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Influence of Heat Treatment on the Weld Structure and Performance of Magnesium Alloy

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To know the influence of heat treatment on the weld structure and performance of magnesium alloy. Use TIG weld method to research the performance variation of AZ31B magnesium alloy at different temperatures. The performance of AZ31B magnesium alloy at 300℃ and 400℃ improves; the performance of AZ31B magnesium alloy at 450℃ declines. The welding at 450℃ goes against improvement of the performance of AZ31B magnesium alloy, which indicates that temperature 450℃ shall not be used in actual heat treatment on AZ31B magnesium alloy.

1. Introduction

As modern most important light structural material, magnesium alloy performs better in many aspects (such as specific strength, specific stiffness, damping and electromagnetic shielding) comparing with other metal materials and engineering plastics. Therefore, this material has attracted extensive attention of modern people. Welding technique is usually used as connection method in application of magnesium alloy. In addition, this technique is the most common one among modern heat treatment technologies. It can effectively guarantee the quality of connection among magnesium alloys and contribute to magnesium alloy playing its performance.

To research the influence of heat treatment on the weld structure and performance of magnesium alloy, take AZ31B magnesium alloy for research sample and use several welding heat treatment technologies which have property difference after adjustment to collect the parameters of AZ31B magnesium alloy in welding technique. This paper mainly researches the influence of welding current and composite surfactant on the macroscopic features, microscopic structure and mechanical property of the joint of argon tungsten-arc welding (A-TIG) with activation of AZ31B magnesium alloy. It discusses the influence of coating of composite surfactant on fusion depth of TIG welding joint of AZ31B magnesium alloy, discusses the formation mechanism of defect of weld joint, systematically researches the influence of the variation of post-weld heat treatment parameters on the microscopic structure and mechanical property of A-TIG welding joints of AZ31B magnesium alloy aiming at the poor mechanical property of A-TIG welding joints of magnesium alloy, and ascertains the evolution laws of the microscopic structure of welding joints and the relationship between it and mechanical property.

2. Overview

Alloying is an effective way to improve the mechanical properties of the alloy. The solid solution of alloy elements to the alloy, the pinning of the solute atoms to the dislocation of the alloy and the dispersion strengthening of the precipitated phase can be applied to the magnesium alloy. Electromagnetic stirring is a magnetic field that uses alternating current to form a changing magnetic field. Through electromagnetic induction, it produces current in the metal liquid, and the metal liquid with current is subjected to the effect of electromagnetic force in the changing magnetic field. It makes the metal fluid convective during solidification, so that the solidification structure is promoted and the performance is improved.

Lei et al. studied the effect of electromagnetic stirring at different voltages (50-140V) on the microstructure and mechanical properties of Mg-9Li-5Al-Zn alloy. It is found that when the voltage is above 110V, the phase of α-

Mg becomes spheroidal, and β phase around α-Mg is distributed more widely, and small particles are found in the β phase. When the voltage is 110V, the tensile strength of the alloy reaches the maximum value of 195MPa, and the elongation reaches the maximum value of 25.75% when the voltage is 80V. The electromagnetic stirring also causes the change of the element content, which makes Zn distributed more widely in the β phase. In the alloy matrix, the metastable phase MgLi2Zn and the equilibrium phase MgLiZn are precipitated. The small particles in the β phase are MgLi2Zn and MgLiZn phases. These small particles play a dispersion strengthening effect and increase the mechanical properties of the alloy (Lei et al., 2010).

Mg-Gd-Zn semi-solid slurry was prepared by electromagnetic stirring process by Wang et al. The influence of different electromagnetic stirring voltage, electromagnetic stirring frequency and super-cooling degree on the alloy was studied. It was found that with the increase of voltage (0V, 200-380V) and frequency (10-20Hz), the size of α-Mg decreased first and then increased. With the decrease of super-cooling degree (0.5-2.6K/min), the size of α-Mg decreases, and the distribution of Gd in the alloy is greatly affected by the change of cold degree, while Zn is smaller (Wang et al., 2015).

Li and others carried out the positive rotation / reversal electromagnetic stirring of AZCa912 for different switching times, and the frequency was 250Hz. It was found that the microstructure refinement of the alloy was more obvious with the increase of exchange time (0.05-0.5s). It was believed that the solid particles moved faster because of the smaller resistivity of solid particles than the liquid, and the interaction force was generated in the solid liquid. This interaction forced the dendrites and promoted the formation of small crystal (Li et al., 2016).

