

Effect of Fe content on the friction and abrasion properties of copper base overlay on steel substrate by TIG welding

Lü Shixiong, Song Jianling, Liu Lei and Yang Shiqin

吕世雄, 宋建岭, 刘磊, 杨士勤 *

Abstract Copper base alloy was overlaid onto 35CrMnSiA steel plate by tungsten inert gas (TIG) welding method. The heat transfer process was simulated, the microstructures of the copper base overlay were analyzed by scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS), and the friction and abrasion properties of the overlay were measured. The results show that the Fe content increases in the overlay with increasing the welding current. And with the increase of Fe content in the overlay, the friction coefficient increases and the wear mechanism changes from oxidation wear to abrasive wear and plough wear, which is related to the size and quantity of Fe grains in the overlay. While with the increase of Fe content in the overlay, the protection of oxidation layer against the oxidation wear on the melted metal decreases.

Key words Fe content, copper base alloy, TIG welding overlay, friction and abrasion

0 Introduction

Copper alloys are widely used in mechanical industry for their abilities of abrasion and corrosion resistance. However, it is very expensive to make the whole set of equipments with copper alloys. Overlaying copper alloy on the steel substrate surface provides a method to decrease resource consumption and improve efficiency. Laser melting^[1], submerged arc welding (SAW)^[2], electrosag welding^[3] and tungsten inert gas (TIG)^[4] welding processes have been used to make abrasion resistant layer. TIG overlaying has more advantages than other methods, such as lower cost, easier operation and higher efficiency, so as to be used widely. However, it should be noticed that with any overlaying method, the substrate material can not be prevented from diffusing and melting into the coating materials, which will change the structure and composition of the overlay and the resulting frictional behavior. While overlaying copper alloy onto the steel surface, Fe element will be brought into the coating layer because of the fusion of the substrate material, diffusion effect and electromagnetic force^[5]. In this paper, the microstructures of the copper base overlay were studied with the different heat input and the effect of Fe content on the friction and abra-

sion properties of the copper base overlay was analyzed.

1 Experimental procedure

HS201 copper base welding wire with a melting point of 1080 °C was overlaid onto 35CrMnSiA steel plate. Their normal compositions are listed in Table 1 and Table 2, respectively. Before welding, the workpiece was polished with 240 – 1000 # abrasive papers to remove the oxide film and cleaned with acetone. The welding current was 180 A, 210 A, 240 A, 270 A, 300 A and 330 A. The travel speed was 71 mm/min. Based on a previous research, the distribution of Fe element in the overlay was not uniform^[5]. In this paper, the overlay was cut off from the weld, then remelted with high-frequency induction heating method under pure Argon environment to make the composition of the overlay distribute uniformly.

The microstructure, composition and worn shape of the overlaid layer were investigated with SEM (S-3400 N). Friction and wear tests were performed with a ball-on-disc tribotester under dry sliding at room temperature; the load is 3 N, rotating speed 200 r/min, GCr15 counterpart ball of 6.35 mm diameter and testing time 120 min. After each test, specimens were cleaned ultrasonically in etha-

* Lü Shixiong, Song Jianling, Liu Lei and Yang Shiqin, State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin, 150001. Lü Shixiong, Corresponding author, E-mail: lvsx@hit.edu.cn

nol to remove the loose wear debris and wear-generated oxidized layers. Mass loss measurements were carried out on a balance with a precision of 0.1 mg and a maximum weight of 100 g.

