International Journal of Advanced Culture Technology Vol.3 No.1 153-160 (2015)
http://dx.doi.org/10.17703/IJACT.2015.3.1.153

IJACT 15-1-19

Effect of Resistance Spot Welding Parameters on AA1100 Aluminum Alloy and SGACD Zinc coated Lap Joint Properties

Sakchai Chantasri[1], Pramote Poonnayom[2], Jesada Kaewwichit[3], Waraporn Roybang[4],
Kittipong Kimapong[5]

[1,2,3,4,5]*Department of Industrial Engineering, Faculty of Engineering,*
Rajamangala University of Technology Thanyaburi, Pathumthani, THAILAND
sakchai.c@en.rmutt.ac.th[1], pramote.p@en.rmutt.ac.th[2], jesada.t@hotmail.com[3],
waraporn2029@gmail.com[4],kittipong.k@en.rmutt.ac.th[5]

Abstract

This article is aimed to study the effects of resistance spot welding (RSW) on the lap joint properties between AA1100 aluminum alloy and SGACD zinc coated steel and its properties. The summarized experimental results are as follows. The summarized experimental results are as follows. The optimum welding parameters that produced maximum tensile shear strength of 2200 N was a welding current of 95 kA, a holding time of 10 cycles, and a welding pressure of 0.10 MPa. Increasing of welding current, increased the tensile shear strength of the joint and also increased the amount of aluminum dispersion at the joint interface. The lap joint of steel over the aluminum (Type I) showed the higher joint tensile shear strength than a lap joint of aluminum over the steel (Type II). The indentation depth and the ratio of the indentation depth to the plate thickness decreased when the welding current was increased in the type I lap joint and also decreased when the welding current was decreased in the type II lap joint. The interface structure showed the formation of the brittle $FeAl_3$ *intermetallic compound that deteriorated the joint strength.*

Keywords: *resistance spot welding, dissimilar materials, lap joint, strength,*

1. INTRODUCTION

In an automobile industry nowadays, the car manufacturers are targeted to produce the car that consumes less fuel for a reason to preserve energy and environment. Recently, a replacement of a lightweight material that indicated a higher ratio of strength/mass is noticed. This is the weight reduction method and could be successfully applied in car manufacturing industry. These light materials include high strength alloy, aluminum, magnesium, composite materials or plastic, etc. [1-2]. The weight reduction method also promotes a dissimilar material joint in car structure that could indicate the advantages of both metals and g

---

Manuscript Received: Mar. 23, 2015 / Revised: Apr. 17, 2015 / Accepted: May 21, 2015
Corresponding Author: sakchai.c@en.rmutt.ac.th
Tel: +66 2549 4083, Fax: +66 2549 4900
Department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Thanyaburi

ive a unique mechanical property [3]. Various research papers have been reporting that the fusion welding of dissimilar metal joint is difficult because the difference of mechanical, and physical properties of the metals trends to produce a stress concentration, a stress discontinuity and a residual stress at the joint interface [4]. Furthermore, the difference in chemical composition of the metals can produce the hard-brittle intermetallic compound phases such as Fe_2Al_5 and $FeAl_3$ in the weld metal during solidification of a weld metal. These Al-rich intermetallic compounds directly affected to deteriorate the dissimilar Al/Fe metals joint strength. [5]

Resistance spot welding (RSW) is an important welding process for joining sheet metal lap joint in automobile structures. The number of the RSW joint in the automobile structures was more than 1000 joints. [6]. This RSW process could also successfully produce the lap joint between aluminum and steel such as A5052/SPCC, SAE1008/5182-O [7], A5052/SUS304/SPCC [8-11], AISI316L/DIN 10130-99 [12], H220YD steel/6008-T66 [13], etc. Some RSW Al/Fe laps joint, such as SAE1008/5182-O lap joint indicated the static and dynamic joint strength under lap shear and cross tension test were slightly higher than that of the dissimilar SAE1008/5182-O lap joint that were produced by self-piercing rivet. The main cause that affected to deteriorate the joint strength was the formation of intermetallic compound (IMC) in the weld metal. Increasing of IMCs thickness and continuous formation of IMC phases at the joint interface directly affected to deteriorate the lap joint strength [7-11]. Therefore, the control of IMCs formation at the joint interface of dissimilar Al/Fe lap joint produced by RSW was the important key to increase the joint strength.

The present work is aimed to resistance spot welding of a lap joint between AA1100 aluminum alloy and zinc coated steel by the various welding currents and to investigate the relationship between the joint strength and interface metallography of the dissimilar AA1100 aluminum alloy and zinc coated steel lap joint.

