Osmangazi Üniversitesi Müh.Mim.Fak.Dergisi C.XVII, S.2, 2004
Eng.&Arch.Fac.Osmangazi University, Vol.XVII, No: 2, 2004

THE ABRASIVE WEAR BEHAVIOUR OF BORON STEELS

Ümit ER[1]

ABSTRACT : *In this study, the abrasive wear behaviour of untreated and heat treated AISI (SAE) 15B35H and 15B41H boron steel specimens are experimentally investigated in the laboratory conditions and the wear results are compared with respect to their hardnesses. At the end of the study, it is observed that the abrasive wear resistance of boron steel specimens increased with increasing hardness values of the test material.*

KEYWORDS : *Boron steel, wear, abrasive wear*

BORLU ÇELİKLERİN ABRAZİF AŞINMA DAVRANIŞLARI

ÖZET : *Bu çalışmada, AISI (SAE) 15B35H ve 15B41H işlemsiz ve ısıl işlemli borlu çelik numunelerin abrazif aşınma davranışları laboratuvar şartlarında deneysel olarak incelenmiş ve aşınma sonuçları sertlikleri açısından karşılaştırılmıştır. Çalışma sonunda, borlu çelik numunelerin abrazif aşınma dirençlerinin test malzemesinin artan sertlik değerleriyle arttığı gözlenmiştir.*

ANAHTAR KELİMELER : *Borlu çelikler, aşınma, abrazif aşınma*

Osmangazi Üniversitesi, Mühendislik-Mimarlık Fakültesi, Makina Mühendisliği Bölümü,
Batı Meşelik, 26480 ESKİŞEHİR

I. INTRODUCTION

Wear can be defined as the removal of material from a solid surface as a result of mechanical interactions [1,2,3]. There are two main types of wear found in the majority of industrial situations; abrasive (50 %) and adhesive (15 %) wear [1]. Abrasive wear can be defined as the removal of material due to penetration of hard particles or surface asperities of a harder counterbody into the softer surface of a solid in sliding contact [2,4]. Abrasive wear generally occurs in coal conversion processes, earthmoving, mining, mineral benification, tillage, and many other situations. Abrasive wear processes are divided into two categories: two-body and three-body abrasive wear [1,5]. Two-body abrasive wear occurs when a rough surface or fixed abrasive particles slide across a surface to remove material. In three-body abrasive wear, the particles are loose and may move relative to one another while sliding across the wearing surface [1,5,6,7]. The former accounts for the majority of industrial situations met in practice. Two-body abrasive wear testing is more often carried out with pin-on-disc arrangements [1].

There are three principal ways of strengthening the structure of steels by (a) alloying, (b) heat treating and (c) cold work hardening [6]. Their relative effects on abrasive wear are shown in Figure 1. Pure metals and annealed steels show direct proportionality between abrasive wear resistance and bulk hardness whereas hardened steels depart from this line, showing improved abrasive wear resistance over the annealed state. The abrasive wear behaviour of heat treated carbon steels is thought to be a function of carbon content, represented by a family of wear curves in Figure 1. [6,8,9].

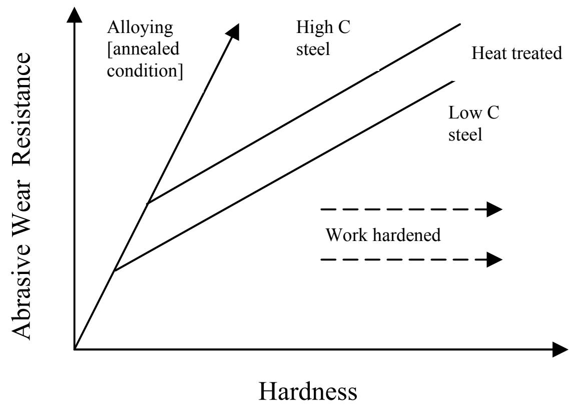

Figure 1. The effect of structural state on the abrasive wear resistance of steels [6].

Boron is added to steels in order to increase their hardenability. The addition of only 0.0015 % soluble boron to a suitably protected base steel can produce an increased hardenability compared to that obtained by additions of about 0.6 % Mn, 0.7 % Cr, 0.5 % Mo or 1.5 % Ni [10,11]. Typical applications for boron steels are earthmoving and agricultural tools, track segments for forestry machines, snow plough wear plates, crushers and other process machinery, forklift truck arms, mower blades, chain components and fasteners [11,12].

