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Friction Spot Welding of Similar AA5754 to AA5754 Aluminum Alloys And Dissimilar AA5754 Aluminum to AZ31 Magnesium Alloys

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Abstract. Friction spot welding is a solid-state spot welding process developed and patented by Helmholtz-Zentrum Geesthacht, Germany. A non-consumable rotating tool consisting of two rotating parts, a pin and a sleeve, and one stationary clamping ring is used to join two or more similar/dissimilar sheets of materials in lap configuration. The result is a spot welded lap connection with minimal material loss and a flat surface without keyhole. The present work presents a summary of results from studies in similar AA5754 to AA5754 Al alloys and dissimilar AA5754 Al to AZ31 Mg alloys.

Introduction

Friction spot welding (FSpW), also known as refill friction stir spot welding, is a solid state joining process used to weld two or more materials in a lap joint configuration using a non-consumable tool. FSpW was developed and patented by Helmholtz Zentrum Geesthacht, HZG, Germany. The non-consumable tool consists of three independent moving parts: two rotating sleeve and pin, and a stationary clamping ring. Fig. 1 presents a schematic illustration of the FSpW process. First, the stationary clamping ring holds the material against an anvil (Fig. 1a). Next, the rotating sleeve penetrates into the materials and the rotating pin moves in the reverse direction (Fig. 1b). The rotating tool introduces plastic deformation and generates frictional heating. The penetrating sleeve squeezes the softened material, filling the cavity left by the retracting pin. Then, the sleeve and the pin move back to their initial positions, pushing the softened material back into the joint (Fig. 1c). Finally, the tool is retracted from the weld surface, leaving a weld without keyhole (Fig. 1d).

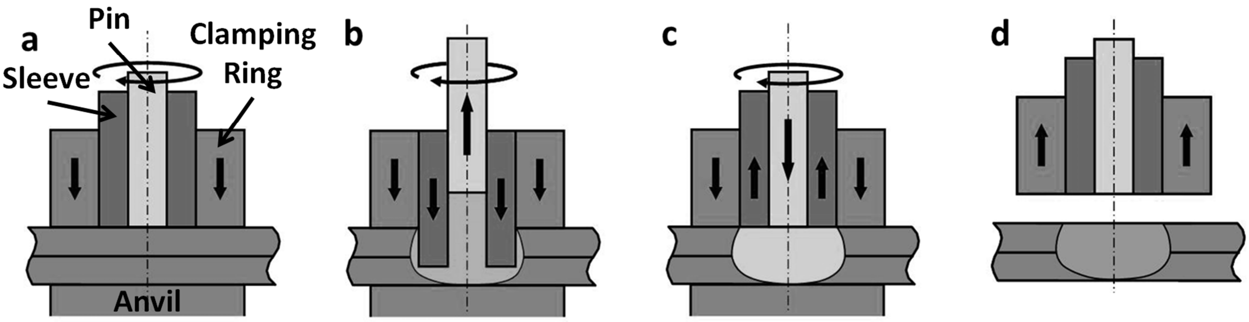

Fig. 1 Schematic illustration of the FSpW process.

FSpW offers some advantages, such as an ability to produce a weld with good mechanical properties, free-keyhole surface and relatively fast process [1-5]. FSpW has been successfully used to join similar welds [1,3] and has been used to join dissimilar materials, such as Al and Mg [4,5]. This paper contains general overview of friction spot welds in Al-based similar and dissimilar joints of AA5754/AA5754 and AA5754/AZ31 joint configurations, respectively.

Similar friction spot welding of AA5754/AA5754

Low magnification overview and some regions of interest in the welded area are presented in Fig. 2. Lack of refill on the surface in the outer area of the weld can be observed, as highlighted by arrows. However, parameter optimization eliminates the presence of this defect.

