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Effects of process parameters on the mechanical properties and microstructure of Al-steel joint by magnetic pulse welding

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Abstract. In this paper, the effects of process parameters of Magnetic pulse welding (MPW) on the mechanical properties and microstructure of dissimilar metal joints of 6063-O and 20 steel tubes were investigated according to experiments. The experimental results show that the tensile strength of MPW joint is higher than that of the aluminium tube when the discharging energy of MPW attaches a certain value as well as the process parameters are reasonable, in which the mechanical joining was happened. Through the FEM analysis and experiments verification, the metallurgical joints were obtained with the moderate discharging energy, reasonable impact angle and radial gap. The results of micro hardness test show that the transition zone has a big change because the grain structure of joints in the interface was refined.

1. Introduction

Lightweight can reduce energy consumption and emissions of the automobile effectively, which makes a contribution to environmental protection [1]. Using lightweight structural materials such as aluminium alloy is an effective way to reduce weight in the automotive industry. However, in consideration of the poor forming process and the expensive production cost of aluminium, the steel is still the major materials in automotive industry. Therefore, the problem of dissimilar metals welding is inevitable in the industrial production. At the same time, how to achieve the high performance of dissimilar metal combinations of aluminium alloy-steel effectively and economically is one of the hottest issues in the recent researches [2, 3].

In the methods of dissimilar metal welding, inter-metallic compounds are easy to form in the process of welding. In general, inter-metallic compounds are the phases of fragile and hard which result in the mechanical properties degradation of the joints. To achieve the high performance of dissimilar metal joints, some new welding technique and welding technology are proposed to avoid the fragile and hard phases. For example, the third metal is added during the process of diffusion welding, and solid state welding techniques is proposed [4, 5].

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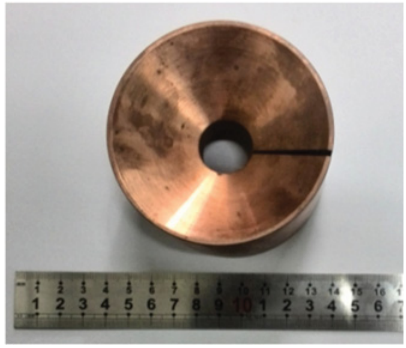

Figure 1. The shaper field.

Electromagnetic forming is a high-rate-forming technology which can improve the formability of metals [6, 7]. Based on the EMF technology, magnetic pulse welding (MPW) having a great prospect in resolving the problems of dissimilar metal welding for the advantages of convenient operation, easy processing control and easy realization of mechanization and automation [8, 9]. Research shows that the mechanical properties of the MPW joint are of good performance; the tension and torsion strength values of joints are higher than the weaker parent material [10]. In this paper, the MPW experiments of 6063 aluminium alloy and 20 steel tubes were performed and the mechanical properties and microstructure of MPW joint were investigated. The micro-pattern of interface and transition zone was observed and the distribution of basic elements across the transition zone was analyzed.

2. Experimental

In this paper, the experimental equipment for the MPW is WG-IV high voltage electromagnetic forming machine, rated discharge energy is of 60 kJ. The capacitance value of the equipment is 440 μF, the rated discharge voltage of the equipment is 20 kV. In the experiment, the variable range of discharge voltage ranges from 4.0 to10.0 kV.

Since the field shaper assisted coil can greatly improve the efficiency of the energy transfer and the service life of the coil, the field shaper assisted coil become the preferred coil device in the process of the MPW. In the process of MPW experiment, the joint length is short relative to the length of workpiece, so the field shaper device is very necessary. In this study, the field shaper used in the experiments is shown in Fig. 1, and the coil and the experimental tools are shown in Fig. 2 and Fig. 3 respectively. The fixture is composed of bakelite and aluminium blocks; the cross plain vices are used to make sure that the coil is coaxial and concentric with the tube. The experimental materials are the 6063-O aluminium alloy and 20 steel. The dimension of outer tube is $\Phi 20 \times 10 \times 150$ mm. The dimension of inner tube is $\Phi 16 \times 8 \times 120$ mm. The experiments under different process parameters were carried out. The mechanical properties of joints were analyzed by peeling test and tension test, and the microstructure and the interface pattern were observed by OM and SEM.

