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Enhanced boronizing kinetics and high temperature wear resistance of H13 steel with boriding treatment assisted by air blast shot peening

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ABSTRACT

A nanostructured surface layer was fabricated on H13 steel by means of air blast shot peening (ABSP). A much thicker borided layer on the ABSP sample can be synthesized by a duplex boronizing treatment (DBT) at 600 °C for 2 h, which is followed by at a higher temperature for a certain time. The borided layer was composed with monophase of Fe_2B and the growth of it exhibited a (002) preferred orientation. Moreover, the activation energy of boron diffusion for the ABSP sample is 227.4 kJ/mol, which is lower than 260.4 kJ/mol for the coarse-grained counterpart. The results indicate that the boronizing kinetics can be effectively enhanced in the ABSP sample with DBT. The high temperature wear resistance of H13 steel with DBT can be improved significantly. Furthermore, the H13 steel with DBT assisted by ABSP possesses more superior wear resistance property at elevated temperatures than that of coarse-grained sample with DBT, which can be attributed to the fact that the thickness and microhardness of the borided layer can be increased with the help of ABSP. Meanwhile, the fatigue crack initiation and propagation in borided layer during the wear test can be impeded by the compressive residual stress and the refined grains in the borides of ABSP sample with DBT.

1. Introduction

The AISI H13 hot work die steels are used extensively for extrusion dies as well as for die cast of aluminium alloy. They are usually characterized with high strength and toughness. However, this kind of die steels is commonly used in aggressive environments. It is necessary to adopt thermochemical treatment technique to improve their surface properties, such as wear resistance, thermal fatigue resistance and corrosion resistance. One of the effective surface treatments is boriding technique. Owning to the nature of the diffusion process, the borided layers possess excellent adhesion to the substrate when compared to prevalent physical coating process. It also has the advantage of high hardness when compared with conventional surface treatments, such as carburizing, nitriding and carbonitriding [1,2], due to the superior hardness of borides (1500–2000 HV).

The boriding technique can be carried out in solid, liquid or gaseous medium [3]. Genel et al. [4] prepared both phases of FeB and Fe_2B on the surface of H13 in the solid medium consisting of Ekabor-I powders at 800, 900, 1000 °C for periods of 1–5 h. Taktak et al. [5] reported the FeB and Fe_2B can form on the surface of H13 steels in slurry salt bath consisting of borax, boric acid and ferrosilicon at temperature range of 800–950 °C for 3, 5 and 7 h. In fact, many previous literatures have reported the boriding techniques which are used to prepare borided layers on the surface of steels. Among the various boronizing processes, solid-state pack boriding treatment is the most frequently used. Yet most of them have the disadvantages of requiring relative high processing temperature or time consuming. Studies have been carried out to improve the efficiency of pack boriding treatment over the past decades.

It is well known that borided layers generated in thermochemical treatment depend on boriding condition and on the properties of the materials itself. Both factors are strongly affected by grain boundaries and defect densities in the surface layer. The combination of pack boriding treatment with surface mechanical attrition treatment (SMAT) could improve the efficiency of boronizing kinetics. After SMAT, various metals, such as pure Fe [6], 38CrMoAl [7], AISI 321 austenitic stainless [8] and other alloys [9] possess a nanostructured surface layer. Due to the significant enhanced diffusion and chemical reaction kinetics in the formed nanostructured surface layer, the hardened diffusion layer on the substrate has been fabricated on several ferrous alloys after the subsequent gas nitriding [6,7] or packed powder chromizing treatment [10,11]. However, the method of SMAT has the disadvantage of its restriction on the flat shape of workpiece, which impedes its application in industrial production. Fortunately, air blast shot peening (ABSP) can also be used to refine grains and produce high density of defects in the surface layer, which could be a promising method that can be used in thermochemical treatment for many kinds of steels. More importantly, ABSP has been applied extensively in material processing.

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Here, we report that pack boriding treatment was carried out for the hot work die steel H13 assisted by ABSP. The boronizing kinetics in the nanostructured surface layer fabricated by ABSP was studied. Furthermore, the high temperature wear resistances of the borided H13 steels with and without ABSP pretreatment were investigated by reciprocating sliding wear tests at 700 °C under the applied loads of 20 N.

2. Experimental

2.1. Test materials and ABSP treatment

The chemical compositions of AISI H13 steel used in the experiments contain (wt.%) 0.42C, 4.93Cr, 1.40Mo, 0.98Si, 0.87V, 0.30Mn, 0.018P, 0.005S and balance Fe. The spheroidizing annealing process was used for the original H13 steel with the shape of 60 × 60 × 4 mm, which was annealed at 840 °C for 2 h. Before ABSP, the annealed steel was mirror polished. Then, the sample was processed by a flow of cast steel balls with diameter of 0.8 mm at 0.5 MPa for six cyclic deformation, and the time of each cycle was 5 min. The angle between the shot jet and the sample surface is in the range of 70–90°. The ABSP samples with dimensions of 15 × 15 × 4 mm were machined from the bulk sample mentioned above and ultrasonically cleaned in acetone.

