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Microstructure analysis and mechanical properties of dissimilar AA6061-AA7075 laser brazing with prefixed ER5356 filler

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Abstract. Laser brazing uses a filler metal for joining without melting the base material. This process is a versatile joining technique for a wide range of applications including automotive, aerospace, and medical field because of the ability in joining dissimilar metal and resulted good quality in surface's joint. This study consists of aluminium alloy of AA6061 and AA7075 as a base material with aluminium based ER5356 as a wire filler. Laser brazing was performed using 1.2 kW of laser power, while wire filler was let to be prefixed without using the wire feeder because of using the existing laser welding machine. Microstructure of the joints were studied using 3D measuring laser microscope OLS5000. Besides that, mechanical properties of the joints were evaluated by performing tensile test and hardness test. Microstructures of the brazed joints show the differences in the grain structure followed by the difference's hardness value on each region. The brazed joint shows the average ultimate tensile strength reached 154.71 MPa which was 50% of joint efficiency. However, there is porosities at the fracture surface of the joint.

Keywords: Laser Brazing; Aluminium Alloy; Dissimilar Metal; Joining Process; Automotive.

1. Introduction

In the last few years, significant development has been made in the automotive sector, particularly in the manufacturing of dissimilar thin sheet metals, especially when joining the body part of a car [1]. The application of joining dissimilar thin sheet metals is typically found as an alternative way to weight reduction in automotive, aircraft and electronic devices [2]. There are many types of joining method in manufacturing processes such as solder, adhesive, bolt, welding and brazing technique [3]. In all types of joining, brazing gives a better joining appearance, especially in certain parts of the body car assembles. It is one of the techniques that have been applied crucially towards metal in manufacturing industries for joint goods. As a promising method of joining thin sheets of various materials, laser brazing has been explored.

Nowadays, luxurious brand in automotive industries has started to use this latest technology to produce a smooth surface joint and therefore is often used in the outer car skin areas when the joints must be invisible to the eye. Brazing is a method of joining metals in which base metals are joined using a braze filler metal without exceeding the base metal's melting point [4]. Therefore, minimal thermal distortion and high precision heat input can be achieved through this process [5]. Brazing is commonly used for joining dissimilar metal including different aluminium alloy. Laser brazing has several advantages compared to conventional welding and laser welding which is minimal heat affected zone, higher degree of mechanical stability and the high aesthetic quality of the joint.

For laser brazing process, only filler metal will be melted and almost not affected the base materials [6]. This process aims to minimize from mixing of the two materials. Meanwhile for laser welding, it is a mechanism that induces material coalescence with the heat obtained from the intense coherent light beam that affects the surfaces to be joined [7]. In certain part of assembling a car body, laser brazing will be more suitable to be applied compared to laser welding as the joining need to be smoother and better appearance such as trunk lid, roof panel and side panel. Technically, both processes use the same power source which is fiber laser as a heat source. In a fiber laser, the laser light is produced in an active fiber and directed through a flexible delivery fiber that acts as a "light guide" to the work piece [8]. Therefore, with some improvement and modification, laser brazing could be run from the existing conventional laser welding machine. Generally, for laser brazing machine, wire feeder was attached to the laser head and the laser beam will focus on filler to melt. Apart from that, scanning speed will be proportional to the wire feed rate. However, for this recent study, conventional laser welding setup will be used as this method can reduce cost and easy to setup. Therefore, prefixed wire filler will be placed directly towards the sheet metal that need to be joined.

During the laser brazing process, there are a few input parameters that determine the brazing quality, which was defined in terms of properties such as mechanical properties and filler spreadability [9]. One of the parameters that need to be highlighted is the wire filler position during the process. With the proper controlled for those parameters, microstructure, and mechanical properties of the joint could be improved [10]. Generally, the microstructure will be related to the reaction of filler metal towards base metal. This is because the growth of the reaction layer will affect the tensile strength and hardness of the joint.

