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INVESTIGATION ON BRAZING INTERFACE BONDING CHARACTERISTIC OF AA7075 AND AA6061 ALUMINUM ALLOY WITH AR500 STEEL USING Al-Si-Zn FILLER METAL

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Abstract

This paper presents the study on interface bonding characteristic of AA7075 and AA6061 aluminum alloy with AR500 steel by torch brazing bonding process. The weight reduction in vehicles component is required for energy saving in the automobile industry. Lightweight metals such as aluminum joining with other metal especially with steel, have started replaced steel parts in automobile structures but the effect of intermetallic compound (IMC) layer formation have limited the application in this industry due to strength matter. The torch brazing method was done to join the dissimilar metal with Al-Si-Zn base filler metal for the process. The shear strength of the AA6061/AR500 joint was higher than the AA7075/AR500 joint when the joining conditions were the same. The IMC formation was observed at the joint interface, and the joints mainly fractured at this region.

Keywords: Dissimilar metal, brazing, intermetallic compound, shear strength, filler metal

Abstrak

Kertas ini membentangkan kajian mengenai sifat-sifat cantuman antara muka antara aloi aluminium AA7075 dan AA6061 dengan keluli AR500 menggunakan kaedah tunu pateri keras. Pengurangan berat badan dalam komponen kenderaan adalah satu langkah berkesan untuk penjimatan tenaga dalam industri automotif. Logam ringan seperti aluminium atau pengabungan dengan logam yang lain terutamanya dengan keluli, telah mula menggantikan bahagian tertentu keluli dalam struktur kenderaan. Tetapi kesan pembentukan lapisan sebatian antara logam (IMC) telah menghadkan aplikasinya dalam industri ini kerana memberi kesan pada kekuatan. Kaedah tunu pateri keras dilakukan dengan mengunakan logam pengisi berasakan Al -Si –Zn sebagai cantuman logam yang berlainan tersebut. Kekuatan ricih bagi cantuman antara AA6061 / AR500 adalah lebih tinggi daripada cantuman antara AA7075 / AR500 dalam kaedah cantuman yang sama. Pemerhatian pembentukan lapisan sebatian antara logam (IMC) diantara cantuman dilakukan dan kegagalan cantuman keseluruhan berlaku pada cantuman logam tersebut.

Kata kunci: Logam berlainan, pateri keras, sebatian antara logam, kekuatan ricih, logam pengisi

1.0 INTRODUCTION

Joining dissimilar metal is very useful for many industries such as automotive, electronics and aerospace due to their attractive properties, such as low density, high conductivity, high specific strength and stiffness [1]. The industry researcher and academic researcher had proposed various methods to join dissimilar metal and materials together including fusion welding (e.g., resistance spot welding, resistance seam welding, arc welding), solid state bonding (e.g., explosive welding, friction welding, electromagnetic welding, roll bonding, diffusion bonding), brazing (e.g., burner brazing, arc brazing, laser brazing), mechanical joining (e.g., self-pierce riveting (SPR), flow drill screw (FDS), blind riveting), and adhesive bonding. In addition, joining methods using coating or inserts also have been studied [2].

In automotive industry, joining of dissimilar metal between aluminum and steel is used widely due to their properties and cost. The major attractive of this joining method is reduction of weight in product. The common method to join aluminum and steel is fusion welding techniques. However, aluminum and steel have large differences and serious influence in their properties, especially in melting point, heat conductivity and coefficient of linear expansion [3, 4]. So, the welding between dissimilar metal with large difference of melting point is difficult such as aluminum/titanium and aluminum/steel. In other matter the joining method that requires high temperatures such as aluminum and steel joint formed a brittle layer of intermetallic compound (IMC) at the joint interface and cause the joining metal difficulty to obtain the desired joint strength [2]. The joint of brazing and fusion- brazing are suitable because of their advantages such as little IMC formation, small distortion and high dimensional accuracy. The joint of brazing can be improved by studying their weak points such as joint format, producing efficiency or mechanical properties [5]. The formation of a brittle aluminum-rich Al-Fe intermetallic compound (IMC) layer are common problem at the bonded interface in joining aluminum and steel and it causes the low strength in aluminum and steel dissimilar metal joints [6]. The tough oxide layer on the aluminum alloy and steel surface and the ability reduce the formation intermetallic compound (IMC) thickness are the major issues to be studied in joining of aluminum alloys and steel [7].

