Application News

Electron Probe Microanalyzer EPMA-8050G

Analysis of Bonded Interface of Friction Stir Spot Welded Materials

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User Benefits

- Useful in research related to macroscopic analysis of the composition of the entire weld.
- Useful in research related to analysis of the film thickness and microstructure of the intermetallic compound layer, which affect bond strength.

■ Introduction

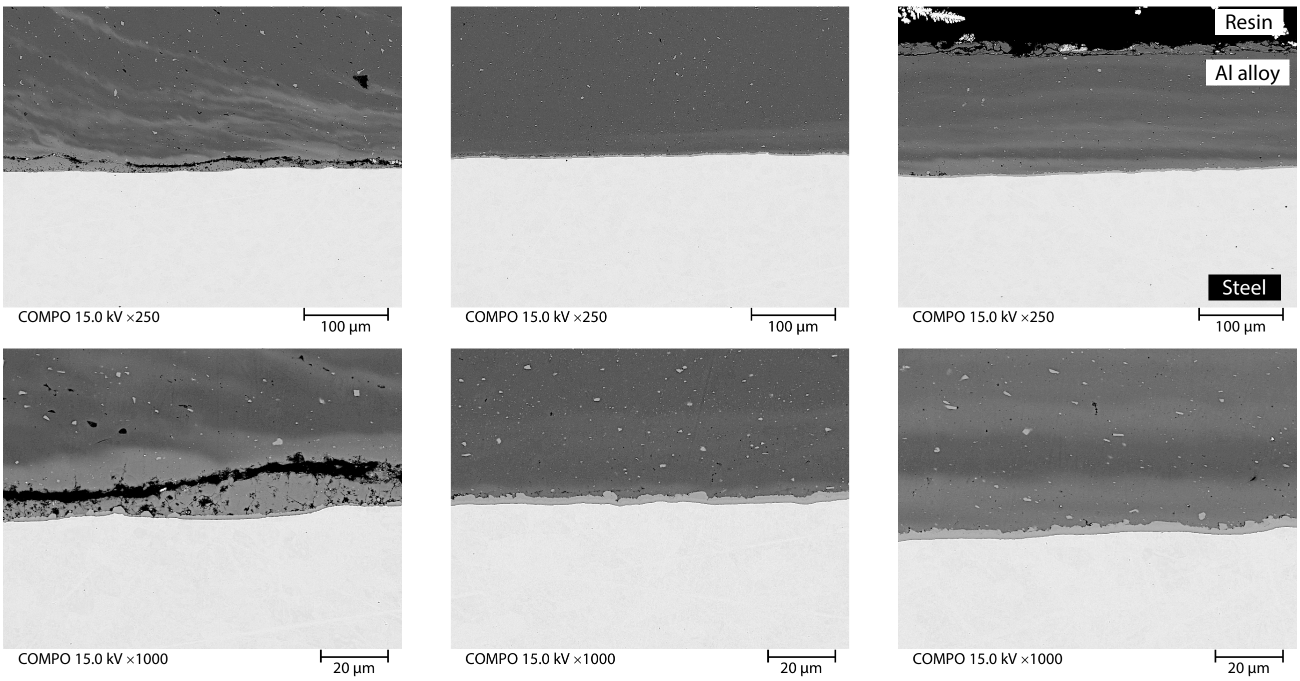
Friction stir welding (FSW) is a method of solid-state welding of dissimilar materials by using the frictional heat generated by rotation of a tool, and is widely used for the purpose of weight reduction in various fields, including not only automobiles, but also railway rolling stock, aircraft, ships, civil structures, and electrical equipment. In recent years, lighter weight products and improved production efficiency have been required in response to demand for protection of the global environment and energy saving, and various research and development have progressed with the aims of optimization of the welding process and microstructural control of the juncture/interface in FSW welds.

Like FSW, friction stir spot welding (FSSW) is a spot welding method which utilizes the friction stirring phenomenon and has already been applied practically in automobile production lines.

This article introduces an example of analysis of the bonded interface of an FSSW weld of an aluminum alloy and a zinc-coated steel sheet using a Shimadzu EPMA-8050G EPMA™ electron probe microanalyzer.

