Application News

Electron Probe Microanalyzer EPMA-8050G
inspeXio™SMX™-225CT FPD HR Plus Microfocus X-Ray CT System

# Analysis of Fe-Al Bonded Dissimilar Materials by EPMA and X-Ray CT

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## User Benefits

- X-ray CT (computed tomography) is useful in research such as study of welding conditions, as changes in composition and internal microstructure can be captured nondestructively.
- Also useful in research related to analysis of the film thickness and internal microstructure of the intermetallic compound layer, which affect bond strength.

## ■ Introduction

Weight reduction of transportation machinery is being promoted with the aim of achieving Japan's "2050 Carbon Neutral Goal." Friction stir welding (FSW) and friction stir spot welding (FSSW) are solid phase bonding methods for joining dissimilar materials by utilizing the frictional heat generated by rotation of a tool, and has been applied to the engine cradle, suspension arms, front subframe, and other parts in the auto industry. These techniques are also widely used for weight reduction in various other fields, including railway rolling stock, aircraft, ships, civil structures, and electrical machinery, and research on optimization of the welding process and microstructural control of the weld bond and interface is underway.

This article introduces an example in which the bond of dissimilar materials welded by FSSW was analyzed using an EPMA-8050G EPMA™ electron probe microanalyzer, together with the results obtained with the inspeXio SMX-225CT FPD HR Plus microfocus X-ray CT system.

## ■ Friction Stir Spot Welding (FSSW)

In FSSW of an aluminum alloy and a 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 the heat generated by frictional resistance during stirring. In this process, the coating material at the bonded interface is expelled and a newly-formed surface appears on the surface of the steel sheet, and the two materials are welded by the intermetallic compound (IMC) layer formed at this time. FSSW joints have a button-shaped hole in the center. The joint is formed around the full periphery of the hole, and a flash-like protruding part is formed on the outer side of the tool shoulder.

In this experiment, test pieces were prepared by applying FSSW to an aluminum alloy (A6061) and hot-dip galvannealed steel sheet (GA) under two joining conditions (pressing time: short, long). Fig. 1 shows the appearance of a welded test piece.

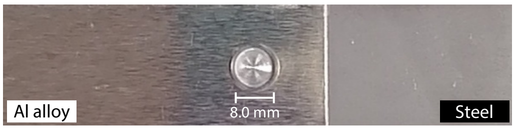


Fig. 1 Appearance of Test Piece (Showing the Joint in the Center)

## ■ Macroscopic Observation by X-Ray CT System and EPMA

The X-ray CT system enables nondestructive observation of the cross section, and makes it possible to acquire cross-sectional images of any arbitrary cross section by visualization of the differences in the internal density of the target by X-ray irradiation (areas with higher densities appear are shown by lighter contrast). Fig. 2 (a) shows an image of the transverse section through the central part of a joint. Here, the difference in contrast due to expulsion of the zinc (Zn) of the coating layer (film thickness: approx. 6 µm) around the hole at the bonded interface can be observed. Fig. 2 (b) is an image of the vertical section of the bond surface at the position shown by the arrow in Fig. 2 (a). A difference in contrast indicating expulsion of Zn can be confirmed around the full periphery of the hole.

After nondestructive observation by the X-ray CT system, as described above, a sample for cross-sectional observation was prepared by cutting the test piece, embedding the sample in resin, and polishing the sample surface. The results of the EPMA mapping analysis in Fig. 3 showed that the Zn of the coating layer was expelled to the outer side of the button-shaped hole of the FSSW joint, but some Zn also remained in the bonded interface.