Chen and others carried out electromagnetic stirring at different time, voltage and frequency of semisolid Mg-Nd-Zn- (Zr) alloy. After electromagnetic stirring, it was found that α-Mg changed from dendrite to three forms: Rosa shape, dendritic shape and spherical shape. With the increase of voltage and frequency, the size of α-Mg first decreased and then increased, and the optimum of NZ30 and NZ30K was determined. The average grain size of NZ30 decreased from 879μm to 457μm. The electromagnetic force caused the dendrites to be broken, and the broken particles moved along with the convective motion of the electromagnetic force and gradually grew up to refine the grain. But the too high electromagnetic force would make the broken particles reunite and grow together to make the tissue coarsened (Chen et al., 2016).

When the solute atoms enter the matrix, the lattice constants of the matrix will be changed in the form of replacement atoms or in the form of interstitial atoms. Therefore, the distortion energy is generated to enhance the strength of the alloy. When the solute enters the matrix in the form of the replacement atom, the greater the difference between the solute and the solvent source is, the more obvious the effect of the solute is strengthened. After the solid solution treatment, the supersaturated solid solution will be formed in the quenching state, and the aging treatment is carried out. The second phases will precipitate in a large amount of dispersion state, forming dispersion strengthening and improving the mechanical properties of the alloy. However, the magnesium alloys rarely form an infinite solid solution, so it is limited to solid solubility and the alloy elements cannot be dissolved indefinitely. In addition, the grain will grow up at high temperature. As a result, the content of the alloy elements and the technological parameters of the solution treatment determine the solid solution strengthening effect.

The influence of solution treatment and electromagnetic stirring on ZK60 magnesium alloy was studied by Li and Yu. The results show that after the electromagnetic stirring, the microstructure of ZK60 magnesium alloy is mainly composed of α-Mg matrix and a non-equilibrium eutectic phase (Mg+MgZn+MgZn2). Compared with the ZK60 magnesium alloy without electromagnetic stirring, the reticular eutectic structure of the ZK60 magnesium alloy at the grain boundary is finer, and the grain size is refined and the size is more uniform. After solid solution treatment, the microstructure of ZK60 alloy with electromagnetic stirring is more uniform than that without electromagnetic stirring. The main factor of this phenomenon is the dissolution of the second phase. In mechanical properties, after electromagnetic stirring, the hardness of the alloy decreased, while tensile strength, yield strength and elongation increased. With the increase of the solid solution time (4-16h), the hardness of the two alloys decreased, the tensile strength, yield strength and elongation first increased and then decreased, and the maximum value was obtained at 12h. The tensile strength, yield strength and elongation of the electromagnetic stirring ZK60 magnesium alloy are 284MPa, 196MPa and 15.5%, respectively (Li and Yu, 2013).

Pei et al. used the first principle to study the effect of Y element doping on the stacking fault energy of Mg based solid solution. The results show that the addition of Y element can improve the stability of error energy of Mg in the upper layer, but at the same time, it will reduce the stability of the {11-22} <11-23> in the non-base slip system (Pei et al., 2013).

Feng and so on found that there were many defects in the traditional welding method of magnesium alloys, such as the sensitivity of thermal crack, segregation of components and the defects of precipitation, which greatly restricts the application of magnesium alloys (Feng et al., 2013). Yang and others can get good shaped joints through FSW, and good matching joints can be obtained by good ω/v. However, the

microstructure of the welded joint is distinct, the weld core area and the heat affected zone as well as the influence zone of the heat engine differ greatly from the microstructures of the parent material. And the grain difference is large in each region, which makes the softening area appear in the heat affected zone or the influence zone of the hot machine, and the fracture of the material often occurs in this area (Yang et al, 2014).
To sum up, the above research work is mainly to refine the crystal particles of magnesium alloys to ensure that the plasticity of magnesium alloys can be overcome during welding, but the research on the microstructure and mechanical properties of magnesium alloys is less. Therefore, based on the above research status, the effect of solution treatment and aging treatment on the microstructure and mechanical properties of electromagnetic stirring AZ91 magnesium alloy is studied. The microstructure of AZ91 magnesium alloy is improved and the mechanical properties of the alloy are improved. The thermal stability, electronic and elastic properties of the β phase and Mg based solid solution are calculated by the first principle.

3. Methods

3.1 Heat treatment methods of magnesium alloy

Common heat treatment methods of magnesium alloy include annealing, homogenization treatment, aging treatment etc. Basic heat treatment species and symbols are listed in Table 1. Concrete heat treatment methods depend on the categories of magnesium alloy (wrought magnesium alloy or casting magnesium alloy) and anticipative service conditions.