In this study, the abrasive wear behaviour of two different boron steels are investigated and the wear results are compared in view of their hardnesses. Thus, the relation between the wear rates and the hardness values of boron steels considered is investigated and comparison is made with the variation given in Figure 1. Additionally, a research on boron steels produced recently by Erdemir Iron and Steel Plant in form of plate and provided to the industry is also carried.

II. EXPERIMENTAL DETAILS

II.1. Materials

In this study, AISI (SAE) 15B35H and 15B41H boron steels were chosen as test materials. Chemical composition of these steels were shown in Table 1. All tests were carried out heat treated and untreated cubic (12.7x12.7x12.7 mm^3) steel specimens. The heat treated specimens were austenitized at 843 °C for 30 min and quenched to room temperature in water or in oil and some samples tempered for 1 and 2 hours at 400 °C. No other heat treatment was applied to the untreated specimens made up of hot-rolled steels. Heraeus K1252 furnace was used for heat treatment and Zwick 3106 type macrohardness tester was used to measure the hardness of all specimens. Microstructure photographs were taken with Nikon Eclipse L150 optical microskope.

Table 1. Chemical compositions of specimens (wt %)

Material	**C**	**Si**	**Mn**	**P**	**B**
15B35H	0.33	0.22	1.13	0.01	0.0012
15B41H	0.41	0.20	1.39	0.01	0.0012

II.2. Abrasive Wear Test

Abrasive wear tests were carried out with block-on-disc configuration on a Plint TE53 universal wear test machine (Fig. 2). The metal disc (60 mm diameter and 16 mm width) of the wear test machine was coated with 240 grit silicon carbide (SiC) abrasive paper (3M 734). 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, the speed of the disc was chosen as 0.31 m s^{-1} (100 rev min^{-1}) and weight losses were measured after 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. After each experiment the weight losses were measured with a Precisa XB 220A scales which had a precision's degree of 10^{-4} g. The wear experiments were repeated three times and the average of the results of weight losses was used. The wear rates (w) were calculated according to the formula [13] 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 Δm in specimen weight per the specimen material density ρ ($w = \Delta m / \rho LS$). All the wear tests were performed at room temperature and humidity. The hardness measurements were repeated five times.

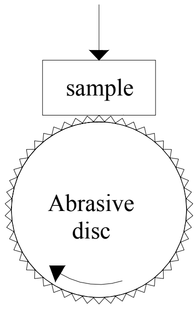

Figure 2. Schematic illustration of the abrasive wear test configuration.

III. RESULTS AND DISCUSSION

The minimum and maximum hardness values measured of all specimens are given in Table 2. Considering the results of hardnesses of all specimens, it is observed that there is a significiant increase in the heat treated samples in comparison with the untreated samples. Tempering of the quenched in water or in oil steel specimens at 400 °C for 1 and 2 h seems to reduce the hardness of the steel substrates. When the measured minimum and maximum hardness values of AISI 15B35H steel are compared, as a result of quenched in water min. 54 HRC and max. 57.5 HRC is obtained but the hardness value in the untreated samples is measured as around 19 HRC. The measured minimum and maximum hardness values of AISI 15B41H steel are compared; again in water quenched samples min. 58 HRC and max. 61 HRC is obtained and in the untreated samples average 23 HRC is measured.

Table 2. Minimum and maximum hardnesses of all specimens (HRC)

Material	Heat treatment condition	Min.-max. hardness
15B35H	Untreated	19 – 19.5
	QW	54 – 57.5
	QW and tempered at 400 °C for 1 h	45 – 48
	QW and tempered at 400 °C for 2 h	44 – 47
	QO	50 – 52
	QO and tempered at 400 °C for 1 h	42 – 47
	QO and tempered at 400 °C for 2 h	44 – 46
15B41H	Untreated	21 – 24.5
	QW	58 – 61
	QW and tempered at 400 °C for 1 h	48.5 – 49
	QW and tempered at 400 °C for 2 h	47 – 48
	QO	57 – 57
	QO and tempered at 400 °C for 1 h	48 – 49
	QO and tempered at 400 °C for 2 h	46 – 47

QW=Quenched in water; QO=Quenched in oil

The comparison of the hardness results of quenched in water and quenched in oil specimens, shows the fact that the results of quenched in water are much harder than that of the quenched in oil. When Table 2 is examined, it is also observed for each of the test materials that the hardness increases with the increase in the carbon content of steel.

