A Review on Al-Al/Al-Steel Resistance Spot Welding Technologies for Light Weight Vehicles

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1. Introduction

The main focuses of automotive industries are to reduce weight, increase fuel efficiency, and reduce air pollution. To fulfill the demands of fuel economy, lowering the mass of the auto structure can be achieved by substituting steels with light weight materials (like aluminum (Al) and magnesium (Mg) alloys[1]) or steels combined with those. There are lots of advantages to use Al instead of steels; corrosion-resistance, non-magnetic, no color change during heating, and mechanical properties of some of its alloys are superior compared to mild steel. Use of multi-materials in manufacturing process enables low cost production and improvement of joint strength. Al alloys and steels are the most important and indispensable construction materials. Uses of sounds joining technique of those materials ensure the low cost fabrication process to be employed. Welding of steel and Al is not a simple issue to be solved easily. Because conventional welding process resulted in brittle intermetallic compounds (IMC) which are detrimental to joint as it made joint brittle and weak[2].

Since electrical and thermal conductivity of aluminum alloys are significantly high; which required higher current (2.5 to 3 times as of steel), and shorter weld time. Consistency of uniform pressure and current are fundamental needs for Al resistance spot welding. Deterioration of electrodes is vital issue, which may occur due to non uniformity of pressure and current. Electrode erosion eventually leads to undersized welds which should be avoided by using proper surface coatings and treatments on electrodes. Aluminum has high tendency to react with oxygen in the atmosphere and form oxide films on the surface of metal. This oxide films has high resistivity and corrosion protection ability which resists forming weld nugget in RSW. Auhl and Patrick et al.[3] reported that breaking down of oxide layer and ensures proper weld nugget formation usually required high electrode pressure. Many researchers[3-7] demonstrated that surface cleaned with chemicals; resulted thinnest oxide layer which improves the electrode life. Among the other types of chemically treated surface conditions, pretreated/lubricated surface is the most effective to apply for mass production automotive application.

Resistance Spot Welding (RSW) is the primary methods of joining automotive, which is beneficial due to low-cost, high speed production, and availability of multi-materials welding at a same time. Few researchers[8-10] reported that the main barrier to use RSW in Al vehicles is the degradation of electrode life. In this review paper, a few techniques of Al-Al/Al-Steel RSW and possible ways of overcoming the difficulties of welding processes were discussed.

2. Equipments and Power Selection

2.1 Equipments

Unlike RSW equipments for steel, Al RSW required high welding current and high electrode forces, and the values ranging up to 40 kA and 0.2 to 8 kN, respectively. Low electrode forces used for on-line electrode dressing operations, and high force is needed for suppressing expulsion as well as for welding thicker gauge aluminium

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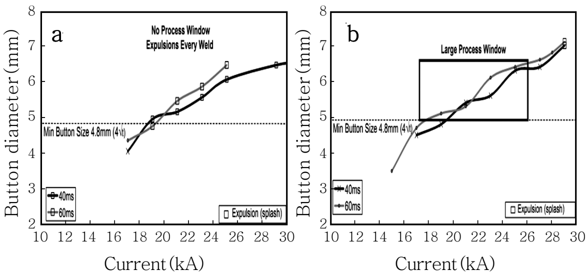

Fig. 1 Process windows with different electrode force used; a) 3 kN electrode force, and b) 6 kN electrode force[11)]

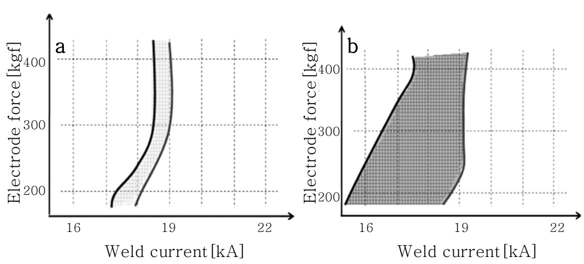

Fig. 2 Lobe diagram at weld time of 7 cycles for aluminum alloy (5J32); a) with SCR type spot welder, and b) with inverter DC type spot welder[12)]

materials and for weld bonding[11)]. Welding force is more influencing factor for nugget formation rather than weld time which is showing in Fig. 1.

