The Abrasive Wear Behaviour of Boronized and Untreated AISI1008 and AISI1045 Steels

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ABSTRACT: In this study, the abrasive wear resistance of surface hardened AISI 1008 and AISI 1045 plain carbon steel specimens by pack boronizing method at 950 °C for 2, 4 and 6 hours and the untreated specimens made of the same kind of steels are experimentally compared and investigated in laboratory conditions. The surface hardnesses and the observed boride layer thicknesses are also measured. At the end of the study, it is observed that surface hardness and abrasive wear resistance of boronized AISI 1008 and AISI 1045 steels are much better than the untreated ones.

1. INTRODUCTION

The use of boron derivatives on metal surfaces is one of the oldest technologies of human civilization (Rus et. al., 1985). Among various uses, Moissan has applied boron diffusion technique for the first time on pieces of metal surfaces in 1895 for hardening and wear resistance of the material used (Özsoy, 1991; Hunger and Trute, 1994). Boronizing has achieved its first industrial applications as an alternative surface hardening methods in the early 1970's, and has been continuing (Özsoy, 1991). In nature, boron exists only in the form of compounds, e.g. boric acid (H3BO3), boric acid salts (Ca and Na), well-known one is borax ($Na2B4O_7.10H_2O$). The borates namely; colemanite, tincal, ulexite and kernite are the most commercial sources for purified boron derivatives. Amorphous Boron, boron trioxide, boron carbide, boron nitride, diborane and ferroboron are the mainly consumed chemicals, especially in the USA, EU, Japan and Russia (Bozkurt, 1984). The frequent consumption of these raw and fine materials are in glass, ceramic, textile, leather, cosmetic, detergent, pharmaceutical, agricultural, and chemical industries. Another important usage is in the nuclear reactors for protection and control due to high neutron absorption property. Major applications are in the metallurgy field as hard metal and alloying element, surface hardening materials, and as lubricants and corrosion inhibitors for steel in wire drawing operations.

The estimated boron world reserves are 1.21 billion tons of which 644 million tons are known to be located in Turkey, representing 63% of the total (Anonymous, 2001). In contrast, 70 % of the borate production is conducted in the United States whereas 18 % is produced in Turkey and the remaining 12 % among various countries (Bozkurt, 1984). Although Turkey possesses the biggest reserves on boron, it has lower share with 19 % in the world market (Anonymous, 2001).

2. GENERAL FEATURES OF BORONIZING

Boronizing is a thermochemical surface hardening process in which boron atoms are diffused into the surface of a metal workpiece to form a hard layer of metal borides with the base material (Hutchings, 1992; Hunger and Trute, 1994). This process is especially applied to steels and carried out above the austenite transformation temperature between 800 and 1050 °C, and generally time range varies from 1 to 8 hours depending on the boronizing method used (Hutchings, 1992).

The formation of boride layers depends on the material composition, boron chemical activity of the boronizing media, boronizing temperature and time of treatment, additional heat treatments, as well as the boronizing method (Tsipas and Rus, 1987). If ferrous based or steel materials are boronized, iron boride layer contained ($FeB+Fe_2B$) or (FeB or FejB) microstructure will be obtained on material surface (Subrahmanyam and Gopinath, 1984; Tsipas and Rus, 1987; Gopalakrishnan et. al., 2001). Iron bondes are quite interesting compounds, presenting not only the typical properties of special ceramic materials such as very high hardness but also metal properties such as thermal and electrical conductivity (Palombarini and Carbuciccbio, 1987). In the case of iron boride layer formations, a single-phase FeiB saw-tooth shaped layers are needed for many industrial applications to avoid brittleness, crack formation, and flaking compared to the two-phase iron boride layers (Biddulph, 1977; Rus et. al., 1985; Hutchings, 1992).