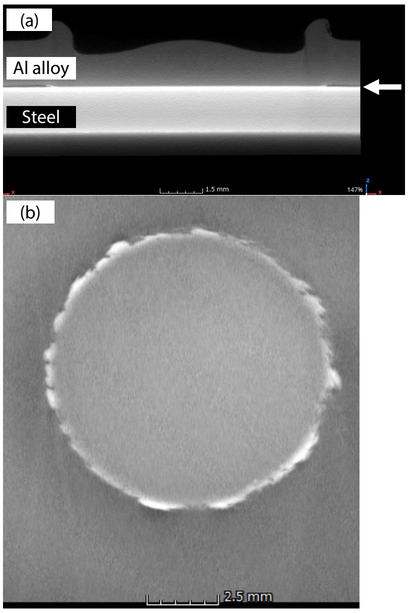


Fig. 2 X-Ray CT Images of Joint Sections (Pressing Time: Short); (a) Transverse Section, (b) Vertical Section

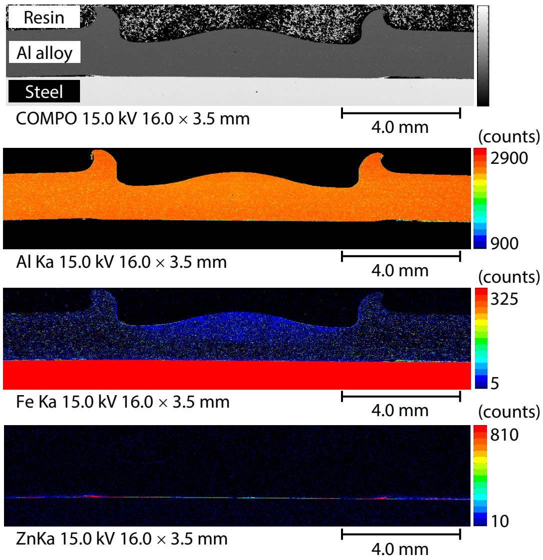


Fig. 3 EPMA Mapping of Joint Cross Section (Pressing Time: Short)

## ■ EPMA Analysis of FSSW Welds

As a distinctive feature of FSSW, formation of IMCs, which affect bond strength, is slight due to the small heat input during welding. The film thickness of the IMC layer is thicker in the central area than at the edge. In GA steel, the coating layer is replaced by IMC, and as a result of this phenomenon, an IMC layer with a thickness of several µm is formed over the entire bonded region.

Fig. 4 shows COMPO images of the bonded interface for the two FSSW welding conditions of short and long pressing time. It can be understood that the IMC layer has formed at the bonded interface between the aluminum alloy and the GA steel sheet.

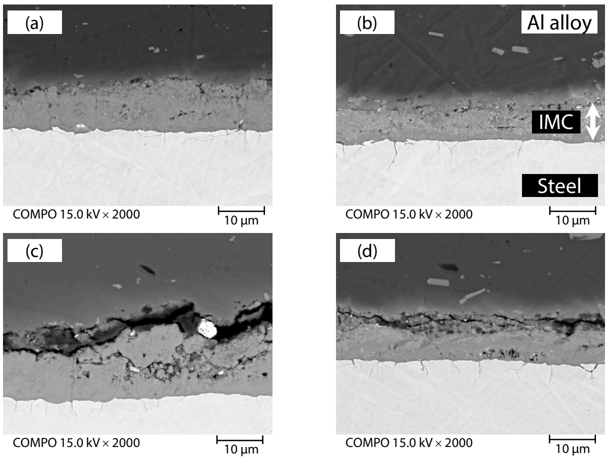


Fig. 4 IMC Layer:
(a) Short, Center, (b) Short, Edge, (c) Long, Center, (d) Long, Edge

Fig. 5 shows the results of a mapping analysis of the weld edge portion under the short pressing time condition (Fig. 4 (b)). The thickness of the IMC layer at the weld edge is approximately 5 µm, and distribution of Al, Fe and Zn can be observed. However, the Zn of the coating layer has not been completely expelled, and a larger amount has remained on the Al alloy side. The overlay image in Fig. 5 in which Al is shown by red, Fe by green, and Zn by blue. The region containing a large amount of residual Zn is shown by magenta, and the Al-Fe IMC layer region is shown by gold.

