Study on Cr-Rare earth-Boronizing of the steel 45 at low temperature

Xingdong Yuan\textsuperscript{a,b}, Bin Xu\textsuperscript{b*}, Yucheng Caib\textsuperscript{*}
\textsuperscript{a} School of Materials Science and Engineering, Shandong University, Jinan 250061, China
\textsuperscript{b} School of Materials Science and Engineering, Shandong Jianzhu University, Jinan 250101, China

Abstract

The Cr-Rare earth-boronized layers were fabricated on the steel 45 at 650°C for 6h. The microstructure, phase composition, microhardness and tribological properties were studied using X-ray diffraction (XRD), scanning electron microscopy (SEM), microhardness tester and wear tester. The results showed the Cr-Rare earth-boronized layer was composed of single Fe2B phase. A sawtooth morphology was obtained in the Cr-Rare earth-boronized layer and the microstructure of the Cr-Rare earth-boronized layer was compact and dense. The thickness of the boride layer is about 23\textmu m. The boride tooth was thin and straight. The microhardness of the Cr-Rare earth-boronized layer was 1200HV~1700HV, and first increased with the increase of distance from surface and then decreased when the distance from surface is longer than 7.5\textmu m. The hardness gradient of the boride layer is lessened. The wear resistance of steel 45 is greatly improved by Cr-Rare earth-boronizing.

© 2013 The Authors. Published by Elsevier B.V.
Selection and peer-review under responsibility of the Chinese Heat Treatment Society.

Key words: Cr-Rare earth-Boronizing; low temperature; surface; wear resistance

1. Introduction

1.1. Boronizing, an effective surface modification technique, has been widely used in industry. This is a technique by which active boron atoms are penetrated by thermodiffusion followed by chemical reaction into the surface (P.X. Yan, Y.C. Su,1995;M. Keddam,2006). Due to boron being an element of relatively small size, a number of metals can be boronized (ferrous, nickel and cobalt alloys; metal-bonded carbides; etc.) (M.A. Béjar , R. Henríquez, 2009; Cataldo J, Harraden D, Galligani F,2000). Boriding can be made through mixtures of powders, salts, molten...
oxides, as well as gas mediums and pastes (I. Campos et al., 2005; A.K. Sinha, Boronizing et al., 1991; A. Graf von Matuschka. Boronising et al., 1980; G. Wahl). This treatment is generally performed between 973K and 1277 K (K. Bartsch, A. Leonhardt, 1999). Many studies have been done on the acquisition of boronized layers, boronizing mechanism, phases of boride layers and their properties (I. Campos et al., 2007; I. Campos et al., 2008; I. Campos et al., 2007; P.X. Yan et al., 2001; I. Campos et al., 2008). There is one problem in this process, however, that the structure and properties of the base materials are influenced considerably by the high temperature and long time of treatment (Junji Morimoto et al., 2009). In order to decrease the boronizing temperature, few research works had been carried out (K. Bartsch, A. Leonhardt, 1999; Junji Morimoto et al., 2009).

The aim of the present work was to fabricate Cr-Rare earth-boronized layers on the surface of steel 45 at 650°C for 6h.

2. Experimental procedure

45# carbon steel was used for the RE-Chrome-Boronizing process. The steel sample was cut into two kinds of specimens with size of 10mm×10mm×12mm and 31mm×6.5mm×3mm. The samples were cleaned first with 200 grade emery paper, then with acetone ultrasonically. The solid boronizing technique was used to boronize the steel samples. The source of boron for the boronizing treatment was the powder consisting of ferroboron, fluoroborate potassium, high carbon ferrochrome, lanthanum chloride, graphite and other constituents, which is listed detailed in Table 1. All the samples were covered with this powder inside a sealed metallic container, and then the sealed metallic container was placed inside a conventional furnace. All the boronizing processes were carried out at the temperature of 650°C for 6h. The morphology and thickness of boride layers were investigated using a digital low vacuum scanning electron microscopy. The presence of boride formed in the borided layer at the surface of the steel 45 were determined by XRD analysis using a Cu Kα radiation and the voltage and current values were 40KV and 40mA, respectively. The Vickers microhardness tests were carried out with HX-1000 microhardness tester. The tribological property of boronized layers was performed on a block-on-ring wear tester (Model M-2000) under oil-lubricated condition. All tests were carried out at a velocity of 200r/min and the load of 1500N. In order to detect the tribological properties of boronized layers, some steel 45 samples were quenched in water with the hardness of 52~53HRC. The wear test was conducted on the surfaces of steel 45 quenched in water and the surfaces of steel 45 Cr-Rare earth-boronized at 650°C for 6h.