The good joint result between two metals by brazing method also influences by suitable filler metal usage. The low melting temperature filler is better for joining two metals with high difference in melting temperature and also for metal with high formation of oxide layer due to affected by high temperature reaction. By referring to this situation, Zn-Al-Si based filler metals is suitable for this joint because of the low melting point and best price

This paper investigates the joint properties and characteristics of torch brazing joining between AR500 steel with AA6061 and AA7075 aluminum alloy. Particular emphasis and study concentrated on shear strength, intermetallic compound layer (IMC) and interface microstructures. This study reflects the considerable demand and importance for industrial application of such dissimilar joints between aluminum and steel, particularly in heavy duty commercial transportation industry.

2.0 MATERIALS AND EXPERIMENTALS STUDIES

Materials for this study are AA7075, AA6061 aluminum alloy and AR500 high strength steel. The chemical compositions of the materials are listed in Table 1,2 and 3 respectively

Table 1 Composition of AA7075 aluminum alloy (wt.%)

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

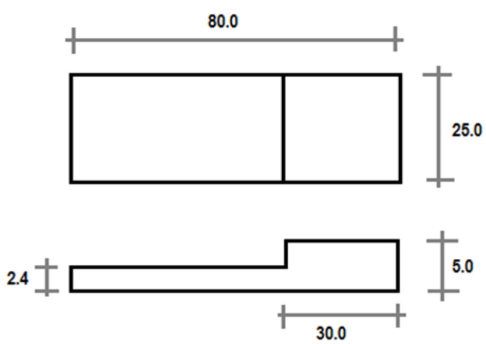
Table 2 Composition of AA6061 aluminum alloy (wt.%)

Si	Fe	Cu	Mn	Mg
0.42	0.26	0.13	0.04	0.64
Cr	Zn	Ti	Zr	Al
0.12	0.03	0.03	<0.001	Balance

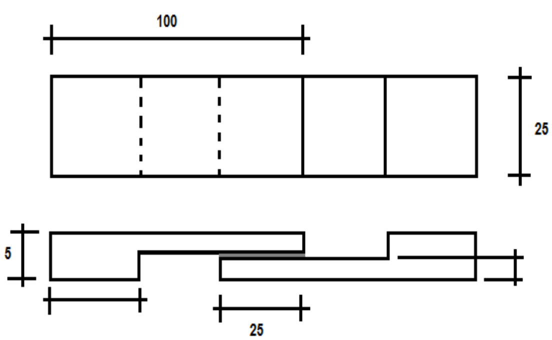
Table 3 Composition of AR500 high strength steel (wt.%)

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

Materials supplied as plate were cut to lengths suitable for shear strength testing. Both steel and aluminum samples fabricated by wire cut machine to 80 mm in length and 25 mm in width with 2.4 mm thickness as shown in Figure1. The surfaces oxide film of both plate surfaces was removed by 180 grit silicon carbide paper. Joint between the materials was produced by torch brazing process with Al-Si-Zn base filler metal as joining mechanism. The chemical compositions of the filler metal are shown in Table 4. The filler metal with size 3.5mm x 25mm x 0.05mm are arranged to fill the surface of base metal. The AA7075 and AA6061 aluminum alloy was overlapped by the high strength steel plate with filler metal in the between as shown in Figure 1. Torch brazing process was conducted with flame produced by butane gas and heated on the surface of steel until the metal filler is melt as shown in Figure 2. The brazing were conducted with three different flame time (1,2 and 5 minute).



(a) Dimension of steel and aluminum specimen



(b) Overlapped dimension of steel and aluminum for joint process

Figure 1 Specimen preparation for the joint process

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

Zn	Si	Al
>14.40	14.84	53.0

(a) Schematic illustrations torch brazing process

(b) Specimen produced after brazing process

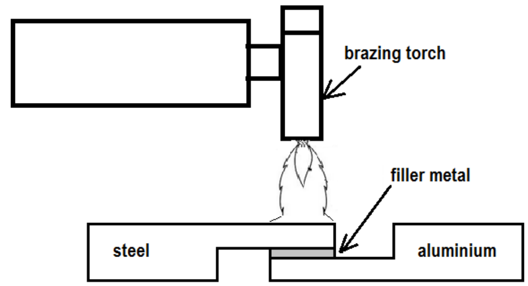


Figure 2 Torch brazing process view

The joint strength evaluated by the shear strength test. Shear tests carried out in an universal testing machine with a load cell (model Zwick Roell Z100). The cross section of the brazed joint was observed using the high resolution microscope (model Nikon Eclipse MA 200). The surface fracture was also observed using stereo microscope (model Olympus SZ61).