Table 1 Composition of 35CrMnSiA steel (wt%)

C	Mn	Si	Cr	Ni	Fe
0.32 - 0.39	0.8 - 1.1	1.3 - 1.6	1.1 - 1.4	0.05	Balance

Table 2 Composition of HS201 welding wire (wt%)

Cu	Si	Mn	Sn
Balance	≤0.4	≤0.4	≤1.1

2 Results and discussion

2.1 Temperature distribution on the substrate surface

Since the arc length is constant during TIG welding process, the welding heat input and quantity of melted material from the substrate are controlled by the welding current. The temperature distribution on the substrate surface is obtained under different welding current, as shown in Fig. 1. It can be seen that, when the welding current increased, the peak temperature on the substrate surface remarkably increases and the time of the temperature higher than the melting point of HS201 (1 080 °C) also increases, which suggests that the degree of supercooling decreases. Since the separation of Fe-Cu liquid phase is determined by the degree of supercooling, the microstructure of the overlay is affected significantly by welding current. From the simulation results, it can be seen that the peak temperature exceeds the melting point of the substrate material when welding current is 240 A, but only a little amount of substrate material is melted since the dwelling time over the liquidus temperature is short. However, when welding current is 330 A, the surface temperature of the substrate increases up to 1 800 °C, which can melt much more substrate material.

2.2 Microstructures of the copper base overlay

Fig. 2 shows the SEM images of the overlay under different welding currents. When welding current is lower than 240 A, there is almost no Fe particle in the overlay.

However, when welding current is higher than 240 A, the size and quantity of iron-rich intermetallics increases. While welding current increases up to 330 A, the block or strip iron-rich intermetallics occur in the overlay.

Fig. 3 shows the relationship between welding current and Fe content in the overlay. It can be seen that the Fe content suddenly increases at 240 A of welding current. When the welding current is lower than 240 A, the substrate is not melted (as seen in Fig. 1), so Fe element is brought into the overlay by diffusion and solution. However when the welding current is higher than 240 A, part of the substrate is melted, a great deal of Fe elements enter into the overlay under the mixing of the arc force. Cu - Fe phase diagram reveals that the solid solubility of Fe in copper alloy is very limited, and Fe content beyond the solid solubility exists as individual iron-rich phase. Since the melt point of Fe is higher than Cu, Fe solidifies first into globular grain. With melting of more substrate material, the iron-rich phase increases in quantity and joins with each other into strip structure as shown in Fig. 2f.

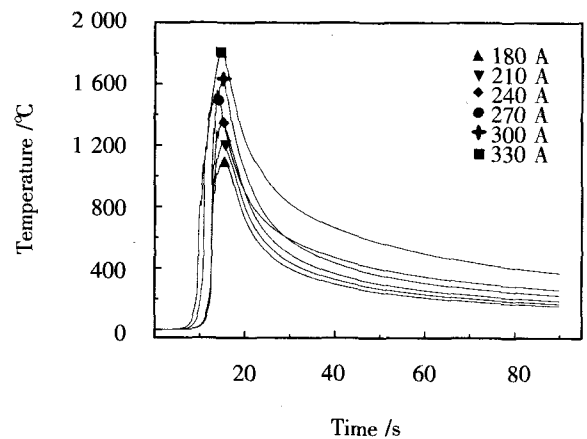


Fig. 1 Temperature distribution on the substrate surface under different welding currents

2.3 Effect of welding current on the tribological properties of the copper base overlay

Fig. 4 shows the effect of welding current on the friction coefficient of the overlay. It can be seen that the friction coefficient increases when welding current increases. During wearing test, friction enhances the temperature of the sample. And the surface of the sample is smoothed