Microstructures of the specimens of untreated, quenched in water and quenched in oil AISI 15B35H and 15B41H steels are shown in Figure 3.

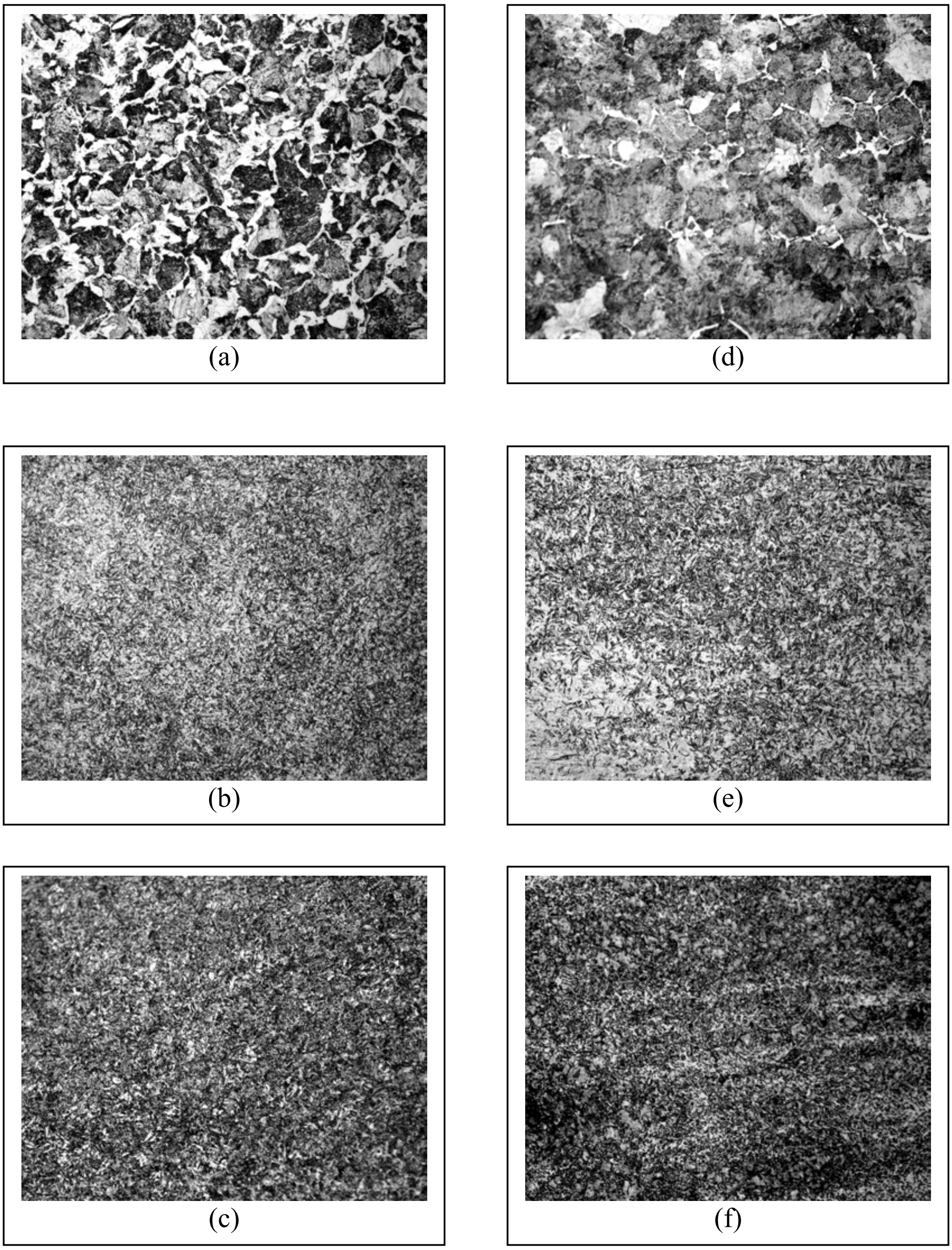

Figure 3. Microstructures of AISI 15B35H steel untreated, (b) quenched in water, (c) quenched in oil and AISI 15B41H steel (d) untreated, (e) quenched in water, (f) quenched in oil (× 200).

At the end of the wear experiments, abrasive wear test results are determined as the weight losses of the samples of untreated, quenched in water or in oil and quenched and tempered at 400 °C temperature for 1 and 2 h AISI 15B35H and 15B41H steel specimens. Then the wear rates are calculated. The results are summarized comprehensively in Tables 3 and 4 and shown in Figures 4, 5 and 6.