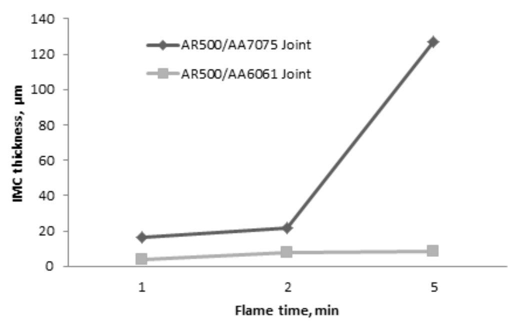
3.0 RESULT AND DISCUSSION

3.1 Intermetallic Compound Layer Formation

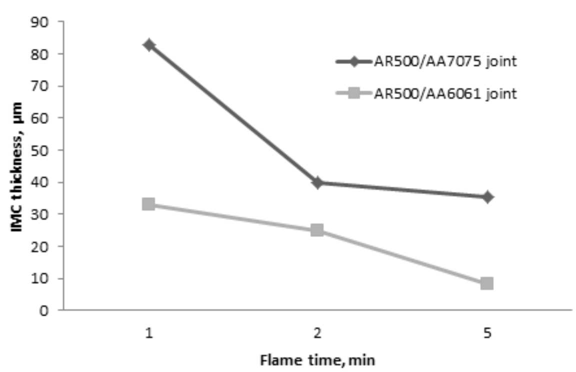
Intermetallic compound, IMC is known to affect the crack sensitivity, ductility and strength of the joint. A thicker layer of this will result in brittle joints and reduce the strength and hardness [8]. Thickness of IMC was observed between AR500 steel /filler metal, AA7075 aluminum alloy/filler metal and AA6061/filler metal. Figure 3 showed the thickness of IMCs formed between AR500, AA7075 and AA6061 with filler metal in three different flame times (1, 2 and 5 minutes). In generally, the result of IMC formation and thickness are increased due to increase of flame time and brazing temperature. Table 5 shows the temperature recorded at 1, 2 and 3 minutes flame time for both of joint type. The investigation showed the formation and thickness of IMC between AR500 steel and filler metal increased with increasing of flame time in both type of joints. In reaction of aluminum and filler, the IMC thickness between AA7075 and filler metal decreases with increasing of flame time but IMC formation between AA6061 and filler showed increment. The high resolution microscope image for IMC's formation between base metal and filler metal of both type of joint with different time of flame are shown in Fig. 4-6. The current progress study shown, the formation of IMC is consisting of Al-Zn-O phase and Fe-Al phase. The phase changed by increasing of temperature and flame time.