■ Friction Stir Spot Welding (FSSW)

In FSSW of an aluminum alloy and a zinc-coated steel sheet, a tool consisting of a probe and a shoulder is pressed on the aluminum alloy, and the aluminum alloy and the coating of the steel sheet are softened by heat generation accompanying frictional resistance during stirring. In this process, the coating at the bonded interface is expelled and at the same time, a newly-formed surface appears on the steel sheet surface, and the two materials are welded by the intermetallic compound (IMC) layer formed by the reaction with the aluminum alloy where the oxide film has been destroyed. FSSW joints have a button-shaped hole in the center, and the joint is formed around the entire periphery of the hole, while a flash-like protruding part is formed on the outer side of the tool shoulder. Fig. 1 shows SEM images of the cross section of the aluminum alloy and zinc-coated steel sheet welded by FSSW. (In this figure, the lower row shows enlarged images of the central area in the upper row.) A condition in which the Zn of the coating layer (thickness: approximately 20 µm) has been expelled to the aluminum alloy, and formation of a continuous IMC layer with a film thickness of several µm at the bonded interface can be observed. Particularly at the edge of the weld, the marble pattern accompanying diffusion of Zn into the aluminum alloy is remarkable, and a crack with a length of several 100 µm has formed.



(a) Weld edge (3.87 mm from center) (b) Weld intermediate region (1.55 mm from center) (c) Weld center

Fig. 1 SEM Images of FSSW Cross Section

■ Analysis of Intermetallic Compound Layer

As one distinctive feature of FSSW, formation of IMC, which affect bond strength, is slight due to the small heat input during welding. The IMC layer is thicker in the central area than at the edge, and it is generally thought that high bond strength is obtained when an IMC layer with a thickness on the order of 1 µm is formed uniformly over a wide area.

Figs. 2, 3, and 4 show enlarged mapping images of the FSSW weld center, the weld intermediate region between the center and the weld edge, and edge, respectively. The film thickness of the IMC layer is several µm in the weld center and intermediate region, the IMC consists of multiple IMC layers, and virtually all of the Zn contained in the coating layer has been expelled. However, at the weld edge, the Zn coating layer was not completely expelled and appearance of a new surface was difficult, and as a result, it is thought that the film thickness of the IMC layer was thin and the crack formed.

Fig. 5 shows an enlarged mapping image of the IMC layer in the central part of the weld. The IMC layer consists of three layers (shown by A, B, and C from the steel sheet side). The approximate film thicknesses of layers A, B, and C are 0.4 µm, 1.7 µm, and 0.7 µm, respectively. From the element distributions of Al, Si, Fe, and Zn in each layer, the existence of different IMC layers and related elements can be identified, and it can be understood that a slight amount of residual Zn has remained.

■ Quantitative Analysis of Intermetallic Compound Layer

Table 1 shows the result of a quantitative analysis of the IMC layers in the central part of the weld. From the quantitative values, it is estimated that layer A on the steel sheet side consists of Fe_2Al_5 (*η* phase) and the intermediate layer B is $FeAl_3$ (*θ* phase), while layer C on the aluminum alloy side contains about 4 wt% of Zn in the coating layer which was not expelled from the weld.

Table 1 Result of Quantitative Analysis of IMC Layers (wt%)

Layer \ Element	Al	Si	Fe	Zn
IMC layer A	51.2	1.6	45.3	2.0
IMC layer B	58.5	1.3	38.7	1.5
IMC layer C	60.8	5.0	30.2	3.9

■ Conclusion

In analysis of the cross sections of FSSW welds, it is possible to investigate the changes in the composition of the weld zone and the stirred portion by a macroscopic analysis. Microscopically, the EPMA technique can also be applied to research on bond strength by investigating the film thickness, element distribution, and composition ratio of the IMC layers.