2. EXPERIMENTAL PROCEDURE

Table 1. Chemicalcomposition of the experimental materials. (%wt)

Mateials	Al	Fe	C	Zn	Si	Mn	Cu	P	S
AA1100	Bal.	-	-	-	0.095	0.050	0.15	0.006	-
SGACD	-	Bal.	0.15	0.25	-	-	-	0.014	0.240

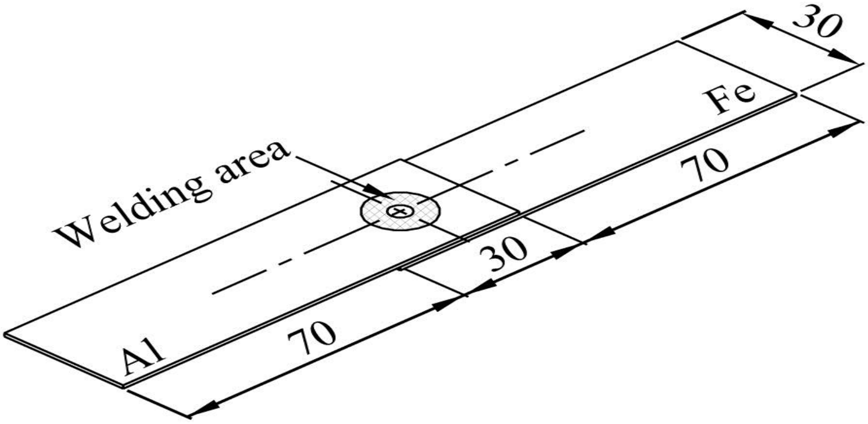
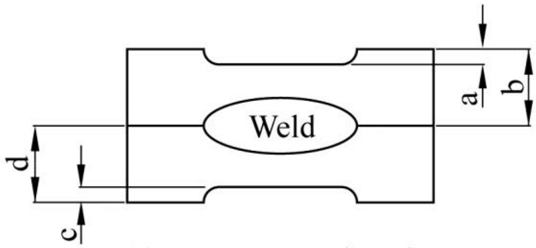


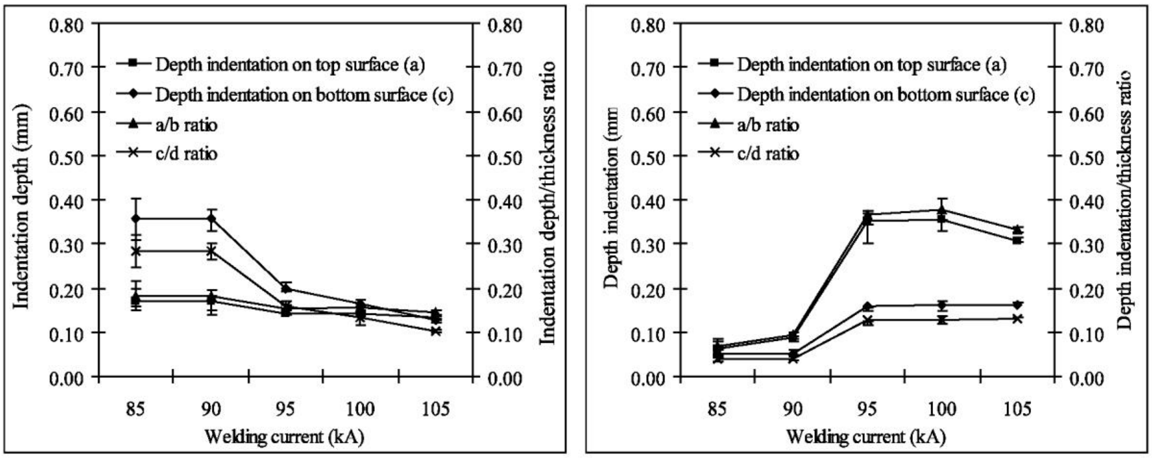
Fig. 1. Confrigulation of test specimen. (In mm.)

