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Microstructure and Mechanical Properties of the Magnetic Pressure Seam Welded SPCC/6111-T4 Plates

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Abstract

Lap-joints of SPCC (steel)/6111-T4 (aluminium alloy) were fabricated using the magnetic pressure welding method. Interfacial microstructures between SPCC and 6111 plates and tensile properties of the weld joint were examined. The duration required for the present welding was less than 100 μs. This resulted in very little microstructural change in the parent plates except for the vicinity of the weld interface. Characteristic wavy interface morphology and formation of intermetallic compound layers were observed at the weld interface. Strong lap-joints were obtained and no tensile fracture took place in the weld region when the adequate welding condition was selected.

1. Introduction

Further weight reduction of automobile has been required in order to decrease CO_2 emission. Application of aluminium products to the automobiles is one of the answers for the requirement of weight reduction. Development of the new welding method of dissimilar materials, particularly for steel/aluminium joint, is a key technology. Recently one of the present authors (Aizawa) developed a unique seam-welding technique, which was called magnetic pressure seam welding[1],[2]. In the present study, the lap joints of SPCC/A6111 were fabricated using the magnetic pressure seam welding, and the interfacial microstructure of the weld and tensile properties of the lap joint were examined.

2. Experimental Procedure

2.1 Mechanism of Magnetic Pressure seam Welding

Figures 1(a)~(c) show schematic diagrams of the circuit for the magnetic pressure seam welding. The present circuit consists of a capacitor, C, an electric discharge gap switch, G, and an H-shaped plate-type upper coil and another plate-type coil. There is a slit in the middle of the latter coil. They are made of Cu-Cr alloy. Figures 1(a) and (c) are ground plans of the coil plate. Figure 1(b) is a side view of the coil with a discharge circuit. Lapped Al/Fe sheets are placed over the upper coil with a fixture as shown in Figures 1 (d) and (e).

Figure 1(d) is a longitudinal–cross section view of the coils and Al and Fe plates. Figure 1(e) is the transverse-cross section view. When an impulse current from an energy-storage capacitor bank passes through the so-called “one-turn coil”, a high-density magnetic flux is suddenly generated around the coils as shown Figure 1(e). The generated high density magnetic flux lines cross the end of overlapped Al/Fe sheets. Eddy current is mainly induced inside the Al sheet. The ends of the lapped sheets are joined by both the Joule heat generated in the both sheets and the magnetic pressure being applied from the Al side. This effect is enhanced by the gap prepared between the sheets. The seam welding is carried out along the mid section of the upper H-shaped coil. The welding was achieved within 100 μ s.

