Asia-SAME Transactions on Engineering Sciences, ISSN: 2377-8970
ISBN: 978-1-948012-15-7 https://doi.org/10.7508/aste.01.2020.09.16

Annealing Temperature on Diffusion Bonding Layer of Magnesium Alloy and Aluminum Alloy Based on Finite Element Analysis

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From 2020 International Conference on Engineering Research, Beijing, China. 12-14 April 2020, Organized by University of Science and Technology Beijing and International Association of Management Science and Engineering Technology (IAMSET).

Abstract: Magnesium alloy and aluminum alloy composite materials not only have good conductivity, heat conduction, corrosion resistance and formability of magnesium alloy and aluminum alloy substrates, but also have the advantages of beautiful appearance, light weight and precious metal saving. In addition, magnesium has active chemical properties and low equilibrium potential, which leads to poor corrosion resistance of magnesium alloy. Both disadvantages restrict the further development of magnesium alloy. However, aluminum alloy has the characteristics of corrosion resistance, high strength, easy processing and no brittleness at low temperature. However, the application of magnesium alloy is limited due to its poor plastic deformation ability at room temperature and difficulties in processing and forming. Therefore, the author attempts to analyze the influence of annealing temperature on the diffusion bonding layer of magnesium alloy and aluminum alloy by using finite element technology, so as to take corresponding measures in processing to prevent magnesium alloy chip combustion or explosion accidents.

Keywords: Finite element analysis, annealing temperature, magnesium alloy, aluminium alloy.

Introduction

Magnesium and magnesium alloys are light alloy structural materials that can be applied to engineering fields at present due to their advantages of small specific gravity, high specific strength, high specific modulus of elasticity, good electromagnetic shielding, good shock absorption and shock resistance, high recycling rate, etc. It can be widely used in electric vehicles, packaging materials, energy equipment, household appliances and other fields [1]. The lightest metal engineering structural material in engineering applications can replace plastics, light metal alloys and steel parts. Its density is mostly 1.75-1.85g/cm^3, which is about 1/4 of iron and 2/3 of aluminum Plastics are similar [2]. Magnesium alloy has good cutting performance, but its ignition point is low. The influence of temperature must be considered in the cutting process to prevent chips from burning. Different from the traditional rolling technology, the liquid-solid casting-rolling method can directly use melt to produce composite plates. This method has many advantages, such as lower equipment and operating costs, and less energy and space requirements [3]. Based on the finite element analysis system, the effect of annealing temperature on the microstructure and mechanical properties of the bonding interface of cold-rolled two-layer magnesium alloy and aluminum alloy composite plates was studied to determine the optimal annealing temperature.

Methodology

The cold rolling process is relatively simple in rolling compounding, and the overall service performance of the composite plate depends on the interface performance of magnesium alloy and aluminum alloy [4]. Previous studies have shown that [5] when the extrusion speed of the punch is low, the friction heat between the sample and the die is small and negligible. The materials used in the test are pure aluminum L1060 plate with a thickness of 3mm and pure aluminum T2 plate with a thickness of 1 mm. The main chemical compositions are shown in Table 1. The component metal plate is cut into a plate with a width of 60mm and a length of 500mm, and is subjected to pre-rolling stress annealing treatment at 300 DEG C for 50min. The contact tolerance between the sample and the die is 0.0498mm, the friction type is shear friction, and the friction coefficient is 0.25. Because the cutting speed is faster than the specific heat conduction speed, most of the heat is left on the chips and cannot be transferred to the workpiece, thus preventing the workpiece from warping due to heat. Under the action of temperature and pressure, the microscopic raised areas can contact and deform first, and at the same time, the adsorption layer and the oxide film can be extruded and broken, thus increasing the effective contact area and fully contacting the connection surface. LEICAQ550IW metallographic microscope was used for low-power microscopic observation. FEIQuanta600 scanning electron microscope was used to observe the microstructure and morphology of the composite plate interface (Table 1).

