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Research paper

Microstructure and mechanical properties of resistance spot welded in welding-brazing mode and resistance element welded magnesium alloy/austenitic stainless steel joints

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ABSTRACT

An AZ31 Mg alloy and 316L austenitic stainless steel (ASS) were joined via resistance spot welding (RSW) and resistance element welding (REW). The RSW joints were found to be produced through welding-brazing mode, in which the Mg alloy melted and spread on the solid steel, forming a nugget only in the Mg alloy. The microstructure of the nugget consisted of columnar dendritic structure, indicating that columnar-to-equiaxed transition was interrupted. Shrinkage porosity and cracking were also observed in the RSW nugget. In contrast, a two-zone nugget was formed during REW, consisting of a peripheral nugget on the ASS side and the main nugget. Compared with the RSW joints, the REW joints were obtained at lower welding currents, and they exhibited superior mechanical performance, with 63% higher peak load and 9 times higher energy absorption. Irrespective of the welding current, the RSW joints failed in interfacial failure mode, while the failure mode of the REW joints transited from interfacial to pull out with increased welding current.

1. Introduction

With the increasing application of Mg alloys and ASSs in the transportation industry, it is necessary to develop reliable means of joining them together. Manladan et al. (2017) pointed out that RSW is the most commonly applied sheet joining process because of advantages such as low-cost, high speed, and ease of operation and automation. Fan et al. (2016) stated that there are about 5000 spot welds in a typical car body and more than 10,000 in a railroad passenger vehicle. However, RSW of Mg alloys to steel is extremely challenging because of the metallurgical incompatibility between them and the large differences in physical properties. Limited work has so far been published on RSW of Mg alloy to steels, and most of the work focussed on Mg alloys/zinc-coated steels, including AZ31B Mg alloy/zinc-coated DP600 steel (Liu et al., 2010), AZ31B-H24 Mg alloy/hot-dip galvanized steel (Xu et al., 2012), AZ31B Mg alloy/hot-dip galvanized HSLA steel (Liu et al., 2013), and AZ31B Mg alloy/electro-galvanized DP600 steel (Feng et al., 2016). It was found that the zinc-coating plays a vital role in the joining mechanism. The RSW of Mg alloy to stainless steel is even more challenging because of the absence of any zinc-coating. Therefore, it is scarcely reported in the literature. Only Min et al. (2015) reported on Mg alloy/stainless steel RSW. The authors joined 0.4 mm AZ31B Mg alloy/0.4 mm 443 ferritic stainless steel, and cracking was observed in the nugget.

Resistance element welding (REW), a variant of RSW, could be a reliable alternative to join Mg alloys to stainless steels. The technique was developed to address the challenges of joining Al alloys to steels. As demonstrated by Meschut et al. (2014b), a hole is pre-punched in the Al alloy, and an auxiliary element (a steel rivet) is inserted into the hole, followed by RSW on the rivet/steel. Meschut et al. (2014a) compared the mechanical performance of 2 mm 6016 Al alloy/1.5 mm 22MnB5 boron steel joints produced by REW (using S355 steel rivet as the auxiliary element), friction element welding (FEW), and self-piercing rivet (SPR). The failure load of the joints produced by FEW, REW, and SPR was in the range of approximately 7.2–9.0 kn, 4.5–5.0 kn, and 3.9–4.4 kn, respectively. Qiu et al. (2015) found that the peak load of A6061 Al alloy/Q235 steel joints produced by REW was 37% higher than that produced by RSW. Ling et al. (2016) compared the mechanical performance of 2 mm 6061 Al alloy/1.8 mm uncoated 22MnMoB boron steel joints produced by RSW and REW.

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