Mechanical Behaviour Investigation Of Aluminium Alloy Tailor Welded Blank Developed By Using Friction Stir Welding Technique

Agus Dwi Anggono, Bibit Sugito, Agus Hariyanto, Subroto and Sarjito
Department of Mechanical Engineering, Universitas Muhammadiyah Surakarta, Jl. Ahmad Yani, PO. BOX I Pabelan, Surakarta 57162 Indonesia.

Email: agus.d.anggono@ums.ac.id

Abstract. The objective on the research was to investigate the mechanical properties and microstructure of tailor welded blank (TWB) made from AA6061-T6 and AA1100 using friction stir welding (FSW) process. Due to the dissimilar mechanical properties of the two aluminium alloys, microhardness test was conducted to measure the hardness distribution across the weld nugget. The mixing of two distinct materials was influenced by tool rotation speed. Therefore, microstructure analysis was carried out to investigate the grain size and shape. The grain size of AA6061-T6 has increased in the heat affected zone (HAZ) while for AA1100 has decreased. In the weld nugget, it has found a hook defects in the dissimilar aluminium joining. By using monotonic tensile load, the different weld line direction was observed with the expansion in tool rotation. The joints failure were consistently on the area of AA1100 series. Furthermore, two specimens were investigated, one through the dissimilar aluminium and the other through similair material. Inspection of the weld nugget hardness was shown that nonhomogen material intermixing during the stiring process as confirmed by microhardness measurement.

1 Introduction

Tailor welded blank (TWB) has being used in automotive industries to develop lighter car body. It can decrease fuel consumption, have local strength and reduce production cost. By weight reducing, it can make 0.43 km/litre every 68 kg reduction [1]. It was created from similiar or different properties and thickness of sheet metal. TWBs are used to reinforce the car body in specific area where a stiffness and high strength is needed such as pillars, doors and side frames [1], [2]. The seam of welding could be non-linear or linear. It was called engineered blanks for non-linear welding. The joining of TWB can be done by laser welding, induction welding, electron beam and friction stir welding (FSW). The analysis of TWB can be conducted by using numerical analysis and finite element method. The results have a good agreement with the experimental results [3].

To reduce car body weight, the use of low density material can be applied as well such as aluminium alloys (AA). But the material has low formability and hard to weld by using fusion welding. Joining different aluminium alloy cannot be conducted by using fusion welding due to the formation of intermetallic compounds (IMCs) that cause massive brittle. Voids and cracks usually appear in weld line
as micro defects. Therefore, friction stir welding has good technique to joint aluminium alloy and other metal with solidification problem during welding process. The process can avoid material distortion and residual stress because of the low temperature during FSW compared with the conventional arc welding. Recently, several hard to weld material have been connected successfully by using FSW method such as Al-Al [4], Al-Cu [5], Al-Mg [6], Al-Fe [5], Al-Ti [7], and Mg-Zn. It can be obtained due to the process of welding was in low temperature to minimize the formation of IMCs.

In the FSW process, many parameters were influenced weld performance such as position of specimen, tool rotation, travel speed, tool tilt angle and tool shape. However, FSW performance related to the welding strength still not satisfying. Many efforts have been conducting to meet the industrial need of welding strength, to improve tensile, bending and fatigue, low shrinkage, low distortion, robust technique and quality repeatable. Based on the literature review above, it can be known that the welding parameters needs to be optimized to get a good performance of FSW.

The research objectives to investigate the influences of tool rotation and welding speed on the mechanical properties and microstructure of the FSW joint in the aluminium sheet of AA6061-T6 and AA1100.

2 Materials and Method

In this research, thickness of 2 mm aluminium alloys sheet were selected as a specimens to develop tailor welded blank by using FSW method. Aluminium alloys are widely use in many structures such as building, automotive and aircrafts. That have both of strength and lightweight. Another advantages of AA materials are resistant to corrosion, stress, cracking and toughness [8].

2.1 Materials and tools

There are two types of 2 mm aluminium sheet in this study i.e AA 1100 and AA 6061-T6. Aluminium sheet of 2 mm thick rolled were used as a specimens of FSW. AA1100 is an aluminium family of 1000 or 1xxx series of aluminium based alloy with 99.0% aluminium. AA6061-T6 is an aluminium alloy which have both strength and toughness. The chemical composition of materials can be seen in Table 1. In the FSW process, the tools used in the research were conventional milling with adjustable spindle head, shearing machine, dial indicator, centrofix, caliper and hand grinding. The tool joint for the FSW process was made of Bohler K100 steel without any treatment. Pin tool profile was cylindrical type with CNC lathe finishing. Dimensions of the FSW tool is shown in Figure 1.