Table 1. Chemical composition of L1060 aluminum (mass fraction%)

Si	Fe	Cu	Zn	Mn	Mg
0.13	0.11	0.02	0.02	0.04	0.04

Metallographic specimens were taken from the cross sections of aluminum/magnesium alloy composite plates and explosive composite plates annealed at different temperatures. SEM and ESD analysis were carried out on the morphology characteristics of the joint interface of the composite plates. The magnesium alloy and the aluminum alloy are subjected to explosive recombination according to the established explosive welding parameters. The light weight of magnesium alloy and aluminum alloy parts can be further realized by inlaying a magnesium alloy material lighter than aluminum alloy into a die casting piston made of a single aluminum alloy material. It can be found that the bonding interface morphology of the composite plate prepared by explosive welding presents a good bonding interface. With the increase of heat treatment temperature, obvious transition layer appears at the bonding interface of the composite board, and the thickness of the transition layer shows a trend of increasing. After polishing and polishing the metallographic specimen, it was corroded with 3% nitric acid alcohol. The microstructure morphology of the corroded metallographic specimen was observed by 4XG-MS optical microscope (OM), FEG-450 thermal field emission scanning electron microscope (SEM) and FEG-450 thermal field emission scanning electron microscope-energy spectrometer (SEM-EDS). The cutting heat mainly comes from the plastic deformation in the chip shear zone and the tool-chip interface friction [6]. The combined action of the two causes the tool and workpiece to heat up rapidly. When the temperature rises to 250°C, the boundary line of the matrix is no longer straight, and the diffusion layer gradually appears. When the temperature reaches 150°C, obvious diffusion layer appears, and the whole layer presents two layers with nearly equal thickness. The bonding interface of the composite board is peeled off about 10mm in advance and clamped, and then the bonding strength of the composite board is tested by an electronic universal tensile testing machine.

According to the wall thickness, the calculation method of the die hole size is different. L1060 plate profile is a thin-walled profile with a small wall thickness relative to the cross-sectional area and a long profile length. In general, the overall dimension of the die hole can be determined according to the following formula:

$$D = D_0 = TD_0 = (1 + T)D_0 \qquad (1)$$

Where D_0 represents the nominal size of the product appearance, T is the empirical coefficient, generally 0.006~0.018. The die hole size U of the product wall thickness can be determined by the following formula:

$$U = U_0 + \Delta \qquad (2)$$

In the formula, U_0 is the nominal size of the wall thickness of the product, and $\Delta$is the increment of the die hole size of the wall thickness. When $U_0 \leq 2\,mm$, $\Delta = 0.2\,mm$; When $U_0 > 2\,mm$, take $\Delta = 0.3\,mm$.

The specimen is metallurgically bonded by the mutual movement of atoms at the interface. Due to the high heating temperature required for diffusion bonding in this stage, the energy obtained by atomic motion is large and the atomic motion speed is fast. Diffusion layer can be observed at the interface of magnesium alloy and aluminum alloy composite plates treated at different annealing temperatures. Therefore, the whole structure is divided into the front part and the back part for separate analysis, and each part is divided into grids according to its own structural characteristics. The cutting process is actually a process of relative movement between the workpiece and the tool. If the boundary grid of the workpiece interferes with the tool, the accuracy of the simulation results will be affected. With the increasing thickness of the diffusion layer, two obvious diffusion layers are formed. The thickness of the diffusion layer near the magnesium alloy side is thinner, while the thickness of the diffusion layer near the aluminum alloy side is thicker. The bonding interface has a wide transition area, and there are a few gaps and voids at the interface. The characteristics of small wave combination are that the wave height is smaller than that of large wave, the width of transition region is narrower, and the gap and cavity are obviously reduced than that of large wave combination. At the same time, the method of inlaying magnesium alloy inserts in aluminum alloy castings also avoids the oxide layer problem when aluminum alloy parts are used as inserts, and is more conducive to the implementation of the inlaying process.