Commonly, joint strength and hardness of the joint can be determined and will be analysed through a tensile test and Vickers hardness test. Meanwhile, microstructure and fracture surface will be analysed through 3D laser measuring and the optical microscope, respectively. The reason for the difference in microstructure might be due to the different experimental set up used. The experimental set up of laser brazing process towards existence laser welding machine is mainly studied. Thus, the case study for this research is to analyse the joint that will be brazed with the prefixed wire filler set up.

2. Materials and methods

2.1. Materials used

For this study, aluminium alloy, AA6061-T6 and AA7075-T6 with thickness of 2 mm will be used as a base material. Meanwhile, ER5356 was selected as a wire filler with 2 mm diameter. The filler wire ER5356 is rich in Mg element, which has good thermal cracking resistance and high strength [11]. table 1 shows the physical and mechanical properties for both base materials.

Table 1. Physical and mechanical properties of base materials.

Alloy	Melting point (℃)	Vickers hardness (HV)	Tensile strength (MPa)
AA6061-T6	652	107	310
AA7075-T6	635	175	572

Table 2. Chemical composition for alloys used.

Material	Chemical composition (wt.%)							
AA6061-T6	Al	Mg	Si	Cr	Mn	Ti	Cu	Zn
	95.8 -	0.8 -	0.4 -	0.04 -	Max	Max	0.15 -	Max
	98.6	1.2	0.8	0.35	0.15	0.15	0.4	0.25
AA7075-T6	Al	Mg	Si	Cr	Mn	Ti	Cu	Zn
	87.1 -	2.1 -	Max	0.18 -	Max	Max	1.20 –	5.1 -
	91.4	2.9	0.40	0.28	0.30	0.20	2.0	6.1
ER5356	Si	Fe	Co	Mg	Zi	Ti	Cr	Al
	0.25	0.40	0.10	4.60	0.10	0.15	0.15	Bal

2.2. Experimental setup
The schematic diagram for laser brazing experimental set up was shown in figure 1. This process was performed using Ytterbium Fiber laser (IPG YLS 2000) with continue wave mode operation and capable of delivering maximum 2kW output power. The laser beam is perpendicular 90º to the joint and will move horizontally.

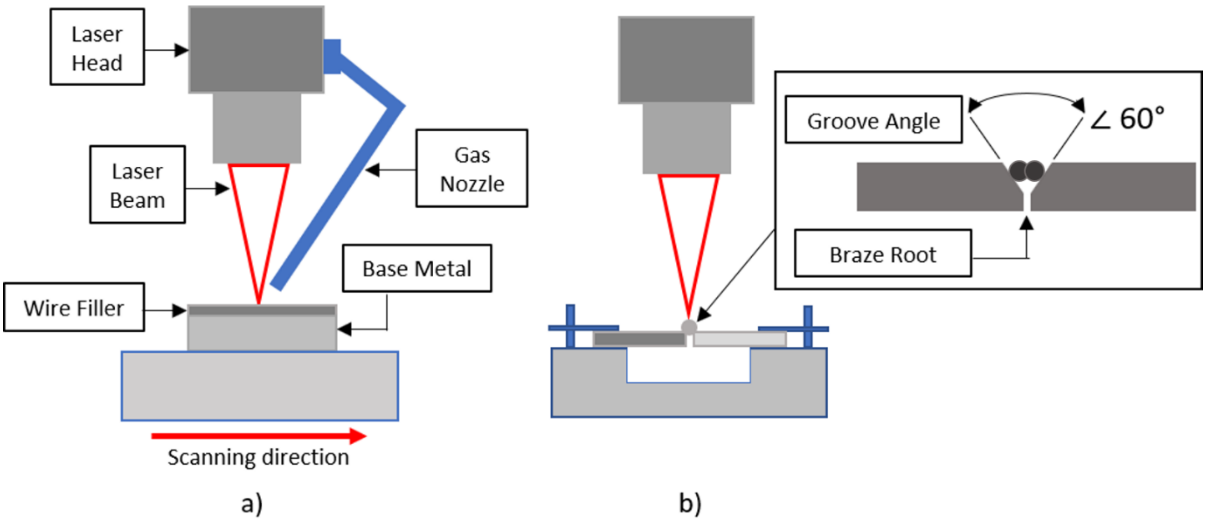

Figure 1. Schematic diagram of laser brazing setup (a) front view (b) side view.