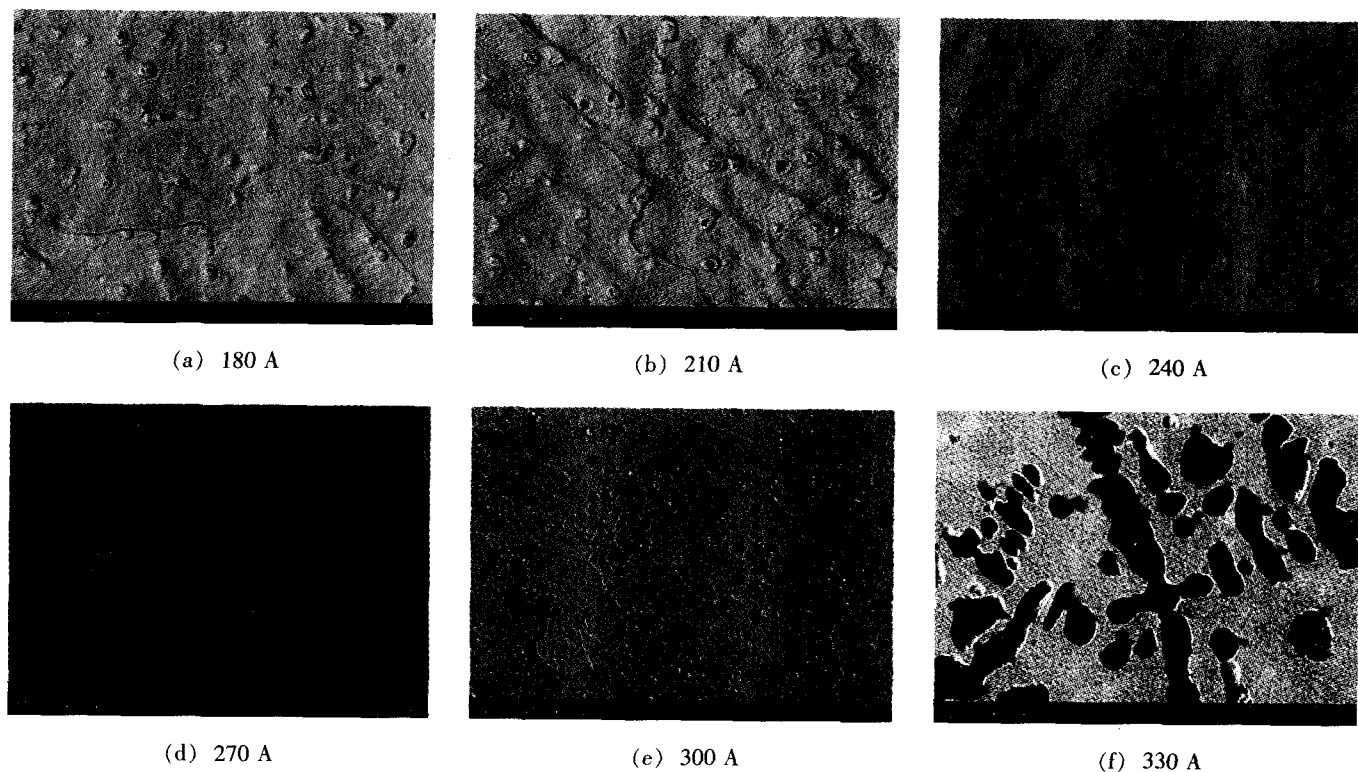


Fig. 2 SEM images of the overlay under different welding currents

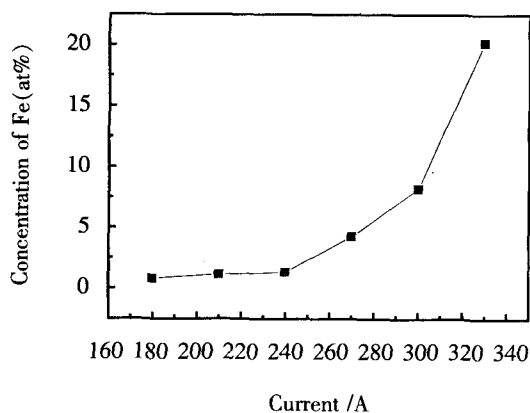


Fig. 3 Relationship between welding current and Fe content in the overlay

and the mechanical property is diminished by high-speed friction. Since the copper is relatively soft, the more Cu content in the overlay can reduce the lower friction coefficient^[6]. However, the Fe element is relatively hard, the Fe particles disperse in the overlay can improve the friction coefficient^[7]. In the wearing test, Fe particles are peeled off from the overlay by the friction force and stayed

in the friction track as hardened particles. These hardened particles are embedded into the overlay and results in a plough effect under tangential force, which can enhance the friction force. At the same time, the similarity of the compositions of iron-rich particles and frictional steel counterparts can increase the friction coefficient by enhancing the local friction force^[8].