Result analysis and discussion

The heat source of deformation zone in high-speed cutting can be divided into shear zone temperature field, knife-chip temperature field and processed surface thin layer temperature field [7]. In addition, when magnesium alloy is heated, the temperature is more difficult to be uniform, so when magnesium and magnesium alloy are hot extruded, only under the condition of ensuring uniform temperature and sufficient lubrication can a uniform flow scene be obtained. The higher the strength of the material, the lower the applied stress level, and the higher the fatigue life of the sample. On the contrary, the fatigue life is lower. In the diffusion annealing process of magnesium alloy and aluminum alloy composite plates, magnesium alloy and aluminum alloy atoms obtain enough energy to generate transition, forming material transmission, and finally showing the formation of diffusion layer. Due to the friction between the sample and the inner wall of the extrusion channel, the extrusion load shows certain fluctuation in the stable deformation stage. When the interfacial wave is formed, the wave crest with a certain height will block the molten metal fluid from flowing forward. The explosion load continues to propagate forward, while the molten metal fluid will stay near the interface wave and form a vortex area at the interface after cooling. However, the inner gate is located at the junction of the aluminum alloy piston base and the sprue, and is the place with the largest cross-sectional area in the gating system, which is very favorable for pressure maintaining and feeding at the end of die casting. With the increase of heat treatment temperature, the thickness of the diffusion layer gradually increases, and the composition of the diffusion layer is magnesium and aluminum intermetallic compound phase.

When the atoms of magnesium alloy and aluminum alloy in the diffusion region reach a certain proportion, intermetallic compounds will be generated, and the type and content of intermetallic compounds will also change with different heat treatment temperatures. Figure 1 is a graph showing the relationship between annealing temperature and diffusion layer thickness.

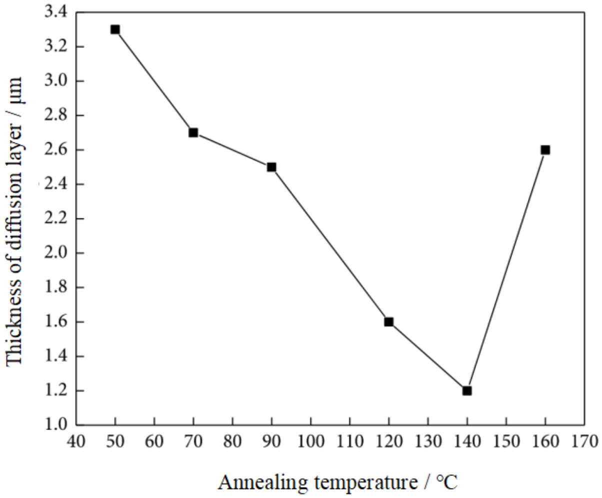

Figure 1. Relation curve between annealing temperature and diffusion layer thickness

The original cast-rolled aluminum-steel composite plate is well bonded, without any defects in the interface region, and has a relatively thin diffusion layer. Diffusion layer can be observed at the interface of magnesium alloy and aluminum alloy composite plates treated at different annealing temperatures. When the temperature is 150℃, the bonding interface is fuzzy and the diffusion layer is thin and unclear. Moreover, the higher the degree of grain recrystallization at the interface is, the more grains are generated, which can fill the void at the interface, thus further improving the welding quality. At the stage of rapidly rising load, the sample undergoes pier rough deformation, and at the same time undergoes severe plastic deformation when passing through the corner, which results in severe work hardening, increased deformation resistance and sharply rising extrusion load. After the temperature is higher than 120℃, the atoms of magnesium alloy and aluminum alloy deviate from the equilibrium position to do high-frequency thermal movement, and interdiffusion occurs, forming obvious diffusion layer. Moreover, the higher the temperature, the more atoms that produce transition, the faster the diffusion, and the greater the thickness of the formed diffusion layer. Magnesium and magnesium alloy have much worse extrusion and welding performance than aluminum alloy, so when extruding pipes, except for a few cases, it is appropriate to use piercing needles or hollow ingots for extrusion. In the diffusion annealing process of magnesium alloy and aluminum alloy composite plates, magnesium alloy and aluminum alloy atoms obtain enough energy to generate transition, forming material transmission, and finally showing the formation of diffusion layer. As chips flow out along the rake face, the surface temperature of the cutting tool gradually decreases outward along the tip of the tool. Because there is a certain contact length between the rake face of the tool and the surface of the workpiece, the temperature of the chip surface decreases less.

