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Interfacial characterization of joint between mild steel and aluminum alloy welded by resistance spot welding

Ranfeng Qiu[a,b,*], *Hongxin Shi*[a], *Keke Zhang*[a], *Yimin Tu*[a], *Chihiro Iwamoto*[c], *Shinobu Satonaka*[c]

[a]*School of Materials Science and Engineering, Henan University of Science and Technology, Luoyang, 471003, China*
[b]*Henan Key Laboratory of Advanced Non-ferrous Metals, Henan University of Science and Technology, Luoyang 471003, China*
[c]*Graduate School of Science and Technology, Kumamoto University, Kurokami 2-39-1, Kumamoto, 860-8555, Japan*

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ABSTRACT

The interfacial characteristics of resistance spot welded steel–aluminum alloy joint have been investigated using electron microscopy. The results reveal that reaction product $FeAl_3$ is generated in the peripheral region of the weld while a reaction layer consisting of Fe_2Al_5 adjacent to steel and $FeAl_3$ adjacent to aluminum alloy forms in the central region of the weld, and that the morphology and thickness of the reaction layer vary with the position at the welding interface.

1. Introduction

In the next few years the automotive industry aims to decrease fuel consumption in order to meet new anti-pollution standards. This objective may be reached by lightening the vehicles, which is why the use of high strength steels and light alloys such as aluminum or magnesium alloys is being investigated [1]. Manufacturing cars using steel and light alloys implies the joining of dissimilar materials such as steel and aluminum alloy. However, intermetallic compounds formed at the welding interface of steel/aluminum alloy can deteriorate mechanical properties of the joint [2–4]. Thus, understanding the interfacial characteristics of the steel/aluminum alloy joint is essential to optimize processing–property relationship so as to obtain a strong joint.

In recent literatures, the reaction layer formed at the welding interface of the steel/aluminum alloy joint, which were fabricated using the several welding methods such as friction welding [5], friction stir welding [6,7] and hybrid welding [1,8], has been investigated. The preceding studies reveal that the types and morphologies of reaction products formed at the welding interface are related to the combination of materials or the welding methods employed. On the other hand, resistance spot welding is a widely used and important welding process in the fields of automotive manufacturing. Nevertheless, few studies have been reported on the

* *Corresponding author*. School of Materials Science and Engineering, Henan University of Science and Technology, Luoyang, 471003, China. Tel./fax: +86 37964231269.
E-mail address: xdqrf@yahoo.com.cn (R. Qiu).

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resistance spot welding between mild steel and aluminum alloy. The aim of this work is to examine the interfacial characteristics of the mild steel–aluminum alloy joint in order to provide some guidance for the prediction and control of interface reactions.

In this study, the mild steel and aluminum alloy sheet were welded using the technique of resistance spot welding with a cover plate. The types, morphology and distribution of interfacial reaction products were characterized in detail.

2. Experimental Procedures

Aluminum alloy A5052 and mild steel sheet with a thickness of 1.0 mm were used in this study. The nominal compositions of the alloys are Mg-2.2%, Fe-0.27%, Cr-0.19%, Si-0.09%, Mn-0.049% and Al-balance for the aluminum alloy and Fe-0.05%C-0.01%P-0.01%S-0.004%Si for the steel (in mass per cent). They were welded using the technique of resistance spot welding with a cover plate, in which the cover plate was placed on the aluminum alloy sheet and welded together as shown in Fig. 1. Further details concerning this procedure of resistance spot welding have been published in the literature [9]. The welding current varied from 6 kA to 12 kA at the fixed welding time of 0.2 s and electrode force of 2 kN.

The microstructure near the welding interface was observed using a scanning electron microscope (SEM; JEOL JSM-6300, acceleration voltage: 20 kV) and a transmission electron microscope (TEM; JEOL JEM-2000FX, acceleration voltage: 200 kV) with energy dispersive spectroscopy (EDS) analysis. The SEM observation was performed on the transverse cross-section of the weld, which was mechanically polished using diamond pastes and finished using 0.04 μm Al_2O_3 particle suspensions. The TEM observation was performed with thin foil, which was prepared with ion milling (3 keV Ar^+) after mechanical polishing of sliced piece from the welded sample.

