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Critical Nugget Diameter of Resistance Spot Welded Stiffened Thin Plate Structure

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Abstract

Stiffened thin plate structure which is mostly applied to the car body structures consists of frame and sheet. It is a low cost method to reach a high-performance vehicle structure because of requirement low volume materials. Frame is thicker than sheet, so it acts as the reinforcement of this structure. The resistance spot welding (RSW) is generally used to join it. In this study failure modes of resistance spot welded thin plate structure, pullout and interfacial failure modes, were investigated based on thickness of joined plates and load secondary voltage to determine the critical nugget diameter. Three pairs of joined plates thickness of 1-1, 2-1 and 3-1 mm were spot welded using varied voltage in a range of 1.6 V to 2.3 V. The spot weld nugget of the stiffened thin plate structure joint were asymmetric form. Increasing welding voltage made the shear load bearing capacity of RSW joint increase. In the pullout failure, the bearing capacity increased if the thickness of joined materials increased. The experimental critical nugget diameter to guarantee pullout failure mode in the unequal sheet thickness joint of the stiffened thin plate structure decreased if the sheet thickness of joined materials increased. It was higher than nugget diameter obtained by AWS formula. AWS formula should be used carefully in the dissimilar sheet thickness joint of the stiffened thin plate structure.

Keywords: stiffened thin plate structure, resistance spot welding, pullout failure, interfacial failure, load secondary voltage, critical nugget diameter

1. Introduction

Stiffened thin plate structure which is mostly applied to the car body structures consists of frame and sheet. It is a low cost method to reach a high-performance vehicle structure because of requirement low volume materials. Frame is thicker than sheet, so it acts as the reinforcement of this structure (Gean et al., 1999). The resistance spot welding (RSW) is generally used to join it. RSW is a joining process of two or more metal sheets by fusion and pressure at discrete points at the interface of joined sheets. The heat required for the weld pool is created by means of resistance when a high welding current is directed through the welded workpieces. Welding heat and pressure will make the joined metal melt and fuse to form nuggets. After a certain period of time called the welding time, electrical current is then turned off and the nuggets cooled and hardened under pressur (Pouranvari & Marashi, 2010). The advantages of using RSW are that it is a quick and economical joining, no filler material is required and dimensional accuracy is better preserved during welding with local heating.

Generally, shear and tensile load combination will be occurred when spot weld lap joint was exposed load. In this condition, two distinct failure modes were observed during static tensile-shear testing: interfacial failure (IF) and nugget pullout failure (PF). When failure occures in the form of crack propagation through the interface of joined sheet and fusion zone (weld nugget), it will be interfacial failure mode, whereas pullout failure mode is indicated by complete (or partial) nugget withdrawal of one sheet. The load bearing capacity of RSW joint can be significantly affected by failure mode. Pullout failure mode specimens have higher load bearing capacity than interfacial failure mode specimens. For this reason, welding process parameters should be controlled so that the pullout failure mode is guaranteed to ensure the reliability of spot welds during vehicle lifetime (Pouranvari & Marashi, 2010).

There are many standars and recomendations from professional organizations such as the American Welding Society (AWS) and Society of Automotive Engineering (SAE) that express the requirements to guarante the joint fail in pullout failure mode (Triyono et al., 2012). They are generally a formula with respect to the critical nugget diameter as a function of plate thickness of joined material. For example, AWS's formula is $d = 4\sqrt{t}$ where t is the thickness of the plate in millimeters. It is very helpful formula to find suitable spot welding parameters for joint of equal thickness of joined sheet. However, there are a lot of spot welds applications in general engineering which involve dissimilar sheet thicknesses joint. In this case, a big question appears is which thickness plate is used in the formula, the thicker one, the thinner one or the average of them. Generally, schedules for this case are developed by and practiced within individual manufacturers (Pouranvari & Marashi, 2010; Agashe & Zhang, 2003).

Unfortunately, the most of spot welding research investigations, as well as most of practice recommendations, have been conducted on welding of equal thickness sheet. Despite of various application of unequal thickness RSWs, there are limited articels which expose physical-mechanical behaviors of them. Therefore, the objective of the present study is to determine the critical nugget diameter of the unequal sheet thickness resistance spot welded carbon steel by using failure mode investigation and compare to nugget diameter of AWS formula.

2. Experimental Method

2.1 Materials and Welding Procedure

Three pairs of mild steel SS400 plates were joined in a lap joint by resistance spot welding (RSW) using welding schedule as shown in Table 1. Tables 2 and 3 respectively show the chemical composition and mechanical properties of research materials.