| Components                  | High carbon ferrochrome | LaCl₃ | KBF₄ | Ferroboron | C | Other constituents |
|-----------------------------|--------------------------|-------|------|------------|---|-------------------|
| composition                 | 5                        | 4     | 5    | 60         | 15| 11                |

3. Results and discussion

3.1 X-ray diffraction

The result of XRD analysis conducted on the steel sample Cr-Rare earth-boronized at 650°C for 6h is shown in Fig. 1. It can be seen in Fig. 1 that the boride layer formed on the surface of steel 45 was composed of single Fe₂B phase. It is reported that the formation of single Fe₂B phase would be beneficial for overcoming the embrittlement of boronized layers (P.X. Yan, X.M. Zhang, J.W. Xu, Z.G. Wu, Q.M. Song, 2001).
3.2 SEM examination of the boronized layer

Fig. 2 shows the SEM micrograph of the cross-section of steel 45 Cr-Rare earth-boronized at 650°C for 6h. It can be seen that the boride layer is compact and dense. It is expected that the vacancies resulted from Kekendaer Effect was filled up by Rare-earth and Cr elements, which leads to the denseness of the boride layer. The zigzag “teeth” shape structure of boride layer can also be observed, which is prerequisite for the adherence with the steel substrate (A. Kuper, X. Qiao, H.R. Stock, P. Mayr. Surf, 2000; K.S. Nam, K.H. Lee, S.R. Lee, S.C, 1998). The boride tooth was thin and straight. The thickness of the boride layer is about 23μm.

3.3 Microhardness measurement

The microhardness value of the boride layer Cr-Rare earth-boronized at 650°C for 6h along the thickness is
shown in fig. 3. It can be seen that a hard boride layer with a hardness of 1200 ~ 1700 HV was obtained. The microhardness of the boride layer first increases with the increase of the distance from the boride layer surface and then decreases when the distance from the boride layer surface is longer than 7.5μm. It also can be seen that the hardness gradient of the boride layer is lessened. The gradual hardness gradient may be attributed to improvement of the embrittlement of the boride layer.

3.4 Tribological properties

The wear of quenched steel 45 and Cr-Rare earth-boronized steel 45 is shown in fig. 4. It can be seen from fig. 4 that the wear of boride layer decreases with the increase of sliding distance. During the early period of friction, abrasive wear happened severely due to the low density of the boride layer. It also can be seen that the wear of quenched steel 45 is higher than that of Cr-Rare earth-boronized sample when the sliding distance is longer than 2250m. In other words, the wear resistance of steel 45 is greatly improved by Cr-Rare earth-boronizing.
Fig. 5 shows the friction coefficient of quenched steel 45 and Cr-Rare earth-boronized steel 45. The result indicates that the friction coefficient of quenched sample is slightly higher than that of Cr-Rare earth-boronized sample. It is expected that the vacancies result from diffusion were occupied by Cr and Rare earth elements, which leads to the densification of the boride layer. Furthermore, the formation of the stable rare earth compounds on the boundaries reduces the brittleness of the boride layer.