Figure 2 shows the effect of different annealing temperatures on the bonding strength of two-layer magnesium alloy and aluminum alloy composites. As can be seen from Figure 2, with the increase of annealing temperature, the bonding strength of the two-layer magnesium alloy and aluminum alloy composite material firstly increases and then decreases, and then tends to be stable.

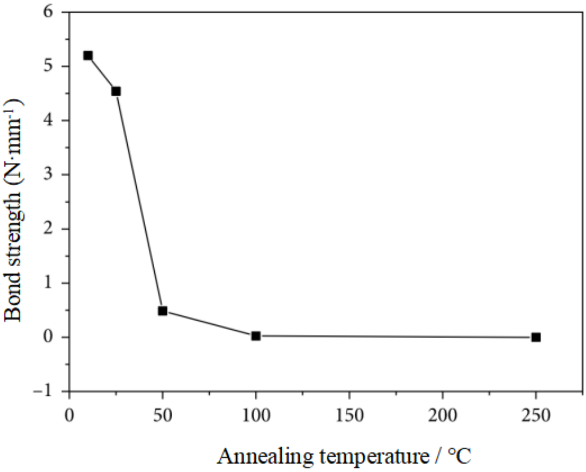

Figure 2. Variation of bonding strength with annealing temperature

The interface of the annealed magnesium alloy and aluminum alloy composite plate will move to the aluminum side. The fundamental reason is that when aluminum and iron atoms on both sides of the interface diffuse into each other's matrix, the diffusion rate of aluminum atoms is much higher than that of the original interface caused by iron atoms, making the interface move to the side with higher diffusion rate. After the bonding interface of the annealed composite plate at 250℃ is enlarged locally, two obvious magnesium and aluminum intermetallic compound phase diffusion layers are also formed at the bonding interface. The interface is in a high-temperature and high-pressure environment, and a melting phenomenon occurs locally at the interface. After melting, the material at the interface cools rapidly, air cannot be discharged in time at the interface, and the residual material forms shrinkage porosity at the interface. This is mainly because in high-speed cutting, the thermal effect has obvious advantages. The shear surface is like a stable heat source, which always heats the material about to enter the shear surface at a high enough temperature to reduce the shear strength of the metal. With the accumulation of metal, the pressure in the welding chamber increases continuously. After the pressure reaches a certain limit value, the metal is extruded from the die hole. The cross-sectional area of the top gate at the joint of the aluminum alloy piston matrix and the gating system is very small. While having the advantages of the top gate, the top gate can also overcome the defect that shrinkage cavity is easily generated at the joint of the die casting and the gate when the aluminum alloy piston matrix adopts the top gate.

Conclusion

To sum up, the cutting model and boundary conditions established in this paper are very practical. Comparing the simulation results with the test results, it can be found that the finite element simulation has strong practical significance. According to the test results of mechanical properties of magnesium alloy itself, i.e. it has higher tensile strength, bending strength, compressive strength and impact resistance than aluminum alloy, the two-layer magnesium alloy and aluminum alloy composite plate prepared by cold rolling composite method can obtain the best interface microstructure and mechanical properties after annealing at 250℃ for 120min. Tensile strength of composite plate decreases with the increase of annealing temperature and holding time, while elongation increases with the increase of annealing temperature and holding time. The diffusion time of metal atoms increases with the increase of pouring temperature, mold preheating temperature and magnesium alloy insert preheating temperature, and basically has a positive correlation. However, with the increase of pouring speed, the variation rule of diffusion time is not obvious and there is certain fluctuation.

Acknowledgements

Scientific and technological research program of Chongqing municipal education commission, Chongqing (KJ201903136636560).

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