Base on the microstructural features, welded area is characterized as having 2 regions of stir zone (SZ), and thermo-mechanically affected zone (TMAZ). Base material (Fig. 2b) has a lamellar structure which is a typical rolling structure. In SZ (Fig. 2c), the microstructure transformed into a fine equiaxed grains. Some studies on friction-based welding on Al alloys [1,2] showed that dynamic recrystallization process took place led to formation of a fine grain structure induced by severe plastic deformation and frictional heating. TMAZ or region d (Fig. 2d) has deformed gain structure in which they align in certain direction. This region experienced plastic deformation and also exposed to high temperature during welding; however, no or only limited recrystallization occurred.

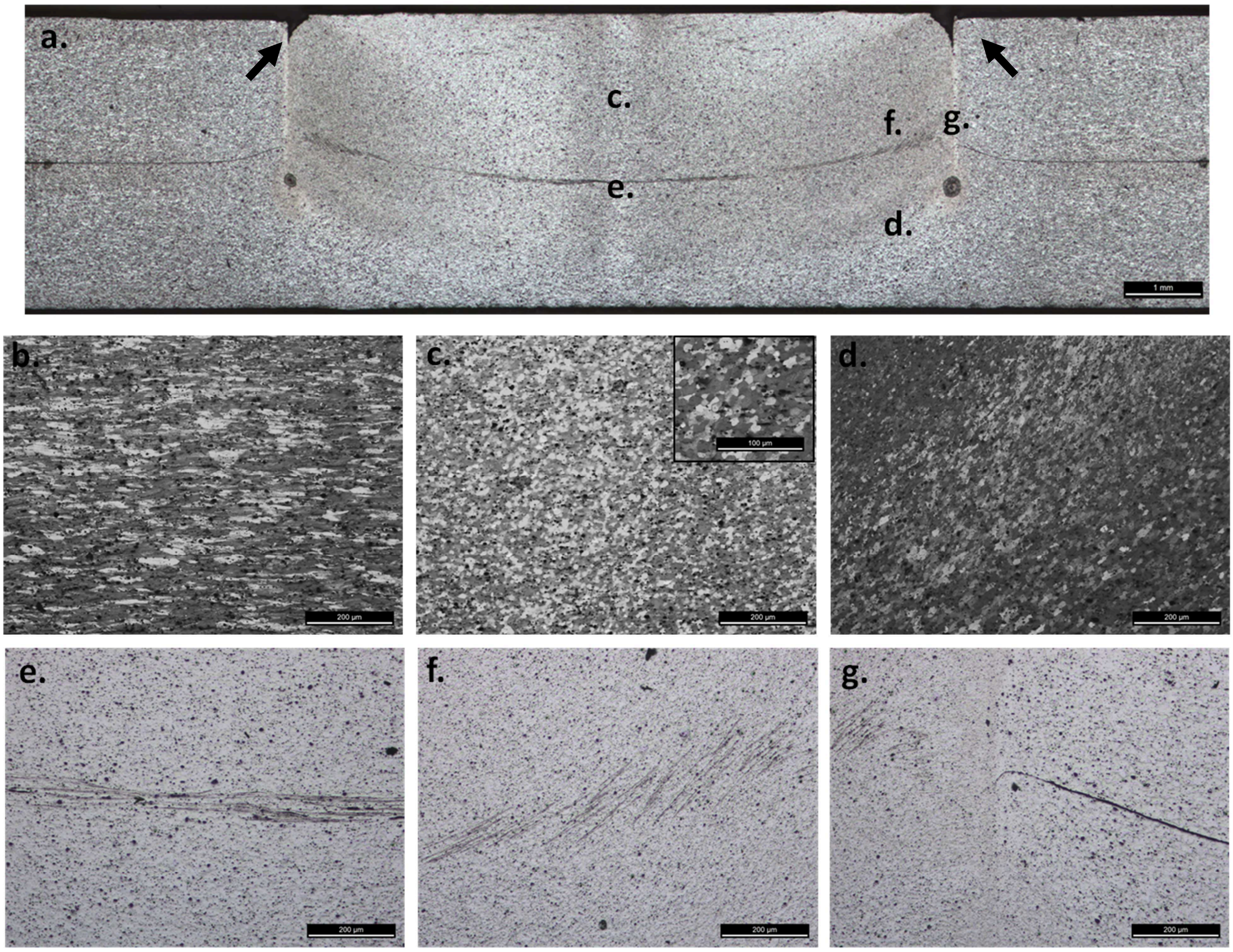

Fig. 2. Cross section of the similar AA5754/AA5754 weld. Macrograph (a) and micrographs of base material (b), stir zone (c), and thermo-mechanically affected zone (d) including oxide layers (e)(f) and hooking (g).

During welding process, oxide layers of Al_2O_3 originally from the surface of the base materials are not dissolved completely due to insufficient deformation and heat to break and dissolve the oxide. Some of the oxide layers can be observed in some regions in the weld as shown in Figs. 2e-g. Difference oxide layer feature relates to the different degree of deformation and its direction during the