Journal of Mechanical Engineering Vol S1 4(2), 289-301, 2017

# The Effect of Surface Texture on the Joint Shear Strength of AR500 Steel and AA7075

*M. N. Muhamed**
*Faculty of Manufacturing Engineering Technology, TATI University College, Telok Kalong, 24000 Kemaman, Terengganu, Malaysia.*

*M. Z. Omar, S. Abdullah , Z. Sajuri, W. F. H. W. Zamri*
*Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia*

**najieb1@gmail.com*

## ABSTRACT

*This paper evaluates the shear strength and failure mode of AR500 steel and AA7075 aluminium alloy brazing joint panels caused by shear loading. The use of steel and aluminium laminated metal composite is increasingly popular since they are well known for lightweight application and stiffness properties and this makes them the material of choice in automotive industry. However, the formation of reaction layer phases has limited the application of this method of joining due to the adverse effect of these phases on the strength of the joint. In this work, AR500 steel and AA7075 aluminium alloy interface joint were fabricated by torch brazing method using Al-Si-Zn base material as its filler metal for different types of surface conditions. The joining was evaluated for shear strength performance. The experimental results showed that the highest shear strength for the panel was recorded at 8010 N. Fractures were mostly seen at the joint interface area. In general, the torch brazing process with different surface joining conditions, had facilitated the joining of these dissimilar metals while improving the mechanical properties of the joint.*

**Keywords:** *Steel, Aluminium, torch brazing, shear strength*

ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2017-05-10
Accepted for publication: 2017-05-31
Published: 2017-09-15

## Introduction

The increasing demand of cost efficient transport system especially low fuel consumption vehicle has influenced the automotive industries to problem by developing light weight car bodies which involves the joining of dissimilar materials.[1] The joining of steels and aluminium alloys were done to achieve weight reduction and to lower the cost of vehicle. Development of steel and aluminium alloy joint was studied by various researchers and organisations in automotive industries.[2]

Several joining methods have been studied to join steel and aluminium together, such as adhesive bonding [3], welding [4,5], riveting [6,7], and brazing [8]-[10]. The brazing of aluminium to steel is a reliable process that has good potential for automotive applications and to reduce the manufacturing cost [11].

The joint between two elements made of dissimilar materials will influence the physical, chemical and metallurgical properties. The greater the differences in the properties , the more difficult to produce the joint. [12] The main issue in joining steels and aluminium alloy is the formation of intermetallic compound layer on the joint commonly in the fusion zone. The formation of brittle intermetallic compound will cause deterioration and reduce the strength of joint.[13,14]

Hence, the purpose of this study is to investigate the mechanical integrity of AR500 steel and AA7075 aluminium alloy joint produced by a simple torch brazing process. Low melting temperature Al-Si-Zn material was used as the filler metal. Results for the surface fracture, hardness and shear strength of the joints were discussed herein. This work is significant because it provides deeper understanding on the interfacial bonding reactions between the two difficult-to-join alloys using a simple torch brazing process.

## Experimental Detail

The materials used for this study are AA7075 aluminium alloy and AR500 high-strength steel. These materials were selected because they have been widely used in the heavy commercial vehicle industry and they have the best properties in terms of strength and wear resistance. The joint between these two metals were produced by a torch-brazing process using $CsAlF_4$ flux-cored Al-Si-Zn base filler wire with 15-20% flux composition. The chemical composition of AA7075 aluminium alloy and AR500 high-strength steel are provided in Table 1 and Table 2, respectively.

