Latest Advancements and Prospects in TIG Repair Welding of Sand-Cast Magnesium Rare-Earth Alloys

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Abstract: The large-scale sand castings of Mg-RE alloys have broad application prospects in the aerospace field. However, some casting defects are often generated in the component, which seriously increases the scrap rate. As a welding technology with high utility and economy, TIG welding can be performed manually, exhibiting unique advantages for repairing some inner structures and cambered surfaces. This report presents a comprehensive summary of the repair welding of sand-cast Mg-RE alloys using TIG welding. The weldability of Mg-RE alloys and the microstructure evolution during repair welding will be discussed. In addition, the effect of the pre- and post-weld heat treatment on the microstructure and mechanical properties of the repair welded joints are also summarized. In particular, the abnormal grain coarsening that occurred in post-weld solid-solution treatment of Mg-RE alloy joints and its regulating method are systematically analyzed. Drawing upon these studies, the existing problems and development trends of repair welding of cast Mg-RE alloys are summarized based on the actual applications.

Keywords: Mg-RE alloys; Cast; Repair welding; heat treatment; Microstructure evolution

1 Introduction

Magnesium rare-earth (Mg-RE) alloys have attracted considerable attention because of their low density, high specific strength, and good creep resistance. The application of Mg-RE alloys in aerospace industries can achieve an obvious weight reduction of the component. Until now, the large-scaled components containing complex structures are mainly fabricated by low- or differential-pressure sand casting process. However, due to the high oxygen affinity of the RE alloying elements, RE is easily oxidized and forms inclusions in the castings. In addition, the mushy zone solidification induced by the low-temperature gradient within the sand mold cavity would also result in the formation of shrinkage porosities and microcracks. Therefore, the development of defect-repair technology for sand-cast Mg-RE alloy is of great importance.

As compared to other welding processes, TIG welding can be performed without a complex welding tool setup, exhibiting higher operability and convenience for repairing large-scale components with complex structures.

Nevertheless, TIG welding shows larger heat input with lower energy density, so the grain size of the fusion zone (FZ) is larger than some other welding methods (e.g., laser welding). Moreover, it is quite difficult to simultaneously achieve the desired strengthening state by conventional heat treatment in the whole joint, because there are various zones with completely different microstructure characteristics.

Given these facts, this report mainly focuses on the TIG repair welding of the sand-cast Mg-RE alloys. The microstructure evolution during the repaired welding as well as the pre- and post-weld heat treatment would be summarized in detail.

Microstructure of TIG-repair welded joint

TIG welding has been used for repairing sand-cast Mg-Gd-Y-Zr [1], Mg-Y-Nd-Gd-Zr [2,3], and Mg-Gd-Nd-Zr [4] alloys. In general, TIG repair welded joints of sand-cast Mg-RE alloy can be divided into four different zones due to their different thermal cycles: FZ, partially melted zone (PMZ), "true heat-affected zone"(T-HAZ), and base material (BM). As compared to the BM, an effective grain refinement can be always achieved in FZ (Fig. 1), because of the combination of Zr dissolution at high temperatures and the rapid cooling rate in the molten pool. Due to the pinning effect of eutectics on grain boundaries, grain coarsening can be negligible in the HAZ of sand-cast Mg-RE alloys, which is quite different from that of the wrought alloys. As reported by our previous study, the grain size of the FZ of the TIG repair welded WE43 alloy is ~13 μm, which is only about 1/4 of that of the sand-cast BM.