2.3. Specimen preparation and experimental procedure
In this present study, base materials were mechanically cut into small size which is 150 x 100 mm. The plate will be grinded with 320 grit sandpaper and cleaned with acetone to remove any burr and residual oil during cutting section. After that, the edge of the plate that will be joint need to be shape a groove to let the filler melting through the joint more efficient. Then, two pieces of 1 mm diameter wire filler has been combined and will be placed manually at the centre of the groove before the experiment start. The plate will be brazed in butt joint configuration. Argon gas was the type of shielding gas used in this experiment in order to prevent oxidation towards the welded aluminium alloy [12]. Argon gas provides an inert atmosphere in which welded metals will not oxidise. Laser brazing parameters applied in this experiment are listed in table 3.

Table 3. Laser brazing process parameter.

Process parameter	Laser brazing
Scanning speed (mm/min)	1200
Argon Flow rate(L/min)	10
Laser Power (kW)	1.3
Defocused length (mm)	+5

After the process was done, a successful joint specimen will be trimmed into ASTM-E8 standard by EDM wire cut machine. Then, the sample will proceed to tensile test and fracture analysis. In addition, cross section was selected at the centre of the joint region will apply on microstructure analysis and micro-hardness test as shown in figure 2.

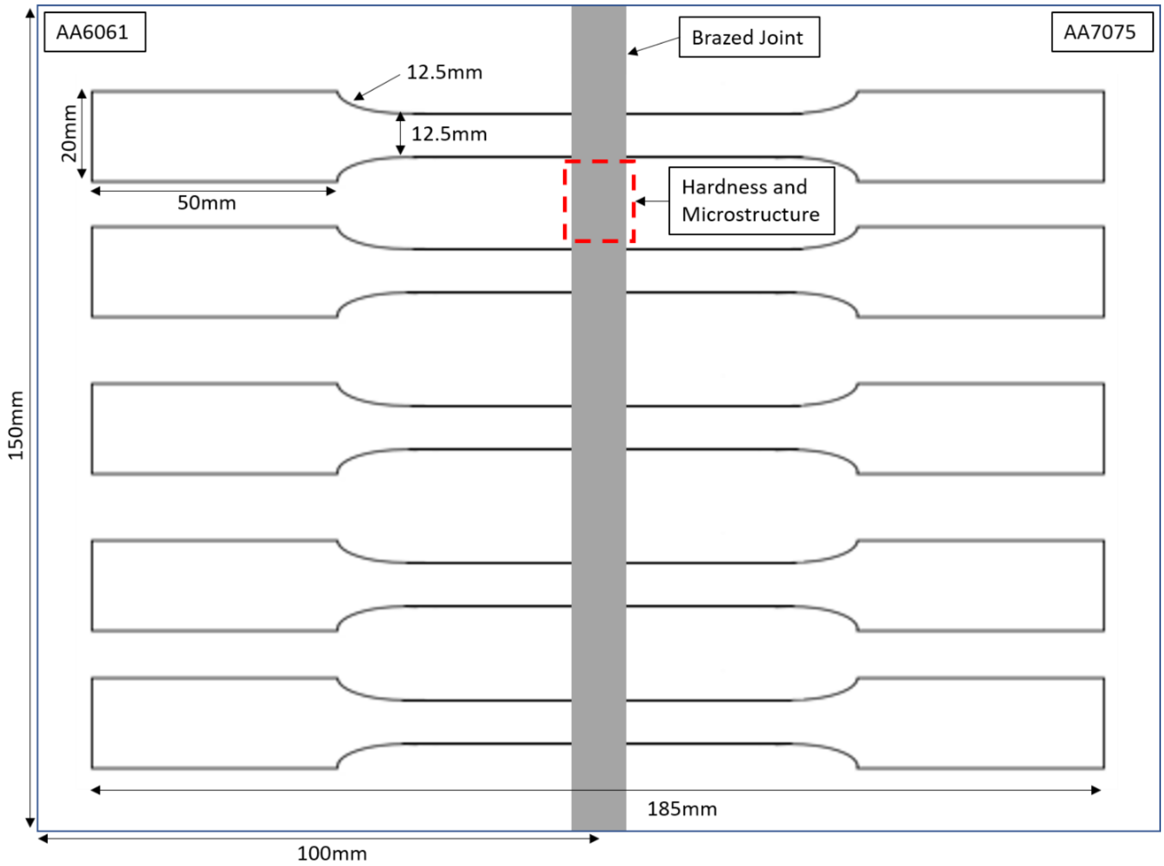

Figure 2. Sample for analysis.

The cross-section of the joints was mounted and chemically etched with Keller's Reagent (2.5 ml HNO_3 + 1.5 ml HCl + 1 ml HF + 95 ml water) for about 15 seconds. The etched specimens were then examined for their grain size of microstructural structure using 3D Measuring Laser Microscope OLS5000. Hardness measurements were carried at the cross-section of laser weld-brazed joints using a Vickers hardness machine (MMT X7) with a load of 500 gf and dwell time of 15 s through ASTM E-384 standard. Besides that, tensile test and fracture analysis were performed by using INSTRON Universal Testing Machine and MEIJI TECHNO EM2-13TR optical microscope, respectively.

3. Results and discussion

3.1 Microstructure of the cross-section joint area

The microstructure from the cross-section brazed joint was examined under the 3D measuring laser microscope with the scale of 300µm while the macrostructure was observed by using optical microscope at applied power laser of 1300 W and scan speed of 1200 mm/min. Typically, the brazed joint could be divided into five phases region: Base Metal (BM) AA6061, Interface (IF) AA6061, Filler Zone (FZ) ER5356, IF AA7075 and BM AA7075 as can be shown in figure 3.

