Diffusion Layers Produced on Carbon Steel Surface by Means of Vacuum Chromizing Process

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This work investigated diffusion layers produced on carbon (C) steel surfaces in the vacuum chromizing process. Studies of layer, thickness, morphology, and chromium (Cr), C, and iron (Fe) concentration depth profiles in the diffusion zone of chromized layers were carried out. The effect of process parameters such as time and temperature on the kinetics of layer growth on steel surface was investigated. The tribocorrosion resistance of chromized layers was determined.

Keywords diffusion layers, thermochemical treatment, vacuum chromizing, wear/corrosion resistance

1. Introduction

Scientists have studied diffusion carbide layers produced on a carbon (C) steel surface using vacuum chromizing processes. Chromizing of steel and its modifications have been intensively developed.[1,2,3] Vacuum chromizing is an ecological treatment (nontoxic substrates, no wastes) by which diffusion layers can be obtained, characterized by high chromium (Cr) concentration with good adherence to the base metal. There is considerable bibliographical data concerning the vacuum chromizing process, which consists in holding steel at a temperature greater than 1000 °C in sublimating metallic Cr vapors under low pressure.[4,5,6]

In this paper a novel vacuum chromizing process is proposed.[7,8] This process uses a static vacuum during the holding period to increase the effectiveness of chromizing. When a dynamic vacuum is used, the continuous operation of vacuum pumps removes not only the atmospheric components from the reaction chamber but also the Cr vapors, which, consequently, provokes a reduction of the effectiveness of the chromizing process. This problem can be avoided by maintaining a static vacuum during the holding period. Under such conditions, because a closed system is obtained when the pumps are turned off, neither gases nor vapors are removed. When static vacuum is used instead of dynamic vacuum during the holding period, the high vacuum initially applied falls to low vacuum conditions.[9,10,11] C content is important in the diffusion chromizing of steels, since its diffusion to the surface (uphill diffusion) during the process leads to its combination with Cr to form carbides. In steels with high C content, the obtained diffusion layers are composed of Cr carbides. Such layers are hard and wear resistant.[12]

The objective of this paper is to determine the microstructure, growth kinetics, and tribological properties of carbide layers produced on C steel surfaces during the vacuum chromizing process.

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2. Experimental

A structural 45 steel (nonalloyed steel of grade equivalent to AISI 1045: 0.45% C) was selected for the experiments. Chromizing of this steel was carried out in a cold wall vacuum furnace at the temperature range of 1050-1150 °C with pressure in the range of 10 Pa to 10^{-2} Pa using the novel method.[13] Crucibles of high temperature-resistant steel were used to contain the steel samples in contact with crushed metallic chromium. After the crucibles were placed in the vacuum furnace, the pumping system was started, and then heating was activated. After the process was terminated, the batch was cooled with the furnace. The resulting layers were investigated by x-ray structural analysis using Philips diffractometer and by spectral line analysis with SU-30 CAMECA, (Courbevoie, France) x-ray microanalyzer. Metallographic examinations and thickness measurements of chromized layers were carried out with an optical microscope, Neophot 2 (Carl Zeiss, Jena, Germany). Layer microstructure was revealed by nital etching. Microhardness of chromized layers was measured by the Vickers method. To determine the tribological properties an Amsler machine of A135 type (Alfred J. Amsler & Co., Schaffhausen, Switzerland) was used. The friction unit was disk and plate.[14] Testing parameters were as follows: speed of disk sample (n), 200 rpm; average sliding friction speed (v), 0.42 m/s; load of frictional system by concentrated contact (P), 25 daN; total friction time (t), 2 h. Lubrication was with 50% water salt solution with a drip feed of 60 drops/min. The damage was determined: Microscopic measurement of linear wear with accuracy of 5 μm was used to estimate tribocorrosion damage.

3. Results

X-ray surface structure analysis of chromized surfaces on the 45 steel revealed the presence of $(Cr,Fe)_7C_3$ carbide. An etched metallographic cross section of the carbide layer is shown in Fig. 1. The layer is unetched.

Concentration depth profiles of Cr, C, and Fe in the layer

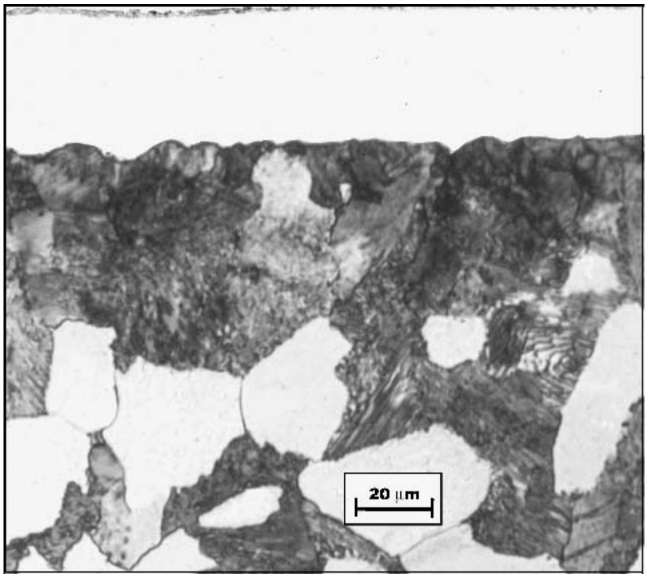

Fig. 1 Microstructure of the diffusion layer obtained with vacuum chromizing on 45 steel

