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Erosion behavior and mechanism of boronised steels

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Abstract: Boronising of steels is a hardening process to get high surface hardness. The erosion resistance of boronised steels was researched with the use of four kinds of erodent, i.e. glass, alumina, quartz and silicon carbide. The erosion rate increases rapidly with erodent hardness and severe erosion occurs with high impacting angle range of hard particles. SEM analysis indicated that chipping is caused by repetitive impacting of glass and quartz, whereas by alumina and silicon carbide impacting, chipping, and that plastic flow take place simultaneously and the erosion rate reaches the peak value when the impacting angle is above 60°.

Keywords: Boronising of steel, Erosion behavior, Erodent
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INTRODUCTION

Boronising of steels has been a specific surface treatment with wide applications in industry. The chemical properties of the boride layer in corrosive environments were studied by Tsipas et al. (1999). Poor cavitation-erosion resistance and high abrasive wear resistance of boronised cast Cr-Ni steel was reported by Mann (1997). Erosion-corrosion behavior and the mechanism of mild steel was investigated by Capan et al. (1994). But the erosion mechanism of mild steel with deeply-boronised surface layer has not been studied systematically.

The boronised layer of steel is generally regarded as brittle. Erosion damage of brittle materials has long been considered as caused by three types of surface fracture: radial crack, conical crack and lateral crack. The last one often leads to material removal, especially at higher impact velocity (Evans, 1979). Plastic flow can also be observed in the erosion process of brittle materials, and even plays an important role in some situations (Evans, 1979; Levy et al., 1987). Chipping may occur by either lateral crack or plastic flow (Hutchings, 1981). The boronized layer of mild steel by common process is typically 100－200 microns thick, not enough against severe wear situations. A newly developed case process for the deeply-boronized surface layer of steel was used to prepare the test samples whose erosion mechanism was studied in this work.

EXPERIMENTAL PROCEDURES

Sample preparation

Test samples were prepared by pack processing with a new type of boronization medium. The boronized layer of 1020 steel was composed of FeB and Fe_2B with thickness of more than 360 microns. The erosion resistance of several materials (mild steel 1020, stainless steel 302 and WC-Co cermet) was measured and compared with that of the deeply-boronized mild steel samples.

Apparatus and procedure

The erosion test was carried out in a blast erosion rig described in the work (Zhu et al., 1987). Erodent impacted on the samples at the rate of 10 g/min at velocity of about 90 m/s. Because of the density difference of the target sample materials, the volume erosion rate E_v (mm^3/g) was employed as the specific worn volume vs. employed erodent mass.

Table 1 Hardness of samples and hardness ratio H_p/H_m

Test materials		Boride	Cermet	302(AISI)	1020(AISI)
Density (g/cm^3)		6.8 7.7	14.5	7.8	7.8
	Hv	1300	1150	206	128
SiC	3200	2.5	2.8	15.5	25.0
Al_2O_3	2500	1.9	2.2	12.1	19.5
SiO_2	1350	1.0	1.2	6.6	10.5
Glass	500	0.4	0.4	2.4	3.9

Note: H_p: hardness of erodent; H_m: hardness of samples; The density of FeB was 6.8; and the average density of FeB and Fe_2B was taken as 7.7. With light impacting of glass and quartz particles, 6.8 was used; and with severe impacting of alumina and silicon carbide, 7.7 was used. Because the soft erodent attacked, the outer most surface layer of FeB, and the hard erodent eroded into the Fe_2B layer.

RESULTS AND DISCUSSIONS

Angular dependence of erosion

The erosion rate of samples with different types of erodent depended on the impacting angle of particles impinging on the sample. It can be seen from Figs. 1 and 2 that the erosion rate of the boronised steel sample by soft particle impacting, glass and silica, appeared to change little with angle increment, similar to the cermet sample whose erosion rate, however, was higher than it. The sample behavior against soft particles erosion was superior to that of both mild steel and stainless steel samples, especially within the low angle range. Figs. 3 and 4 show that with hard erodent attack, however, the erosion rate rose rapidly and reached the peak value above 60°. This behavior is consistent with typically brittle erosion behavior reported (Levy et al., 1987).