The materials used in this experimental study were 1.0 mm thick A1100 aluminum alloy (hereafter, Al) and SPCD 45/45 zinc coated steel (hereafter, Fe) that had a chemical composition as listed in Table 1. The materials were mechanically prepared into rectangular shapes with the dimension of 100 mm in length and 30 mm in width. The material plates were mounted in a jig to set a lap joint, the upper plate overlapped the lower plate by 30 mm as shown in Fig 1. This study investigated 2 types of the dissimilar Fe/Al lap joints. They were the lap joint of Fe plate as the upper plate over an Al plate (hereafter, type I) and the lap joint of Al plate as the upper plate over the Fe plate (hereafter, type II). An electrode that was made of C11000 copper alloy had a tip diameter of 8 mm. The welding parameters were a welding current of 85-105 kA, a welding time of 10 cycles and a welding force of 0.1 MPa. After welding, the lap joint tensile shear test was carried out to compare the joint strength under a crosshead speed of 25 mm/min. Samples for metallographic examination were produced from the welds and mechanically polished. The polished samples were observed and analyzed using a light optical microscope and a scanning electron microscope (SEM) with X-ray energy-dispersive spectroscopy (EDS).

3. RESULTS AND DISCUSION



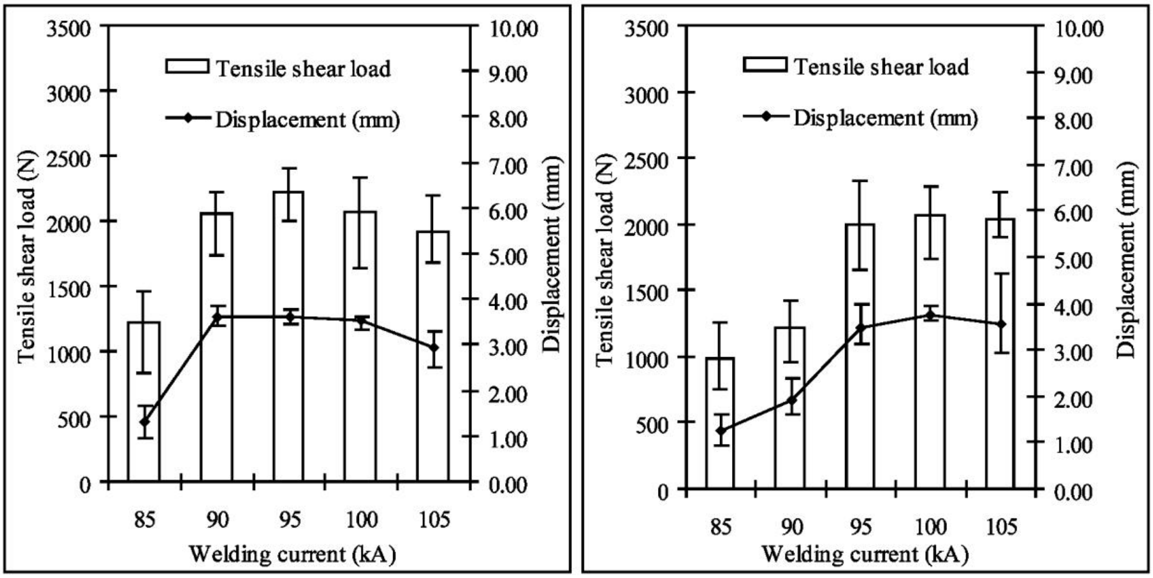
(a) Measuremen location.



(b) Indentation depth of Type I lap joint (c) Indentation depth of Type II lap joint

Figure 2. Relation between welding current and the indentation depth of joint surface. (a=indetation depth of upper surface, b=upper plate thickness, c=indetation depth of lower surface, d=lower plate thickness)

Figure 2 shows the relation between welding current, indentation depth and the ratio of indentation depth to plate thickness that was examined, follows JIS Z3139 [12]. The letter a, b, c and d in figure 2 (a) are an indentation depth of upper surface, an upper plate thickness, an indentation depth of lower surface and a lower plate thickness, respectively. It was found that the increase of the welding current decreaseed the indentation depth of the type I lap joint and increased the indentation depth of the type II lap joint. The increase of the welding current also decreased the ratio of indentation depth to plate thickness of the type I lap joint and increased the ratio of indentation depth to plate thickness of the type II lap joint. The measurement results in Figure 2 (b) and (c) shows that the indentation depth of type I lap joint that was welded by 85 and 90 kA was higher than the 0.3 mm and was not recommended to weld the lap joints required in the automobile industry. The indentation depth of type II lap joint that was higher than that of 0.3 mm could be found when the unsuitable welding current of 95-105 kA was applied to weld the lap joint. The ratio of the indentation depth to the plate thickness showed that the RWS of the type I lap joint could be applied in the automobile industry when the welding currents of 95-105 kA were applied to weld the type I lap joint with the ratio of <0.3. This ratio was also high when the higher current of 95-105 kA was applied to weld the type II lap joint.