Compared to other conventional thermochemical processes like carburizing and nitriding, boronizing results in a much higher hardness (>1500 HV), high resistance to wear, oxidation, erosion, corrosion and a much lower friction coefficient (Mai and Tarkan, 1973; Biddulph, 1977; Rus et. al., 1985; Gopalakrishnan et. al., 2001). Boronizing can be applied to a wide range of steel alloys including carbon steel, low alloy steel, tool and stainless steel and cast iron. In addition, some non-ferrous materials such as nickel, tungsten, cobalt, molybdenum and titanium based alloys can be boronized (Hutchings, 1992; Hunger and Trute, 1994). Morphologic studies of the interfaces between the boride layer and the substrate two different types of layer are observed. First, saw-toothed type interface with the substrate on plain carbon and low alloy steels. Second, relatively straight type interface with the substrate on high carbon and high alloy steels. The saw-tooth type interface has better results than the relatively straight interface by considering the mechanical properties. Since the saw-tooth shaped structure adheres very well to the substrate (Eyre, 1975; Hunger and Trute, 1994). The thickness of boride layer ranges from 20 to 300(xm depending on material, boronizing temperature and time of treatment (Hunger and Trute, 1994). Thick layers (>125um) for abrasive wear reduction and thin layers (>25pm) for adhesive wear reduction are recommended in practice.

In boronizing, very high surface hardness is the main advantage. Remarkable feature of the boride layer is its ability to retain its hardness even after additional heat treatments. Also in sliding wear conditions, friction developed between sliding surfaces produces heat and this may seriously affect the structure of the surface by softening, so wear increases fastly. The boronized surface retained same structure and a high hardness up to 1000 °C and this appears to be unique for surface diffusion treatments (Eyre, 1975; Evtifeev and Sin'kovskii, 1985). For abrasive wear conditions, abrasive wear would be very much reduced if the surface hardness of a metal part is greater than that of the abrasive (Biddulph, 1977; Vasil'eva et. al., 1985). Because of its extremely high hardness, the boronized surfaces provides good resistance against abrasion, wear and erosive damage (Singhal, 1977).

Boronizing process can be carried out in solid, liquid and gaseous state according to the state of boron source. Since conventional boronizing processes such as molten salt baths boronizing and gas phase boronizing have many problems due to environmental contamination, toxic, explosive nature, etc. modified boromzing processes such as the plasma boronizing process have been studied recently (Yoon et. al., 1999). However, boromzing in the solid media having technical and economical advantages is used extensively in present applications.

3. EXPERIMENTAL DETAILS

At the investigation, boronized and untreated AISI 1008 and AISI 1045 steel specimens were compared experimentally for the point of view surface hardness and abrasive wear resistance. Chemical composition of the steels were shown in Table 1. Boronizing was carried out at 950 °C for 2, 4 and 6 hours with a commercial boronizing agent EKabor®2 powders in the heat resistant steel boxes. After boronizing, the boxes were cooled to room temperature and then the specimens were cleaned from the dust for the experiments. No other heat treatment was applied to the untreated specimens made up of hot-rolled steels. The thickness of the boronized layers were measured by Olympus PMG3 optical microscope. Shimadzu HMV-2000 Vickers microhardness equipment was used to measure the surface hardness of the all specimens under 50 g load.

Table 1. Chemical compositions of samples (wt %)

Material	C	Si	Mn	P	S
AISI1008	0.080	0.220	0.430	0.014	0.010
AISI1045	0.483	0.372	0.738	0.016	0.028