process. Hooking (Fig. 2g) is one of the important oxide layers affecting mechanical properties of the joint with regards to its shape and dimension. The hooking is formed due to material flow induced by upward bending of the sheet interface during sleeve retraction from the material, and the pin moved back to its initial position.

Dissimilar friction spot welding of AA5754/AZ31

A low magnification overview of the weld is presented in Fig. 3a. No keyhole or defect, such as voids or cracks, can be observed. For further understanding, detail of some regions will be discussed.

Enlarged images taken from some regions of interest in Fig. 3a are presented in Fig. 3b-d. EDS analysis across the interfacial layer of region 1 in Fig. 3b shows that the composition changes across the interfacial layer indicating diffusion during welding. Interfacial layer in region 2 (Fig. 3c) has a thickness of approximately 20 μm, which consists of grey and dark phases. This layer has a Mg composition of approximately 64 at.% and 81 at.% of grey and dark phases, respectively. According to the binary equilibrium Al-Mg phase diagram, the grey and dark phases consist of γ-$Al_{12}Mg_{17}$ and δ-Mg in different quantities, respectively.

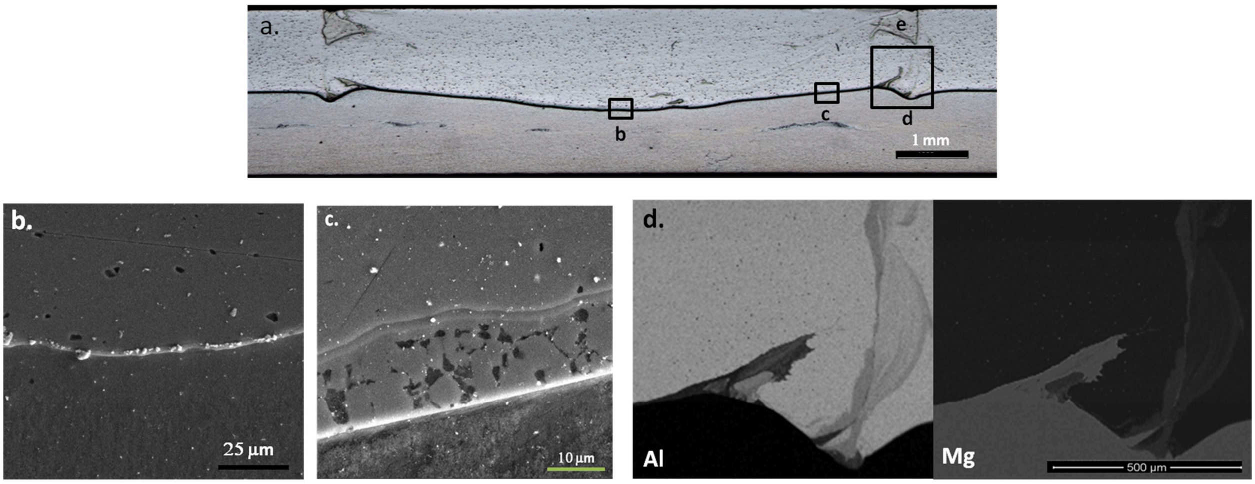

Fig. 3. Cross section of the dissimilar AA5754/AZ31 weld. Macrograph (a) and micrographs of weld center-region 1 (b), region 2 (c), and underneath the sleeve-region 3 (d).