(a) Type I - Fe on Al (b) Type II - Al on Fe

Figure 3. Relation between welding current, tensile shear load and displacement of the dissimilar Al/Fe lap joint.

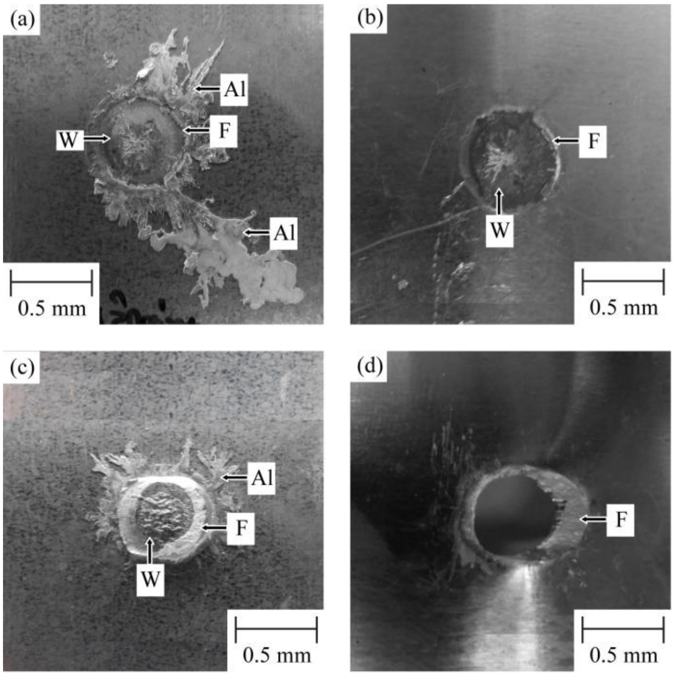
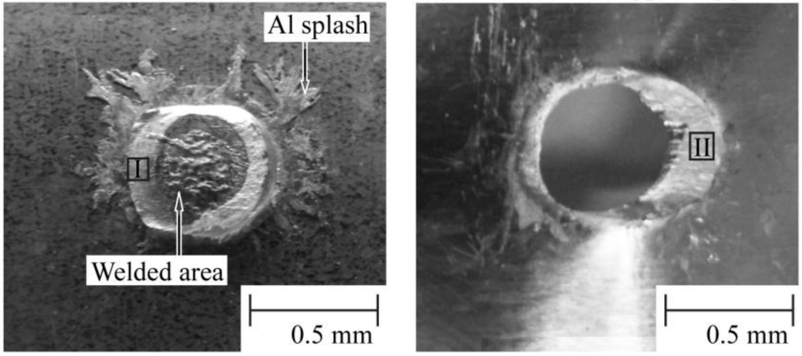


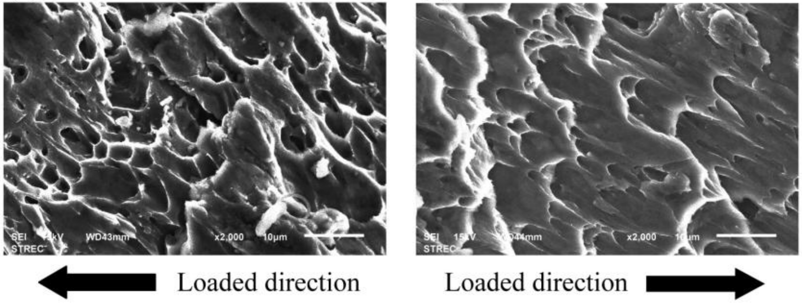
Figure 4: Fracture surface of tensile shear specimens: (a) an interface fracture of Fe side- type I lap joint, (b) an interface fracture of Al side- type I lap joint, (c) a weld metal surface of Fe side- type II lap joint and (d) a weld metal surface of Fe side- type II lap joint. (W=welded area, F=fracture location, loading direction was right to left.)

Figure 3 shows the relationship of welding current, tensile shear load and displacement of 2 dissimilar Al/Fe lap joint types. When the harder Fe metal overlapped the softer Al metal (Type I), the tensile shear load increased when welding current was increased from 85-90 kA as shown in figure 3 (a). However, when the welding current was 90-105 kA, the tensile shear load was slightly changed and had a highest tensile load of 2300 N when the lap joints were welded by the welding current of 95 kA. When compared the tensile shear strength of Type I with Type II, it was found that the tensile shear strength of the type II was slightly lower than that of Type I as shown in figure 3 (b). The trend of the tensile shear strength results of Type II lap joint found, the increase of the welding current increased the tensile shear strength of the lap joint. The maximum tensile shear strength was of the type I lap joint, welded by the welding current of 95 kA and indicated tensile shear strength of 2200 N.



