were thoroughly mixed for one hour in a ball mill type of mixer without using balls.

Experimental

The cylindrical specimen used for pack boriding was carefully ground and polished on series of emery papers. Then it was cleaned in acetone. It was then immersed in the boriding powder mix (preheated for moisture removal) kept in a stainless steel container. On every side of the sample to be borided atleast 20 mm thick powder was maintaned. The space between container and the lid was sealed using fire clay. A small C clamp was used to keep the reaction box setup airtight, otherwise it is liable to open when it gets hot and the gas pressure inside builds up. The entire setup is kept in a graphite crucible filled with sand. A muffle furnance (max temperature 1100°C) was used for boriding treatment. After the treatment, the furnace was switched off. After the crucible cooled down to room temperature it was taken out of the furnace. The lid of the crucible was opened and the borided samples were taken out. The borided specimens were polished with metallographic grade emery sheets. Disc polishing was done to give fine metallographic finish. The specimens were also examined by optical microscopy and microphotographs were taken. The Vickers hardness values of borided and unborided specimens were measured and compared. The specimens were subjected to wear tests, using a pin-on-disc machine supplied by Ducom Company, Bangalore, India for adhesive wear test, as per the following conditions given in Table1.

Table 1: Experimental Conditions

Sliding Velocity	2 m/s
RPM	382
Sliding Distance	1000 m
Load	5 kg
Time	8.33 min
Track Dia	100 mm

Results & Discussions

The optical micrograph indicates the formation of the typical borided microstructure, thus validating the experimental procedure selected as a valid and viable process, bearing cost and quality in mind. Typically only one type of boride has formed, instead of two types of boride phases, FeB and Fe_2B. A single phase boride is always expected to have better wear resistance. (Figure 1). The microhardness value, tested in Vickers Microhardness tester under a 200 gms load was 1200 VPN for the borided specimen, as against 200 VPN for the unborided specimen. When we compare the hardness values obtained by borides using expensive processes on alloy steels, this value of hardness through low cost means on mild steel is appreciable.

The wear tests indicate that the wear in unborided mild steel is significantly more than in borided steels, as seen in weight loss measurements (Table 2). The percentage of material removed in borided specimen is only 7.2% as compared to 12% experienced by mild steel. The wear resistance of mild steel is significantly enhanced by the low cost pack boriding; about 40% increase in wear resistance is observed. The wear rate(in micrometers) plots also indicate that the wear in unborided steel in significantly more than in borided steel after 500 seconds. Also, the rate of wear seems to take an upward slope after 500 seconds, indicating progressively increasing rate of wear in unborided steel. In borided steel, the rate of wear seems to flatten out after 500 seconds (Figures 2 & 3). The frictional force appears to be almost constant with time in both cases. The magnitude of the force is less in the case of unborided specimens

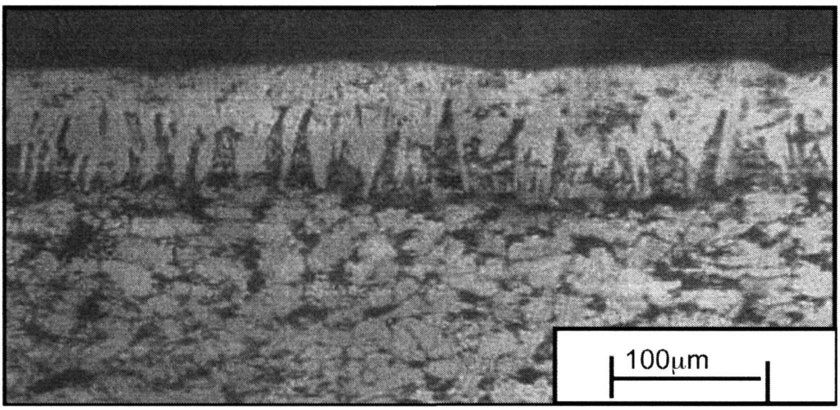

Figure 1: Optical Micrograph of the Borided Specimen

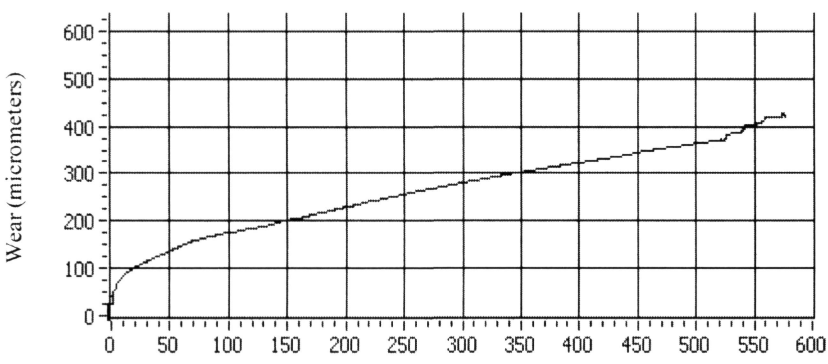

Figure 2: Wear of Mild Steel

than in borided specimens (Figures 4 &5). Mild steel offers a friction force of 10 N after running in. Borided specimen offers a friction force of more than 20 N initially but maintains 17 N after running in period. Thus it can be seen that borided specimen offers higher frictional force and a higher wear resistance as compared to mild steel specimens.