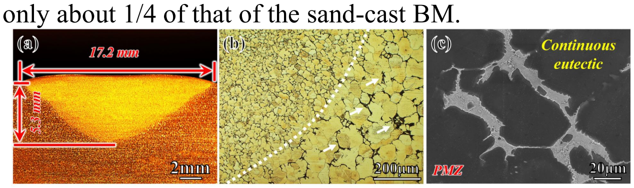

Fig. 1 The repaired welding joint of sand-cast WE43 alloy [2]: (a) macrostructure; (b) fusion line; (c) PMZ

Microstructure stability of repaired joint

The repaired welding process is usually associated with an extremely fast cooling rate, resulting in high residual stress. Therefore, the density of dislocation and vacancy is relatively high within the FZ, and this could decrease the microstructure stability. For instance, during the post-weld solution treatment at high temperatures, the nucleation and growth of recrystallized grains occur, and some abnormally coarsened grains even with an average size of up to 1 mm are formed. The abnormal grain coarsening has been observed in the FZ of the repaired joint of Mg-Y-RE-Zr, Mg-Gd-Y-Zr, Mg-Gd-Nd-Zr series alloys, etc. Tong et al. [2] reported that the abnormal grain coarsening occurred in repair welded Mg-4Y-2Nd-1Gd-0.5Zr alloy even after solution treated at 480℃ for 8 h (Fig. 2a). Thus, it leaves a significant contradiction between the grain refinement and the solid-solution effect.

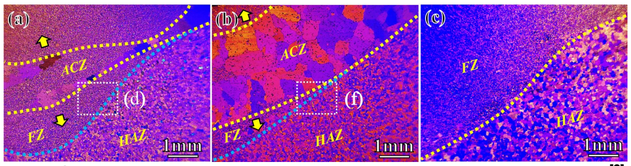

Fig. 2 Grain coarsening during the post-weld solution treatment [2]: (a) 480℃ × 8 h; (b) 520℃ × 8 h; (c) combination of pre- and post-weld solution treatment

Pre- and post-weld heat treatment

To avoid abnormal grain coarsening, several strategies, including the application of the pre-weld solution treatment [2] and the multiple-stage post-weld solution treatment [3,4], have been proposed. The pre-weld solution treatment could eliminate the eutectic structures in sand-cast BM in advance, so the heat-treated time required for the post-weld solution treatment can be shortened (Fig. 2c). But this could weaken the pinning effect of RE-containing phase on grain boundaries, resulting in an increased grain growth in HAZ. On the other hand, as compared to the conventional single-stage treatment (520°C × 8 h), it was found that the eutectics in sand-cast WE43 alloy can be dissolved without abnormal grain coarsening under the two-stage solution treatment (480°C × 6 h + 520°C × 2 h) [3]. However, there were still a few residual eutectics that can be found in HAZ. Therefore, more efforts are still required for the balance between the grain refinement and eutectic dissolution.

Mechanical properties of repair-welded joint

As compared to the sand-cast BM, the repaired welded joint prepared under optimized welding parameters and without heat treatment usually exhibits lower strength but a higher elongation. The improvement of the EL could be attributed to that the fine grains in FZ restrained the crack initiation by affording more deformation before failure [4]. However, due to the weak bonding between the continuous eutectics and the matrix within PMZ, the strength of the joint is reduced significantly, which can be confirmed by the broken eutectic phases exposed on the fracture surface. It was found that the elongation of the repaired joint of sand-cast WE43 alloy was 24.4% higher than the BM, although the tensile strength of the repaired joint was only 87.8% of the BM. However, the elongation of the joint after T6 treatment was significantly reduced (Fig. 3c), and the tensile fracture was located in FZ, because the abnormal grain growth occurred in FZ during the solid solution treatment.

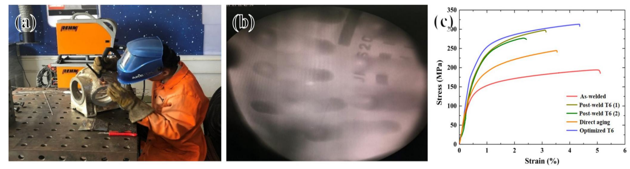

Fig. 3 The repaired welding of sand-cast WE43 alloy: (a) operational process; (b) X-ray detection; (c) tensile curves

2 Conclusion and prospect

The casting defects can be effectively repaired using TIG welding, which is of great value for promoting the application of Mg-RE alloy castings in aerospace. However, the microstructure characteristics of FZ, PMZ and T-HAZ are quite different from that of BM. It is still a big challenge to realize the microstructure coordination between these different regions and improve the stability of the repaired regions in the future.

References

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