(a) Fe side-95 kA-Type I lap joint

(b) Al side-95 kA-Type I lap joint



(c) Location I on Fe side

(d) Location II on Al side

Figure 5. Fracture surface of the Type I specimen that was welded by 95 kA.

The tensile shear strength examination of the 2 types of the lap joints that were welded by various welding currents as shown in figure 3 could be classified on the basis of the fracture surface of the tensile shear strength specimen into 2 types as shown in figure 4. There were an interface fracture as shown in figure 4 (a) and (b) and a weld metal fracture as shown in figure 4 (c) and (d). The interface fracture as shown in figure 4 (a) and (b) was occurring when the lower welding currents such as 85 and 90 kA current were applied to weld the lap joint. Some Al splash was found around the welded area and was the reason to increase the indentation depth of the lap joint as shown in figure 3. Small bonded area was found in the welded area and was the reason of lower tensile shear strength of the lap joint. The weld metal fracture as shown in figure 4 (c) and (d) was occurring when the welding currents such as 95 and 105 kA current were applied to weld the lap joint. Some Al splash was also found around the welded area, but was smaller than the Al splash on the interface fracture as shown in figure 4 (a). The fracture location was located at the middle of the weld metal as shown in figure 4 (c) and caused the Al plate fracture as shown in figure 4 (d). The tensile shear strength specimen that indicated the maximum tensile shear strength and was welded by the welding current of 95 kA was examined using the scanning electron microscope. The fracture Location I of Fe side-type I lap joint and the fracture Location II of Al side-type II lap joint as shown in figure 5 (a) and (b) were enlarged to examine the fracture characteristics. It was found that the fracture surface showed the dimple pattern that was implied to the ductile behavior of the joint and was the reason the joint indicated the maximum tensile shear strength in this study.

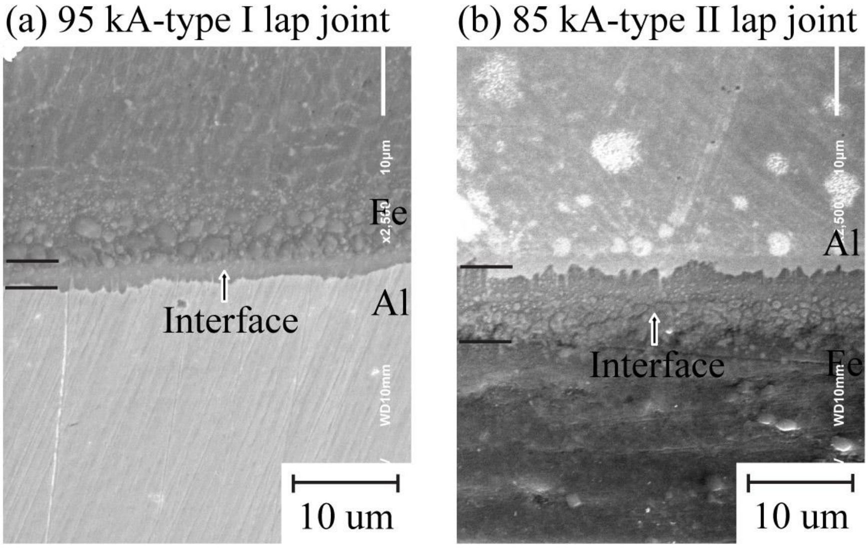


Figure 6. Microstructure of the 95 kA specimen.

Figure 6 shows the SEM micrographs of the interface of the joint that indicated the maximum (Type I lap joint that was welded by 95 kA) and minimum (Type II lap joint that was welded by 85 kA) tensile shear strength of this study. The interface of the both lap joints showed the formation of the combination phase that had a thickness of about 3 and 8 microns for the type I and II lap joint, respectively. Some cracks were observed under the combination phase of type II lap joint that were welded by the welding current of 85 kA as shown by the arrow in figure 6 (b). The chemical composition of the combination phases were analyzed and showed that the combination phase of type I lap joint in figure 6 (a) was $FeAl_3$ intermetallic compound (76.67Al, 23.33Fe, at%) and the combination phase of type I lap joint in figure 6 (a) was $FeAl_3$ intermetallic compound (77.46Al, 22.54Fe, at%). This $FeAl_3$ IMC indicated a brittleness property of the Fe-Al phase system and directly affected to deteriorate the joint strength [13].

