Effect of temperature on the friction and wear of Zn-based coatings on ultra-high strength steel

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Coated ultra-high strength steel (UHSS) has been used in the hot stamping process. The high-temperature friction and wear of coated UHSS during hot stamping may affect its formability and tool life. The effect of temperature on the friction behaviors of alloyed galvannealed (GA), galvanized (GI) and uncoated boron steel sheets were studied through pin-on-disk high-temperature friction and wear tests. The friction coefficients of three kinds of boron steel sheets decrease with the increase in temperature. GI and GA coatings have a lubricating effect at high temperatures, and the oxide layer formed effectively reduces friction and wear.

Keywords: Friction and wear; UHSS; Hot stamping; Zn-based coating; High temperature.

1. Introduction

Vehicle weight reduction can effectively reduce energy consumption, and a weight reduction of 100kg can increase the cruising range of 1km per liter of fuel [1]. Compared with aluminum alloy, glass fiber, and other composite materials, it has the advantages of good formability, high cost-effectiveness, and high safety, which makes the application ratio of ultra-high-strength steel in automobile bodies continue to increase [2].

Hot stamping is the main forming method of ultra-high strength steel sheets, by raising the temperature of the sheet above the austenitizing temperature, then the sheet is quickly put into a hot stamping die for forming, and finally, the part is quenched by the die cooling system while maintaining the pressure which gives the part a fully martensitic structure. The final strength of the parts can reach 1500MPa~2000MPa [3].

With the improvement of automobile safety requirements, the vehicle body-in-white not only needs to have high strength but also energy absorption capacity, which can greatly improve the crashworthiness of the vehicle [5]. To achieve this performance, the most common means is to heat the temperature of some regions of the sheet to above AC-3 temperature and keep other regions below AC-3. Finally, the parts have both high-strength martensitic regions and high-ductile ferritic-pearlite regions. Former researches have mainly focused on the friction properties of coated steel sheets at a single temperature or low temperatures. There are few studies on different high temperatures, especially in the AC-3 temperature range. In this paper, the friction coefficient of and wear rate of GA, GI, and uncoated boron steel plates are obtained by setting friction experiments at different

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high temperatures. The main aim of this work is to analyze the friction and wear of Zn-based boron steels in the hot stamping and determine the difference in tribological property between GA and GI coatings.

2. Experiment

2.1. *Testing Methods*

In this study, pin-on-disk friction and wear tests were carried out on the Rtec-MFT-5000 friction and wear tester equipped with a heating furnace. The pin samples were fixed on the upper fixture and the disk samples were fixed on the lower fixture respectively in the heating furnace. The lower sample was pressed with a pressure cover (Figure 1).

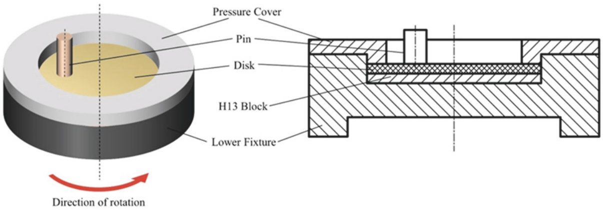


Fig. 1. Schematic diagram of pin on circular disk

When the heating furnace reached the specified temperature, the pin was in contact with the disk under the action of the loading device. When the force reached a predetermined value, the disk sample began to rotate. The normal load F_N and tangential friction force F_X were measured by the electric sensor. The coefficient of friction was calculated from the relationship:

$$\mu = \frac{F_N}{F_X} \tag{1}$$

The tests were carried out with the following working conditions: temperature 650°C, 750°C, and 850°C, contact pressure 3MPa, rotation speed 50rpm, and friction time the 1200s. Each group of tests was repeated three times to ensure the repeatability of the tests.

Samples were weighed by FA-N series electronic balance (precision 0.1mg). The wear loss Δm was obtained by subtraction, and then the wear rate was calculated according to the following formula:

$$W_S = \Delta m / \rho L \tag{2}$$

Where W_s is the wear rate, Δm is the weight loss of sample (g), L is the sliding distance (m), and ρ is the material density (g/cm^3).

2.2. *Testing Material*

In the high-temperature friction and wear test, the upper sample is H13 tool steel processed into pins with a hardness of 55 HRC, as shown in Figure 2(a). The lower specimens were made of boron steel B1500HS with GA coating, GI coating, and no coating respectively.

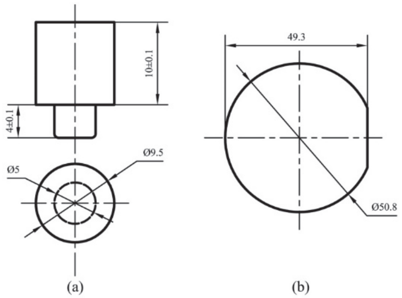
The thickness of the boron steel sheets was 1.4 mm. It was processed by wire cutting into a disc specimen, as shown in Figure 2(b). The chemical compositions of H13 tool steels and B1500HS steel sheets are shown in Table 1.

Table 1. Materials chemical composition (mass fraction, %)

Materials	C	Si	Mn	Cr	Mo	B	V	Fe
B1500HS	0.23	0.25	1.35	0.19	—	0.0032	—	Bal.
H13	0.36	1.0	0.34	5.14	1.37	—	1.0	Bal.