Table 5 Temperature recorded at flame time during brazing process

MATERIAL	FLAME TIME (min)	TEMPERATURE (^{0} C)
AR500 + AA 7075	1	477
	2	580
	5	669
AR500 + AA 6061	1	482
	2	546
	5	660

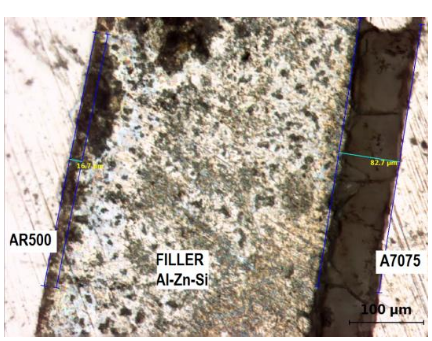


(a) IMC thickness between AR500 steel/filler metal in both joint

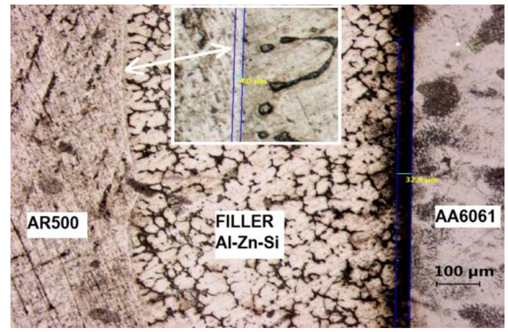


(b) IMC thickness between AA7075/filler metal and AA6061/filler metal

Figure 3 Effect of time on thickness of the intermetallic compound layer

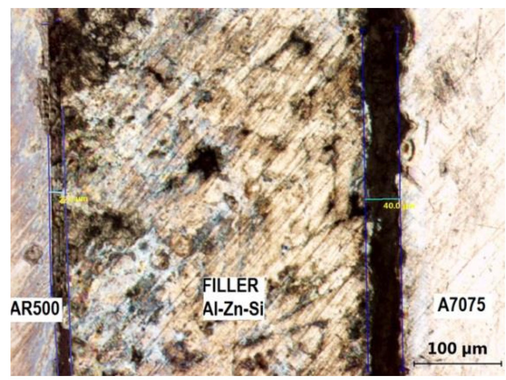


(a) IMC layer between AR500/ filler metal and AA7075/filler metal for AR500/AA7075 joint

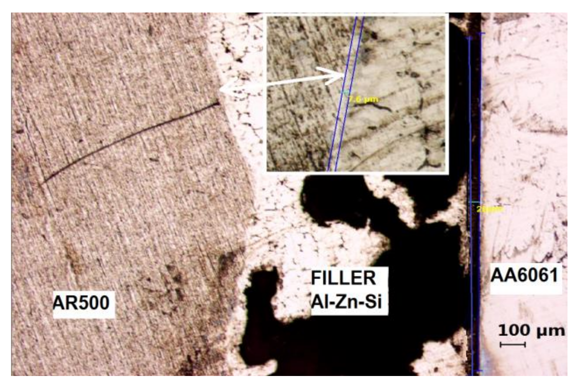


(b) IMC layer between AR500/filler metal and AA6061/filler metal for AR500/AA6061 joint

Figure 4 IMC layer formation on torch brazing joint between AR500 /AA7075 and AR500/AA6061 for flame time 1 minute

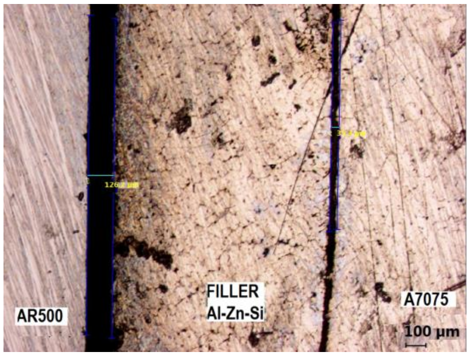


(a) IMC layer between AR500/ filler metal and AA7075/filler metal for AR500/AA7075 joint

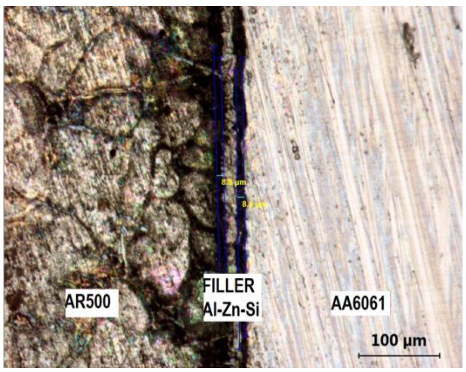


(b) IMC layer between AR500/filler metal and AA6061/filler metal for AR500/AA6061 joint

Figure 5 IMC layer formation on torch brazing joint between AR500 /AA7075 and AR500/AA6061 for flame time 2 minute



(a) IMC layer between AR500/ filler metal and AA7075/filler metal for AR500/AA7075 joint



(b) IMC layer between AR500/filler metal and AA6061/filler metal for AR500/AA6061 joint

Figure 6 IMC layer formation on torch brazing joint between AR500 steel and AA7075 aluminum alloy for 5 minutes flame time.

3.2 Mechanical Properties

Figure 7 showed the shear load of the brazed joint of AR500/AA7075 and AR500/AA6061 with the Zn-Al filler metal. Shear strength achieved in the range of 1340 – 6460 N for joint between AR500 steel and AA7075 aluminum alloy, whereas for joining of AR500 steel and AA7075 aluminum alloy showed the shear strength range of above 9690 – below 1000N. The study showed that the shear load decreased with increasing the flame time. For the joint form at 2 and 5 minutes flame time showed the joint shear load decreased significantly from 1 minute flamed time in both type of joint. The joint failures showed differences between these two joint types. In joint between AR500/AA7075, the shear failure occurred at braze joint for all condition of brazing process and for joint between AR500/AA6061, the failure occurred at joint when brazing process done at flame time 2.5 minutes but the failure occurred at AA6061 plate for brazing done in 1 minute flame time.