Presently, in automobile, most of the industries use pneumatic actuators for controlling electrode force. A few companies are trying to replace pneumatics by servomotor actuators, and their force feedback controls operate accurately at both low and high gun forces. Also using servo guns it can be controlled to increase or decrease the electrode force during the weld, relative to nugget growth.

2.2 Power Selection

Depending on the power, RSW machine can be divided into SCR (Silicon Controlled Rectifier) type and inverter type. Invention of RSW is Medium Frequency Direct Current (MFDC) 1000 Hz welder which provides more reliability to process control over 50/60 Hz spot welder. In addition to process control, 1000 Hz (high frequency) reduced mass and size of the welding transformer.

Kim et al.[12)] reported that the wide weldable condition can be obtained by using inverter type spot welder. Fig. 2 shows the differences of welding power used for RSW of aluminum alloy (5J32).

Also authors[12)] stated that using same welding condition, nugget size is larger with inverter type than SCR type. Both types of welder provides wider lobe diagram with lower welding time, as the welding time increased lobe diagram became narrower.

2.3 Electrode Deterioration

The main causes of heat generation during RSW is oxide layer of the sheet surfaces, as the two surfaces meeting at interface which making higher resistance to current flow than of the outside surfaces. In order to minimize aluminium melting and stick with electrode at electrode-sheet interface, proper welding parameters should be selected. Weld quality deteriorates due to electrode surface pitting and surface coating caused by aluminium oxide film; which result in surface expulsion, undersized/crescent shape button diameter. Regular electrode dressing is effective to increase electrode life from 700 welds to 10,000 welds[11)].

3. Spot Welding Technologies

3.1 RSW Using Cover Plates

In order to avoid the formation of brittle intermetallic reaction layer between aluminium and steel interface a new model was developed which in termed as RSW with cover plate. Due to difficulty in obtaining proper heat at interface for aluminium RSW; as the aluminium alloys are high heat conductive and allows most of the heat to diffuse through the water cooled electrodes. A cover plate was placed at the top surface of two aluminium sheets or aluminium-steel sheet to be joined. Using cover plate it can be possible to obtain 200-300°C higher temperature than without cover plate as reported

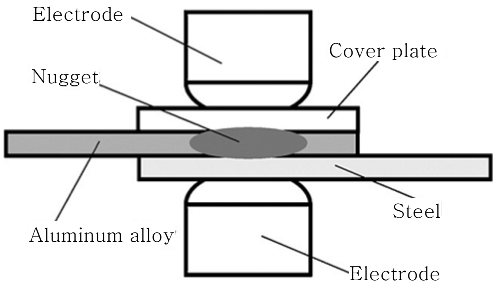

Fig. 3 RSW technique with cover plates[13]

by Sotonaka et al.[14]. It should be taken into consideration that the cover plates must have lower electrical conductivity compare to aluminium alloy, so that generated heat can be conducted into aluminium alloy from cover plate.

3.2 RSW Using Al-Zn Eutectic Reaction

The removal of Fe-Al IMC layer from the joint interface is the main hindrance to achieve appropriate joint strength. To achieve a thin and uniform IMC layer, Miyamoto et al.[15] developed and discussed a new technique to join Al-steel by using Al-Zn eutectic reaction. In that studies, eutectic reaction was used to remove oxide layer form the surface of Al alloy hence it inhibits the formation of a thick Fe-Al IMC layer.

As the contact resistance is high at interface, heat generates at that point when the electric current passed though electrode. As a result, materials soften; the oxide layer of Al alloys and Zn in the coating of GA steels melts. Oxide layer and Zn made a eutectic reaction at low temperature which covered surface of Al alloy by eutectic melt, and removed from the center of the joint to its periphery (Fig. 4 a)). After removal of oxide and Zn with eutectic melts, a diffusion reaction produced between Fe and Al and makes it possible to have thin, uniform Fe-Al IMC layer. Corrosion resistance is another important issue for dissimilar materials joint; any moisture presences in the interface will make corrosion, which needed to be shut out during welding. To ensure proper sealed and moisture free interface, a sealant is used between the two surfaces (Fig. 4 b)). Fig. 4 c) shows the line analysis of Auger Electron Spectroscopy (AES) of the joint interface which confirmed the removal of oxide layer with eutectic molten metal around the periphery of nugget area and thin IMC layer at center of nugget.

