Use of zinc powder on Resistance Spot Welding on Mild Steel and aluminium

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Abstract. This study aims to determine mechanical properties of dissimilar metal resistance spot welding using zinc powder as an intermediate between 4000 series aluminium 1.2 mm thick with mild steel AISI 1008 thick 0.9 mm. The experiment was conducted on current parameters 7000 A, 8000 A, 9000 A, zinc powder mesh 200, and holding time 5 s. Tensile test showed that an optimal value on joining strength is at a current variation of 9000 A time 0.5 s of 1586.46 N. Additionally, Hardness testing in the weld metal area yields an optimal value at similar parameters as 232 HVN for aluminium and 210 HVN for Mild Steel. Based on Macro photo test results show that the current affects the width of the weld metal (nugget), the greater the current the wider the weld metal. Meanwhile, based on micro photos, there is a change of grain size on aluminium and mild steel welding.

1. Introduction
In recent years, the car industry has increased, due to the increasing demand for these types of transportation. This encourages the increasing fuel consumption in the world. Even though the availability of fuel on earth will run out. One of the steps to decrease speed of fuel exhaustion is by increasing efficiency of vehicle engine. Besides that, the fuel consumption of vehicle engines will increase due to the increasing weight of the vehicle. Therefore, by reducing the weight of the vehicle, this will be able to reduce the speed of exhaustion of fuel on the earth.

A number of studies related to vehicle weight and fuel consumption have been carried out. Car weight reduction of 10% will increase the efficiency of the car by 7% [1]. Economic benefits will increase by 0.42 - 0.68% in each percent of vehicle weight loss [2]. In addition, the reduction in vehicle weight will also reduce vehicle exhaust emissions, so that it will be able to protect the environment from air pollution [3]. One of the most appropriate candidates to reduce the weight of the vehicle is to replace the body parts of vehicle that were originally steel to aluminium. However, if all body part is replaced by aluminium, it is feared that it will reduce the vehicle’s traction. Then the replacement of vehicle body panel material can be done only one part, namely the inner panel, meanwhile the outer panel still uses steel. The problem that arises is how to join the material which is not similar, such as steel and aluminium in resistance spot welding. Arghafani conducted research on welding between aluminium-galvanized and between low-carbon aluminium coated with zinc [4]. The effect of zinc coated on microstructure and aluminium-galvanized unhindered welding and low-carbon steel mechanical treatment, the results showed that although the diameter of the carbon steel aluminium nugget was larger,
the diameter of the zinc melted diameter between them was almost the same. For aluminium-galvanized at currents less than 12 kA it has greater strength than low carbon aluminium-steel, but on the contrary of currents above 12 kA, the strength of aluminium-galvanized is lower.

Besides that, Sun conducted a study that tested the hardness of the resistance spot welding (RSW) welding joints of different materials between aluminium AA5052-H32 and magnesium AZ31-H24 with a thickness of 2 mm [5]. Tin (Sn) coated with AISI 1008 steel using electroplating method with a thickness of 0.6 mm is used as a filler between aluminium and magnesium joints. Sn thickness of about 1 μm was measured using scanning electron microscopy (SEM) photos. For connection with interlayer, the steel interlayer hardness value is about 170 ± 10 HV. Fusion zone (FZ) from the Mg side shows a hardness of 59 ± 4 HV which is slightly lower than AZ31-H24 base metal (62 ± 5 HV). This decrease in hardness is due to the cast structure in FZ compared to half hardened Mg base metal and increases as the cooling rate in the weld decreases as in other welding processes such as laser diodes and arc welding. But the decrease in fusion zone (FZ) hardness on the AI side is negligible, 68 ± 2 HV compared to 69 ± 2 HV for Al metal base. On the other hand, it is clear that there is no hardening in the fusion zone produced by the Sn coated steel interlayer. For comparison, the Al/Mg direct connection has a hardness of 245 HV on the nugget, significantly higher than the fusion zone on the connection with the interlayer, which is probably due to the formation of the Al-Mg intermetallic compound.

Balasundaram also examined the effect of zinc on ultrasonic spot welding on aluminium-cooper (copper) joints [6]. Both materials can be joined using zinc coated on the surface of the parent metal. Merging with zinc forms a eutectic layer of Al and Al2Cu. At the center of the weld metal, there is a chemical friction effect caused by the zinc layer. It was different on without using zinc coatings which it fail to join.