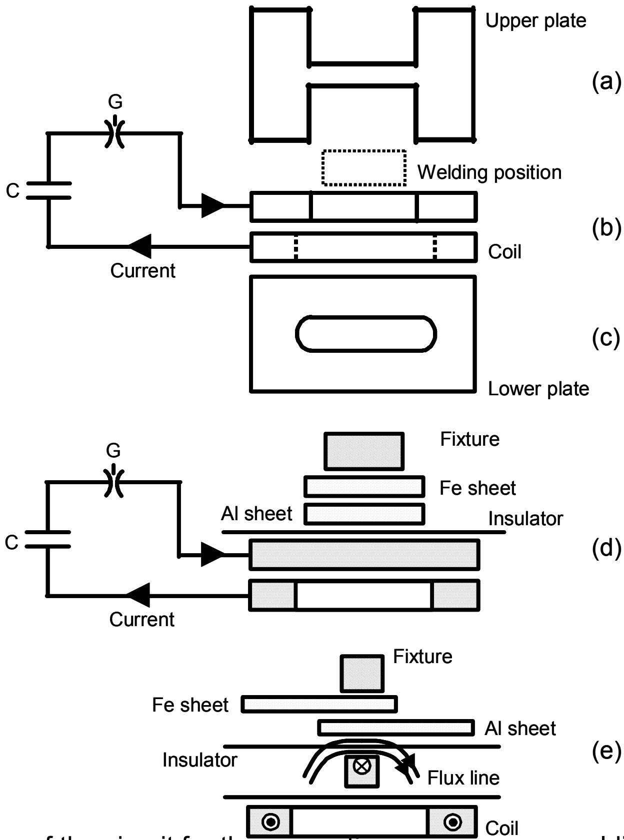


Figure 1: Schematic diagrams of the circuit for the magnetic pressure seam welding: (a) and (c) plan views of coil plates, (b) side view of coil with discharge circuit, (d) longitudinal section view of middle of coil containing lap of Al/Fe sheets with discharge circuit, (e) cross section view of middle of coil and magnetic flux lines.

2.2 Materials

A steel sheet called SPCC (Steel Plate, Cold-rolled, Commercial) and an A6111 aluminium alloy sheet (T4 condition) were used in the present study. Thickness of SPCC and 6111 sheets were 1mm and 1.2mm, respectively. Length and width of the both plates are 12.5cm and 5cm, respectively.

2.3 Microstructural Observation

Microstructural observation was carried out for the weld interface using both an optical microscope and scanning electron microscope with energy dispersive X-ray analyser. Etchants used for metallographic examination were a 5% HNO_3 in ethanol solution for SPCC and a 2% HF aqueous solution for A6111, respectively.

2.4 Tensile Test

Tensile test specimens with shoulders were machined from the SPCC/6111 lap joint. The gage section was 60mm long and 8mm wide and the seam welded section was located in the middle. Several specimens were prepared from the single lap weld joint. Tensile tests were carried out using an Instron-type test machine at a crosshead speed of 1mm/min at room temperature.

3. Results and Discussion

3.1 Microscopic View of the Weld Sheet

Macroscopic appearance of the magnetic pressure seam welded Fe/Al plate is illustrated schematically in Figure 2. The seam welded area was formed like two parallel belts along the two ridge lines of the rectangular portion of the H-shaped coil facing the Al sheet. No bonding was obtained inside them. Figure 3 shows the cross section view of the weld part.

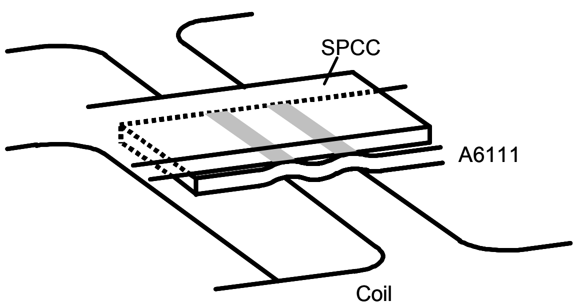


Figure 2: Macroscopic appearance of the magnetic pressure seam welded SPCC/6111 plate

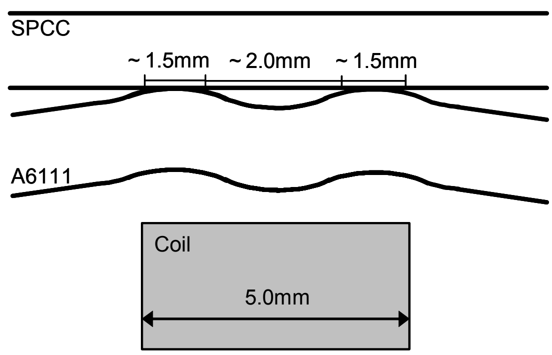


Figure 3: Cross section view of the weld part

3.2 Microscopic Appearance of the Weld Interface

Figure 4(a) shows an optical micrograph of the SPCC/A6111 weld interface. The picture was taken for the as-polished (non-etched) cross section. Wavy interface morphology is clearly observed. Grain structure of the SPCC is shown Figure 4(b). Equiaxed grains are visible in the vicinity of the weld interface. They are equivalent to the original grain structure. The result suggests that the magnetic pressure seam welding hardly affects the microstructure of the SPCC. Figure 4(c) shows grain structure of the 6111. Elongated pancake-like grain structure is the original grain morphology of the present sheet. It is found that grains close to the weld interface are deformed and they exhibit fibrous morphology extended along the weld interface. Such a morphological change took place in the quite vicinity of the weld interface. No morphological change occurred in the aluminium matrix grains away more than 100 μ m from the interface.