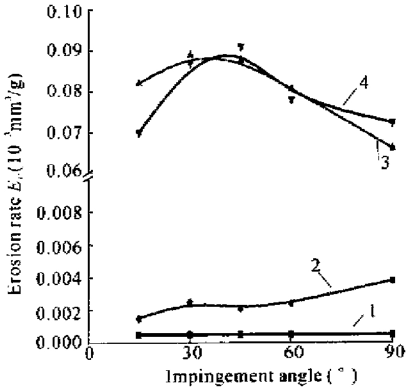


Fig. 1 Angular dependence of erosion rate with glass particles at 90 m/s
1. cemet; 2. boride; 3. 302 (AISI); 4. 1020(AISI)

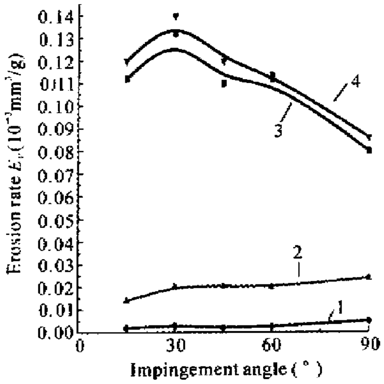


Fig. 2 Angular dependence of erosion rate with quartz particles at 90 m/s
1. cemet; 2. boride; 3. 302 (AISI); 4. 1020(AISI)

The erodent velocity had two effects on surface material removal: plowing and cutting due to its horizontal component and plastic deformation, chipping or pitting due to its vertical component. Under low angle impacting the normal component was small and limited particle penetration into the hard surface of the asboronised sample and, consequently, the plowing and cutting on the sample surface. Therefore, with impacting of either hard or soft erodent particles, the wear rate of boronised samples at low attack angle appeared limited.

With increment of impacting angle above 60° the normal component of the velocity rose accordingly, and the repetitive impacting of the particles caused penetration, deformation, crack and chipping of the sample surface with intrinsically hard and brittle boride layer. In this situation the hardness of the erodent played a main role for surface damage.

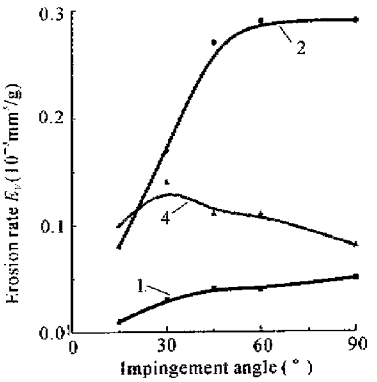


Fig. 3 Angular dependence of erosion rate with Al_2O_3 particles at 90 m/s

1. cemet; 2. boride; 4. 1020(AISI)

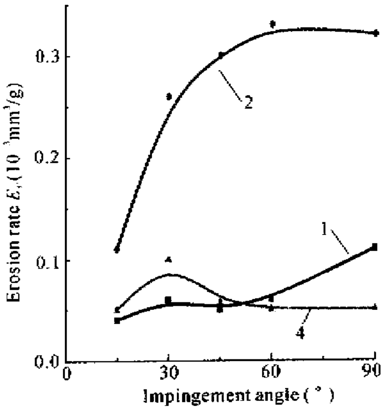


Fig. 4 Angular dependence of erosion rate with SiC particles at 90 m/s

1. cemet; 2. boride; 4. 1020(AISI)

Effect of erodent hardness on wear

The erosion rate of the boronized samples changed greatly with the hardness of the erodent employed. With impact of glass particle of 500 Hv, the erosion rate of the boronised sample was much less than that of any type of steel and was close to that of cermet (Fig. 1). Similar results occured with B 50 Hv quartz particles whose erosion rate was slightly higher than that of cermet (Fig. 2), but rose rapidly with erodent hardness. Fig. 3 and Fig. 4 show that the erosion rate of boronised sample was much higher than that of other samples with alumina and SiC erodents, especially within the high impact angle range where the peak value appeared in plateau form above 60°.

The hardness ratio H_p/H_m of erodent to target was employed to illustrate the hardness effect on erosion behavior. Fig. 5 indicates that when the ratio was less than 1, the boronized layer had good erosion resistance. The erosion rates increased very rapidly with H_p/H_m increment. It seemed that under either low or high impact angle, the particle penetration into the sample surface was the prerequisite condition for the erosion process according to the H_p/H_m value. Besides, the angle dependence of erosion was not significant and the erosion rate curves showed little deviation above 60° impacting angle.

