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Research Paper

OXIDATION WEAR MECHANISM OF CAST STEELS

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The pin-on-disk wear tests were performed in elevated temperature air at 350 ºC for cast steel with different composition. Morphology, structureand oxidation films were measured by using XRD, SEM and TEM.The mechanism of wear was thus clarified. Under elevated temperature air at 350 ºC, typical oxidation wear was presented in the cast steels. Duringsliding oxidation of worn surface takes place. The oxide film formed is one of the main factor in determining wear rate which correlates with Quinn's oxidation wear theory.

Keywords: Oxidation wear, Mechanism, Oxide film, Cast steel, Microstructure

INTRODUCTION

Steels are thermo dynamically unstable like other metals under atmospheric condition. Oxide film on the sliding surface are formed at elevated temperature due to dry sliding wear of steels.

Oxide film breaks off in the sliding area when the critical thickness of sliding is reached. This process is continually and periodically repeated. This formof wear is called as oxidation wear. The role of oxidation in the wear of steels was first found by Fink in 1930 (Fink, 1930). In 1956, Archard and Hirst proposed a classificationof wear into mild and severe wear (Archard and Hirst, 1956). Quinn *et al.* carried out intensive research on oxidation wear of ferroalloy (Quinn, 1978 and 1998; and Quinn *et al.*, 1979 and 1980). They studied the influences ofsliding velocity and load on mild wear and found an expression for the wear rate under mild wear conditions at room or slightly elevated temperatures. Wilson *et al.* studied the influence of wear oxide debris particles in reducing wear, particularly at higher temperature (Wilson *et al.*, 1980). Oxide film may decrease metal-metal contact during the relative sliding motion of metallic parts, protecting them against wear. Oxide films have been found significant in determining wear rate. Due to changes in oxide composition different transition in wear rate are formed. The formation of oxide as protective layer to reduce wear was found in most of the research works on oxidation wear.

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Oxidation wear behavior is closely related to oxide film. The wear mechanism is dependent in the condition of testing. Microstructural changes of steel have no effect on the wear mechanism transition. Thus no differences in wear volume were found due to microstructure. In this research, wear performances in air environment at elevated temperature were studied for the cast alloy steels. The wear rate of cast alloy steel with different composition and microstructure were measured under elevated temperature of 300 ºC. The microstructure, morphology and oxidation films were measured by using XRD, SEM and TEM. The wear characterstics were also analysed.

EXPERIMENTAL PROCEDURE

Cast alloy steels are widely used in got forging die steels. Cast steel were studied using hot forging die. To investigate the effects of alloy elements on elevated-temperature wear, the nominal compositions of the caststeel were designed as follows:

0.1-0.2C wt.%, 2-3 Cr wt.%, 3 Mo wt%, 0.1-1.1 V wt%. Other composition include: 0.2-0.4% Si, 0.3-0.4%Mn, 0.1% S and 0.05% P.

The cast steels were melted in 30 kg medium frequency induction furnace with non-oxidation method. At 1450 ºC, the melt was deoxidized with Al, and then poured. Finally the hedge samples were cast. The steels were austenitized at 920 ºC for 45 minutes and quenched in oil, then tempered at 500 ºC. In this case, the microstructures of the cast steels are tempered with grain size 15-20 µm. The variations of alloy elements mainly lead to the precipitation of different secondary carbides.

RESULTS AND DISCUSSION

The wear tests were performed on apin-ondiskhigh-temperature wear tester. The dry weartest rig was used in this work. The wear tests for all the cast steels were carried out under elevated temperature at 350 ºC with test parameters: 50 N normal load; 0.5 m/s sliding speed and 1600 m sliding for sliding speed.

Pins are made of cast steels with dimension of 4 mm * 10 mm and disks of 52 HRC with dimension of 50 mm * 6 mm. From the pin specimens all of the data of wear were measured. Pins and disks were polished and degreased before tests. The pin specimens were cleaned with acetone and dried before and after test. The wear rate is calculated by using the formula:

$$Ws = V/Pd$$

where *V* is the wear volume loss (m^3); *d* is the sliding distance (*m*); *P* is load (*N*). The morphology, composition and structure of worn surfacewere analyzed with SEM and X-ray diffractometer (XRD). Different wear rates of cast steel persists with different composition. The wear rates of most of the cast steels are relatively low, ranging from $3.9 * 10^{-15}$ m^3/Nm to $4.28 * 10^{-14}$ m^3/Nm. In most of the cast steels oxidation wear should be classified as mild wear. Fe_3O_4 and Fe_2O_3 on worn surfaces of pin specimens areidentified as the predominant oxides for all the cast steels by X-ray diffraction analysis. Thus we can conclude that the wear of cast steel under elevated-temperature air at 300 ºC is a typical oxidation wear. Comparison of the wear-rate data indicates that mild wear predominated throughout the test, with some intrusions into the severe wear. The wear rate of oxidation wear is not always independent of matrix. Some variations of matrix in composition definitely results in transition of mild wear to severewear.