Table 3. Weight losses of AISI 15B35H specimens (mg)

Material: AISI 15B35H	Weight losses (mg)				
Heat treatment condition	**500 rev**	**1000 rev**	**1500 rev**	**2000 rev**	**2500 rev**
Untreated	38,00	42,97	45,73	47,93	49,77
QW	19,07	20,47	21,50	22,33	23,30
QW and tempered at 400 °C for 1 h	29,37	32,53	34,10	35,17	36,07
QW and tempered at 400 °C for 2 h	30,97	33,60	35,03	36,20	37,13
QO	21,07	22,43	23,53	24,37	25,10
QO and tempered at 400 °C for 1 h	30,93	33,27	34,67	36,23	37,20
QO and tempered at 400 °C for 2 h	33,73	36,57	38,20	39,60	40,57

QW=Quenched in water; QO=Quenched in oil

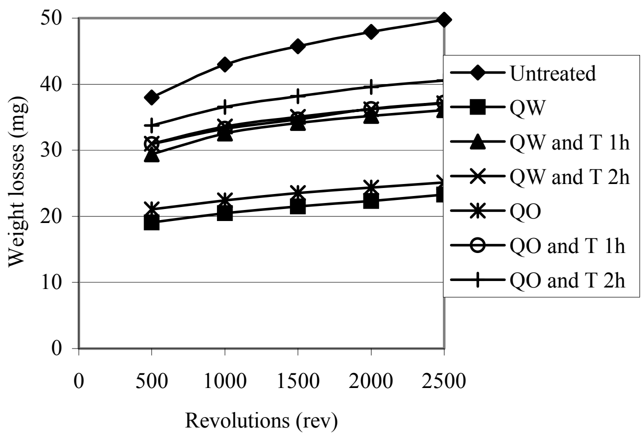

Figure 4. The weight losses of AISI 15B35H specimens (mg) (Abrasive: SiC-240 grit).

Table 4. Weight losses of AISI 15B41H specimens (mg)

Material: AISI 15B41H	Weight losses (mg)				
Heat treatment condition	**500 rev**	**1000 rev**	**1500 rev**	**2000 rev**	**2500 rev**
Untreated	30,03	35,83	38,33	40,00	41,37
QW	18,27	19,70	20,57	21,50	22,20
QW and tempered at 400 °C for 1 h	27,60	29,77	31,17	32,37	33,60
QW and tempered at 400 °C for 2 h	29,27	31,53	33,37	34,43	35,50
QO	17,27	20,00	20,87	22,27	22,97
QO and tempered at 400 °C for 1 h	28,20	30,33	31,83	33,33	34,33
QO and tempered at 400 °C for 2 h	28,13	33,07	35,20	36,37	37,40

QW=Quenched in water; QO=Quenched in oil

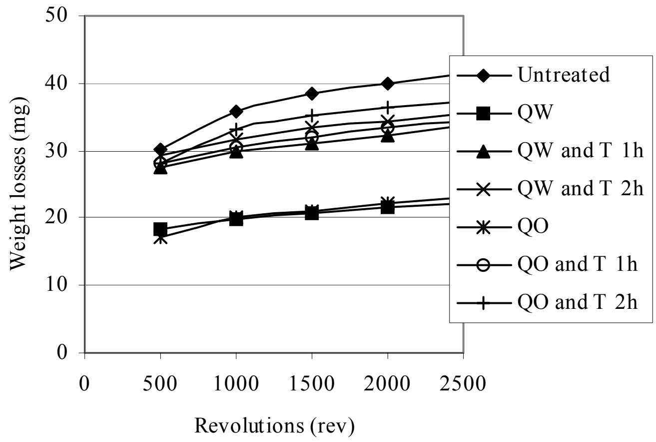

Figure 5. The weight losses of AISI 15B41H specimens (mg) (Abrasive: SiC-240 grit).

As shown in Table 3 and in Figure 4, the highest weight loss is observed in untreated specimens and the least weight loss is observed in water quenched specimens for all samples of AISI 15B35H steel. The highest weight loss is also observed in untreated specimens and the least weight loss is also observed in water quenched specimens for all samples of AISI 15B41H steel as given in Table 4 and in Figure 5. It is also seen in Tables 3, 4 and in Figures 4, 5 that the water quenched and water quenched and tempered boron steel specimens are much wear resistant than the oil quenched and oil quenched and tempered boron steel specimens. When all wear experimental results are investigated, it is obtained that the untreated specimens are the most worn specimens as expected. For all samples studied, the highest weight loss is observed in AISI 15B35H untreated specimens and the least weight loss is observed in AISI 15B41H water quenched specimens. When the experimental wear results of all samples are taken into consideration, it is determined that the weight losses are inversely proportional to the hardnesses.