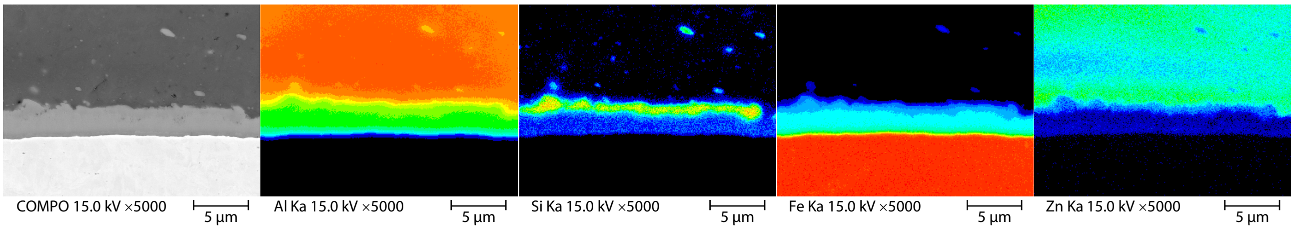


Fig. 2 Mapping of Weld Center

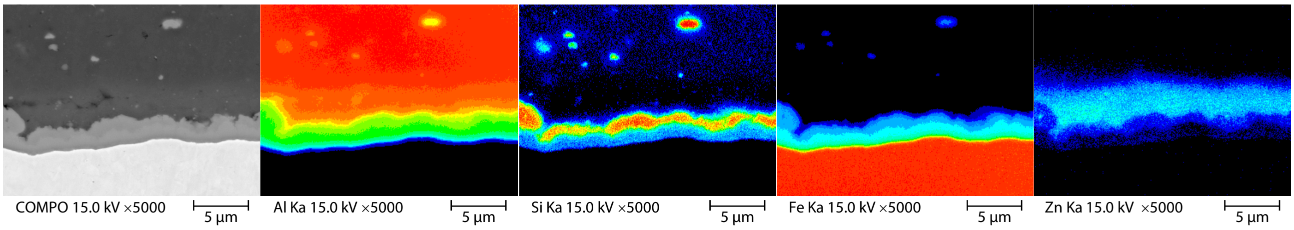


Fig. 3 Mapping of Weld Intermediate Region (1.56 mm from Center)

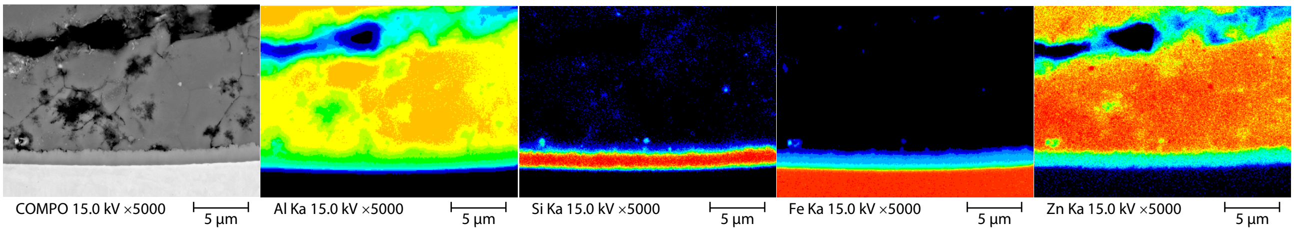


Fig. 4 Mapping of Weld Edge (3.87 mm from Center)

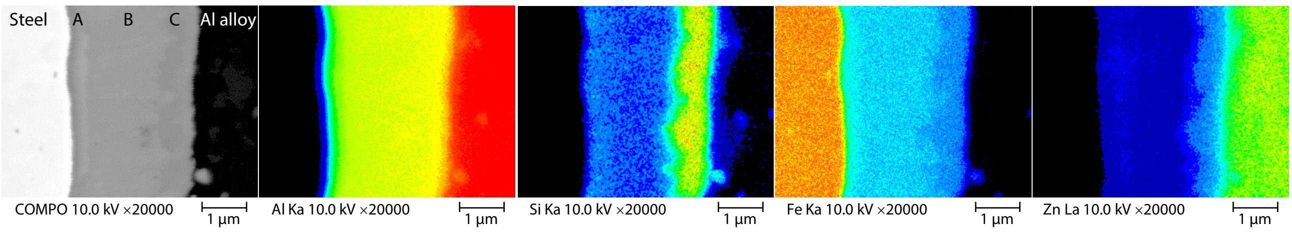


Fig. 5 Mapping of IMC Layer in Weld Center

<Reference>
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Hiroshi Tokisue, Friction Stir Welding (Fundamentals and Applications of FSW (Friction Stir Welding)), Nikkan Kogyo Shimbun, Ltd. (2005).

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