4. Conclusions

(1) The Cr-Rare earth-boronized layer was composed of single Fe$_2$B phase.
(2) A sawtooth morphology was obtained in the Cr-Rare earth-boronized layer and the microstructure of the Cr-Rare earth-boronized layer was compact and dense. The thickness of the boride layer is about 23μm. The boride tooth was thin and straight.
(3) The microhardness of the Cr-Rare earth-boronized layer was 1200HV~1700HV, and first increased with the increase of distance from surface and then decreased when the distance from surface is longer than 7.5μm. The hardness gradient of the boride layer is lessened.
(4) The wear resistance of steel 45 is greatly improved by Cr-Rare earth-boronizing.

Acknowledgments

This work is part of a research program financed by Research Fund for the College science and technology plan of Shandong Province (Project No. J12LA11).

References

P.X. Yan, Y.C. Su,1995.Metal surface modification by B-C-nitriding in a two-temperature-stage process. Materials Chemistry and Physics ; 39: 304-308.
M. Keddam,2006. Computer simulation of monolayer growth kinetics of Fe$_2$B phase during the paste-boriding process: Influence of the paste thickness. Applied Surface Science; 253:757-761.
M.A. Béjar , R. Henríquez, 2009. Surface hardening of steel by plasma-electrolysis boronizing. Materials and Design 30: 1726-1728.
Cataldo J, Harraden D, Galligani F,2000. Boride surface treatments. Adv Mater Process; 157:35-38.
I. Campos, O. Bautista, G. Ramírez, M. Islas, J. De La Parra, L.Zúñiga,2005. Effect of boron paste thickness on the growth kinetics of Fe$_2$B boride layers during the boriding process. Applied Surface Science; 243: 429-436.
A.K. Sinha, Boronizing, ASM Handbook, OH, USA, J,1991. Heat Treatment ;4: 437.
A. Graf von Matushka. Boronising, Carl Hanser Verlag, Munich, FRG, 1980.
G. Wahl.,975. Durferrit-Technical Information. Reprint from VDIZ117. p.785- 789.
K. Bartsch, A. Leonhardt,1999. Formation of iron boride layers on steel by d.c.-plasma boriding and deposition processes. Surface and
Coatings Technology; 116-119: 386-390.
I. Campos, G. Ramírez, U. Figueroa, J. Martínez, O,2007. Morales. Evaluation of boron mobility on the phases FeB, Fe2B and diffusion
zone in AISI 1045 and M2 steels. Applied Surface Science ; 253: 3469-3475.
I. Campos, R. Rosas, U. Figueroa, C. VillaVelázquez, A. Meneses, A. Guevara, 2008. Fracture toughness evaluation using Palmqvist crack
models on AISI 1045 borided steels. Materials Science and Engineering A; 488: 562-568.
I. Campos, M. Islas, G. Ramírez, C. VillaVelázquez, C. Mota, 2007. Growth kinetics of borided layers: Artificial neural network and least
square approaches[J]. Applied Surface Science ; 253: 6226-6231.
P.X. Yan, X.M. Zhang, J.W. Xu, Z.G. Wu, Q.M. Song,2001. High-temperature behavior of the boride layer of 45# carbon steel. Materials
Chemistry and Physics; 71: 107-110.
I. Campos, G. Ramírez, C. VillaVelázquez, U. Figueroa, G. Rodríguez,2008. Study of microcracks morphology produced by Vickers
indentation on AISI 1045 borided steels. Materials Science and Engineering A; 475: 285-292.
Junji Morimoto, Taisuke Ozaki, Toshifumi Kubohori, Shintaro Morimoto, Nobuyuki Abe, Masahiro Tsukamoto,2009. Some properties of
boronized layers on steels with direct diode laser. Vacuum; 83: 185-189.
A. Kuper, X. Qiao, H.R. Stock, P. Mayr, Surf.,2000. Coat. Technol;130: 87.
K.S. Nam, K.H. Lee, S.R. Lee, S.C,1998. Kwon. Surf. Coat. Technol; 98: 886.