Table 1: Composition of AA7075 aluminium alloy (wt.%)

| Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Zr | Al |
|---|---|---|---|---|---|---|---|---|---|
| 0.16 | 0.22 | 1.13 | 0.09 | 2.03 | 0.21 | 6.13 | 0.027 | 0.026 | Bal |

Table 2: Composition of AR500 high-strength steel (wt.%)

| C | Si | Mn | P | S | Ni | Cr | Mo | B | Fe |
|---|---|---|---|---|---|---|---|---|---|
| 0.39 | 0.63 | 0.87 | 0.01 | 0.01 | 0.02 | 0.53 | 0.003 | 0.002 | Bal |

The materials were supplied as plate and were cut to lengths suitable for shear strength testing. The ends of both the steel and aluminium samples were machined by a wire-cutting machine to 79.5 mm in length, 25.4 mm in width, and 2.5 mm in thickness, as shown in Fig. 1. The surface of the specimen was prepared by removing the oxide film on both plates using silicon carbide sand paper and set with different surface condition as in Table 3 and micrograph of surface texture as shown in Fig. 2(a-d).

The filler prepared by rolled the filler wire to 0.5 mm thickness and cut into strips of 3.5 mm x 25 mm and arranged to fill the surface of the base metal, as shown in Fig. 3(a, b). The chemical composition of the filler metal is shown in Table 4. The joining process start with the AA7075 aluminium alloy overlapped the high-strength steel plate and the filler metal is between the two metals, as shown in Fig. 4(a) and then torch-brazing process involved the burning of butane gas was heated to the surface of base metal (AR500 steel), the joining method between these two metals is shown in Fig. 4(b).

The surface of base metal was heated to a temperature within a range where the bonding phase between the molten filler metal and the base metal can occur ($477^{0}C \pm 5^{0}C$). The temperature recorded was interface temperature of overlapped materials.

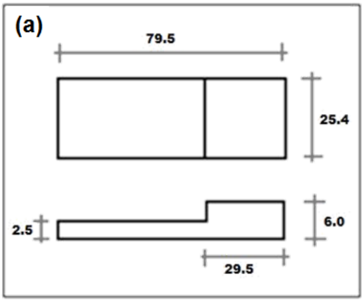


Figure 1: Dimensions of steel and aluminium sample

Table 3: Surface condition of joint plate

| Experiment | Surface Preparation | Surface Roughness / Texture |
|---|---|---|
| 1 | Polished by 180 grit in 3 minute | AR500 – 0.322µm (Fine)<br>AA7075 – 0.663µm |
| 2 | Polished by 40 grit in 3 minute | AR500 –1.427µm (Coarse)<br>AA7075 – 3.047µm |
| 3 | Micro scale groove was produced by wire cut machine | AR500 – 124.07µm (Groove)<br>AA7075 – 124.07µm |
| 4 | Polished by 180 grit + slot | Fine and Slot (diameter 4mm on aluminium plate) |