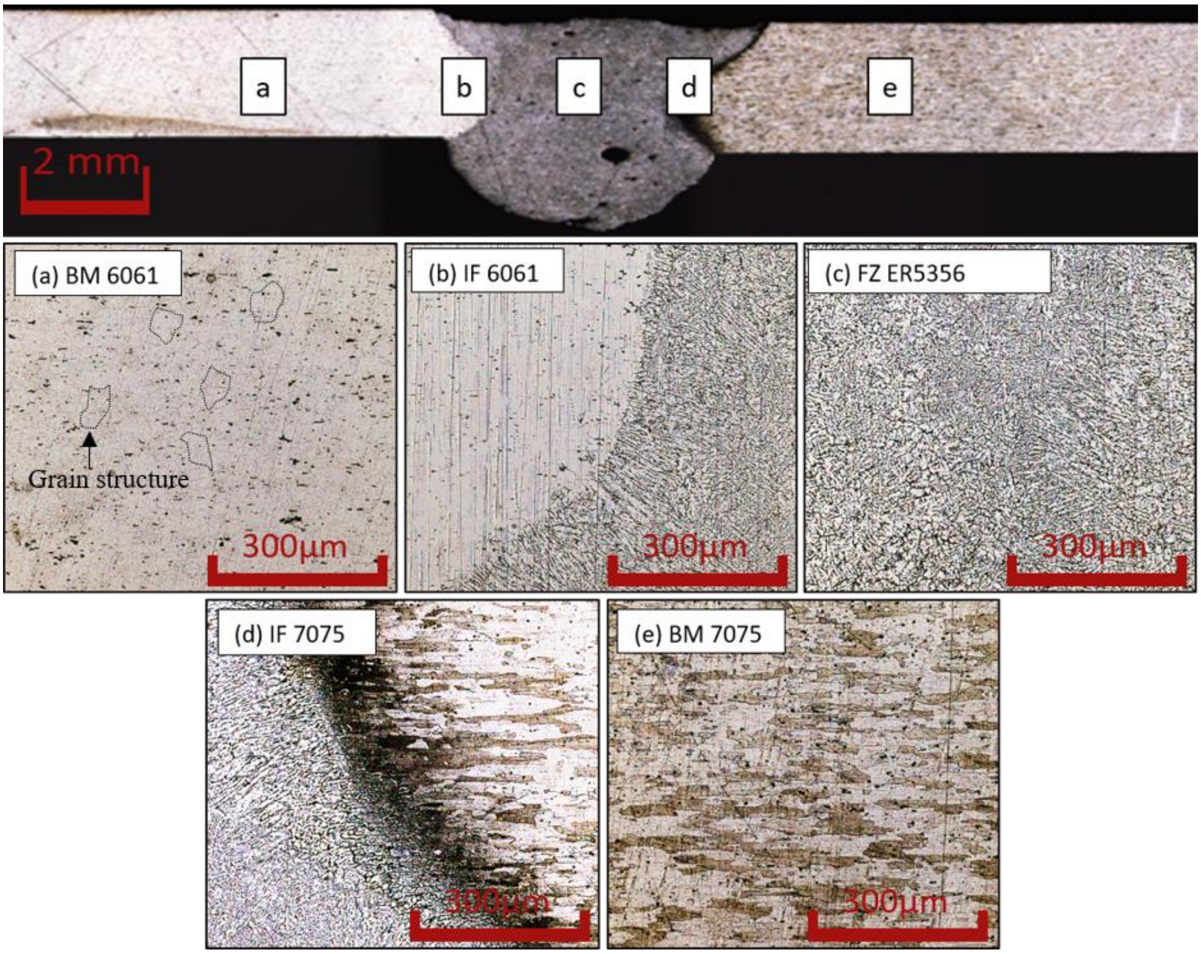

Figure 3. Brazed joint and microstructure of the joint: (a) BM AA6061, (b) IF AA6061, (c) FZ ER5356, (d) IF AA7075, (e) BM AA7075.

Based on the figure 3, grain structure for every region are different because of its own chemical composition for each material. Besides that, figure 3(b), shows clearer observation especially on the reaction layer between the brazed alloy than the reaction layer in figure 3(d). The results shown that the filler wire (ER5356) is more compatible towards AA7075 than AA6061 based on their similarity in chemical composition. Even though the reactions showed up are good but the reaction itself can also bring defect toward the material such as increasing their porosity and obviously will reduce the tensile strength of the materials. For the grain size of the base material, there are two differences which are the size between the base material far from the joint (unaffected) region and base material near the joint (interface) region since this region was affected by heat from laser beam during the laser brazing process [13]. For region AA7075, the average region for interface and unaffected base material were 90.60 µm and 148.27 µm, respectively. Meanwhile, the average grain for region

AA6061 interface and AA6061 BM were resulted 81.25 µm and 101.38 µm. Last but foremost, a very fine grain structure was observed in the filler region as shown in figure 3(c). The average grain size in this region ranged between 10 to 20 µm. Subsequently, the changes in grain size will affect the mechanical properties of the joint [14]. The grain sizes were measured by its diameter and the average was calculated and tabulated in table 3.

Table 4. Average grain size for the brazed region.

Brazed region	Average Grain Size (µm)	Std. Deviation
BM AA6061	101.38	4.88
IF AA6061	81.25	9.08
FZ ER5356	15.37	2.70
IF AA7075	90.60	7.84
BM AA7075	148.27	7.38

3.2. Micro-hardness of the cross-section brazed joint

The analysis will be conducted by using Vickers hardness test in order to differentiate the laser-brazed region and the unaffected base material for justifying the hardness distribution along the cross-section area. The same parameters were used in all the regions, which is using load of 500 gf and 15 seconds of dwell time. Indentations were to be carried out in every region for identify the average microhardness value. The distance between the indentation was varied fixed at 0.5mm in each region.

From the figure 4, it shows that the filler region (ER5356) has the lowest value of Vickers hardness compare to another region which is calculated to be 69.00 HV. This is due to the direct heat into that region and chemical composition that also can give affect towards the microhardness of the material [15]. In addition, the results show a huge difference with the hardness values between an unaffected base metal and the interface of base metal. Therefore, this is due to the affection of heat from the brazed joint area. From the result, the hypothesis that supporting the evidence which said that the finer grain size of microstructure will increasing the hardness value of the brazed joint is not valid for this study.

