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Effect of laser surface melting treatment on properties of electric copper busbar joints ①

LIANG Gong-ying(梁工英)[1], SONG Xiao-ping(宋晓平)[1], GU Lin-yu(顾林喻)[2]
(1. Department of Materials Physics, Science School, Xi′an Jiaotong University, Xi′an 710049, P. R. China;
2. Department of Materials Engineering, Xi′an Institute of Technology, Xi′an 710032, P. R. China)

[Abstract] Electrical conductance and temperature of electric copper busbar joints were measured under different torque moments. Experimental results show that laser surface melting can increase hardness and refine structure of the copper, and it does not deteriorate electric resistance. Meanwhile, the temperature of laser treated joints under electric current is slightly lower than that of original sample. Salt spray test shows that laser treated sample has better salt spray corrosion resistance than the original sample does. The electric resistance of both laser-treated and original samples are increased with salt spray time. For the same salt spray time, the electric resistance of busbar joint is decreased with increasing torque moment.

[Key words] laser melting; electrical copper busbar; electric conductance; corrosion
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1 INTRODUCTION

Electrical copper is widely used in the electric industry because of its high strength, good heat conductivity and electric conductivity. However, as the hardness is quite low, the wear resistance of electrical copper is poor and the corrosion resistance is also fairly limited.

Laser surface treatment is an important method for improving mechanical and chemical properties of metallic materials. It is successfully applied to improve wear resistance and corrosion resistance of ferrous alloys[1,2], aluminum alloys[3,4] and other nonferrous alloys[5,6].

Because of very high reflectivity of copper alloys to CO_2 laser, which is much higher than that of ferrous alloys, titanium alloy and even aluminum alloys, laser melted copper is quite difficult to be obtained and needs much higher laser power density[7]. Up to now, study on laser surface treated copper alloys is lack, and most work mainly concentrates on the laser surface alloying[8,9] and laser clad surface composite[10] in order to improve their wear resistance. Laser melting can refine the grains and increase the hardness of the copper. It also increase the grain boundaries and sub-structure of the copper. But it is not clear how the laser treatment affects the electrical conductivity.

Generally salt spray test is used to evaluate the corrosion resistance to chloride of electric equipment. However, the evaluation of corrosion degree relies on observing the corroded material surface so that this test is often qualitative. For the copper busbars, the corrosion of the surface can affect electrical conductivity, therefore the electric resistance is used to evaluate corrosion degree in this paper.

2 EXPERIMENTAL

The sample was electrical copper busbar T2 material. The size of the samples were 175 mm × 25 mm × 3 mm and 175 mm × 25 mm × 6 mm. Before laser scanning, the surface of samples was cleaned by hydrochloride (HCl). Laser melting treatment was conducted with the laser power density of 1.4×10^5 W/cm^2 and scanning rate of 8 mm/s. The laser scanning trace was overlap. The overlap interval was 0.5 mm.

After polished, the joints of laser treated samples and original ones were fastened together face to face using bolt (as shown in Fig. 1), then different torque moments of 10, 20, 30 and 40 N·m were added on the bolt, busbar, point between bolt and busbar respectively. A CA-10 micro-ohmmeter was used to measure the electric resistance of the samples. The measuring current was 10 A. Measuring point interval is 300 mm. Each sample was measured for 5 times in the same condition to get an average data.

A spot far infrared thermometer (TA-0510F) was used to measure the temperature of joint. During measurement, the passing current was 100 A and 200 A respectively.

3 mm-thick corrosion samples were corroded in a

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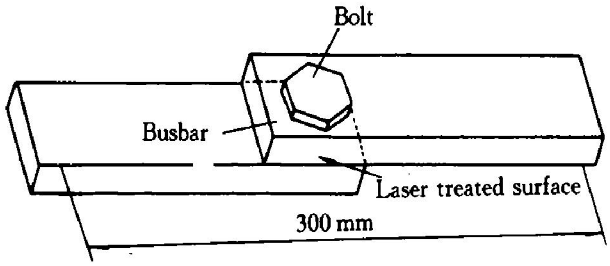

Fig. 1 Schematic drawing of fastened busbar sample

standard salt spray tester for 15 days. The corrosion medium is 5% NaCl solution. The temperature of salt spray chamber is 35 ℃; the temperature of saturated solution is 47 ℃ and the spraying rate of NaCl solution is 5 mL/h. Electric resistance was measured per three days. A Versatart II potentiostat was also used to measure the polarization curves in 3% and 6% sodium chloride (NaCl) solution. In this experiment, the calomel reference electrode and the auxiliary gold electrode was used. The corrosion areas of laser treated and original samples were 78.31 mm^2.