The milling machine specifications are able to move in X, Y and Z direction, Richon X8140A type and the power consumption of 4.5 kVA. The shearing machine was used Ciang Hai Machine Tool brand, QH-II-6x2500 type, cutting thickness of 6mm, cutting width of 2500 mm maximum and the power supply 380V 50Hz. Tensile test was conducted by using universal testing machine with the brand of Instron, 3367 model and the maximum load of 3500 kgf. Micro hardness test was carried out by using Highwood TTS Unlimited Inc, with HWMMT-X7 type.

![Fig 1. Tool joint design.](image-url)
2.2 FSW parameters and method

The FSW parameters used to produce the joints are shown in Table 2, such as tool speed, welding speed, tilt angle of tool and depth plunge. The illustration of tool position and the specimen can be seen in Figure 2.

| No. | Element          | Percentage (%) |
|-----|------------------|----------------|
|     |                  | Material 1     | Material 2     |
| 1   | Aluminium (Al)   | 99.28          | 96.27          |
| 2   | Zinc (Zn)        | 0.036          | 0.25           |
| 3   | Ferit (Fe)       | 0.289          | <=0.70         |
| 4   | Copper (Cu)      | 0.170          | 0.35           |
| 5   | Silicon (Si)     | 0.134          | 0.6            |
| 6   | Manganese (Mn)   | <0.0200        | 0.15           |
| 7   | Magnesium (Mg)   | <0.0500        | 0.85           |
| 8   | Chrom (Cr)       | <0.0150        | 0.35           |
| 9   | Nikel (Ni)       | 0.0249         | 0.036          |
| 10  | Tin (Sn)         | <0.0500        | <0.04          |
| 11  | Titanium (Ti)    | 0.0194         | 0.15           |
| 12  | Lead (Pb)        | <0.0300        | <0.02          |
| 13  | Calsium (Ca)     | 0.0027         | 0.0018         |
| 14  | Vanadium (V)     | 0.012          | 0.013          |
| 15  | Zirconium (Zr)   | 0.0163         | 0.015          |

The preliminary investigation will be conducted by visualize the weld results to check the influence of FSW parameters. It will be about the shape, welding contour and defects which can be seen normally. The welding process will be said successfully if the welding line was smooth and without any hole defects. The specimen is then cut to the standard of ASTM E8, E3 and E384 as seen in Figure 3.

Fig 2. Tool tilt angle and position.
Fig 3. Draft of specimens cutting for testing.

Table 2. FSW parameters

| Materials       | Tool speed (rpm) | Welding speed (mm/mnt) | Tilt angle (deg) | Depth plunge (mm) |
|-----------------|------------------|-------------------------|------------------|-------------------|
| 1100 x 1100     | 1250             | 10                      | 1                | 1.9               |
|                 | 1600             | 12.5                    |                  |                   |
| 6061-T6 x 6061-T6 | 1250           | 12.5                    | 1                | 1.9               |
| 1100 x 6061-T6  | 1250             | 12.5                    | 1                | 1.9               |

3 Results and Discussion

Figure 4(a) was shown the joining results of the same AA1100 series with the parameters of 1250 rpm and 12.5 mm/minutes. The FSW result have many defects such as holes, cracks and rough surface. Unstable welding process and not enough temperature during FSW process will cause many defects [9], [10]. To improve weld quality, another welding parameters were applied i.e 1600 rpm of tool rotation and 10 mm/minutes feedrate. Employing the new parameters has improved the joining quality as seen in the Figure 4(b). Although the welding line surface was seen rough enough.

The joining of same material of Aluminium Alloy 6061-T6 was carried out by using 1250 rpm of tool rotation and welding speed of 12.5 mm/minutes. The result of the FSW process can be seen in Figure 5(a). According to the visualization of the weld line, it was generated smooth surface along the welding line.

The joining results of the same AA 6061-T6 can be seen in the Figure 5(a). The parameters of FSW process were 1250 rpm tool rotation and 12.5 mm/minutes welding speed. The visualization of the specimen is then investigated in the naked eyes. It was clearly seen that the weld line surface was smooth. The hole defects were not appeared on the weld surface. Therefore, the FSW process was run stable and successfully process.

The different aluminium alloy of AA1100 and AA6061-T6 was joined in the same parameters of tool rotation and feeding by using FSW method. According to the investigation of the welding specimen, it was looked in good condition such as smooth welding surface and no hole detected along the welding surface. Nevertheless, on the weld surface was appeared the smooth grain. It can be caused by the difference properties of material. During the stirring process, the mixing of material grain has happened in non homogeneous condition.
Fig. 4. FSW result of 1100x1100, (a) 1250 rpm and 12.5 mm/minutes feed rate; (b) 1600 rpm and 10 mm/minutes feed rate.