3. Results

Fig. 2 shows the optical micrograph of the cross-section of the joint welded at the welding current of 9 kA, in which the aluminum alloy/steel (henceforth abbreviated as Al/steel) interface and thereby were observed using SEM. Fig. 3 presents the SEM images of the welding interface, where images (a to d) indicate the typical morphology at the positions (A to D) in

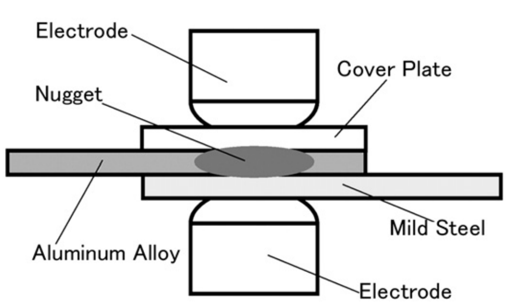

Fig. 1 – Schematic diagram of resistance spot welding with cover plate.

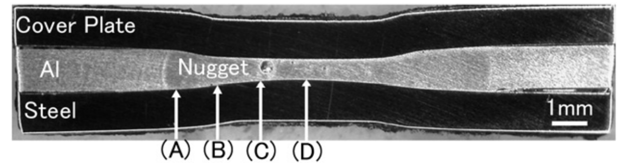

Fig. 2 – Optical micrograph of the weld cross-section.

Fig. 2, respectively. Reaction products were observed in the welding interface as shown in Fig. 3. These interfacial reaction products exhibited the following three characteristics. Firstly, the reaction products interspersed in the peripheral region of the weld (Fig. 2(A)), which changes to the continuous layer as approaching to the central region (Fig. 2(D)). Secondly, the interface between the reaction layer and the steel appeared highly irregular with peaks orientated towards the steel. This tongue-like morphology varied with the position at the welding interface. That is, the tongue profile was narrow in the peripheral region of the weld, while one broadened out as

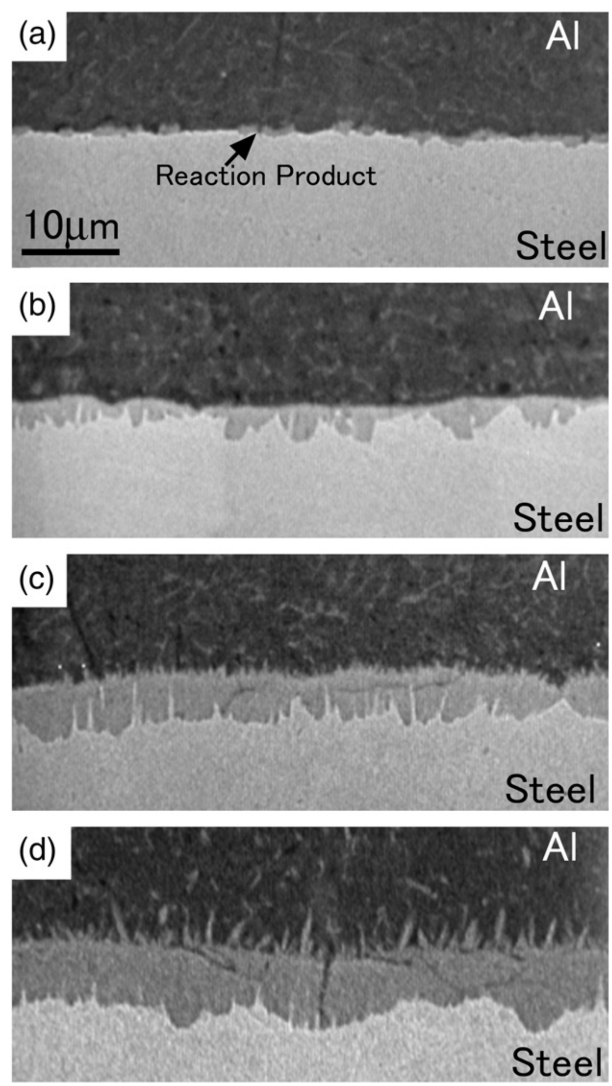

Fig. 3 – SEM images of the weld cross-section at the Al/steel interface; (a), (b), (c) and (d) taken from the positions (A), (B), (C) and (D) in figure 2,respectively.