Resistance Spot Welding of AA5052 Sheet Metal of Dissimilar Thickness

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Abstract. Resistance spot welding of dissimilar thickness of AA5052 aluminum alloy was performed in order to investigate the effect of metal thickness on the weldment strength. Resistance spot welding was done using a spot welder machine available in Coraza Systems Sdn Bhd using a hemispherical of chromium copper electrode tip with radius of 6.00 mm under 14 kA of current and 0.02 bar of pressure for all thickness combinations. Lap joint configuration was produced between 2.0 mm thick sheet and 1.2 – 3.2 mm thick sheet, respectively. Microstructure of joint showed asymmetrical nugget shape that was larger on the thicker side indicating larger molten metal volume. Joint 2.0 mm x 3.2 mm sheets has the lowest hardness in both transverse direction and through thickness direction because less heat left in the weld nugget. The microstructure shows that this joint has coarse grains of HAZ. As thickness of sheet metal increased, the failure load of the joints increased. However, there was no linear correlation established between joint strength and metal thickness due to different shape of fusion zone in dissimilar thickness sheet metal.

1. Introduction
Resistance spot welding (RSW) is a process where in a joint is produced by the heat obtained from contact resistance of working piece to the flow of the electric current through them [1]. This process is ideal for joining low carbon steel, stainless steel and nickel, aluminum or titanium alloy components. This welding method can be used for the bodies and chassis of automobiles, trucks, trailers, buses, and railroad passenger cars, cabinets, office furniture and many other products [2, 3]. Spot welding is a complicated process of multi-factor interaction, the heat input and weld nugget formation are correlated with many welding processing parameters such as welding current, additional current pulse for the heat treatment of preheating of slow cooling, welding time, welding force, electrode face dimension and surface status of
workpiece [4]. Other critical factors are welding temperature distribution, thermal conduction, force and metallurgical reaction in the sheet metal. Even though RSW of ferrous metal has been established but RSW of aluminum alloys is still challenging due to its high thermal conductivity that contribute to fast heat dissipation [5]. In order to produce products with light weight structure, combination of aluminum with dissimilar thickness is also possible. However, different sheet metal thickness requires different welding setting parameters as sheet resistance and heat dissipation vary in both sheets. Thus, this work aimed to investigate the weldability of spot weld joint of AA5052 alloy with dissimilar thickness.

2. Experimental Procedure

All samples were prepared from commercially available Al5052 sheet metal with thickness in the range of 1.0 to 3.2 mm (source from Coraza Sysems Malaysia). This aluminium grade is mostly used in Coraza for manufacturing commercial aluminium casing for electronic and medical appliances. All the welding operation were carried out using a resistance spot welding machine, model WEA S-10-200MF. This A.C type resistance spot welding machine able to deliver relatively high currents and forces required to weld aluminium. Resistance spot welding was performed on the overlapped sheet metals using a pair of truncated cone copper-chromium electrode with radius of 6 mm under 14 kA of current and 3.7 kN of force. One sheet had constant thickness, 2 mm, while the other sheet was varied in thickness from 1.2 to 3.2 mm.

For manually pull test samples, each of the sheet metal strips was 5 cm wide and 10 cm length. These strips were overlapped by 25 mm to form lap joints of dissimilar thickness. Manual peel off test was carried out on the lap joints to determine minimum welding time required to produce high strength joint as indicated by peel off failure mode. Once peel off fracture was achieved during peel test, welding was repeated using that particular welding time to produce lap joints (or coupons) for being tested using peel test but using universal testing machine in order to record the load necessary to fracture the joints. For each aluminium sheet thickness, a minimum of three coupons were provided for peel test. The individual coupons were then tested using an Instron tensile test machine with a crosshead velocity of 10mm/min. Load to fracture the coupons was recorded.

Following peel test, each of the strips was examined and the weld fused area was measured to obtain average diameter value and taken as nugget diameter. Samples for metallographic examination were prepared using standard metallography procedure: cross-sectioned close to the nugget, mounted, ground using silicon carbide paper and polished using diamond paste. The cross-sectioned samples were finally dipped in hydrofluoric acid to reveal its microstructure prior to an observation under optical microscopy. Hardness of the weld was measured by microVickers hardness (HV) under a load of 100 g across the base metal, heat affected zone and fusion zone. Hardness measurements were carried out in two directions (along the radius of the nugget and through the sheet thickness).

3. Results and Discussion

Figure 1 shows the macrostructure of dissimilar thickness joints. Joint of 2.0 mm x 2.3 mm has small weld zone compared to joints 2.0 mm x 1.2 mm and 2.0 mm x 3.2 mm. Asymmetrical nugget shape is larger on thick sheet indicating the volume of molten aluminum is more than in the thin sheet. Figure 2 shows the microstructure of the nugget for dissimilar thickness Al sheets welded joints. The changes in the grain size are due to the high cooling rate during the transition from liquid to solid in the fusion zone, and this gives the residual heat experienced in HAZ, which leads to grain growth [6].