3 EXPERIMENTAL RESULTS

3.1 Electric resistance of fastened busbars

Fig. 2 shows the relationship between electric resistance of fastened busbars and torque forces. It is seen that as for laser treated samples the electric resistance of busbar joints decreases. Meanwhile, the difference of electric resistance between laser treated and original samples of 3 mm in thick is larger than that of 6 mm in thick. With increasing torque moment, the electric resistance of both 3 mm-thick laser-treated and original samples all slightly decrease. However, it is nearly no difference for 6 mm-thick samples with increasing torque moment.

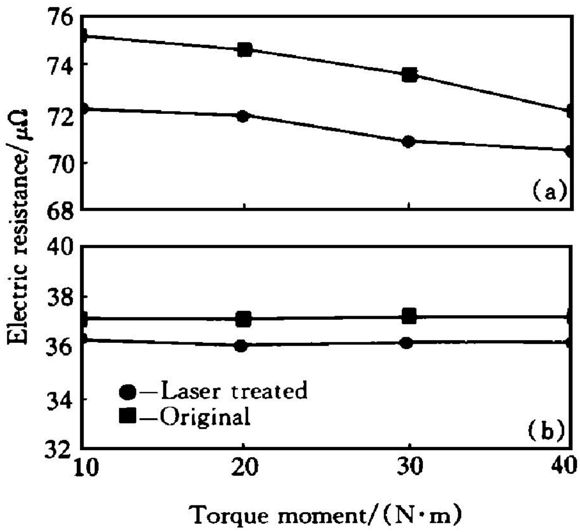

Fig. 2 Relationship between electric resistance of busbars joints and torque moment
(a) —3 mm-thick sample; (b) —6 mm-thick sample

3.2 Exotherm of joints

Fig. 3 shows the relationship between temperature of samples and time under the electric current of 100 A and room temperature of 28.8 ℃. As for 3 mm-thick sample, it can be found that the temperature of joints increase gradually with time. On the bolt, joints temperature of laser treated sample is slight lower than that of original sample. The temperature on the bolt is slightly higher than that on the busbar. As for 6 mm-thick sample, the temperature of laser treated and original samples is basically the same, and they are very near to room temperature. The reason is that under the electric current of 100 A, the heat induced by electric current is equal to dissipated heat in 6 mm-thick busbar.

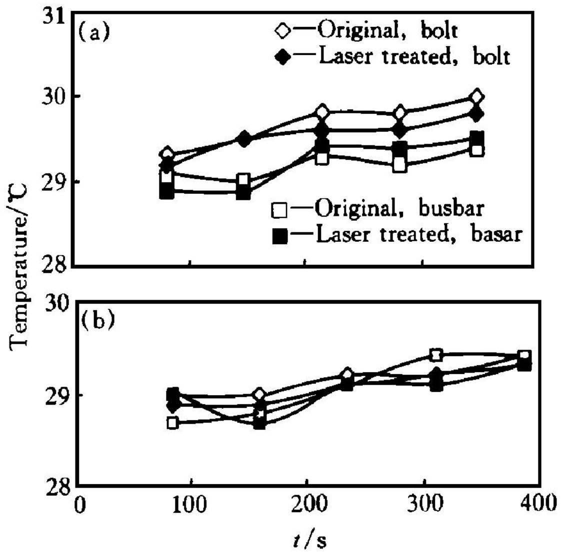

Fig. 3 Relationship between temperature of samples and time
(a) —3 mm-thick samples; (b) —6 mm-thick samples

Fig. 4 shows the relationship between average temperature of joints (3 mm-thick sample) and the torque moment under electric current of 200 A and room temperature (28 ℃). It can be seen that the laser treated samples have lower average temperature than that of original samples. The difference of temperature between laser treated and original samples is reduced with increasing torque moment.

3.3 Corrosion resistance of samples

Fig. 5 shows the relationship between electric resistance of busbar joint and salt spray time. It can be seen that with prolonging salt spray time, the electric resistance increases gradually. This suggests that the corrosion products precipitate on the samples more and more. It also can be seen that with increasing torque moment, the electric resistance is reduced. The electric resistance of laser treated samples is smaller than that of original samples at the same torque moment.