3.3 RSW Using Process Tape

Due to limitation of proper technique for aluminium RSW, manufacturers often choose cost effective mechanical joining process such as self-piercing rivets or screws. For fulfilling the customer demands, deltaspot™ welding technology was adopted and could be successfully apply for complex applications. A process tape is used to protect the electrodes to wear and contamination of deposits by zinc, aluminium or organic residues; and it ensures uninterrupted and reproducible weld quality; as process tape is moving

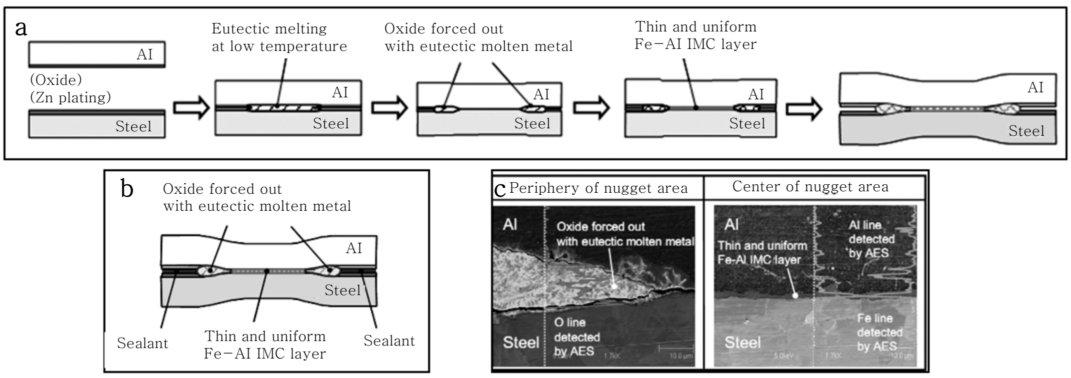

Fig. 4 Joining of Al-steel using Al-Zn eutectic reaction technique; a) Joining process, b) Joint formed by seal spot welding, and c) Cross section of joint interface[15]

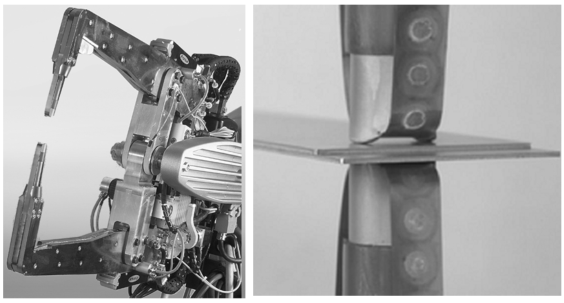

Fig. 5 Set-up and welding operation for deltaSpot™ welding of aluminium[16)]

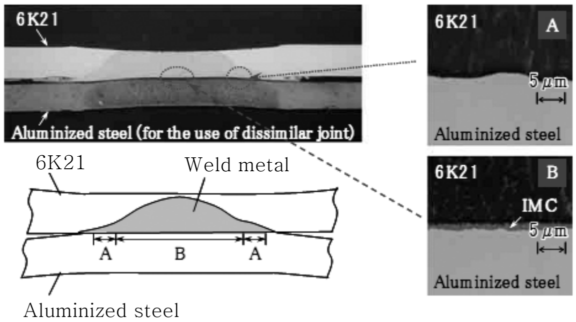

Fig. 6 Interfacial structure of aluminized steel and 6K21 (equivalent to AA6022), (A: IMC free area; B: IMC formed area)[17)]

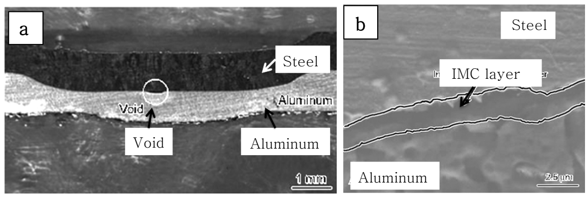

Fig. 7 RSW of Al-Zn coated steels; a) macro-structure of welded part with IMC layer and void, and b) SEM of IMC layer[18)]

continuously forwards. Accurate quality and longevity of electrodes also ensured. Process tape produces additional heat because of its internal resistance and contact resistance which reduces weld current required for welding. For a example, without using process tape, weld current 35 kA to 40 kA is required for 2.0 × 1.0 mm AlMg3 alloy sheets which is cut down to 16 kA with process tape.