![Figure 1. (a) Resistance spot welding process. (b) Specimen dimension based on ASME IX. (c) Hardness test based on AWS D8.9-97](image)

Panner conducted research on different welding materials using spot welding machines [7]. The metal used in the study was aluminium alloy 5754 with Magnesium alloy AZ31B using interlayer in the form of zinc-plated steel plates. Al and Mg sizes are 100 x 35 x 2 mm and galvanized steel with a thickness of 0.7 mm pure Zn layer with a thickness of 0.25 mm with a size of 20 x 20 mm. Parameters used in welding 16-32 kA, with cycle time 5, welding force 4 kN electrode diameter 50.8 mm. The results of this study are the width of nuggets and violence. The study stated that the current affects the width of aluminium nugget. As much as the current, the diameter of the weld metal (nugget) is greater. For microstructure using SEM test. Therefore, this paper will present the development of resistance spot welding on non-similar materials, mild steel and aluminium alloy which uses zinc powder as an intermediate material.

2. Methods and Experiment

2.1. Shear Test

Material used in this study is mild steel type thickness of 0.9 mm and 4000 series type aluminium thickness of 1.2 mm. Specimen material is cut according to ASME IX QW-462.9 dimensions for tension-shear test, while for microhardness Vickers test used is AWS D8.9-97 standard. Joining
two materials used a foot pedal operated spot-welding machine. The scheme of welding process in the machine can be seen on figure 1 (a) and figure 1 (b). Parameter of welding process are weld current: 7000A, 8000A, 9000 A and weld time; 0.3, 0.4 and 0.5 seconds.

After welding process finished, tension shear test and hardness test were carried out immediately. In hardness test, material is cut in the middle of specimen so that the three parts of the workpiece can be viewed, they are nugget (weld metal), HAZ and parent metal. Hardness test is carried out starting from the midpoint of the weld metal region, then indentation is made at any distance less than 1 mm, as in figure 1 (c). Variations on the experiments can be seen in table 1. After the two tests are carried out, macrostructure and microstructure were observed by microscope.

### Table 1: Welding parameters in RSW

| Experiment | Current (Amper) | Weld time (second) | Holding Time (second) |
|------------|----------------|--------------------|-----------------------|
| 1          | 7000           | 0.3                | 5                     |
| 2          | 7000           | 0.4                | 5                     |
| 3          | 7000           | 0.5                | 5                     |
| 4          | 8000           | 0.3                | 5                     |
| 5          | 8000           | 0.4                | 5                     |
| 6          | 8000           | 0.5                | 5                     |
| 7          | 9000           | 0.3                | 5                     |
| 8          | 9000           | 0.4                | 5                     |
| 9          | 9000           | 0.5                | 5                     |

### 3. Results and Discussion

#### 3.1. Tensile shear test

From the first test that has been done, it is obtained the data of the magnitude of the shear tensile force of various variations of the welding process parameters, this can be seen in table 2.

### Table 2: Result of tensile shear load test on two treatments

| No | Arus (A) | Waktu (s) | F1 (N) | F2 (N) | F Rata-Rata |
|----|----------|-----------|--------|--------|-------------|
| 1  | 7000     | 0.3       | 854.81 | 818.51 | 836.66      |
|    |          | 0.4       | 882.35 | 852.30 | 867.33      |
|    |          | 0.5       | 893.01 | 872.29 | 882.65      |
|    |          | 0.3       | 908.00 | 905.35 | 906.68      |
| 2  | 8000     | 0.4       | 964.46 | 925.50 | 944.98      |
|    |          | 0.5       | 998.65 | 938.65 | 968.65      |
|    |          | 0.3       | 1434.67| 1309.98| 1372.33     |
| 3  | 9000     | 0.4       | 1510.63| 1447.36| 1479.00     |
|    |          | 0.5       | 1654.29| 1518.62| 1586.46     |

The results showed that the value of the shear strength of the weld joint increases with the increase in welding time given. This is in accordance with the basic equation for heat input in spot welding, namely \( H = I^2 \times R \times t \) where if there is an increase in welding current, the shear strength also increases. The optimal value of the shear strength of the weld joint is found in
Figure 2: Shear load on various currents

the variation of the current 9000 A at 0.5 s, which is 1586.46 N while the lowest shear strength value is at the current variation of 7000 A at 0.5 s at 882.65 N.