3. Mechanical properties evaluation

The MPW joints were measured by the peeling test. There are obvious percussion marks in the face of inner tube under discharge voltage of 6 kV, and the outer tube is easy to be peeled off. Under the discharge voltage of 10 kV, radial gap of 1.4 mm and the preset angle of 5 °C, rough dent appears in the entire connection region, which is the result of jet formation in the impact process. At this moment,

Figure 2. The MPW coil.

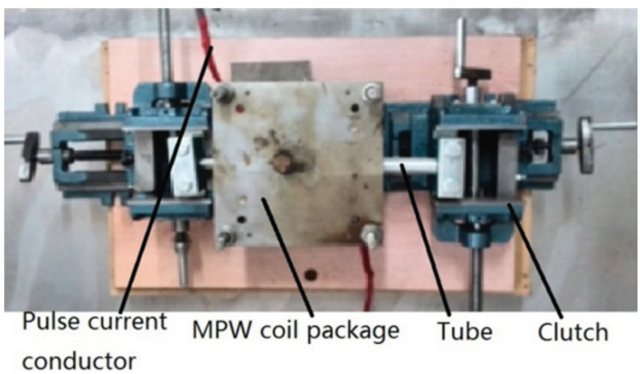

Figure 3. Experimental tools.

the outer tube is hard to be peeled off. It indicates that the metallurgical joint has been obtained, and the bonding force increases with the increase of discharge voltage.

The MPW joints under different process parameters were measured by the tension test. The tension test results show that the MPW joint is pulled off when the discharge voltage is lower than 5 kV. When the discharge voltage is higher than 5 kV, the aluminium alloy tube is broken. The load-displacement curve of the joint under discharge voltage of 10 kV, radial gap of 1.4 mm and the preset angle of 5 °C is shown in Fig. 4. The maximum load is 6.1 N and the maximum tensile strength is 77 MPa.

4. Microstructure analysis of the MPW joint

The cross section microstructure of the MPW joint was observed by OM. The microstructure near the interface is shown in Fig. 5. The grains are elongated along the radial and the grain refinement occurs in the steel near the interface. This shows that the severe plastic deformation occurs in the interface. The more close to the interface, the finer the grain is. It indicates that closer to the interface, the stronger the plastic deformation is. The microstructure of joints under different discharge voltage is shown in Fig. 6. The result shows that the discharge voltage is higher; the grain refinement is more obvious. It indicates that the grain refinement is related with the impact velocity, when the impact velocity is higher, the plastic deformation is more strongly.

The micro-hardness of the joint under 10 kV was investigated by HV-1000A Vickers hardness tester. The distribution of test points and the micro-hardness values are shown in Fig. 7. The micro-hardness in

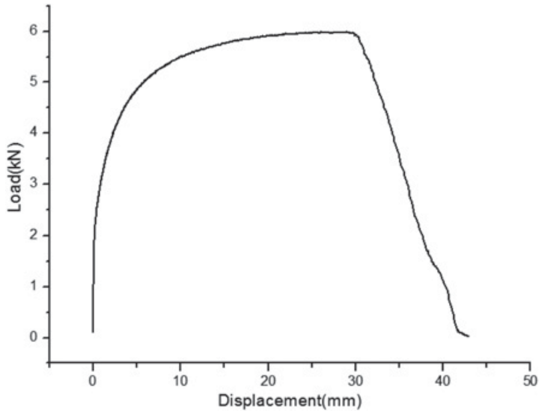

Figure 4. Load-displacement curve.

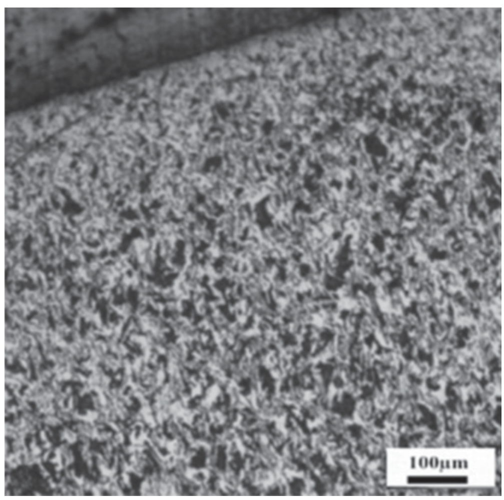

Figure 5. Microstructure near the interface.