Fig. 5. FSW result of 1250 rpm and 12.5 mm/minutes feed rate; (a) 6061-T6x6061-T6; (b) 1100x6061-T6

To see the grain size and shape, the photo-micro is then conducted. The first investigation is done for the base metal. Base metal is the area that it was not influenced by the temperature field and stirring during the FSW process. It can be seen clearly in Figure 6 that the grain shape was ellipse. The shape was developed due to the material forming process and grain size will be smaller than before. Rolling process usually used to form metal plate with the specific thickness. The ellipse thickness of grain was influenced by the ratio of plate thickness reduction.
Heat affected zone (HAZ) is an area that is influenced by thermal cycle without any plastic deformation in the welding process [11]. Therefore, in the HAZ area, the grain size will change which the size transformation is depend on the material characteristic, temperature, time of heating, and the cooling rate. As seen in Figure 7, the grain size of AA 1100 was transformed into smaller than the base metal. It could be caused by the heat generation, stirring and pressure during the process of FSW. On the contrary, the bigger grain size was delivered by AA 6061-T6 compared to the base metal. Phenomenon of grain size transformation will influence the strength of material joint. The higher grain size will decrease its hardness and tensile strength.

Figure 8 shows the micro photo of weld nugget area. That is an area which was influenced by temperature field generated from friction of stirring process during FSW. It has plastic deformation as well. Hence, the stirring process has delivered recrystallization which has produced smaller grain size in the stirring area. More crystal boundary has significant mean of smaller grain size which has higher barrier energy to the dislocation movement. It was denoted the stronger material [6], [12].
In the tensile test of 0° weld angle, it was broken in the weld nugget area for both specimens 1100x1100 and 6061-T6x6061-T6. The broken section has perpendicular to the load direction. It has indicated appearance defects in the weld nugget that could decrease the joint strength. On the other hand, the FSW of 1100x6061-T6 has broken on the HAZ area of AA1100. It could be caused by the stirring process of two different materials increasing the weld strength. So, the broken area was not in the weld nugget but in the low strength materials i.e AA 1100.

Almost all specimens of FSW 45° weld angle have broken in the HAZ area during tensile test. Only one specimen of 1100x1100 has broken on the weld nugget due to many defects and voids. It can be seen that the weld angle of 45° was able to employ more tensile loading compare with the weld angle of 0° as shown in Figure 8.

Hardness test of the specimen 1100x1100 has increased on the weld zone compared with base metal. As known that Aluminium 1100 is a non heat-treatable material. Increasing of hardness could be caused by stirring process and high pressure from the tool. The highest hardness was 78.1 HV on point 3 of the weld nugget as seen in Figure 9. From the hardness investigation of FSW AA 6061-T6, it was decreased in the weld zone compared with the base AA 6061-T6. The characteristic of AA 6061-T6 is a heat-treatable material. During the process of FSW, the material was suffered of heat due to the tool friction. Therefore, it could be overaging in the HAZ area. So, the hardness was decreased as 47.7 HV on point 1 (Figure 9). The fluctuative value of hardness was delivered by the specimen of 1100x6061-T6. The hardness was shown increase compared with the 1100 but it was decreased when compared with the 6061-T6.

![Photo micro of weld nugget](image)

**Fig. 8.** Photo micro of weld nugget, (a) 1100x1100; (b) 6061-T6x6061-T6; (c) 1100x6061-T6

![Comparison of ultimate tensile strength](image)

**Fig. 9.** Comparison of ultimate tensile strength.
4 Conclusions

The tensile test was shown the highest value of 78.07 MPa delivered by joining material of 1100x6061-T6 with the welding direction of 0°. For the weld direction of 45°, it was given 75.26 MPa. Whereas, the strain value was delivered 10.99% and 13.8% for the weld direction of 0° and 45° respectively. Therefore, in this research, the highest tensile strength of the FSW was given by specimen of 1100x6061-T6.

The hardness test of the weld zone of 1100x6061-T6 specimen was detected fluctuative. The highest value of hardness test was 55.1 HVN and the lowest was 31.9 HVN. It could be caused by many factors such as homogenity and the defections or void.

In the investigation of micro structure, it can be said that it was grain size transformed happen during FSW process. In the HAZ area of 1100 material, it was smaller grain size compared to the base metal. The bigger grain size was indicated in the material of 6061-T6. While on the weld nugget, it was grain refinement in materials both 1100 and 6061-T6. It can be influenced by temperature and stirng during the welding process.

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