Abrasive wear tests were carried out with block-on-disc configuration on a Plint TE53 universal wear test machine (Fig. 1). The metal disc (60 mm diameter and 16 mm width) of the wear test machine was coated with 500 grit aluminium oxide ($A1_20_3$) abrasive paper. The contact between the specimen and the abrasive paper covered disc was supplied by a constant 42 N load which was the minimum load in the wear test machine. In all wear experiments, a speed of the disc 100 rev min^{-1} (0.31 m s^{-1}) was chosen and weight losses were measured after 250, 500, 1000, 1500, 2000 and 2500 revolutions (rev). The specimen run on a single track during the test and fresh abrasive paper was used for each wear test. Weighing processes after the wear experiments were done by Précisa 125 A deal which was precise as 10^{-4} g. The wear experiments were repeated three times and their average was used in the reporting. The wear rates were calculated according to the formula (Anonymous, 1994) given on the operating instructions manual of Plint TE53 universal wear test machine used in the present study. These values were used for comparison. The wear rate *w* was defined as the volume of material removed per the applied load *L* per the total sliding distance *S* after 2500 rev fulfilled in where the volume removed was defined as the mass loss *Am* in specimen weight per the specimen material density *p (w - Am / pLS).* All the wear tests were performed at room temperature and humidity. The surface hardness and boride layer thickness measurements were repeated ten times.

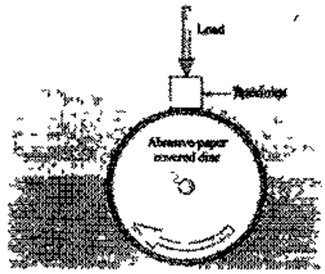
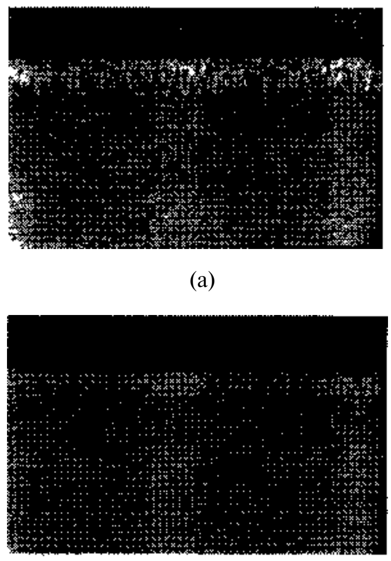


Figure 1. Schematic illustration of the abrasive wear test configuration.

4. RESULTS AND DISCUSSION

At the end of the boronizing on the surface of AISI 1008 and AISI 1045 steels obtained boride layer is shown in Figure 2. The measured minimum and maximum surface hardness values of all specimens are given in Table 2 and the average boride layer thicknesses of all boronized specimens are given in Table 3.



(a)

(b)

Figure 2. Microstructures of the 950° C 4 hrs boronized (a) AISI 1008 (b) AISI 1045 steel (x50).

Table 2. Minimum and maximum surface hardnesses of all specimens (HVo.os)

	Material	
Treatment condition	AISI1008	AISI 1045
Untreated	125-135	205-225
Boronizing 2h	1211-1563	1239-1584
Boronizing 4h	1268-1648	1268-1648
Boronizing 6h	1211-1648	1378-1839

Considering the results of surface hardnesses of all specimens, it is observed that there is a significiant increase in the boronized samples in comparison with untreated samples. When the surface hardness values of AISI 1008 steel are compared, as a result of boronizing minimum 1211 HV and maximum 1648 HV is obtained but the hardness value in the untreated samples is measured as around 130 HV. The surface hardness values of AISI 1045 steel are compared; in boronized samples minimum 1239 HV and maximum 1839 HV and the untreated samples average 215 HV is measured.

Table 3. Average boride layer thicknesses of all boronized specimens (urn)

	Material	
Boronizing condition	AISI 1008	AISI 1045
950°C-2h	84.10	68.80
950°C-4h	95.10	78.25
950°C-6h	143.50	111.25

When Table 3 is examined, for each test materials it is clearly observed that the boride layer thickness is increased with increase of the duration of boronizing. In Table 3, it is also observed that with increasing carbon content of the steel, the layer thickness values decrease.

At the end of the wear experiments, the samples boronized at 950 °C temperature for 2, 4 and 6 hours AISI 1008 and AISI 1045 steel specimens abrasive wear test results determined as the weight losses, the wear rates and results are given in Tables 4, 5 and shown in Figure 3.