Fig. 6 shows the relationship between electric resistance of busbar joint and torque moment. The variance of electric resistance of samples without salt spraying is much small, and it is basically linear. After salt sprayed for 70 h, the resistance increases

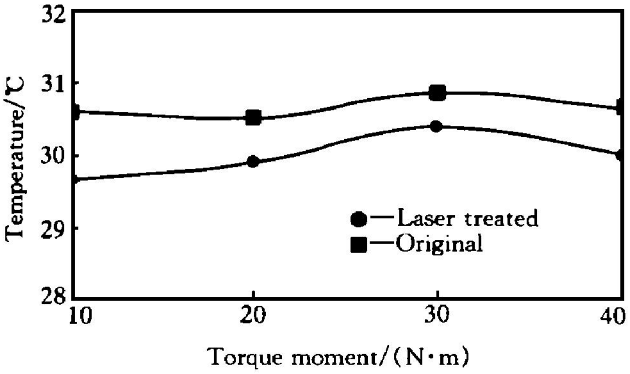

Fig. 4 Relationship between average temperature of joints and torque moment
(I = 100 A, 3 mm-think sample)

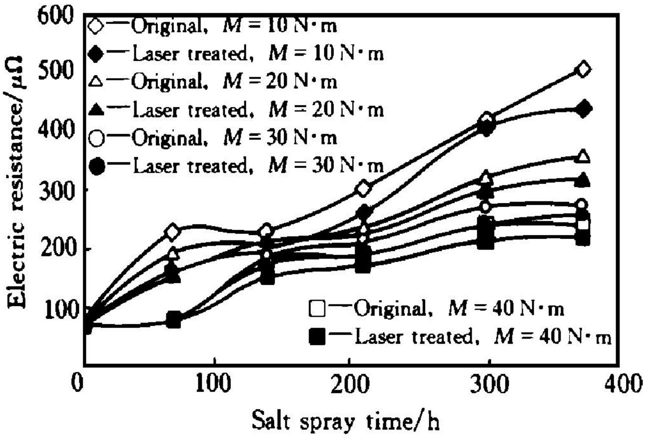

Fig. 5 Relationship between electric resistance of busbar joints and salt spray time

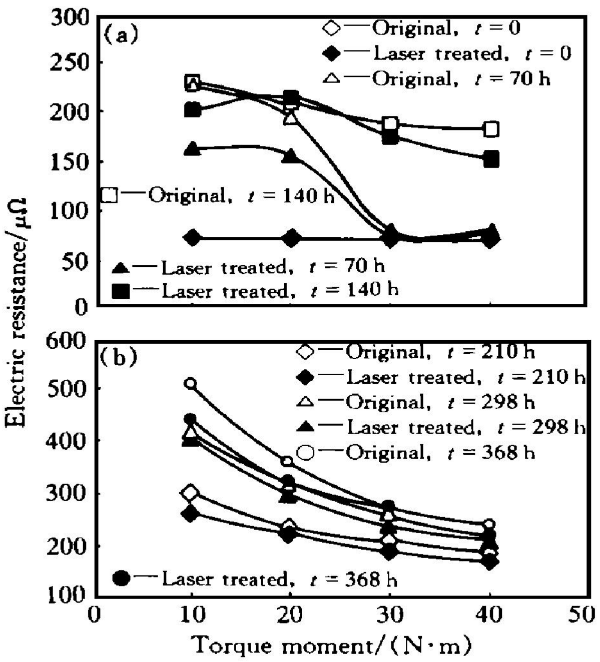

Fig. 6 Relationship between electric resistance of busbar joint and torque moment
(a) —Salt spray time < 140 h;
(b) —Salt spray time > 140 h

greatly at the low torque (10 and 20 N·m). With increasing torque moment (30 and 40 N·m), the resistance drops sharply to near that without corrosion sample. This is because there are some loose corrosion products on the sample and they cause greater electric resistance under the lower torque. However, under the large torque moment, the effect of these corrosion products on resistance becomes small. After salt sprayed for 140 h, even under the torque moment of 40 N·m, there exists large electric resistance. This is because that the layer of more compact corrosion products form. It is also found the laser treated samples have low resistance than that of original samples.

4 DISCUSSION

The hardness of laser treated sample is HV78, and the original sample is HV71. After laser treatment, the hardness increases about 10%. Fig. 7 shows the SEM photos of laser treated sample and original sample. From two images, it can be seen that the grains are fine and many substructure boundaries in the grain appears in the laser treated sample. The microstructure is quite homogeneous in the original sample. By measuring, the average grain sizes are 30.5 μm to 10.2 μm for original and laser treated samples. Fine grains and sub-substructure cause surface hardness increase.