High ambient temperature and friction heat cause oxidation of sliding surface under atmospheric condition. Plastic deformation of worn surface accelerates oxidation process. Hence oxidation speed should be higher than that of staticoxidation. Plastic deformation of worn surface accelerates oxidation process. Hence oxidation speed should be higher than that of staticoxidation. Formation of oxide film on worn surface requires a period of time in the process of elevated-temperature wear. An oxidational wear mechanism was established for all the steels tested after a short running-in period. Oxygen content on worn surface is toolow to form enough thick oxide film in running-in period. The oxide film cannot provide protective film for reducing wear. Thus severe wear occurs. After running-in period, oxygen content increases enough toform thick oxide film and spread over the whole area. But when oxide film reaches critical thickness, oxide film becomes unstable and breaks up to form wear debris because of brittleness and internal stress of oxide. A steady oxidational wear continues with alternating process of oxide-film formation and delamination. The fluctuation of friction coefficients corresponds to variation of sliding surface state resulted from delamination of oxide film. When certain-thickness oxide film is formed, sliding surface state is relatively smooth with lower coefficient of friction. When oxide film breaks off sliding surface state is relatively rough with higher coefficient of friction. The wear rate mainly depends on oxide-film delamination, which decides amount of generated oxide debris. It is well known that oxide film has an important role in oxidation wear. The oxide films on worn surfaces of all the cast steels were examined using SEM.

Figure 1: SEM Images of Wear Debris of the Cast Steel

In low wear-rate specimens, a thick oxide filmwas formed on the worn surface with closely bonding interface. In high wear-rate specimens, exceptfor a thick oxide film formed on the worn surface, crack andoxide in crack was found to exist in matrix under oxide film. At high ambient temperature, oxide film has a thick oxide layer which directly grows on the steel surface.

In the most of cast steels, delamination of oxide film occurs inside oxide film or at interface between oxide film and matrix. A new delamination pattern of oxide film is found in the specimens with high wear rate. It can be seen that crack initiates and propagates in matrix under oxide film. This is different from oxide-film delamination pattern of mild oxidation wear. Consequently, the wear rate is obviously elevated. This should be classified as severe wear.

Figure 2 (a) Variation of Sn/S atomic ratio with substrate temperature (the source

Figure 2: Delamination Patterns of Oxide Film in the Cast Steels with Low Wear Rate

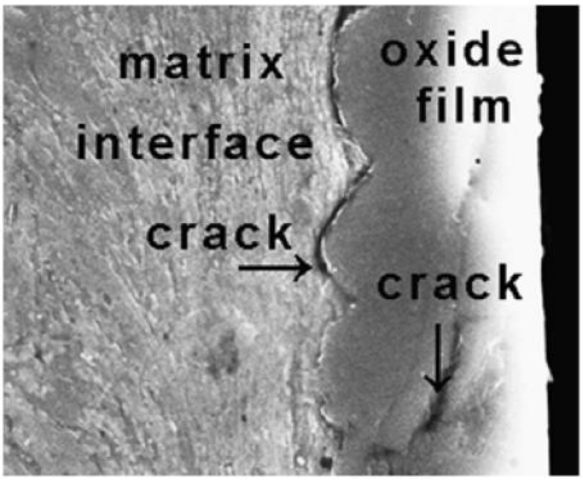
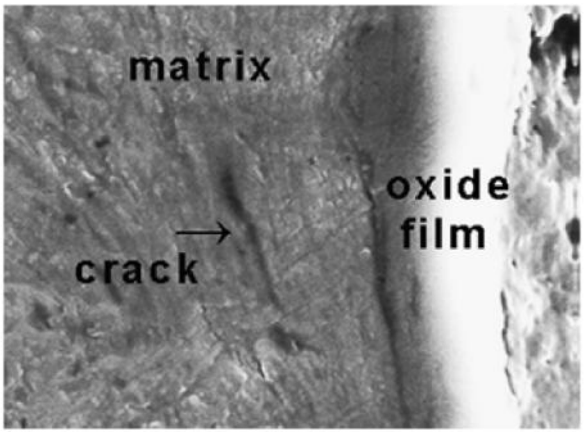


Figure 3: Delamination Patterns of Oxide Film in the Cast Steels with High Wear Rate



temperature was kept constant at 300 °C and deposition time constant at 1.5 min).

CONCLUSION

Above-experimental results show that lower wear rates were found for the most cast steels. This is oxidation-dominated mild wear. However, under the same testing condition, considerable higher wear rates were observed for the special steels. This transition of mild wear to severe wear should be attributed to microstructure resulting from the variation of composition. The transition of mild wear to severe wear is realized through changes of delamination pattern of oxide film. Delamination from inside oxide film or oxide/ matrix interface was consider to be normal pattern in oxidation wear. This pattern show that wear behavior mainly depends on oxide film. Oxidation of worn surface and fatigue delamination of oxide film proceed alternatively during wear. As there are not coarse second phases in steel, delamination of oxide film takes place inside of oxide film or at interface of matrix and oxide film, which is classified as mild oxidation wear with lower wear rate. The experimental results conform to Quinn's oxidation wear theory.

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I would also like to dedicate this research work to my father late R S Mishra and mother K L Mishra.

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