4. CONCLUSION

The lap joint between AA1100 aluminum alloy and SGACD zinc coated steel was resistance spot welded using various welding currents into 2 types of the lap joint. The tensile shear strength and the interface structure were examined for optimization of the welding current. The summarized results are as follows.

4.1 The optimum welding parameters that produced maximum tensile shear strength of 2200 N was a welding current of 95 kA, a holding time of 10 cycles, and a welding pressure of 0.10 MPa.

4.2 Increasing of welding current increased the tensile shear strength of the joint and also increased the amount of aluminum dispersion at the joint interface.

4.3 The lap joint that of steel over the aluminum showed the higher joint tensile shear strength than a lap joint of aluminum over the steel.

4.4 The indentation depth and the ratio of the indentation depth to the plate thickness were decreased when the welding current was increased in the type I lap joint and were decreased when the welding current was decreased in the type II lap joint.

4.5 The interface structure showed the formation of the brittle $FeAl_3$ intermetallic compound that deteriorated the joint strength.

REFERENCES

[1] Qiu, R., Shi, H., Zhang, K., Tu, Y., Iwamoto, C. and Satonaka, S., "Interfacial characterization of joint between mild steel and aluminum alloy welded by resistance spot welding," *Materials Characterization*, Vol. 61, pp. 684-688, 2010.

[2] Su, Y, Hua, X, Wu, Y., "Quatitative characterization of porosity in Fe-Al dissimilar materials lap joint made by gas metal arc welding with different current modes," *Journal of Materials Processing Technology*, Vol. 214, pp. 81-86, 2012.

[3] Zhang, H., Liu J., "Microstructure characteristics and mechanical property of aluminum alloy/stainless steel lap joint fabricated by MIG welding-brazing process," *Materials Science and Engineering A.*,Vol. 528, pp. 6179-6185, 2011.

[4] Dehmolaei, R., Shamanian, M., Kermanpur A., "Microstructural characterization of dissimilar welds between alloy 800 and HP heat-resistant steel," *Materials Characterization*, Vol. 59, pp. 1447-1454, 2008.

[5] S. Kobayashi and T. Yakou, "Control of Interme tallic Compound Layers at Interface between Steel and Aluminum by diffusion-treatment," *Materials Science and Engineering: A*, Vol. 338, pp. 44-53, 2002.

[6] Vural, M., Akkus, A. and Eryurek, B., "Effect of Welding nugget diameter on the fatigue strength of the resistance spot welded joints of different steel sheets," *J. of Materials Processing Technology*, Vol. 176, pp. 127-132, 2006.

[7] Sun, X., Stephens, E.V., Khaleel, M.A., Shao, H. and Kimchi, M., "Resistance Spot Welding of Aluminum Alloy to Steel with Transition Materials – From Process to Performance – Part I: Experimental Study," *Welding Journal*, Vol. 84, No. 6, pp. 188-195, 2004.

[8] Qiu, R, Iwamoto, C. and Satonaka, S., "Interfacial microstructure and strength of steel/aluminum alloy joints welded by resistance spot welding with cover plate," *J. of Materials Processing Technology*, Vol. 209, pp. 4186-4193, 2009.

[9] Qiu, R, Iwamoto, C. and Satonaka, S., "The Influence of reaction layer on the strength of aluminum/steel joint welded by resistance spot welding," *Materials Characterization*, Vol. 60, pp. 156-159, 2009.

[10] Qiu, R., Shi, H., Zhang, K., Tu, Y., Iwamoto, C. and Satonaka, S., "Interfacial characterization of joint between mild steel and aluminum alloy welded by resistance spot welding," *Materials Characterization*, Vol. 61, pp. 684-688, 2010.

[11] Qiu, R, Satonaka, S. and Iwamoto, C., "Effect of interfacial reaction layer on tensile strength of resistance spot welded joints between aluminum alloy and steels," *Materials and design*, Vol. 30, pp. 3686-3689, 2009.

[12] JIS Z3139 (1978), *Method of Macro Test for Section of Spot Welded Joint*, JIS Handbook of Welding, Tokyo, Japanese Industrial Standard Association, 1997.

[13] Kobayashi, S., Yakou, T., "Control of Intermetallic Compound Layers at Interface between Steel and Aluminum by Diffusion-treatment," *Materials Science and Engineering A*, Vol. 338, pp. 44-53, 2002.