Pre-forming evaluation of dissimilar aluminium alloys blank fabricated using friction stir welding technique.

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Abstract. Friction stir welding (FSW) is a solid-state welding that is using to weld the relatively difficult to weld materials such as aluminium alloy. FSW also can weld different material type and thickness to produce tailor welded blanks (TWBs). Although FSW capable to join dissimilar material or similar material hence from different grades, the properties of welded blanks may affect as compared to base material. In this study, performance of three aluminium alloy grades i.e. AA6061, AA5052, and AA1100 blanks that were combined among them and evaluated. Furthermore, the effect rolling direction was also considered. The welding was performed at constant speed, welding speed and tool angle using flat pin tool on a conventional milling machine. The performance is based on few mechanical properties such as hardness and tensile strength. In addition, crack pattern on the welded blank was also observed using three-point bending test. Based on the result, the hardness reduced at the stir zone (SZ) as compared to the base material, even though from different rolling direction. As expected, for tensile behaviour, the maximum load can be found on combination of similar material i.e. AA6061-T6 compared than other combinations. While based on the crack pattern, there are unsuitable combinations because of inappropriate welding parameters, and it is complying with the previous observation on tensile properties.

1. Introduction
Recently, automotive industries have high demand of light weight sheet metal material such as aluminium. Many European automotive companies had implemented tailor welded blank (TWBs) technology to achieve lighter vehicle structure. Aluminium alloy has got great attention due to its advantages. Each of the alloys have been developed to meet certain criteria and characteristic. For example, AA5052 is the strongest non-heat treatable aluminium that usually used as an alternative to steel in aerospace, marine and automotive industries because of their light weight, good formability. Good strength and high corrosion resistance [1-2]. There are numbers of studies and findings made on friction stir welding of various dissimilar aluminium alloys. Lin et al., [3] found that dissimilar aluminium alloy is difficult to be joined using friction stir welding because of the difference in material properties as it is difficult to choose the suitable welding parameters. Although difficult, there are number of success, for example, Balaji et al., [4] found that the most suitable rotational speed to weld AA2024 and AA7075 is between 600-1200 RPM. They also discovered that the tensile test shows the strength reduced by only 10% as compared to the based materials. This is in agreement to Liu et al., [5],
as they claimed that the maximum tensile strength to joining different materials is approximately 85% of the base Al alloy. Hasan et al.,[6] indicated that weld hardness drop at the HAZ on the softer material. This is based their investigated-on friction stir welding of AA7075-T651 and AA2024-T351. Tool profile also influence the performance of the weld, this is based on study by Ilangovan et al., [7] on AA6061 and AA5086 and Krisna et al., [8] on AA2024 combined with AA7075. Furthermore, welding parameters such as welding speed and tool rotation speed effect on tensile strength and micro hardness also carried out on AA2024 and AA7075 and they found that higher tensile strength obtain when 31.5mm/min and under 900rpm rotation speed. In other work, Piccini and Svoboda,[9] studied the effect of tool depth to blank made by combination of AA5052 and AA6063 on the lap joint. They discovered that when the AA6063 positioning at upper material the fracture load will increase. In this paper, tensile and hardness test of few combinations from commonly used aluminium alloys will be carried out. The present work would form the basis for subsequent studied in the fabrication of aluminium-based TWBs using friction stir welding technology

2. Methodology
In this study, the specimen in 3mm thickness from three aluminium alloy grades i.e. AA6061, AA5052 and AA1100 plates were prepared in 200mm x 80mm size. Pair of specimens arrange in a butt-weld configuration were clamped on a fixed mounted on a conventional milling machine as shown in figure 1. The feed rates (welding speed), tool angle and spindle speed (rotational speed) were set constant. The clamp is as shown in Figure 2(a), was fabricated based on the design recommendation by Kamble [10].The fixture was assembly, was designed with left and right fixture plate that can ensured firm hold of the specimens, irrespective of their thicknesses. In addition, prevent specimen from lifting or bending during welding. The cylindrical FSW tool is made from hardened tool steel. Figure 2(b) show the dimensions and it consists of 2mm pin and 10mm shoulder profile, both are unthreaded.

![Figure 1. Experimental set-up on the conventional milling machine](image)

![Figure 2. (a) Design of the Fixture and (b) schematic diagram of the tool (unit in mm).](image)
The two plates of AA6061 and AA6061, measuring 200 mm x 80 mm x 3 mm, were arranged in a butt-weld configuration onto the clamp, as shown in figure 3. Then repeat with AA6061 and AA5052, and AA6061 and AA1100. The feed rates (welding speeds) and the spindle speeds (rotational speed) are set on the control panel of the milling machine.

2.1. Hardness Test
The hardness values were measured along and perpendicular to the welding direction, as shown in figure 4. A Rockwell harness tester was used to determine the hardness using a steel ball with a diameter 1.588 mm and 100 kg of loading.