Region 3 (Fig. 3d) is located underneath the sleeve during the welding process. The interface at this region has an irregular shape. Enlarged EDS mapping pictures of Al and Mg taken from this region is presented in Fig. 3d. It is likely some Mg elements have been transported into the Al base material, which presumably correspond to the material flow induced by the pin and sleeve movement. A eutectic phase has been observed in this region indicating formation of the liquid phase during the welding process.

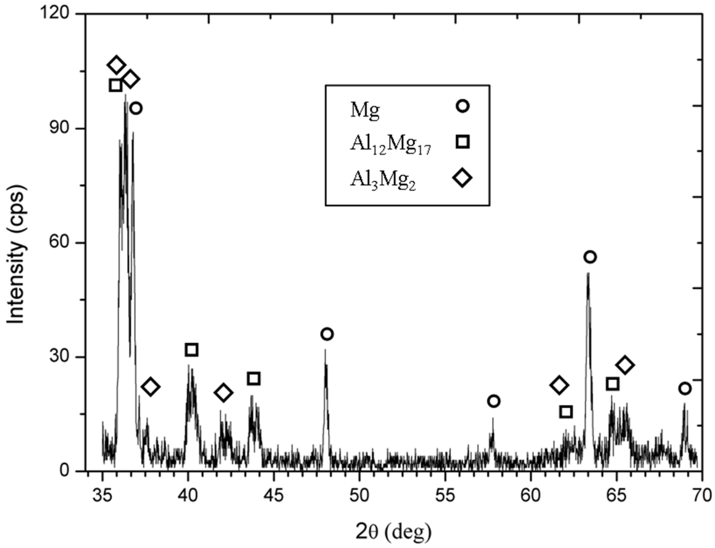

Fig. 4 X-ray diffraction data taken from the fracture surface.

Meanwhile, region as indicated by e in Fig. 3a has a single phase of a grey phase exhibiting approximately 35 at.% Mg. According to the binary equilibrium Al-Mg phase diagram, the region is primarily composed of Al_3Mg_2 and α-Al.

Phase identification by x-ray diffraction technique of the fracture surfaces after a shear test reveals presence of the $Al_{12}Mg_{17}$ and Al_3Mg_2 intermetallics at the interface as shown in Fig. 4.

Previous studies [4,5] showed the tool movement introduces plastic deformation and generates frictional heating lead to the formation of intercalated layers of Al and Mg, and fine grain structure at the interface. The formation both of the intercalated layers and fine grain structure enhances the interdiffusion of Al and Mg atoms during the process. As soon as the composition of the Al-Mg reached the composition of the eutectic structure, a liquid phase was formed. Due to the material flow induced by tool movement, redistribution of the liquid phase and an extensive diffusion process during sleeve retraction lead to in homogeneous intermetallics distribution in the weld [5].

Summary

Current paper discusses friction spot welding of similar AA5754 to AA5754 Al alloys and dissimilar AA5754 Al alloy toAZ31 Mg alloy. In similar joint configuration, introduction of severe plastic deformation and generation of frictional heating induced by the tool lead to transformation of the lamellar grain structure into the fine grain structure in stir zone and the deformed structure in thermo-mechanically affected zone. Some imperfections associated to the material flow were found such as presence of oxide layer i.e. hooking.

Although friction spot welding is characterized as a solid state joining process, formation of the liquid phase in Al/Mg dissimilar weld is inevitable. During cooling, the liquid phase transformed to the $Al_{12}Mg_{17}$ and Al_3Mg_2 intermetallics. Intermetallics distributed in homogeneously in the welded area dictated by material flow during the welding process.

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