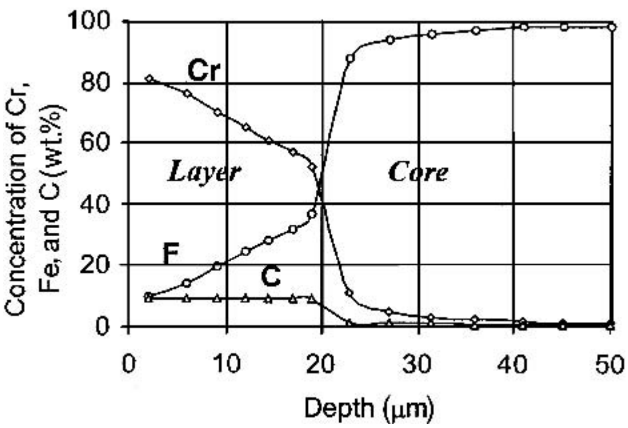

Fig. 2 Depth profiles of Cr, Fe, and C concentrations in the carbide layer produced on the 45 steel surface

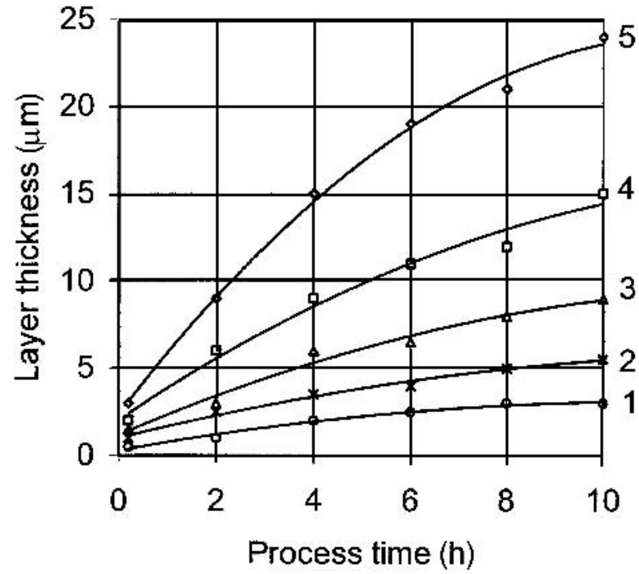

Fig. 3 Thickness of the chromized layers produced on the 45 steel surface vs process time at: (1) 1050 °C, (2) 1075 °C, (3) 1100 °C, (4) 1125 °C, (5) 1150 °C

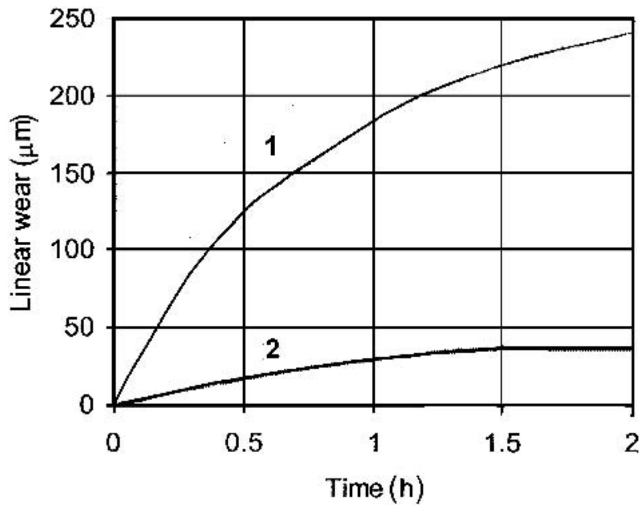

Fig. 4 Run of wear of (1) toughened and (2) diffusion chromized 45 steel subjected to tribocorrosion damage

diffusion zone are shown in Fig. 2. Surface concentration of Cr in the layer was about 80 wt.% and dropped gradually with the distance from the surface to about 50 wt.% at the boundary zone between the layer and the steel core. The reduction of Cr concentration in the layer was associated with the simultaneous increase of iron concentration, while the concentration of C remained at the same level of about 9 wt.%.

Kinetics of layer growth on the 45 steel surface was studied by performing a series of chromizing processes for various times: 0.2, 2, 4, 6, 8, and 10 h at temperatures of 1050, 1075, 1100, 1125, and 1150 °C. The effect of time on layer thickness for various temperatures is illustrated in Fig. 3. A parabolic dependence of layer thickness on the time suggests that the chromizing process is controlled by the diffusion in steel. Thickness of the carbide layers produced on the 45 steel surface during the vacuum chromizing process reached about 24 μm in 10 h at a temperature of 1150 °C. The layer microhardness was about 1600 HV, similar to that achieved with other chromizing methods, e.g., the powder or gaseous method.[1,2,3]

Results of wear resistance of the chromized layer subjected to tribocorrosion damage are presented in Fig. 4, which shows linear wear as a function of friction time. For comparison, the tribological characteristic obtained for toughened 45 steel is also shown.

The results presented in Fig. 4 show very high wear resistance of chromized steel. The friction coefficients of toughened and chromized steel were 0.28 and 0.18, respectively. Thus the chromized C steel showed a very high wear resistance in conditions of sliding friction by concentrated contact in the presence of a corrosion medium.

4. Conclusions

Based on the results, it is possible to formulate the following conclusions.

- The application of vacuum chromizing enables the formation of carbide layers on the surface of 45 steel, consisting of (Cr,Fe)7C3 carbide with a microhardness of approximately 1600 HV. The surface Cr concentration in the carbide layer was 80 wt.%. The average C concentration in this layer was about 9 wt.%. The carbide layer thickness reached about 25 μm in 10 h at 1150 °C.
- The growth of chromized carbide layers on a steel surface is controlled by the diffusion in steel.
- Diffusion layers obtained in the vacuum chromizing process are characterized by high tribocorrosion resistance and a low coefficient of sliding friction by concentrated contact.

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