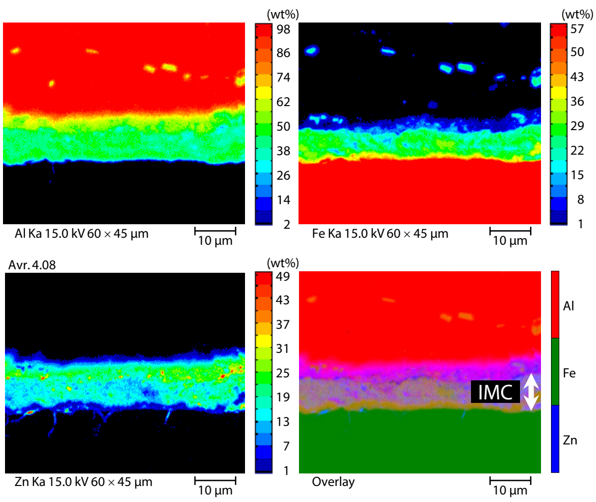


Fig. 5 Mapping of IMC Layer at Short, Weld Edge
(3.69 mm to Right (R) from Center)

## ■ IMC Layer and Cracks

As shown in Fig. 4, the thickness of the IMC layer differs depending on the welding conditions and the distance from the center of the hole. Fig. 6 shows the result of film thickness measurements of the center, intermediate, and edge regions at the same magnification. The thickness of the IMC layer decreases with distance from the center toward the edge, and the entire weld region is thicker with the longer pressing time.

Zn has not been completely expelled from the bonded interface, and some amount remains. As in the Zn distribution images in Fig. 5, Fig. 7 shows the results of a measurement of the average Zn concentration in fields of view calculated at each distance from the center for the two welding conditions. Because Zn is expelled from the center to the periphery by the rotation of the FSSW tool, almost all of the Zn has been expelled from the weld center, and a larger amount of Zn remains at the weld edge. In the intermediate region between the center and the edge, it is thought that Zn is expelled more easily with the short pressing time.

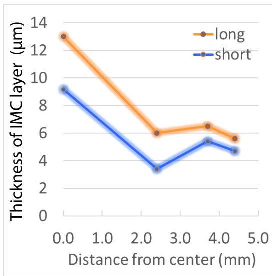


Fig. 6 Film Thickness of IMC Layer

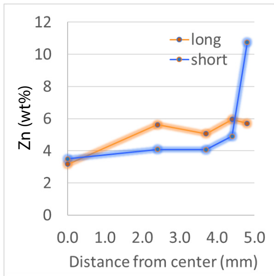


Fig. 7 Average Zn Concentration

Cracks were detected at the bonded interface, and their area ratio was measured. Fig. 8 is a trimmed COMPO image of the vicinity of the crack region, showing the color gradation and area ratio. Because the crack region is shown by black, the area ratio of the black portion of the COMPO image in Fig. 8 depending on the differences in the welding condition and the distance from the center was measured. Fig. 9 shows the results of measurement (-R and -L indicate the distance from the center to the right and left, respectively). It can be understood that the area ratio of cracking in the intermediate region between the weld center and edge was larger with the long pressing time.

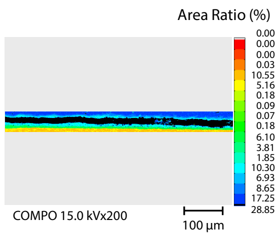


Fig. 8 Area Ratio

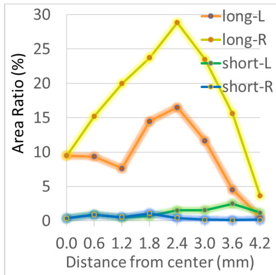


Fig. 9 Crack Area Ratio

## ■ Conclusion

The condition in which Zn is expelled to the periphery of an FSSW weld can be confirmed from cross-sectional images captured by the X-ray CT system. The position of cross-sectional observation by the EPMA can then be determined efficiently by referring to the X-ray CT images. When expulsion of Zn is inadequate, the EPMA analysis revealed that the crack area ratio increases with the film thickness of the IMC layer, and in this case, fracture occurs easily.

<References>
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