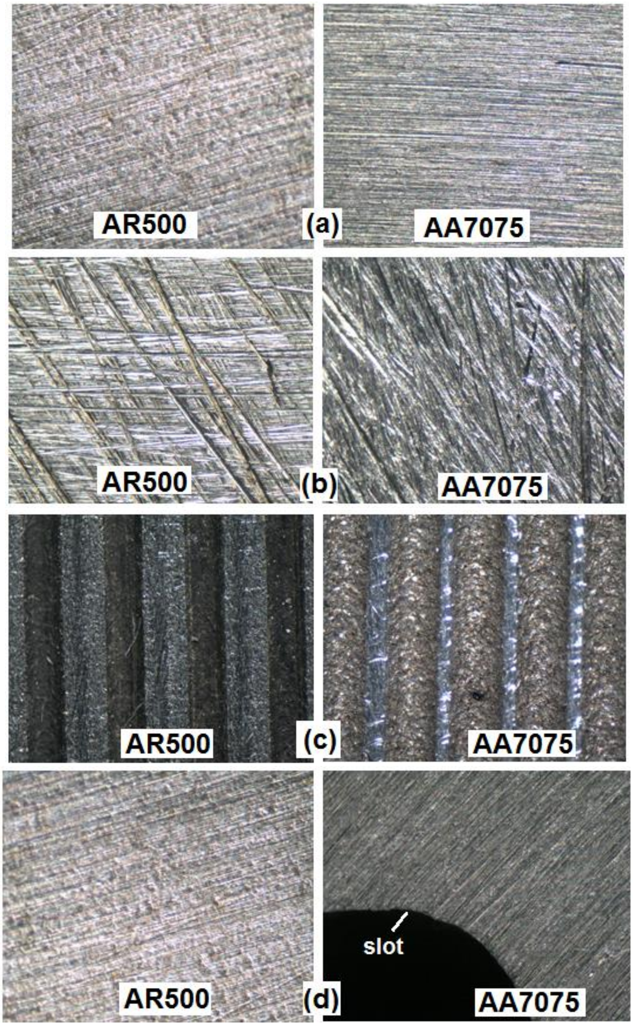


Figure 2: Micrograph of surface texture: (a) polished by 180 grit SiC paper, (b) polished by 40 grit SiC paper, (c) micro scale groove, (d) polished by 180 grit SiC paper + slot on AA7075

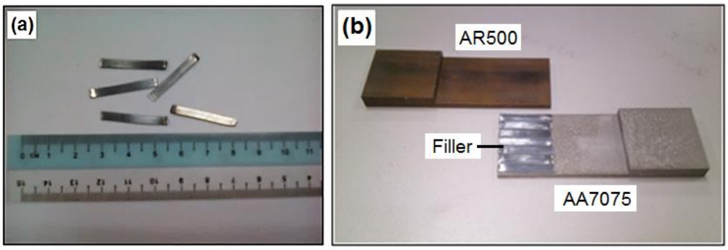


Figure 3: Filler metal preparation: (a) filler metal, (b) filler metal arrangement in specimen

Table 4: Composition of Al-Si-Zn base filler metal (wt.%)

| Si | Fe | Cu | Mn | Mg | Cr | Ni |
|---|---|---|---|---|---|---|
| 14.84 | 3.13 | 0.58 | 1.42 | 1.70 | 0.06 | 1.49 |
| Zn | Ti | Ag | Pb | Sn | V | Al |
| 15.60 | 2.02 | 0.1 | 0.87 | 3.75 | 0.13 | Balance |

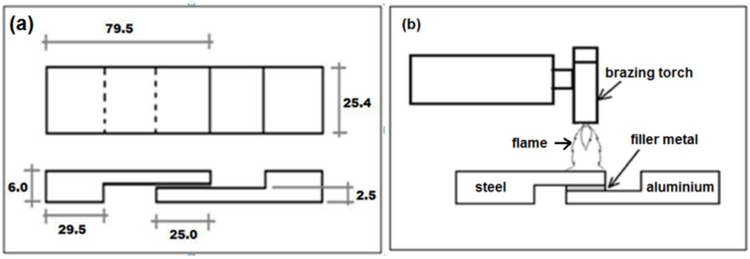


Figure 4: Joining process: (a) overlap of steel and aluminium for joining process (b) torch brazing process

The joint strength of brazed specimen was evaluated by shear testing. The shear strength was evaluated as average values using three specimens for each condition. Shear tests were carried out in a universal testing machine with a load cell (model Zwick Roell Z100). The cross-section of the brazed joint after shear testing was observed by using a variable pressure scanning electron microscope (VP-SEM) (model Zeiss Evo Ma 10). Specimens for SEM were provided by cutting both metals to the size of 10 mm x 10 mm x

2.5 mm and carried out brazing process. The surface fractures caused by the shear test were observed by using a digital camera and the hardness test with three reading of each condition was conducted by using a Rockwell Brinell machine (model Shimadzu DXT).

## Result and Discussion

### Shear strength

Figure 5 summarizes the shear strength of the joints brazed in four types of surface condition (the result was average of 3 sample of specimen). The results indicated that the strength of the brazed joints are different in relation to the surface condition. The joint on fine surface with slot showed the highest value-8010N, while the joints of fine and coarse surface condition were 6540 N and 2080 N, but the joining on groove surface was unsuccessful. The join strength on fine surface content slot increased 18% compared to only on fine surface. Therefore, the surface content slot is beneficial to increase the strength of the joints. From these preliminary results, it appears that fine surface gives favourable joint strength than the coarse surface.