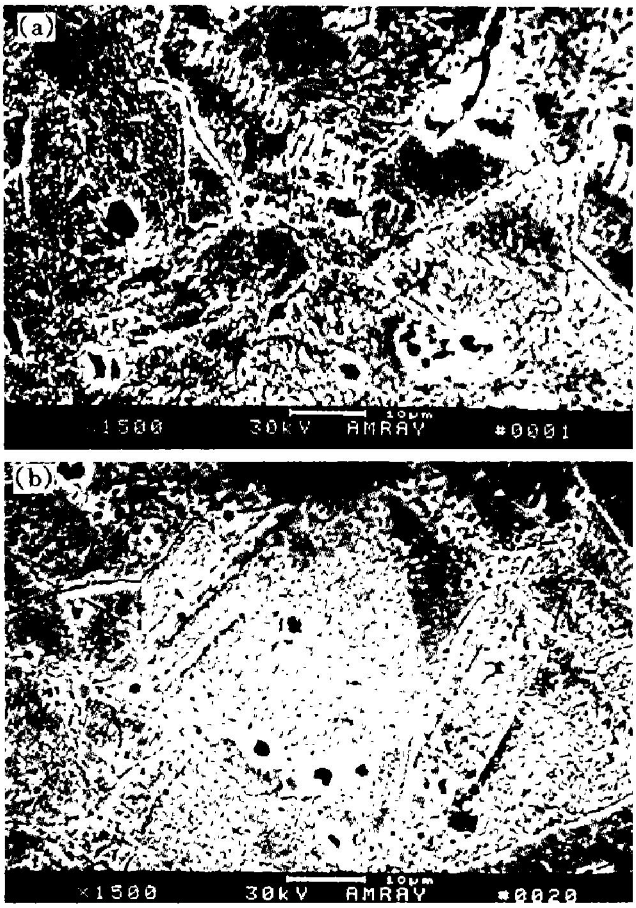

Fig. 7 SEM images of laser melted sample (a) and original sample (b)

The copper busbars are produced by rolling, whose surface is always quite smooth. When two busbars are fastened together, some partial region may not contact very well at low torque force because of slight deformation. Laser melting treatment causes the hardness of busbar increase and form many micro-protuberances of substructure. These micro-uneven structures may improve the touch of two busbars at low torque force. With increasing torque, the effect of substructure is also reduced.

Fig. 8 shows anodic polarization curves of laser treated sample and original sample in 3% and 6% NaCl solutions. In the active corrosion stage, corrosion current of laser treated samples is slight less than that of original samples. According to electrochemical principle, the sample with lower corrosion current has lower corrosion rate in the active corrosion stage. As the passivation of original sample occurs in the lower corrosion current compared with laser treated sample, the passive tendency of original samples is better than that of laser treated samples. As the corrosion current is small during salt spraying, the corrosion process is often in the active corrosion stage. This causes the corrosion degree of laser treated samples to be smaller than that of original sample after salt spraying. That is, the corrosion resistance of laser treated samples is better than that of original samples during salt spraying.

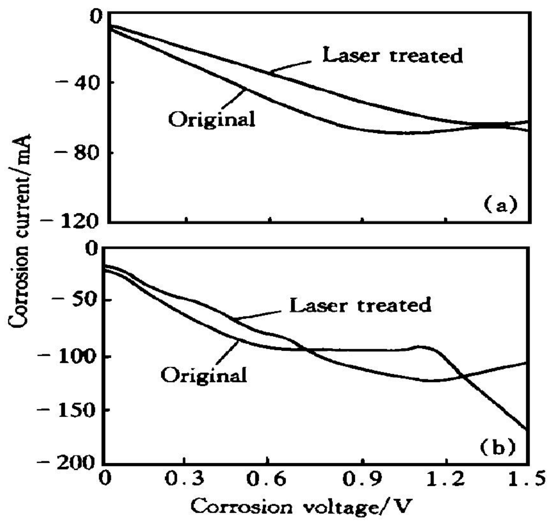

Fig. 8 Anodic polarization curves of samples in 3% (a) and 6% (b) NaCl solution

5 CONCLUSIONS

1) Laser melting treatment can increase hardness and refine grains of busbars. It can also reduce slightly electric resistance. With increasing torque moment, the effect on reducing electrical resistance decreases.

2) In the salt spraying, with increasing salt spray time, the electric resistance of laser treated and original samples is increased. With increasing torque moment, the electric resistance of laser treated and original samples decreases.

3) Laser treated samples have lower electric resistance than the original samples do, that is, their salt spray corrosion resistance is better than that of the original sample.

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