2.2. Boriding process

Two kinds of samples were used in the duplex boronizing treatment (DBT), which include the annealed coarse-grained (CG) sample and the annealed ABSP sample. The pack boriding treatment was as follows: the constituents of the boriding media were B_4C (10 wt.%), KBF_4 (5 wt.%), charcoal (5 wt.%) with the balance of SiC. The ABSP sample and the CG sample were packed together with a suitable distance from each other in the powder mix and sealed in a stainless steel container. In order to stabilize the nanostructures in the surface layer fabricated by ABSP, a duplex boriding treatment at $T_1 = 600$ °C followed by at a higher temperatures (T_2) for a certain time was carried out in an electrical resistance furnace. In the first stage, the samples were heated to $T_1 = 600$ °C for 2 h. In the second stage, the temperature was increased to $T_2 = 750$ °C, 800 °C and 850 °C for 2, 4 and 8 h, respectively. After the boriding treatment, the container was removed from the furnace and cooled in air. At last, all the borided samples and the annealed CG sample without boriding treatment were quenched at 1030 °C and subsequently tempered twice at 580 °C in a vacuum oven.

2.3. High temperature friction and wear testing procedure

A UMT-3 tribometer (Fig. 1) equipped with a reciprocating configuration placed in a heating furnace was used to carry out the friction and wear tests at elevated temperatures. A ball holder is connected to both a vertical and lateral linear motion system. The samples are pinned to a reciprocating stage in a high temperature chamber that allows testing temperatures up to 1000 °C. Three kinds of samples were used in the wear tests at high temperature, which include the quenched and tempered sample, the CG sample with DBT and the ABSP sample with DBT. The size and geometry of a high temperature friction and wear test specimen are shown in Fig. 2. The surface (10 × 35.6 mm) is used for friction and wear test. The dry sliding wear tests were operated by the parameters which are shown in Table 1. Silicon carbide balls with a diameter of 9.5 mm and hardness of 2800 HV were chosen as the counterpart in order to evaluate the wear properties of the borided layers at high temperatures. The wear rate is calculated by the equation as follows:

$$Ws = \Delta V/(p \cdot d) \quad (1)$$

where ΔV is the wear volume. P is the loading force and d is the total sliding distance.

2.4. Characterization

The X-ray diffraction (XRD) measurements were obtained with a RigakuD/Max-RBX-ray diffractometer by using CuKa (40 kV, 40 mA)

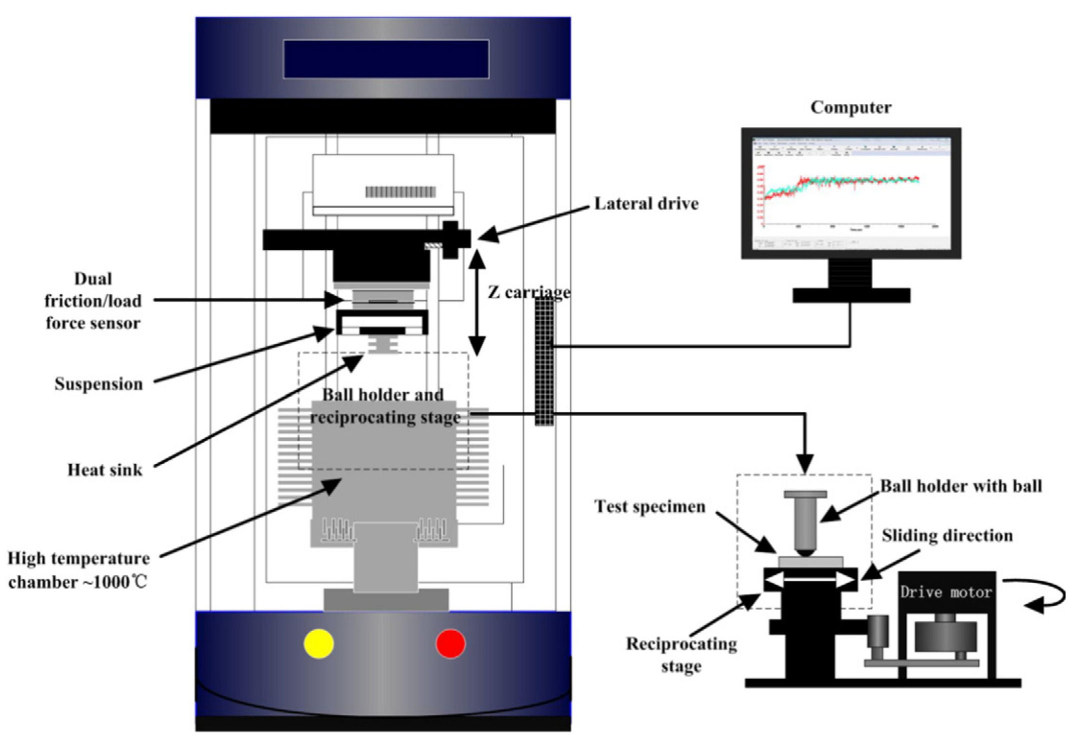

Fig. 1. Schematic representation of the UMT-3 high temperature friction and wear test system.