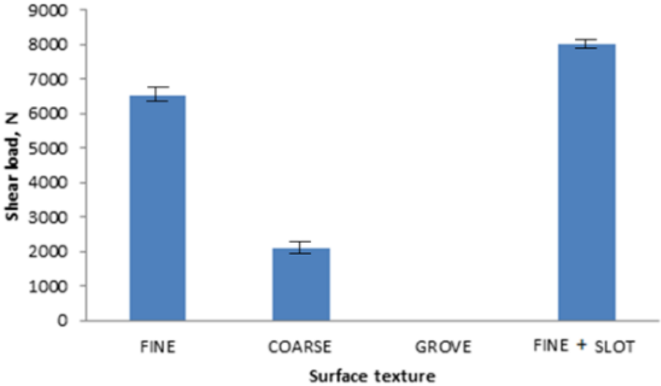


Figure 5: Shear load vs surface texture for torch brazing of joint between AR500 steel and AA7075 aluminium alloy

### Hardness of base metal

The resulting hardness on AR500 steel and AA7075 aluminium alloy after brazing process was also investigated. The hardness of base metal was tested on the outer surface of the joint metals (average hardness values of 3 readings for each condition). Figure 6 shows these hardness values of metals. Figure 6 indicates there was no significant change in the hardness of the steel base metal. The temperature has start an effect on the microstructure and properties of steel at around 738°C (eutectoid temperature which is the minimum temperature for austenite)[15]. The temperature used in the brazing process in the current study was 477°C, therefore no significant change in the hardness value of the steel took place. The hardness of aluminium decreased as a result of annealing. According to Isadare et al., coarse grains of the MgZn2 phase were formed during the annealing process at 470°C and non-uniformly distributed in the aluminium matrix [16]. This brazing process caused the reduction of base metal hardness by approximately 10% on AR500 steel and 35% on AA7075 aluminium alloy.

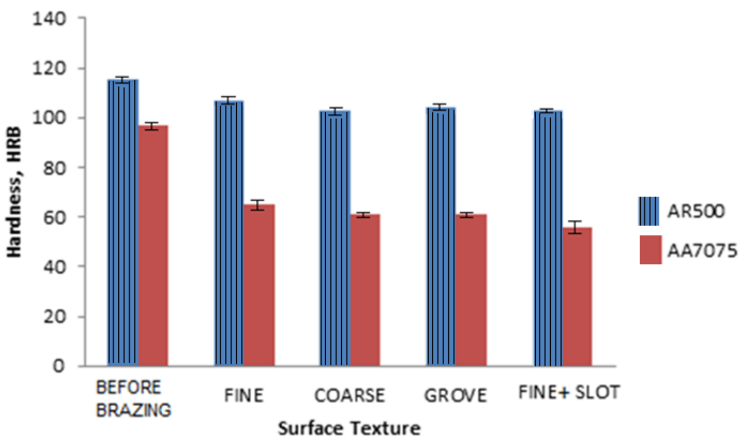


Figure 6: Hardness vs surface condition for AR500 and AA7075 specimen plates

**SEM and EDX analysis on AR500 steel and AA7075 aluminium alloy joint**

The results of the SEM and EDX analysis on AR500 steel and AA7075 aluminium alloy joint shown in Fig. 5. They show that the reaction layer or the IMC formed on the AR500/filler consisted of C, Cs, Al, Zn and O elements, whereas on the AA7075/filler metal the reaction layer and IMC consisted of Fe, Al, Zn and O elements. The formation IMC (Fe-Al) and oxide in the interface of filler metal and base metal caused the joint strength to reduce [13,14]. The EDX analysis in Fig. 7 shows that the IMC formed in the brazed joint consists of a Zn -rich compound. The side containing low zinc compound causes the IMC to decrease and increase the shear strength [17,18]. This condition causes the fracture occurred in the AA7075 aluminium alloy and filler interface where the IMC consists of a high zinc compound. The several spot area in EDX analysis was done, the results show the constant value of element and compound form in reaction layer and IMC area.