Table 1: Symbols of the basic heat treatment species

Symbol	Significance	Symbol	Significance
F	Processing state	T4	Solid solution treatment
O	Complete hardening	T5	Artificial aging
H1	Machining hardening	T6	Artificial aging after solid solution treatment
H2	Post hardening annealing	T7	Stabilization treatment after solid solution treatment
T2	Stress annealing	T8	Cold processing and artificial aging after solid solution treatment
T3	Cold processing after solid solution treatment	T9	Cold processing after solid solution treatment after artificial aging

Annealing can eliminate or decrease the ingredient unevenness and residual stress in workpieces of magnesium alloy, optimize the structure of magnesium alloy, improve ductility and toughness of alloy and prepare for subsequent machining. Common magnesium alloy annealing methods are high-temperature complete annealing, destressing annealing and homogenization annealing. High-temperature complete annealing (O) can eliminate the machining hardening caused by the plastic deformation of magnesium alloy, recover and improve ductility and toughness of workpieces for subsequent processing and deformation. Commonly, the temperature of high-temperature complete annealing is high and heat preservation time is long. Magnesium alloy takes shape at high temperature. High-temperature complete annealing is seldom used to magnesium alloy. Destress annealing (T2) can eliminate or decrease the residual stress produced in the process of taking shape, hot and cold processing, rectification and welding of deformed magnesium alloy products. Machining can also cause residual stress of magnesium alloy workpieces. Therefore, destress annealing is often operated on magnesium alloy workpieces before machining.
Homogenizing annealing is usually operated before deformation of magnesium alloy to eliminate the eutectic structure with low melting point in as-cast alloy, decrease the stress concentration caused by deformation of magnesium alloy, improve element segregation in casting, enhance ductility and toughness of workpieces and prepare for separating out strengthening phase in subsequent deformation process. The principle of homogenizing annealing is to heat ingot casting, casting or forging stock for long term at the temperature that is slightly lower than solidus curve to eliminate or decease segregation of chemical components or microscopic structures. It can be achieved by atoms' diffusion and dissolution of phase. The speed of atoms' diffusion is influenced by annealing temperature and annealing time. The higher annealing temperature is and the longer annealing time is, the larger speed of atoms' diffusion will be. Atoms can not only diffuse in crystal but also diffuse at crystal boundary. Diffusion of atoms at crystal boundary can dissolve the strengthening phases and intermetallic compounds gathering at boundary of crystalline grains and network of dendritic crystals. In this way, the structure and processing performance of ingot castings can be improved.
Researches show that large eutectic compound $Mg_{17}Al_{12}$ with low melting point distributing at crystal boundary of magnesium alloy gradually dissolves on matrix when homogenization annealing is operated on

AZ magnesium alloy. As shown in Figure 1 and Figure 2. The intensity and plasticity of workpieces are improved.

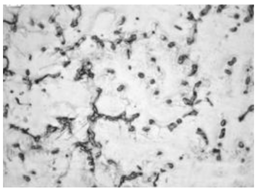

Figure 1: Pre-homogenization annealing of cast magnesium alloy

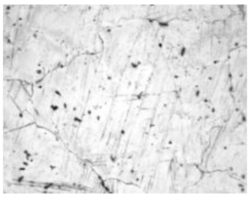

Figure 2: Post-homogenization annealing of cast magnesium alloy

After solid solution treatment, the intensity, ductility and toughness of magnesium alloy can be improved without artificial aging (T4). The diffusion of alloying elements in magnesium alloy is slow. Sufficient solid solution of alloying elements needs long time of heat preservation at high temperature. The solid solution time of alloying elements in sand casting with thick wall made of magnesium alloy is longest. The solid solution time of alloying elements in casting with thin wall is secondary. The solid solution time of alloying elements in deformed magnesium alloy is shortest. In the process of solid solution, the decomposition of alloy phase and diffusion of alloying elements are slow. Quenching sensitivity is low. There is no need to cool it rapidly during quenching. It can be just cooled in atmosphere. Natural aging has little influence on the performance of magnesium alloy. After quenching, solid solution state can be maintained at room temperature for long term. After solid solution treatment, the second phase of magnesium alloy dissolves in matrix. The structure becomes homogeneous; mechanical property is improved prominently.

Most magnesium alloys are not sensitive to natural aging. In production process, artificial aging (T5) is directly operated on the magnesium alloy that has been cast and processed without solid solution treatment. This technological procedure can eliminate the stress concentration in workpieces and improve workpieces' strength of extension. Especially for Mg-Zn alloy, crystal particles will become thick after solid solution treatment. After thermal deformation, artificial aging can get good aging strengthening effect. After artificial aging is operated on RE metamorphic ZA84 magnesium alloy, it is found that mechanical property of magnesium alloy can be improved prominently. Damping performance is improved after artificial aging.

3.2 Test methods and equipment

The welding equipment in this test is 300GP AC/DC TIG electric welding machine of Lianhe Huili.

The equipment for observing base material and welding joint is Leica optical microscope (Figure 3). Before observation, the sample is eroded by picric acid solution (0.85g picric acid, 2ml acetic acid, 14ml ethyl alcohol and 2ml distilled water).