A Mechanism to describe the potassium fluo-borate activated pack boriding of steels is proposed as follows:

$$KBF_4 = KF + BF_3 \tag{i}$$

$$4\ Fe + 2\ BF_3 = 2\ Fe_2B + 3F_2 \tag{ii}$$

$$B_4C + 6\ F_2 + O_2 = 4\ BF_3 + CO_2 \tag{iii}$$

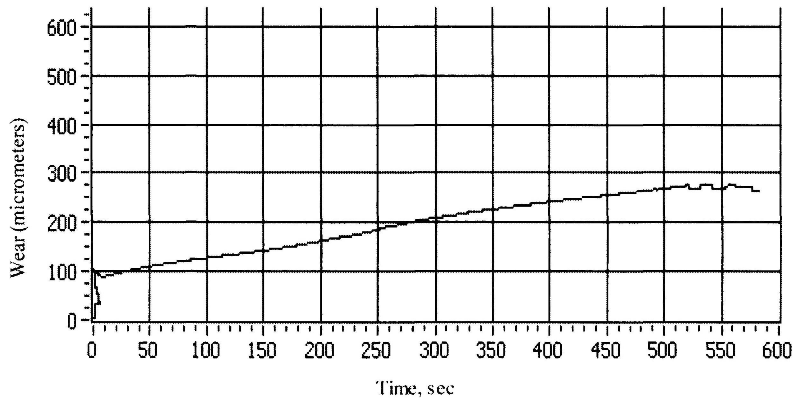

Figure 3: Wear of Borided Steel

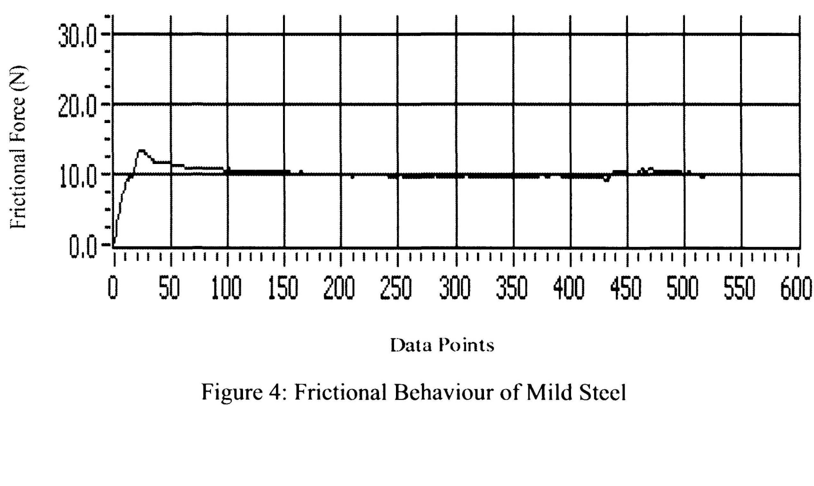

Figure 4: Frictional Behaviour of Mild Steel

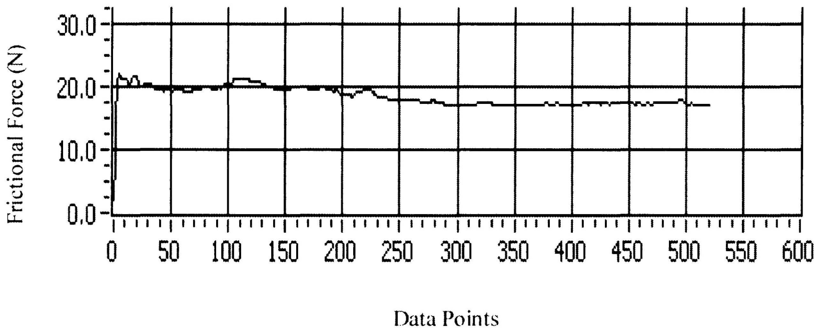

Figure 5: Frictional Behaviour of Borided Steel

Table 2: Material Removal by Wear

Specimen	Original weight	Material removed	Percentage of Material Removed
Mild Steel	3.361g	0.401g	12%
Borided Steel	3.534g	0.254g	7.2%

The process occurs via three stages: The first is the release of boron trifluoride gas from the potassium fluoborate activator. This boron trifluoride gas then reacts with hot iron surface and releases nascent boron atoms into the steel surface forming a thin layer of iron boride. The fluorine gas formed reacts with boron carbide in the presence of oxygen. The presence of carbon dioxide in the container gives a protective atmosphere, thus preventing oxidation and scaling of the steel surface. The silicon carbide or alumina used as filler provides free space for the movement of the gas phase.

Conclusions

A boriding mix of 90% SiC, 4% BC, 6% Potassium Fluoborate is found to give good results through pack boriding. The borided specimen has attained a hardness of 1200 VPN whereas the mild steel has a hardness of only 200 VPN under a 200 gms load. Friction and wear tests using pin-on-disc test rig is presented; It is found that borided steel offers higher co-efficient of friction and higher wear resistance as compared to mild steel. A Mechanism to describe the potassium fluo-borate activated pack boriding of steels is presented. Pack boriding is a low cost surface hardening process, which can be profitably employed to decrease the wear in steel components in moving parts in machinery.

Acknowledgements

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