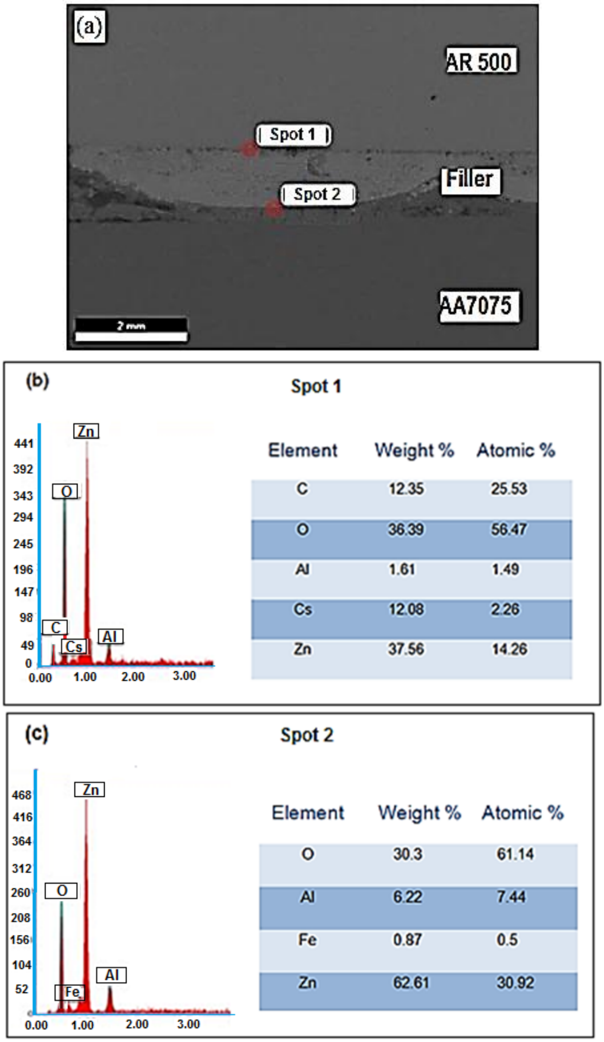


Figure 7: EDX analysis of torch-brazed joint between AR500 steel and AA7075 aluminium alloy: (a) SEM image of spot areas, (b) analysis of spot area 1 (reaction layer of AR500/filler), (c) analysis of spot area 2 (reaction layer of AA7075/filler)

## Fracture surface observation

Figure 8 shows images of the fracture surfaces after the shear test. In all specimens, fractures occurred at the metal and filler interface except for the joint with groove surface in which the joining was unsuccessful. The joint fracture of AR500/AA7075 joint occurred between AA7075 and filler interface for fine and coarse surface. While, for the joining on fine with slot surface, the fracture was occured on AR500 and filler interface. Observation on failure surfaces shows dark reaction layer formed on aluminium surface considered as oxide and entrapped flux [19]. This formation of layer caused the problem in the joining process by reducing capillary action between filler metal and base metal.

Observation in Fig. 8(b) and 8(c) shows, the amount of dark reaction layer was high and covered the aluminium surface on coarse and groves surface. This was inline with several studies, whereby, the increase in surface roughness of the base metal influenced the spreading of molten filler on it. According to the studies, asperities present on a rough and groves surface acted as barriers needed to be overcome by molten filler while spreading. [20,21]. This situation caused some flux to be entrapped and the filler metal prevented from spreading to whole joint area and reacting with aluminium surface. This situation caused the joint process to fail or led to decrease in the strength.