During contacting period the particle energy was composed of the following portions: elastic and plastic deformation energy, crack nucleation and propagation energy of the target samples; elastic and plastic deformation energy, rebound energy and particle-split energy of the erodent; contact heat energy, etc. (Zhu et al., 1987). For soft particle impacting the penetration effect on the boronised sample was limited and so cutting, plowing or chipping were limited as the erodent's kinetic energy was largely consumed on itself in rebounding, splitting, contact-heating, etc. The hard erodent's penetration into the surface of the boride sample, resulting in consequent cracking within high angle range impacting, and plowing and chipping within low angle range impacting, led to wear of the boronised steel sample.

Study of wear mechanism

The erosion mechanism of the boronized samples changed greatly with erodent hardness. At the initial stage, hard erodents caused severe crack of the outermost brittle FeB layer and consequent removal of surface material (Fig. 6). The crack net could be transmitted into the subsurface layer (Fig. 7a) and expose the less brittle Fe_2B phase to erodent impacting. Microchipping also had an important role at high angle impacting (Fig. 7b) and obvious plastic flow and microchipping occured at low angle impacting

(Fig. 8). The debris are shown in Fig. 9. The morphology comparison of the crack net and debris suggested that chipping resulting from brittle microcrack was a little deformed by hard particles impacting. It is generally regarded that erosion of mild steel with hard erodent is dependent on the multiparticle impacting effect(Evans, 1979). Therefore the boronized samples had higher erosion rate than that of steel samples, especially within high impacting angle range.

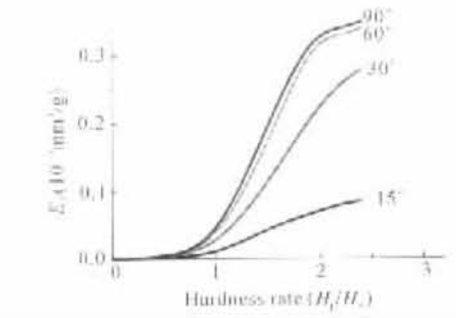
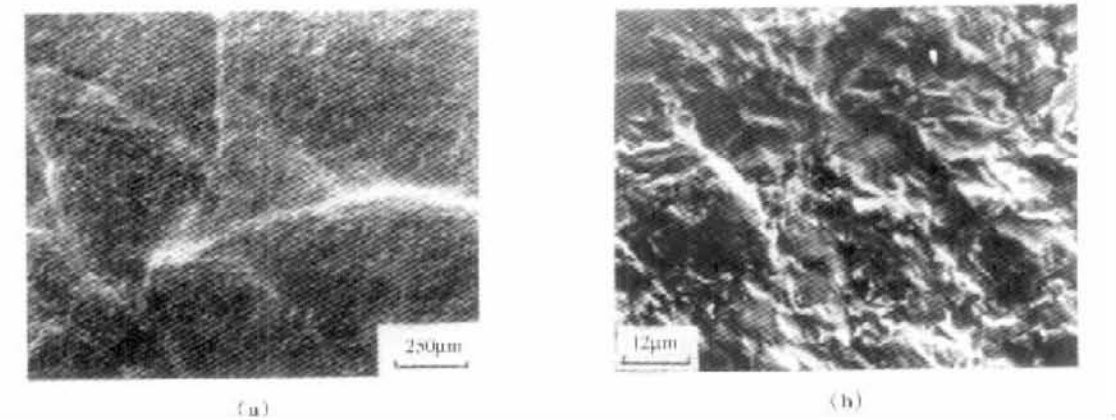


Fig. 5 **Effect of hardness ratio on erosion of boronised samples.**

Fig. 6 **SEM of worn boronised sample in the initial stage with Al_2O_3 at 90° impacting angle.**



(a) (b)

Fig. 7 **SEM of worn boride sample in the steady stage with Al_2O_3 at 90° impacting angle.**
(a)microcrock net; (b) microchipping