The specimen wear rate is found in all cases to be constant over the revolution (rev) of the wear test. Figure 6 shows the result of mean wear rate over the 2500 rev wear test duration versus heat treatment condition for the AISI 15B35H and AISI 15B41H steel is worn by silicon carbide 240 grit abrasive paper under a fixed load of 42 N.

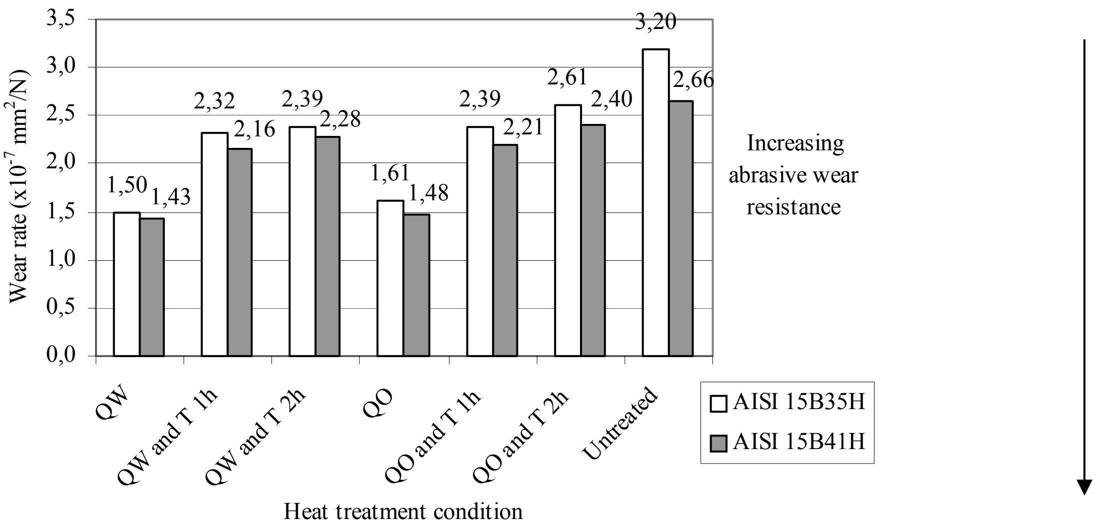

Figure 6. Wear rates of AISI 15B35H and 15B41H specimens (Abrasive: SiC-240 grit).

In Figure 6, it is seen that the all AISI 15B41H specimens are worn less in comparison with all AISI 15B35H specimens. The highest wear rate is determined in AISI 15B35H untreated specimens (3.20 x 10^{-7} mm^2/N) and the least wear rate is determined in AISI 15B41H water quenched specimens (1.43 x 10^{-7} mm^2/N) when the results of abrasive wear experiments carried against silicon carbide abrasive papers of all specimens are compared. Comparison of the wear experimental results of untreated specimens shows that AISI 15B41H steel specimens are worn 1.2 times less than AISI 15B35H steel specimens because the increase in hardness with increase in carbon content in the untreated specimens results in a decrease in the wear rates. In Figure 6, it is also seen that all the heat treated specimens are much wear resistant than the same untreated steels. Thus, all the heat treated specimens tested in the laboratory abrasive wear test are found to have a lower wear rate than the untreated specimens. This result show that the increasing hardness have a positive effect upon an increase in the abrasive wear resistance. The results of the present study are in good accordance with the characteristics given in Figure 1.

IV. CONCLUSION

In the present study, the abrasive wear behaviour of two different boron steels are compared experimentally by considering hardness and abrasive wear rate.

The hardnesses of untreated AISI 15B35H and AISI 15B41H boron steel specimens are increased with increasing carbon content of the test material and this positively effect the abrasive wear resistance.

The wear rate obtained from the oil quenched and the oil quenched and tempered conditions is higher than that obtained from the water quenched and the water quenched and tempered conditions.

Boron steels investigated show an inverse proportionality between the wear rate (or the weight loss) and the hardness.

The effect of the different boron and carbon content included boron steels has to be investigated in detail for the point of abrasive wear behaviour view.

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