The joint in Fig. 8(a) and 8(d) shows only small quantity of reaction layer formed in the surface of aluminium, this situation influenced the better capillary action between filler metal and aluminium. This situation caused the joint strength to increase. The result shows, the join strength on fine surface with slot is better than fine surface. This is due to the fact that the slot hole on the surface helped the flowing out of flux and reduced the entrapped flux in joint surface. The filler metal brazed in the slot area also caused the joint strength increased. The joint at this surface condition was the highest joint strength acquired.

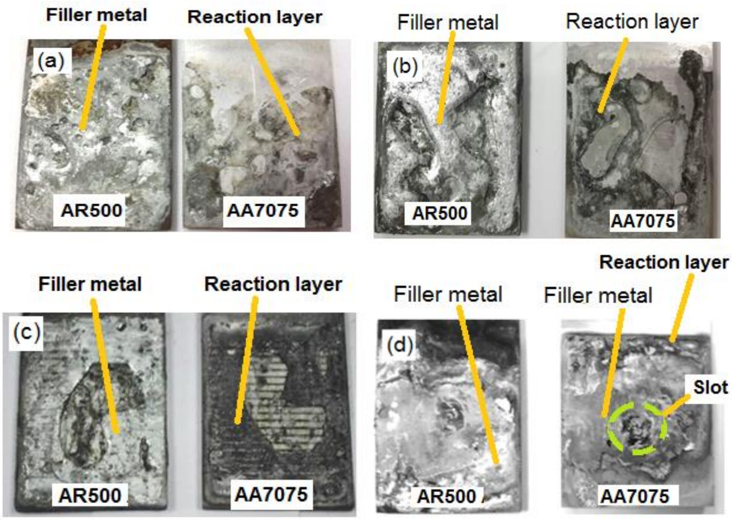


Figure 8: Fractured surfaces of AR500 steel and AA7075 brazed joint: (a) joint fracture surface for fine surface, (b) joint fracture surface for coarse surface, (c) joint fracture surface for groove surface, (d) joint fracture surface for slot surface.

## Conclusion

In this study, the joining of AR500 steel and AA7075 aluminium alloy using torch brazing method was successfully carried out. The effect of surface texture was investigated and the results obtained can be summarized as listed below:

1. The study shows that the joining on combination of fine surface and slot is better than fine, coarse and groove surface condition.

2. The highest shear load was 8010 N, which was obtained by brazing on combination of fine and slot surface.

3. The hardness of the aluminium base metal declined during the brazing process. The decrease in hardness was due to the increasing grain size of the aluminium base metal caused by annealing process.

4. Fractures occurred on the surface of the aluminium/filler. From visual observation, it would seem that the formation of a reaction

layer on aluminium surface can be considered as an oxide layer and entrapped flux which affected the capillary action of filler with aluminium surface and thus significantly reducing the strength of the joint.

## Acknowledgement

The authors wish to express their gratitude to Ministry of Higher Education Malaysia, Universiti Kebangsaan Malaysia and Universiti Pertahanan Nasional Malaysia for the research grant LRGS/2013/UPNM-UKM/04

## References

[1] T. Ogura, K. Ueda, Y. Saito and A. Hirose, "Nanoindentation measurement of interfacial reaction layers in 6000 series aluminum alloys and steel dissimilar metal joints with alloying elements", *Materials Transactions* 52(5), 979 -984 (2011).

[2] T. Murakami, K. Nakata, H.Tong and M. Ushio, "Disimillar metal joint of steel to aluminium by lap joint MIG arc", *Transaction JWRI* 32(1), 35-37 (2003).

[3] F. Zhang, H. P. Wang, C. Hicks, X. Yang, B. E. Carlson and Q. Zhou, "Experimental study of initial strengths and hydrothermal degradationof adhesive joints between thin aluminum and steel substrates", *International Journal of Adhesion and Adhesives* 43, 14–25 (2013).