2.2. Tensile Test
Tensile tests were conducted in accordance to ASTM E8. The specimens were cut perpendicular to the weld and carried on three tensile specimens for each combination.

3. Result and Discussion
3.1. Hardness pattern
The discussion will be focus on the effect of the studied parameters to the springback pattern. Before that, material properties such as UTS, yield stress and hardness distribution need to be determined first. Figure 3 show the hardness distribution for all combinations. In general hardness will reduce at the weld area and start to increase from the distance of 5 mm from the centre. The hardness of the weld zone was found to be lower than the hardness of the base materials. From the three-combinations tested, hardness of the combination AA6061-T6 – AA1100-H14 with 45° rolling direction has the highest value on the centre of weld line which is 65 RHB. It similar with figure 6 (b) the combination of AA6061-T6 – AA5052-H32 in this research that the hardness starts to decrease at the AA6061-T6 to the weld zone then increase at AA5052-H32.
3.2. Tensile Result

Figure 4 shows the stress-strain graph for three combination specimens with different rolling direction. From the graph shows that the combination of AA6061-T6 – AA6061-T6 with rolling direction 0° has the highest tensile strength of 172 MPa. It can be seen that the 0° of rolling direction give highest value of tensile strength for the combination of AA6061-AA6061 and AA6061-AA1100. But for the combination of AA6061-AA5052, the 90° shows the highest. Najib et al. [11] said in their research that 0° orientations will give high strength and higher Young’s Modulus if it is properly heat treated but the ultimate tensile stress increase as rolling direction increase which mean 90° has the highest UTS. From the three combination, the combination with both AA6061-T6 has the highest tensile strength followed by AA6061-T6 – AA5052-H32 and the combination AA6061-T6 – AA1100-H14 has the lowest strength. This is because according to Hasan et al. [12] the join efficiency in dissimilar FSW is based on the strength of softer material. In this research AA1100-H14 has the lowest strength from the three grades that affecting the combination of AA6061-T6 – AA1100-H14 had the lowest tensile strength. This is because necking and fracture will happened on the heat affected zone (HAZ) on the softer grades [5].
Figure 4. Stress-Strain curve of the specimen at different combinations, (a) AA6061-T6 – AA6061-T6, (b) AA6061-T6 – AA5052-H14 and (c) AA6061-T6 - AA1100-H14.

3.3. Crack Pattern

Figure 5 shows the crack pattern that occur on the combination AA6061-AA1100 when bending test were done at different stroke. The crack happened on 90° of rolling direction (RD) and parallel bending direction (BD). The crack happened due the undesirable defect that exists in the welding, namely as void or wormhole defect. The wormhole defect is a cavity below the weld surface that cannot be detect by human eye. Abnormality in term of material flow cause by the unsuitable welding speed i.e. feed rate and rotational speed i.e. spindle speed are the primary reason for wormhole appearance [13] as shown in Figure 8. The wormhole will reduce the mechanical properties of the joint so that is one of the reasons why cracking happened as expected. It also could be a detect that is refer as kissing bond defects or zigzag defect [14], as can be seen in figure 5(b) and (c) from top view. This defect is believed cause by high welding speed but low rotational speed, that lead to insufficient stirring of metal that can lead to cracking or material break. Furthermore, incomplete root penetration[15]is another defect that typically found on this friction stirred blank. This type of defect is located below the stir zone at the interface of the faying surface of the joint (Figure 5). This is because of the inproper plunge depth or the pin was too short. So that the bottom of the joint of the specimen was not properly weld.

Based in this experiment as well, the effect of selected joining materials and also BD could result cracking on the specimen. In this experiment, the cracking only happened on the combination AA6061-AA1100 with the 90° of RD and when parallel BD was performed on the specimen. But for the perpendicular BD or the others RD, there was no cracking happened. This is could be because of the defect stated above that happened during the welding process. The combination of AA6061-T6 - AA1100-H14 might be unsuitable for joining with the following welding parameters.
4. Conclusions and Future Work

The friction stir welding process was successfully join the dissimilar grades of aluminium alloys. The effect of rolling direction and combined materials were evaluated on the hardness and tensile test. From the study, the hardness will be reduced on the stir zone (SZ) and start to increase from heat affected zone (HAZ) towards the base materials. The result shows that with 45° of rolling direction on the AA6061-T6 – AA1100-H14 give the highest hardness value on the welding zone. From the tensile result, it was notices that the combination on both AA6061-T6 with 0° rolling direction has the highest maximum load which is 3100N. The defect in FSW such as wormhole and kissing bond also need to be considered in this experiment to prevent cracking. The most important thing to be controlled to avoid defect is the welding parameters such as welding speed and rotational speed. In the future, the formability test or post forming test can be carried out on the dissimilar grades of aluminium to further explore on the FSW research.

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