The size of HAZ zone is different in both transverse and through thickness direction due to different thickness of sheet metals. From Figure 3, joint 2.0 mm x 1.2 mm have small grain size in HAZ and nugget (or fusion) zone compared to other joints. This is due to fast heat dissipation to surrounding as less Al volume available to adsorb the heat. For joint 2.0 mm x 3.2 mm, larger volume of solid aluminum slow down the cooling of joint after welding contributed to grain growth.
Figure 2: Macrostructure of a RSW nugget for dissimilar thickness Al joints

Figure 3: Microstructure of nugget of welded joints for dissimilar thickness joints, BZ – base metal, HAZ - heat affected zone, FZ - fusion zone
During peel test, welded joints showed either peel off or interfacial fracture failure mode (Figure 4). Peel of failure mode is frequently associated with high failure load, which is more preferred for high strength joint [7]. The welding time and nugget diameter of the joints required for peel off mode fracture increased with increasing of the materials thickness (Figure 5 and Figure 6). The inherent properties of heat sink via aluminum alloy sheet increased rapidly with the increasing Al thickness [8]. The results also suggested that a longer weld time was required to form larger weld nugget.

![Image](image1.png)

Figure 5: Variation of welding time for joints of dissimilar thickness a combination of 2 mm thick sheet metal and 1.2 mm, 1.6 mm, 2.0 mm, 2.3 mm, 2.5 mm, 3.0 mm and 3.2 mm thick sheet metal, respectively

Figure 6 illustrates the effect of materials thickness on the failure load of the welds for dissimilar thickness Al joints. The ascending trend was caused by the overall increase in the nugget diameter. However, it is difficult to control the size of nugget for dissimilar thickness joints, as shown by non-linear trend in Figure 7, due to different heat dissipation in both sheets of dissimilar thickness joining [9]. In addition, the molten metal formed in different volume in each sheet metal.
The strength was calculated after the peel off test and there was no linear correlation obtained (Figure 8). This is due to different heat dissipation in both sheet metals. Joint 2.0 mm x 2.3 mm has the highest value of strength which is 72.22 N/mm². This joint have nugget area about 21.63 mm² that is less than joint 2.0 mm x 1.6mm but give higher strength because of sufficient welding heat was generated. Joint 2.0 mm x 1.6 mm exhibited the lowest value of strength which is 29.10 N/mm² although it has large nugget area.
The effect of dissimilar materials thickness on hardness distribution through the cross section of welds, in transverse and through thickness directions, is illustrated in Figure 9. Hardness ranges for three thickness combinations varied significantly. The variation became obvious in transverse direction because more volume of Al available to absorb heat from weld nugget [6]. Microhardness through thickness is much higher compared transverse because less volume of solid aluminum was available to slow down the cooling process after weldment was formed. As the result, grain growth happened in the nugget zone and HAZ which later reduce the hardness [10]. The explanation of fine grain formation is similar to fast quenching in metal casting.

In a distance of -1.5 mm to 1.5 mm from weld centre, the hardness ranges in transverse direction were 50 to 65 Hv for 2.0 mm x 3.2 mm, 55 to 70 Hv for 2.0 mm x 2.3 mm and 60 to 70 Hv for 2.0 mm x 1.2 mm whereas through thickness direction, the hardness were 55 to 70 Hv for 2.0 mm x 3.2 mm, 60 to 70 Hv for 2.0 mm x 2.3 mm and 60 to 75 Hv for 2.0 mm x 1.2 mm. Joint 2.0 mm x 3.2 mm sheets has the lowest hardness in both transverse direction and through thickness direction because less heat left in the weld nugget. More heat was absorbed by the thicker Al sheet itself. The microstructure shows that this joint has coarse grains of HAZ. Joint 2.0 mm x 1.2 mm sheet has the higher hardness either transverse direction or through thickness direction. This is due to small grains of HAZ was observed in microstructure because of insufficient time in HAZ to experience excessive grain growth.
Figure 4.14: Microhardness plot for dissimilar thickness Al joint in (a) transverse direction and (b) through thickness direction

**Conclusion**

Resistance spot welding of dissimilar thickness of AA5052 aluminum alloy was performed in order to investigate the effect of metal thickness combination on the weldability of this alloy. Increasing in materials thickness increased the nugget diameter, welds time and coarsened the microstructure. As thickness of sheet metal increased, the failure load of dissimilar thickness joints increased in the beginning but reducing as reached 2.3 mm. Due to different heat dissipation in dissimilar thickness sheet metal, the microstructure and hardness of the joint in through and transverse direction also differ. The highest strength was obtained for dissimilar joint of 2.0 mm x 2.3 mm with 72.22 N/mm^2.

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