[4] K. Kimapong and T. Watanabe, "Lap joint of A5083 aluminum alloy and SS400 steel by friction stir welding". *Materials Transactions* 46(4), 835-841 (2005).

[5] M. Kenji, N. Shigeyuki, S. Chika, S. H. Hiroshi and H. Akiro, "Dissimilar joining of aluminum alloy and steel by resistance spot welding", *SAE Int. J. Mater. Manf.* 2(1),58-67 (2009).

[6] K. Moria, Y. Abe and T. Kato, "Self-pierce riveting of multiple steel and aluminium alloy sheets", *Journal of Materials Processing Technology* 214(10), 2002–2008 (2014).

[7] J. Mucha and W. Witkowski, "The structure of strength of riveted joints determined in lap joint tensile shear test", *Acta Mechanica Et Automatica* 9(1), 44-49 (2015).

[8] D. Wei, X. Songbai, L. Jiyuan and W. Shuiqing, "Microstructure and properties of 6061 aluminum alloy brazing joint with Al-Si-Zn filler metal", *Materials Transactions* 53(9), 1638-1643 (2012)

[9] J. C. Feng, "High frequency induction contact reactive brazing of aluminum to stainless steel", *Transactions of Nonferrous Metals Society of China* 15, 11-15 (2005)

[10] J. Lin, N. Ma, Y. Lei and H. Murakawa, "Investigation of interface layer failure and shear strength of CMT brazed lap joints in dissimilar materials", *Transaction of JWRI* 40(1),101-107 (2011).

[11] T. Sakiyama, G. Murayama, Y. Naito, K. Saita, Y. Miyazaki, H. Oikawa and T. Nose, "Dissimilar metal joining technologies for steel sheet and aluminum alloy sheet in auto body", *Nippon Steel Technical Report* 103, 91-98 (2013).

[12] C.M. Chen and R. Kovacevic, "Joining of Al 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding", *International Journal of Machine Tools & Manufacture* 44, 1205–1214 (2004).

[13] N. Yamamoto, M. Takahashi, K. Ikuechi and M. Aritosh, "Interfacial layer in friction-bonded joint of low carbon steel to Al-Mg alloy (AA5083) and its influence on bond strength", *Materials Transactions* 45(2), 296-299 (2004).

[14] Q. Wang, X. Leng, T. Yang and J. Yan, "Effects of Fe−Al intermetallic compounds on interfacial bonding of clad materials", *Transactions of Nonferrous Metals Society of China* 24, 279-284 (2014).

[15] H . Okamoto, "The C-Fe (Carbon-Iron) system", *Journal of Phase Equilibria* 13(5), 543-565 (1992).

[16] A. D. Isadare, B. Aremo, M. O. Adeoye, O. J. Olawale and M. D. Shittuc, "Effect of heat treatment on some mechanical properties of 7075 aluminium alloy", *Materials Research* 16(1), 190-194 (2013).

[17] E. Siahaan, B. Soegijono and M. Hikam, "The effect of zinc composition in melting point and microstructure of lead-free solder", *International Journal of Basic & Applied Sciences* 14(2), 17-20 (2014).

[18] N. Hamada, T. Uesugi, Y. Takigawa and K. Higashi, "Effect of addition of small amount of zinc on microstructural evolution and thermal shock behavior in low-Ag SnAgCu solder joints during thermal cycling", *Materials Transactions* 54(5), 796-805 (2013)

[19] M. M. Schwart, *Brazing 2nd Edition.* (ASM International, USA, 2003), pp. 266-267.

[20] Y. Chen and J. Duh. "The effect of substrate surface roughness on the wettability of Sn-Bi solders", *Journal of Material Sciences: Materials in Electronics 11*, 279-283 (2000).

[21] H. Zhao, S. Elbel & P. S. Hrnjak. "Influence of surface morphology on wetting behaviors of liquid metal during aluminum heat exchanger fabrication", *Proceding 15th International Refrigeration and Air Conditioning Conference* at Purdue 2461, 1-8 (2014)