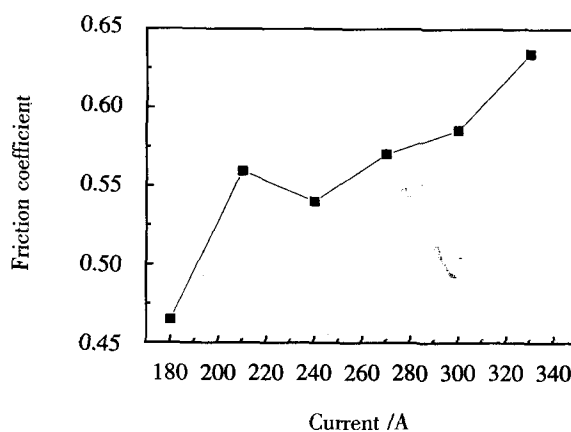


Fig. 4 Effect of welding current on the friction coefficient

Fig. 5 shows the relationship between welding current and abrasion. Negative wear loss is observed when welding current is lower than 240 A, and it is opposite when the welding current is higher than 240 A. When the welding current is low, the hardness and strength of the base metal is enhanced by the solution strengthening of Fe particle, so the wear loss decreases.

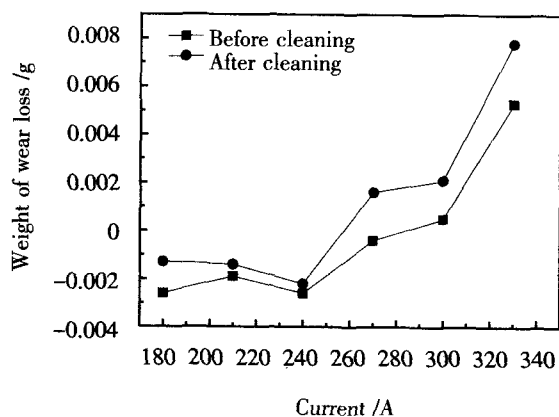


Fig. 5 Effect of welding current on the wear loss

Moreover, the increase of the temperature from the friction makes the copper easier to be oxidized, the oxide film can accumulate on the wear track to protect the surface of the sample. And the absorbed oxygen increases the weight of the sample. When the welding current is high, a lot of Fe particles are peeled off and stayed in the wear track, which results in severe abrasion and plough effect and a lot of wear loss. Therefore, the wear loss positively correlates to the size and quantity of Fe particles in the overlay.

Fig. 6 shows the SEM images of worn surfaces of the samples. Fig. 6a, Fig. 6c and Fig. 6e show the images of the real contact surface before ultrasonically cleaning. Fig. 6b, Fig. 6d and Fig. 6f show the images after ultrasonically cleaning with 120 min. It can be seen from Fig. 6a that compact oxide film completely covers the sample surface, while parts of the substrate material and abrasive sliding marks can be observed in Fig. 6c and Fig. 6e. The plough marks occurs after the hardened particles removes part of oxide film on the surface of the sample. A severe