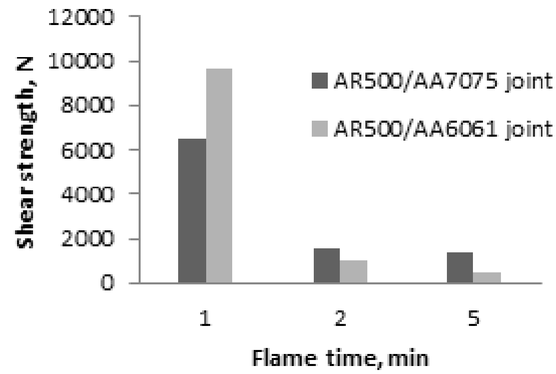
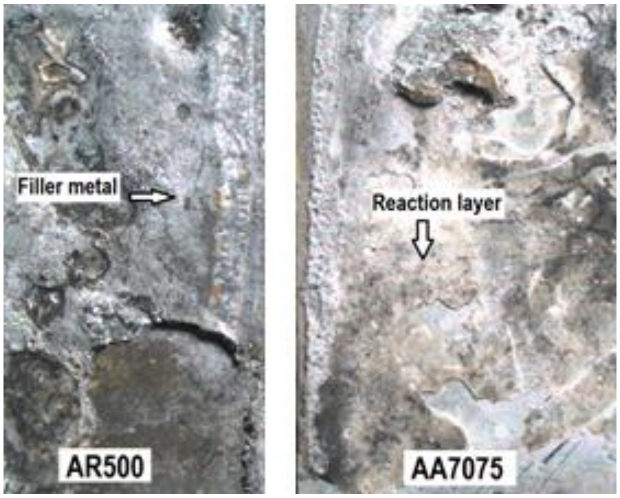


Figure 7 Shear strength vs flame time for torch brazing joint between AR500 /AA7075 and AR500/AA6061

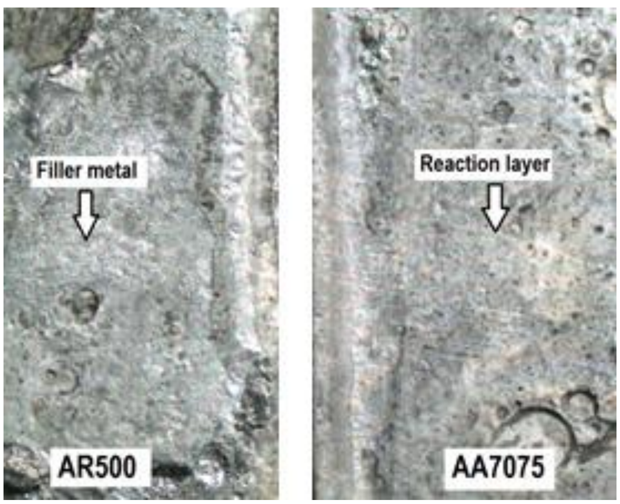
3.3 Fracture Surface Observation

Figure 8-9 showed stereo microscope images of the fractured surfaces after the shear test. In all specimens, fracture occurred in the joint interface between filler and base metal except for joint of AR500/AA6061 at flame time 1 minute, where the fracture occurred at AA6061 plate. The joint fracture of AR500/AA7075 joint occurred at AA7075/filler metal for flame time at 1and 2 minute, where the filler metal was detached from AA7075 aluminum alloy base metal. By increasing the flame time, the brittleness and thickness of IMC layer also increased. For joint prepared at 5 minute flame time, the joint fractured between AR500 steel and filler metal. The observation showed, the filler metal attached at AA7075 aluminum alloy and detached from AR500 steel surface.