2.3. *Testing Methods*

200#, 400#, 600#, 800#, and 1200# sandpapers were used to burnish pins surfaces before the test, then pins and disks were cleaned in an ultrasonic cleaning machine with anhydrous ethanol. Samples were heated to the specified temperature and kept for 3 minutes, and then the friction and wear test was started. The mass loss before and after the experiment was recorded by precision balance, and the wear rate was calculated. Each sample was weighed 5 times and the average value was recorded.



Note: (a)Pin (b)Disk

Fig. 2. Shape and size of friction and wear specimens

3. Effect of temperature on friction and wear of coated boron steels

As shown in Figure 3(a), the friction coefficient of uncoated sheets increased from 0.18 to 0.25 after sliding for 300s at 650°C, and then stabilized at about 0.25. The friction coefficient of at 750°C was similar to that at 650°C, reaching a stable value of 0.25 after 300s, but it continued to rise after 800s. At 850°C, initially, there were huge fluctuations in the friction coefficient, then the friction coefficient increased from 0.17 to 0.22. After 800s, the friction coefficient was stable at about 0.22.

Figure 3(b) shows the friction coefficient of GA-coated boron steel sheets. The friction coefficient at 650°C increased from 0.13 to 0.29 and after 500s stabilized at about 0.28. At 750°C and 850°C, the friction coefficient had the same trend but the difference was that friction coefficient at 850°C was lower than that at 750°C, and finally stabilized at about 0.22 and 0.17. The friction coefficient of GI-coated sheets, shown in Figure 3(c), had a clear upward trend and needed a longer time to reach stability, which followed the same method of GA coating. At 650°C, the friction coefficient stabilized at about 0.25, and at

750°C and 850°C, it stabilized at about 0.23 and 0.21. Which is in accordance with the result in Pelcastre et al [4].

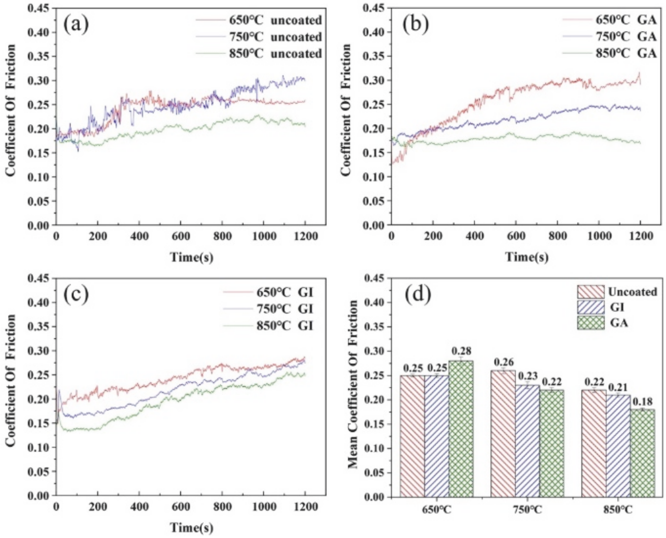


Fig. 3. Friction coefficients of boron steel sheets at different temperatures

As shown in Figure 3(d), the stable friction coefficient at 650°C was GA>GI and uncoated. At 750°C and 850°C, the friction coefficient was uncoated>GI>GA. This is because the surfaces of GI and GA coatings act as a viscous fluid at high temperature, and play a role in lubrication, thus causing a reduction of the friction coefficient.

Figure 4 show the wear rates of three kinds of boron steel sheets. The wear rates increased with the increase in temperature. Compared with uncoated sheets, the wear rates of GI and GA-coated sheets were significantly lower, indicating that the Zn-based coatings can reduce the wear of boron steel during high-temperature friction. Among the three kinds of boron steel sheets, GA-coated steel sheets exhibit the best wear resistance and uncoated boron steel sheets illustrate the worst [6].

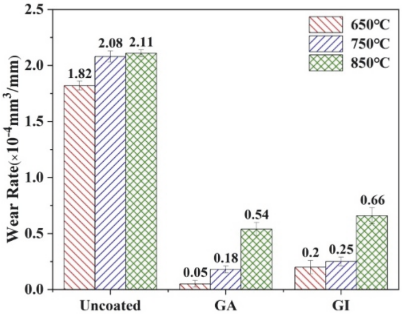


Fig. 4. Wear rate of born steel sheets at different temperatures

4. Conclusion

The effect of temperature on the tribological characteristics and wear mechanisms of B1500HS-H13 tribopair have been investigated. The main conclusions are as follows:

(1) The friction coefficient of three kinds of boron steel sheets decreased with increasing temperature. At 750°C and 850°C, the viscous fluid GI and GA coatings can reduce the friction coefficient, and the friction coefficient of three coated boron steel sheets are uncoated＞GI＞GA.

(2) GI and GA coatings reduce the wear of boron steel sheets in the high-temperature friction. GA-coated boron steel sheets exhibit the best wear resistance. Uncoated boron steel sheets exhibit the worst wear resistance at various temperatures.

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Disclosure statement

The authors report there are no competing interests to declare.

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