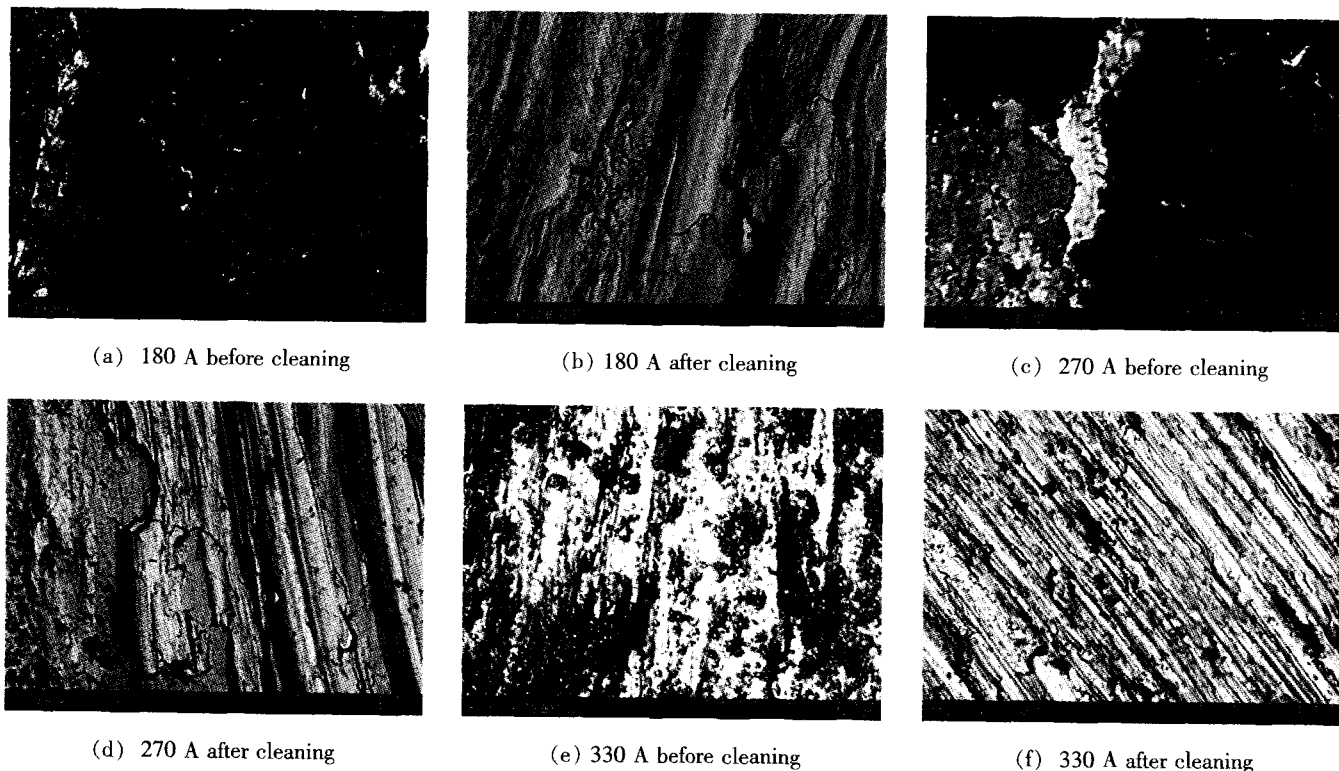


Fig. 6 SEM images of worn traces under different welding currents

deformation is seen in Fig. 6b, while slighter deformation and more plough tracks happen as seen from Fig. 6d and Fig. 6f. Fe particle can enhance the anti-plastic deformation ability of Cu base material. But too much Fe content can change the abrasion mechanism and increase the wear loss. The size and quantity of Fe particles should be controlled to improve the abrasion resistance of the material.

Fig. 7 shows the SEM images of the friction counterpart balls under 330A of welding current. When the welding current is lower than 240 A, almost no worn plane on the balls can be found. However, when the welding current increases, the size of the worn plane increases correspondingly. EDS analysis on area A and area B, as seen in Table 3, exhibits that some copper transfers onto the ball and works as a lubricant and protective layer to diminish the wear loss of the balls.

Table 3 EDS analysis of the counterpart ball (wt%)

Point	C	Cu	Cr	Fe
A	4.50	8.68	1.24	74.13
B	4.87	72.31	1.26	21.56



Fig. 7 SEM image of the counterpart ball

3 Conclusions

(1) Temperature zone on the substrate material

can be divided into three parts: Base metal is not melted; only a little base metal is melted; a lot base metal is melted.

(2) With increasing welding current, Fe content in the overlay increases and its shape changes from fine particles to bulk or strip structure.

(3) With increasing the size and quantity of Fe particle, the friction coefficient of the overlay is enhanced and the wear loss is increased and the protection effect of oxide layer generated during the wear test is weakened.

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