Table 4. Weight losses and wear rates of AISI 1008 steel untreated and boronized specimens

			Boronizing 950 °C		
	AISI 1008	Untreated	2 h	4 h	6 h
Weight losses (mg)	250 rev	26.8	4.2	4.4	4.4
	500 rev	37.9	6.1	5.7	5.5
	1000 rev	52.3	7.2	6.7	6.2
	1500 rev	64.0	8.0	7.6	7.1
	2000 rev	80.8	8.8	8.2	7.6
	2500 rev	103.7	9.7	9.1	8.2
Wear rates ($x10^{-8}$ mm^2/N)		66.56	6.22	5.84	5.26

Table 5. Weight losses and wear rates of AISI 1045 steel untreated and boronized specimens

			Boronizing 950 °C		
	AISI 1045	Untreated	2 h	4 h	6 h
Weight losses (mg)	250 rev	21.7	4.1	3.2	4.7
	500 rev	29.9	5.1	4.7	5.6
	1000 rev	41.0	6.2	6.3	6.4
	1500 rev	55.8	7.5	7.2	6.9
	2000 rev	64.0	8.2	8.0	7.3
	2500 rev	72.9	8.9	8.9	8.1
Wear rates ($x10^{-8}$ mm^2/N)		46.83	5.71	5.71	5.20

When Table 4 is examined, it is observed that the amount of wear rates of untreated AISI 1008 steel specimens is 10.7 to 12.6 times higher than the boronized specimens. When Table 5 is examined, it is observed that boronized AISI 1045 steel specimens are worn 8.2 to 9 times less than the untreated specimens. Comparison of the wear experimental results of untreated specimens, AISI 1045 steel specimens worn 1.42 times less than AISI 1008 steel specimens. Thus, increase surface hardness in the untreated specimens results in a decrease in weight losses (or wear rates).

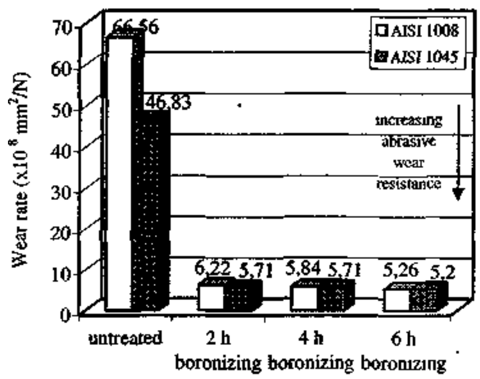


Figure 3. Abrasive wear test results of AISI 1008 and AISI 1045 steels (Abrasive: Al_2O_3- 500 grit abrasive paper).

When all wear experimental results are investigated, the untreated samples are the most worn samples as expected (Fig. 3). For all samples studied, the highest weight loss is observed in AISI 1008 untreated specimens and the least weight loss is observed in AISI 1045 steel 950 °C six-hour-boronized specimens. When the wear experimental results of all boronized samples are taken into consideration, it is observed that all boronized samples show nearly the same wear behaviour. In Figure 3, it is also seen that all boronized samples are much wear resistant than the same untreated steels.

5. CONCLUSIONS

At the end of the boronizing process, the surface hardness values and abrasive wear resistance (against alumina abrasive paper) of AISI 1008 and AISI 1045 steel samples increase more than the untreated steel samples.

The boronized specimens showed that while the boride layer thicknesses are decreased, the surface hardness values are nearly the same with increasing carbon content of the test material.

Boride layer thicknesses are increased with increasing duration of boronizing process and positively affect the wear mass loss.

When boronized AISI 1008 and AISI 1045 Steel wear behaviour are compared with each other, the boride layers do not show significant difference in wear behaviour: However, the effect of the boronized plain carbon steel on the abrasive wear resistance for different carbon content in materials as a substrate has to be investigated in detail.

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