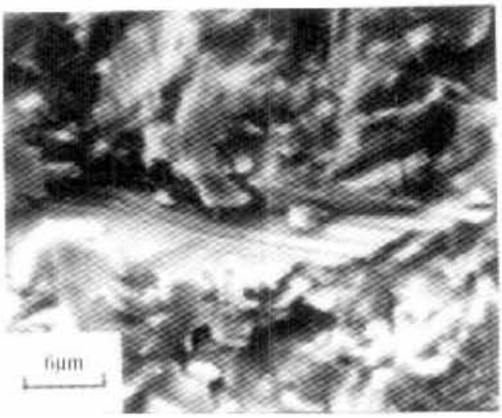


Fig. 8 **SEM of worn boronised sample in the steady stage with Al_2O_3 at 30° impacting angle.**

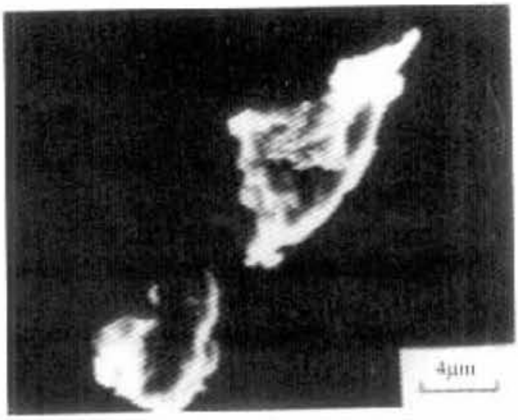


Fig. 9 **SEM of debris of boronised sample with Al_2O_3 at 90° impacting angle.**

Under soft impacting, the sample surface was smooth and without evident plastic flow (Fig. 10a), although a crack net was found on the worn surface (Fig. 10b). Therefore the erosion mechanism can be derived as cracking and chipping by repetitive impacting. The reason for the less severe erosion could be that the soft particles broke down during the impacting process and consequently spent some impact energy, thus leading to less surface damage(Zhu et al., 1987).

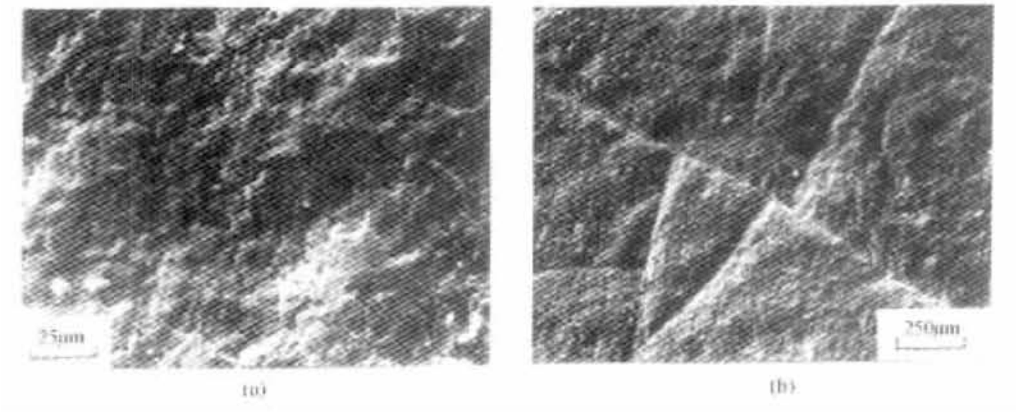


Fig. 10 SEM of worn boride sample in the steady stage with SiO_2 at 90° impacting angle.
(a)smooth sample surface; (b) a microcrack net

Different erosion mechanisms have different angular dependence. With glass and quartz impacting, chipping causes material removal of the boride sample, especially within high impingement angle range. With alumina and SiC impacting, plastic flow, cracking and chipping occur. Plastic flow (plowing) has an role at low impingement angle range. The effect of cracking and chipping led to erosion peak value above 60°angle.

CONCLUSIONS

1. The deeply-boronized layer of 1020 steel has superior resistance to soft particles erosion by glass and quartz, especially within the low impingement angle range. However, with hard erodent(such as alumina and SiC) impacting the erosion rate increases rapidly. The new type of boronizition processing has a potential application in soft particle erosion environments.

2. With soft particle erosion, surface cracking and chipping of the boronised samples occurs by repetitive impacting, especially within high impacting angle range.

3. With hard erodent, the material removal of the samples is caused by surface chipping accompanied with plastic flow, and severe cracking occurs , especially above 60° impingement angle.

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