3.3. Tensile strength

Table 5 shows the tensile strength result for the brazed joint specimen. The highest tensile strength of the brazed sample was 178.56 MPa while the lowest strength was resulted at 132.52 MPa. All the samples show in different strength even though there were all in same specimen since this method uses a prefixed filler wire setup. Therefore, the inconsistency of heating the wire filler occurs during this process.

$$\text{Welding efficiency (\%)} = \frac{UTS\ of\ welded\ sample}{UTS\ of\ base\ metal} \quad (1)$$

The average UTS of the brazed sample achieved 154.71 MPa that is equivalent to 50% of the joint efficiency. The UTS of AA6061 was 310 MPa as mentioned above. Moreover, standard deviation for this tensile result was 19.38MPa, approximately 12.52%, indicating that the tensile values along the brazed line are consistent. Figure 5 shows the fracture surface of the brazed joint. All the tensile samples having a fracture at the brazed area, which show that the brazed joint was not strong enough.

Table 5. Tensile strength result for the laser-brazed joint.

Samples	Ultimate Tensile Strength (MPa)
1	144.09
2	132.52
3	147.16
4	178.56
5	171.20
Average, UTS	154.71
Std. Deviation	19.38(12.52%)
Joint efficiency (%)	50%

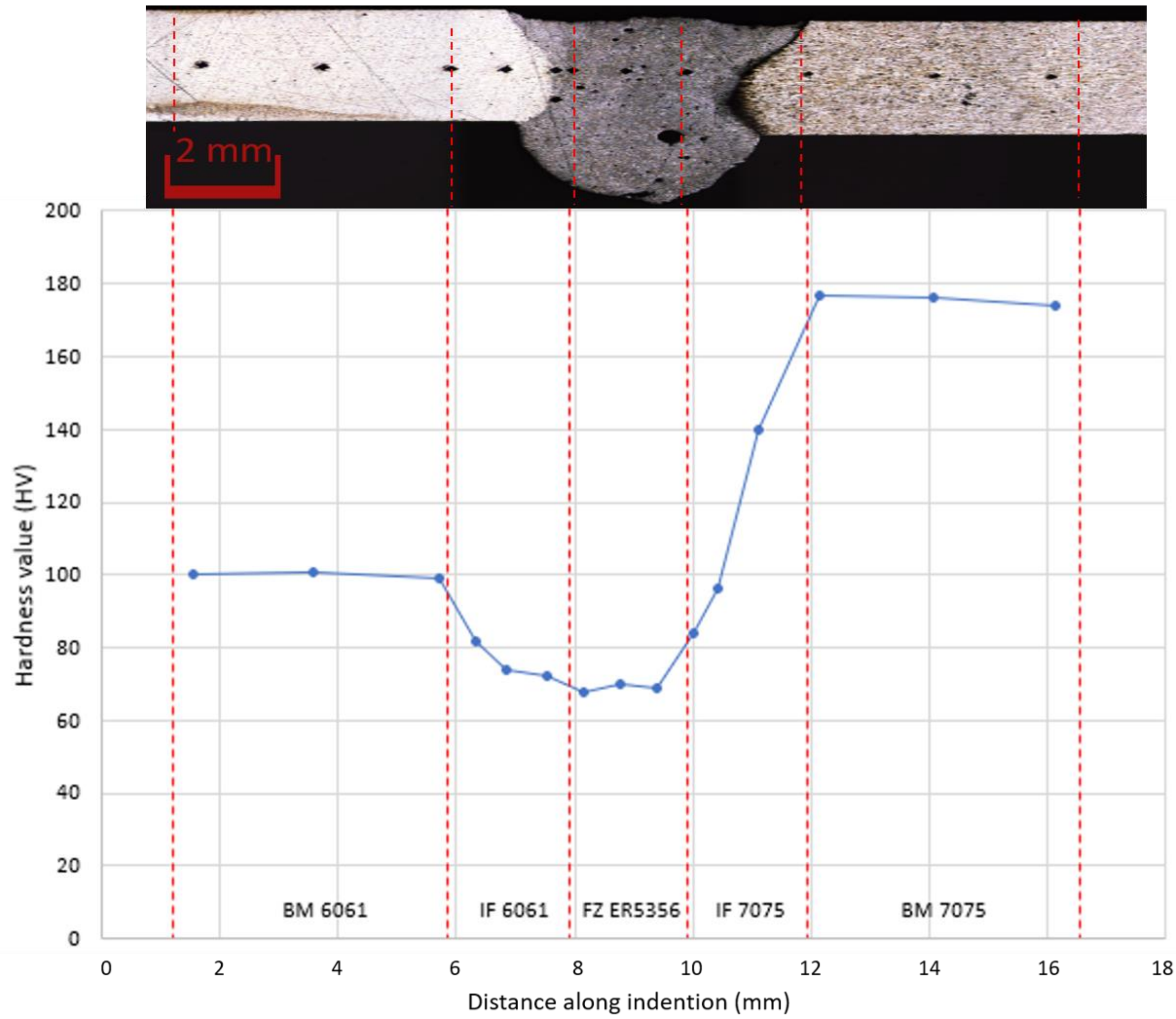

Figure 4. Graph of microhardness for all brazed region.

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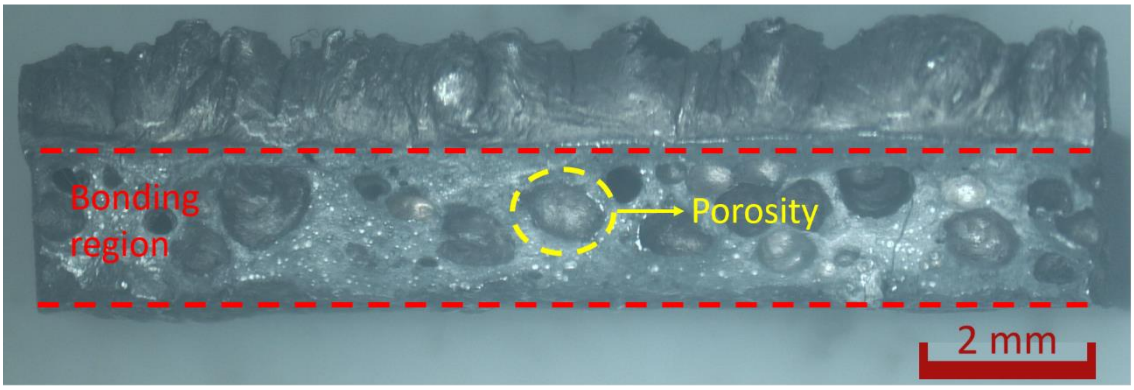

Figure 5. Fracture surface of the brazed joint.

Besides, there were several large porosities along the fracture surface which will affect the mechanical properties of the joint. This defect shows that the laser beam was not uniformly heating during the process. Apart from that, this makes the wire filler not consistently melt and affected the solidification process.

4. Conclusion

As the experimental work has been done successfully, which is laser brazing process for dissimilar metal butt joint with prefixed wire filler mechanism, some conclusion has been stated:

a) Laser beam scanning changed the microstructure at the filler and interface region. Besides, there is a difference in size grain at the interface region compare to the base metal region since the filler reaction occurs in the area.
b) The Vickers hardness value (HV) at the filler region resulted in the lowest hardness value, which is 69.00 HV. This is due to the direct heat into that region and chemical composition also can give an affect towards the microhardness of the material.
c) All the tensile samples were fractured at the centre of the joint area. The average UTS of the brazed joint was 154.71 MPa which was 50% of the joint efficiency.

Overall, the result was quite good since this experiment was still at the beginning of the research, and the wire filler was set up in prefixed condition as mentioned early. This process has been successfully done by conducting it on the existence of laser welding machine. By further modification and improvement on the experimental setup, the better result will be gained in the future. It can be concluded that the position and feed rate of the wire filler plays a significant role in laser brazing process.

Acknowledgements

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