3.3 Intermetallic Compound at the Weld Interface

Careful observation using SEM revealed that the formation of intermetallic compound layer on the weld interface as shown in Figure 5. The weld interface is covered with this intermetallic compound layer. The layer exhibit wavy morphology and complicated contrast.

EDX analysis found that the layer consists of several kinds of Al-Fe base intermetallic compounds.

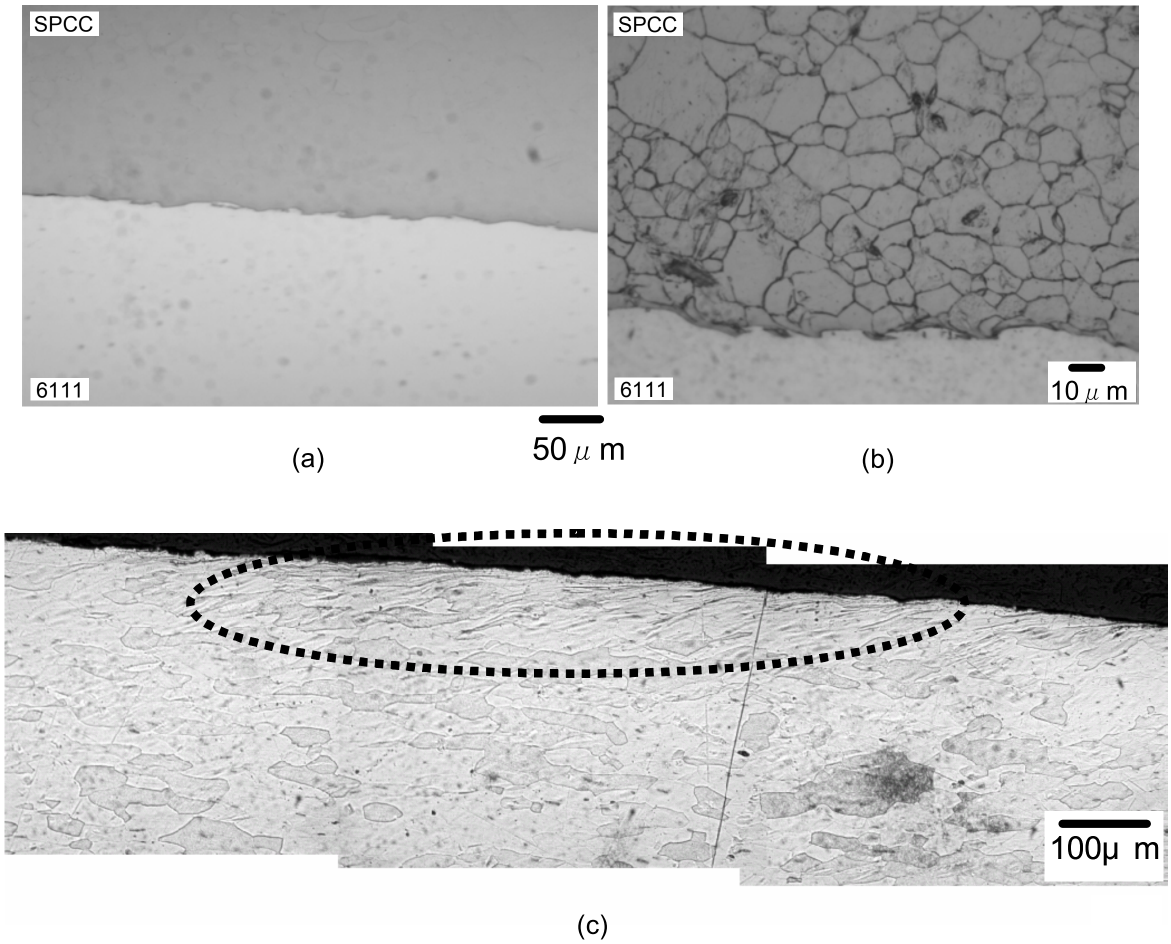


Figure 4:. Optical micrograph of the SPCC/6111 weld interface: (a) cross section of the weld interface as-polished (non-etched), (b) grain structure of SPCC, (c) grain structure of 6111.