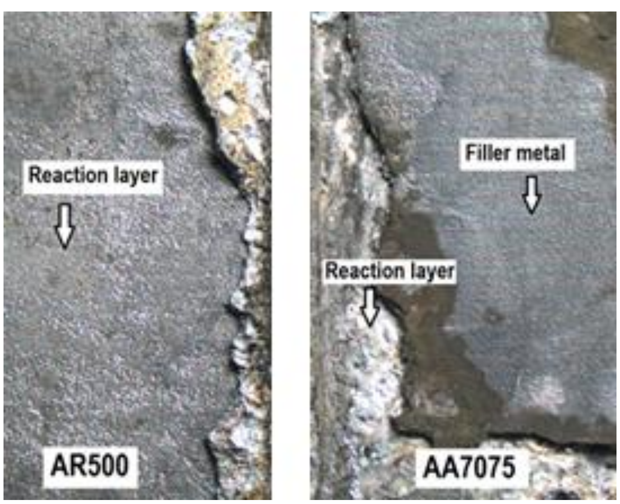
For the joint of AR500/AA6061 all the fracture occurred at joint between AA6061/filler metal and the filler metal are detached from AR500. This condition showed that with increasing the brazing temperature and time, the weak bonding increased by increasing of IMC thickness. At the same time reaction layer also form between base metal and filler metal joint, whereas it considered as oxide layer formation during heating or flame process [9]. The formation of reaction layer will reduce the diffusion of filler metal to base metal and also reduce the strength of joint [10].



(a) Joint fracture surface for flame time 1 minute

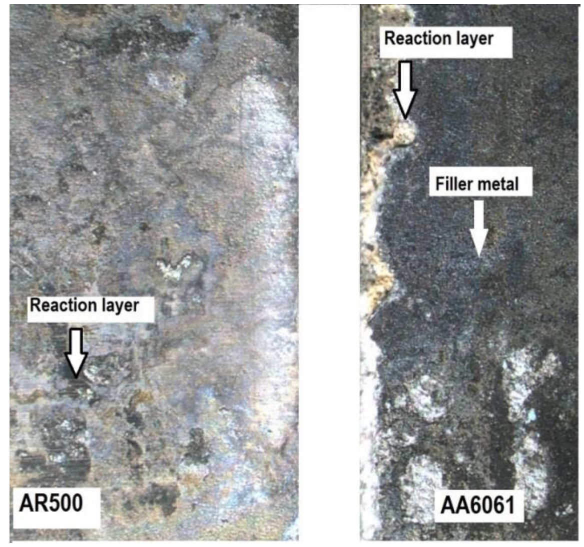


(b) Joint fracture surface for flame time 2 minute

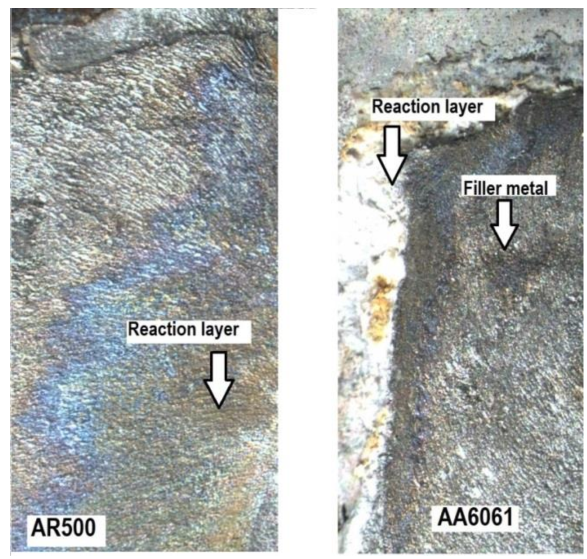


(c) Joint fracture surface for flame time 5 minute

Figure 8 Fractured surfaces of AR500 steel and AA7075 brazing joint



(a) Joint fracture surface for 2 minutes flame time



(b) Joint fracture surface for 5 minutes flame

Figure 9 Fractured surfaces of AR500 steel and AA 6061 brazing joint

4.0 CONCLUSSON

Joining of AR500 steel between AA7075 and AA6061 aluminum alloy using torch brazing has been done successfully. Effect of brazing time was investigated and the results concluded that the formation of IMC between base metal/filler metal of AR500/AA7075 joint is higher than AR500/AA6061 joint. The IMC formation between steel/filler increased with increasing of flame time and at aluminum/filler joint side, the IMC reduced with increasing the flame time. The highest shear load obtained at flame time of 1 minute for both joint of AR500/AA7075 and AR500/AA6061. The result showed AR500/AA6061 joint is higher than AR500/AA7075. In overall, the result of shear strength shown that the interface joint strength decreased with increasing flame time and brazing temperature. Fractured surface showed the failure occurred at the joint of base metal/filler with high of IMC thickness. The visual observation showed the formation of reaction layer between base metal and filler metal which considered as oxide layer. The oxide layer was affected by the absorption of filler metal to capillary in base metal which significantly influenced the strength of joint.

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