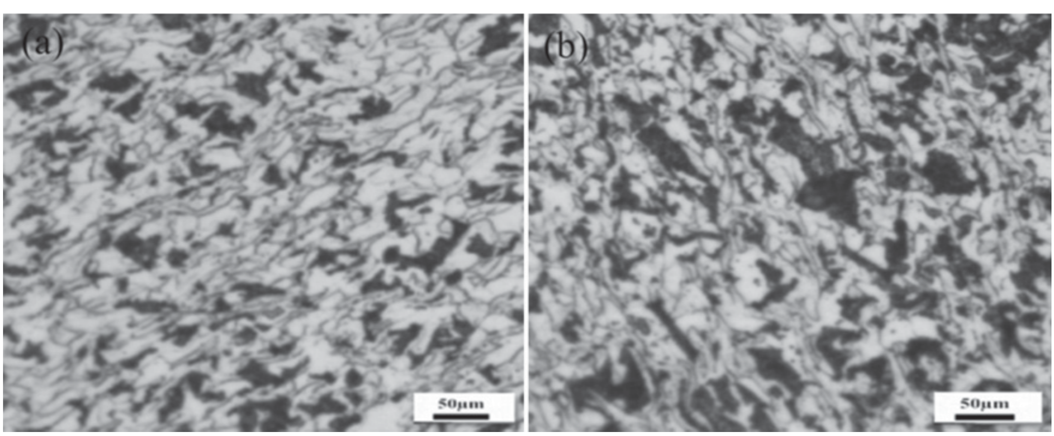

Figure 6. Microstructure: (a) Under discharge voltage of 10 kV, (b) Under discharge voltage of 8 kV.

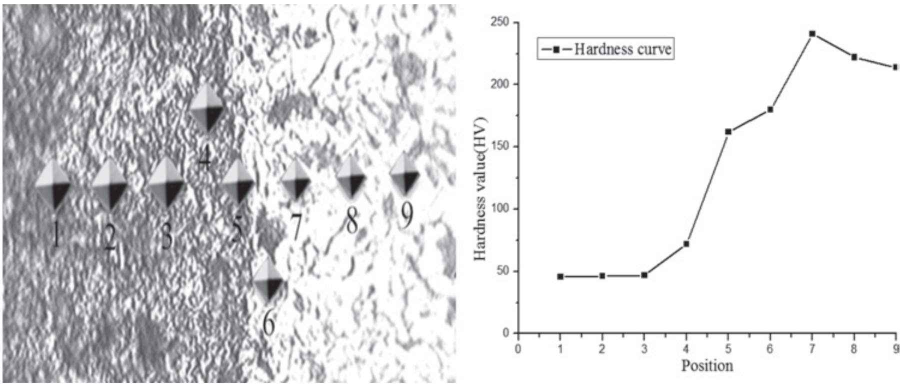

Figure 7. The distribution of test points and the micro-hardness values.

the side of aluminium alloy (1, 2, 3) is low and tends to level. In the side of 20 steel, micro-hardness is higher when the test point is closer to the interface. This is due to closer to the interface, grain refinement is more obvious. In the transition region, the micro-hardness of the test point mainly depends on the parent material close to it. However, due to the grain refinement and plastic deformation in the interface, the micro-hardness rises successively.

5. Conclusions

(1) Magnetic pulse forming can get a metallurgical joint only when the discharge energy is enough, though the dissimilar metal tube can be joined when the discharge energy is lower.
(2) With the increase of discharge voltage, the tensile strength of MPW joints increase.
(3) Due to the grain refinement and plastic deformation in the interface, the micro-hardness rises successively. In the transition region, the micro-hardness of the test point mainly depends on the parent material close to it.

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