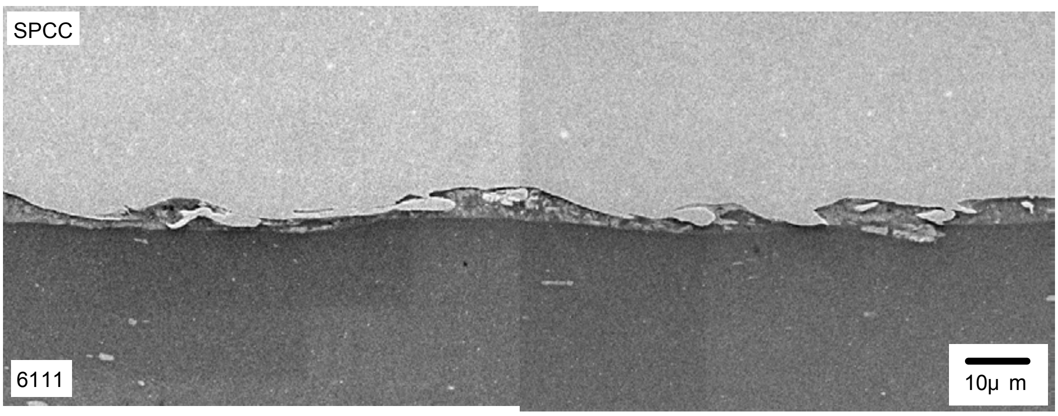
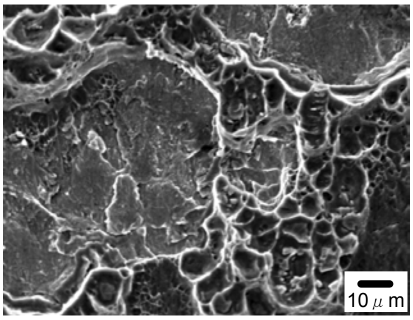


Figure 5:. SEM micrograph of the SPCC/6111 weld interface.

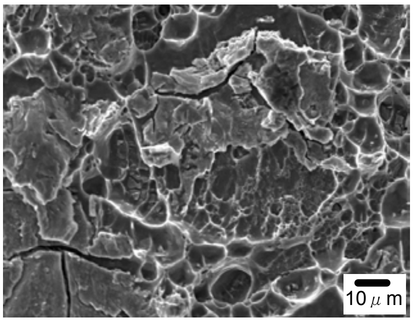
3.4 Tensile Properties

Most of the weld joints showed high bonding strength and no fracture occurred at the weld region. Fracture took place is in the SPCC sheet. This results from the following reason. The 6111-T4 aluminium alloy used in the preset study has equivalent tensile strength to that of SPCC. Thickness of the 6111-T4 plate used for the lap joint was slightly larger than that of SPCC.

Some specimens were fractured at the weld region. In this case, fracture stress (load) was low and the fractural surface exhibited two parallel band regions with bright contrast on both side of the joint. SEM observation found that these regions were covered with elongated dimple fracture surface as shown Figure 6. This means that the weld interface was intact and the fracture took place in the aluminium matrix near the weld interface.



(a)



(b)

Figure 6: SEM micrograph of the elongated dimple fracture surface: (a) SPCC side, (b) 6111 side.

4. Summary

Lap-joints of SPCC (steel)/6111-T4 (aluminium alloy) were fabricated using the magnetic pressure seam welding method. Interfacial microstructure of the joint was characterized by wavy weld interface, formation of intermetallic compound layers at the weld interface and a very little microstructural change in the both parent plates. The magnetic pressure seam welded joints showed high bonding strength and no fracture occurred at the weld region.

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References

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