In general, there are 2 failure patterns that occur in the point weld shear test, namely interfacial failure (IF) and Pull out failure (PF). Interfacial failure is a failure in nugget where there is damage or cracks in the weld metal area. This failure show that quality of welding is not good. Meanwhile, Pull out failure is a failure characterized by damage to the plate until it is torn. This failure give a prove that bonding between zinc-mild steel is larger than zinc-aluminium. It may due to the treatment at the time of sanding which gives a different emphasis to the sandpaper on the aluminium material. The difference in sanding force results in different levels of the aluminium oxide being eroded.

Based on table 3, it can be seen that the number of specimens which is classified interfacial failure (IF) larger than pull out failure (PF). This may be due to different treatments, such as the inequality of the aluminium sanding process, variations in electrode force or changes in the diameter of the electrode tip during the welding process.

The distribution of hardness in the Vickers microhardness test is shown in Figure 4 (a) - (c), where the weld metal area (nugget) has an optimal hardness value compared to the HAZ and base metal areas. The hardness value of the specimen in the parent metal area is the same, this is because the main metal is not exposed to heat input at all, so the hardness value is considered constant. Meanwhile, the hardness value in the HAZ and weld metal (nuggets) area tends to be different because the heat input received by each specimen area is different. The optimal value of hardness at the current variation of 7000 A time 0.5 obtained an average hardness value of 152.0 HVN for mild steel and 110.0 HVN for aluminium. The current variation of 8000 A at
0.5 s has an average hardness value of 172.7 HVN for mild steel and 112.0 HVN for aluminium. The current variation of 9000 A at 0.5 s has an average hardness value of 224.7 HVN on mild steel and 154.3 HVN aluminium.

![Figure 4](image)

**Figure 4**: (a). Distribution of Hardness Profile on weld time 0.3s. (b). Distribution of Hardness Profile on weld time 0.4s and (c). Distribution of Hardness Profile on weld time 0.5s

### 3.2. Testing of Macro and Micro Structures

The following are the test results for macro and micro photos for welding dissimilar metals between aluminium and mild steel which use zinc powder as intermediate metal.

The results showed that the variation of welding current had an effect on the width of the weld metal diameter. This is in accordance with the formula $H = I^2 \cdot R \cdot t$, that the greater the welding current, the greater the heat input that occurs. The width of the weld metal diameter between mild steel and aluminium is not the same. The largest weld metal width in aluminium is in the current variation of 9000 A at 0.5 s, which is 5.91 mm and the largest width of weld metal in mild steel is in the current variation of 9000 A at 0.5 s, which is 3.96 mm. Previous research, Arghavani stated that aluminium sheet with a layer of zinc melts greater in low carbon steel welding than welding aluminium sheet with galvanized steel, when welding aluminium sheet with a zinc layer it will form a larger weld metal (nuggets) due to melting, zinc metal to aluminium [4].

Besides that, based on figure 1 and figure 3, this is related to each other where the greater the diameter of the nugget and the welding current, the greater the strength of the welding joint. The size of the diameter of the nugget indicates that the base metal that is melting from the two materials is getting larger, so that the strength of the weld joint will also be greater [8].
This is shown in the previous research, which treatment of zinc interlayer on steel has larger diameter than without zinc when it is welded with aluminium [9]. Based on figure 5, there is a change of grain size on aluminium, the greater of weld current then the smaller of grain size. This shows that when the welding current increases, the heat that occurs will also increase, but because aluminium is a metal with a good conductor, the cooling process will also be faster. This condition causes the grain size of aluminium to be small. In addition, it is also seen that the smaller the grains indicate that the hardness will also increase. This phenomenon is similar on mild steel also.
4. Conclusion
Based on data analysis and discussion, the following conclusions can be drawn: The variation of welding current has an effect on the shear strength of the weld joint, with an average value for the current variation of 7000 A at 0.5 s at 882.65 N, 8000 A current variation for 0.5 s at 968.65 N, and 9000 A current variation for 0.5 at 1586.46 N. The macro photo test results show that the welding current affects the width of the weld metal diameter. The greater the current, the greater the diameter of the weld metal. The results for micro-photos occur in grain changes in aluminium and mild steel. The optimal micro Vickers hardness test results at a current variation of 7000 A time 0.5 obtained an average hardness value of 152.0 HVN for mild steel welding and 110.0 HVN for aluminium welding. The current variation of 8000 A at 0.5 s has an average hardness value of 172.7 HVN for mild steel welding and 112.0 HVN for aluminium. The current variation of 9000 A at 0.5 s has an average hardness value of 224.7 HVN on mild steel and 154.3 HVN weld metal. From all the test results the optimal value occurs at 9000 A current variation and 0.5 s welding time.

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