3.4 Joining of Aluminum Alloy and Hot-Dip Aluminized Sheet

RSW between aluminium and steel usually produces poor weld bonding due to formation of brittle intermetallic compounds (IMCs) at its joint interface. To produce IMC free weld joint, aluminized steel sheets introduced, in which no intermetallic compound is formed around the periphery of nugget[17)]. IMC free weld periphery offers high strength, which helps to propagate cracking path along thickness direction rather than in interface direction. And eventually produce button fracture. This kind of hot-dip aluminized sheet has nitrogen-rich layer at its surface which prevents inter-diffusion between Fe and Al. Fig. 6 shows the interface of resistance spot welded aluminized steel and 6K21 aluminum alloy. It can be seen an IMC zone (5 μm) produces at center of the interface (Fig. 6 b)), whereas Fig. 6 a) shows IMC free along periphery of weld nugget.

3.5 Joining of Aluminum- Zinc Coated Steels

Fig. 7 a) shows the presence of welding discontinuities in Al-steel interface, which is due to shrinkage stresses as reported by Choi et al.[18)]. Fig. 6 b) represents the Al-steel IMC layer which separated two materials. Choi et al.[18)] also demonstrated that IMCs is rich of Fe, and the thickness of IMC layer increased with weld time. Post welding time also favors to increase IMC layer. Welding current has less significant effect on formation of IMC layer, however IMC growth observed in Al sheet side.

4. Microstructure Analysis

The various structures of welded aluminum alloys are not clearly distinguishable. Fig. 8 shows the equiaxed grain structure at the center of the nugget and columnar crystals structure near the fusion line with a directional solidification towards the center of the nugget. The temperature gradient in HAZ is significantly high; so, there is a possibility to develop large thermal stress in this region. Partially melted zone (PMZ) presence adjacent to the nugget

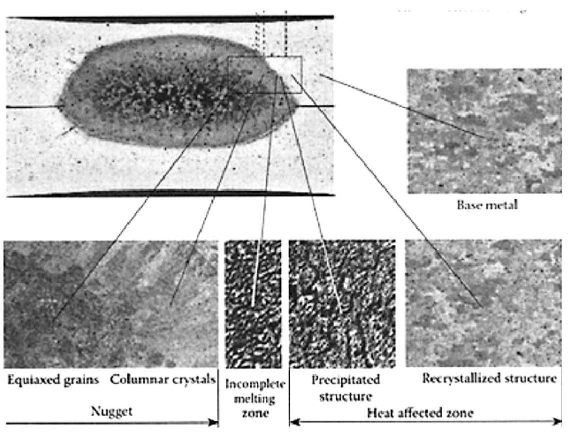

Fig. 8 Different zones of resistance spot welded 5754 aluminum alloy[19]

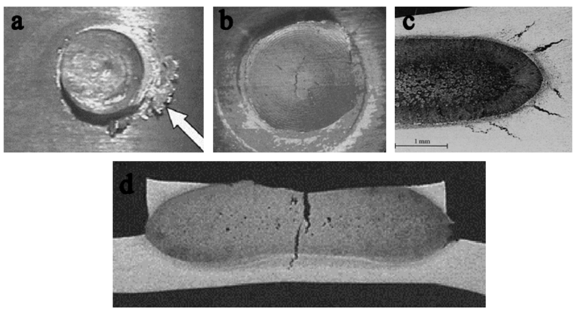

Fig. 9 Welding discontinuities of aluminum alloys; a) Surface expulsion (AA5754 alloy), b) Surface cracks (AA6111 alloy), c) HAZ liquation cracks (AA5754 alloy), and d) Cracks in weldment (AA6111 Alloy)[19]

and this zone is highly favorable for elements segregation which subsequently leads to HAZ liquation cracking[19].

5. Welding Imperfections

Welding discontinuities are associated with improper uses of welding schedule, electrode, and welding machine, etc[19]. Some of the discontinuities have crucial effect on welded structure, while others have aesthetic effect. The common types of welding discontinuities for aluminum RSW are shown in Fig. 9.

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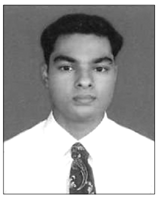

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