Figure 3: Leica optical microscope

Figure 4: Medium temperature box type resistance furnace

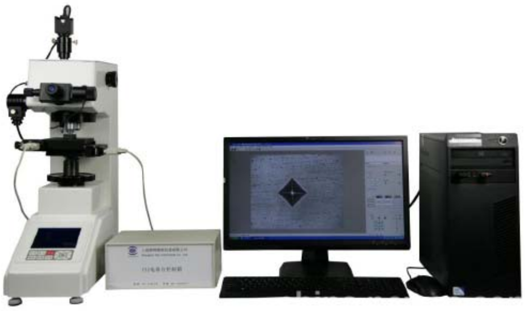

Figure 5: Vickers hardness tester

The equipment used in this heat treatment test for annealing and homogenization treatment is medium temperature box type resistance furnace (Figure 4). Samples are divided into 2 groups. 1 group is for annealing treatment. Annealing temperatures are 200℃, 250℃, 300℃, 350℃, 400℃ and 450℃. Annealing duration is 1 hour. After annealing, the samples are cooled at room temperature. The number of samples at each annealing temperature is 4. The other group is for homogenization treatment. Homogenization temperatures are 250℃, 300℃, 350℃, 400℃ and 450℃. Homogenization duration is 10 hours. After homogenization, the samples are cooled at room temperature. In the process of homogenization, the decomposition of alloy phase and diffusion of alloying elements are slow; quenching sensitivity is low; there is no need to be cooled rapidly during quenching. It can be cooled in atmosphere.
The hardness of base material and the weld joint of welding joints is tested in different heat treatment conditions. In the process of testing Vickers hardness, rhombus is drawn by manual operation with personal error. We choose to get average hardness in the same area. Figure 5 shows Vickers hardness tester.

4. Result and analysis

4.1 Influence of annealing on joint structure

As for the optical microscopic structure from weld joint to base material area, particles separated out are fully distributed on the surface of weld joint, which blurs crystal boundary. After annealing treatment, the particles separated out at weld joint gradually dissolve in matrix following the rise of annealing temperature. Using line interception method, average particle size at weld joint reaches its maximum value 37μm at 350℃ after annealing for 1 hour. After annealing for 1 hour at 400℃, average particle size at weld joint reaches its minimum value 20μm. After annealing of joint for 1 hour at 400℃, the crystal particles at weld joint become more homogeneous and smaller. When annealing temperature rises to 450℃, the crystal particles at weld joint become larger. Therefore, it is known that the crystal particles at weld joint just complete static recrystallization at 400℃ 1 hour later. As for the reasons of recrystallization, one is high annealing temperature that has reached temperature of recrystallization; the other is that stress of fixture on welded workpiece offers driving force to the recrystallization of casting structure in weld joint area.

4.1 Influence of annealing on ingredients of weld joint

In this test, large ball particles are fully distributed in weld joint area of joint before annealing treatment. In the process of annealing treatment, the ball particles become small gradually and dissolve in matrix. When annealing temperature is higher than 350℃, large particles will become smaller and dissolve in matrix. Some large particles are distributed in weld joint area. Energy spectrum analysis is made on the particles in gloss white color. In analysis results: the percentage composition of atoms at point a is Mg 68 At%, Al 20.1 At%, Mn 11.8 At%, Zn 0.1 At%. The content of Al and Mn is much larger than that of normal welding wires and matrixes. The percentage composition of atoms at point b is Mg 80.5 At%, Al 16.6 At%, Mn 0.1 At%, Zn 2.8 At%. The content of Al and Zn is much larger than that of welding wires and matrixes of magnesium alloy.

4.2 Influence of annealing on tensile property of joint

Considering the variation of weld joint group of joint in conditions of annealing treatment, this phenomenon can be explained to be: weld joint structure just completes static recrystallization at 400℃ 1h later in annealing treatment; average size of crystal particles reaches its minimum value. According to Hall-Petch formula $\alpha_y \alpha_o + k_y d^{-1/2}$, α_o and k_y are material constants at certain temperature and strain rate. Yield strength

α_y depends on particles' size d. Table 2 shows the ultimate strength and elongation of the joints after annealing treatment.

Table 2: The ultimate strength and elongation of the joints after annealing treatment

Annealing T/℃	Ultimate tensile strength，σb/MPa	Elongation δ/%
200	173	6.0
250	180	6.0
300	194	6.5
350	200	8.5
400	210	11.0
450	194	4.9

5. Conclusions

To know the influence of heat treatment on the weld structure and performance of magnesium alloy, AZ31B deformed magnesium alloy is used as sample and TIG weld method is used for research. In the annealing and homogenization treatment at different temperatures, structure of joints and ingredients in weld joint area in different processes of annealing and homogenization treatment are recorded. Aiming at the variation of mechanical property of welded structure of AZ31B deformed magnesium alloy, analysis and record are made.

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