2.2 Metallography and Microhardness Measurements

Standard metallographic procedure according to the ASTM E3-01 was used to prepare macrostructure specimen. It cut cross section passing through the center of weld nugget. To reveal the macrostructure, HNO_3 2.5% solution was used. Macrostructure observations were carried out using a stereo zoom microscopy.

The hardness of the weld nugget, HAZ (heat affected zone), and the base metal were measured using microvickers methode on the metallographic specimens with a load of 500 g.

Table 1. Thickness of joined plate and welding schedule

No.	Thickness t_1 (mm)	Thickness t_2 (mm)	Voltage (Volt)
1	3	1	1.79
			2.02
			2.30
			2.67
2	2	1	1.79
			2.02
			2.30
			2.67
3	1	1	1.60
			1.79
			2.02
			2.30

Table 2. The chemical composition of test materials, Wt-%

Material	C	Mn	Cr	Ni	P	Si	Cu	Mo
SS400	0.05	0.225	0.04	0.07	0.094	0.15	0.16	0.05

Table 3. The physical and mechanical properties of test materials

Material	Melting Point	Thermal Conductivity	Coefficient of Thermal Expansion	Tensile Strength
SS400	1495-1525 °C	12.6 W/mK	13.0 μm/m/°C	240 Mpa

2.3 Shear Load Bearing Capacity Tests

The tensile-shear tests sample had the same geometry and dimensions as the sample used in a work which was carried out by Gean et al. (1999). Figure 1 illustrates the geometry and dimensions of it. The nugget is represented as dark region at the center of the assembly. The overlap is equal to the width of the metal sheet. The shear load bearing capacity tests of the spot-welded joint were performed by universal testing machine. Plate whit length of 38 mm were placed at both ends of the specimen in order to minimize bending load during test.

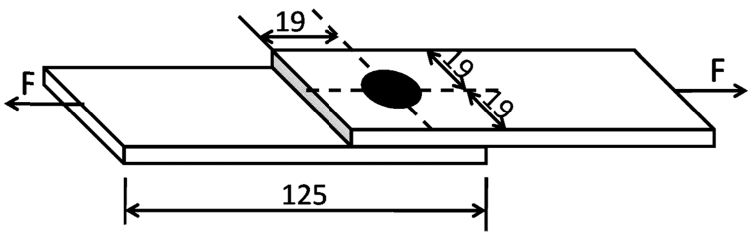
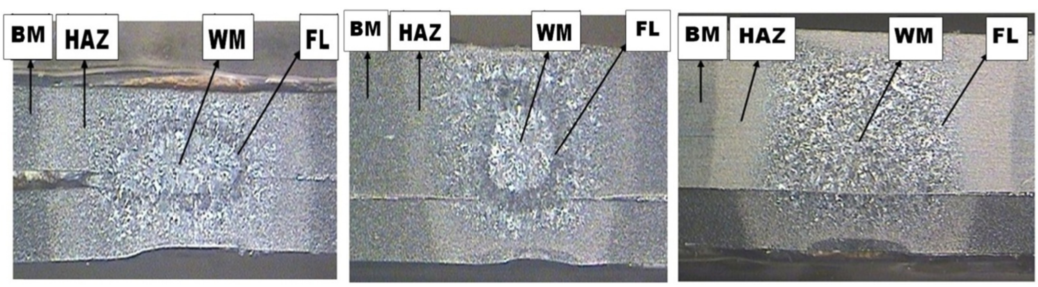


Figure 1. Dimension of tensile-shear test specimens (in mm)

3. Results and Discussion

The nature of the stiffened thin plate structure is that it has different thickness of joined sheet materials. It leads to the difference electrical resistance. The thinner plate, the lower electrical resistance. Electrical resistance controls heat generation and affects weld nugget formation and its growth. Lower electrical resistance of the thinner plate leads to smaller welding heat and fusion zone size. On the contrary, the thicker plate generates the higher welding heat and fusion zone size. This condition led to unbalance heat on joined sheet of the stiffened thin plate structure. Consequently, the asymmetrical weld nugget will be formed, where the nugget size and depth of penetration of the thinner plate side are smaller than those of thicker plate side. This phenomenon is evidenced in Figure 2. It was found that the weld nugget of 2-1 mm and 3-1 mm specimens were asymmetric form while symmetrical weld nugget was appeared in similar thickness joint (1-1 mm joint). The heat unbalance would be occurred when different thickness of the same materials, simillar thicknesses of different materials, or a combination of the two were joined using resistance spot welding (Hasanbasoglu & Kacar, 2007).



(a) (b) (c)

Figure 2. Macrostructure (a) 1-1 mm (b) 2-1 mm (c) 3-1 mm

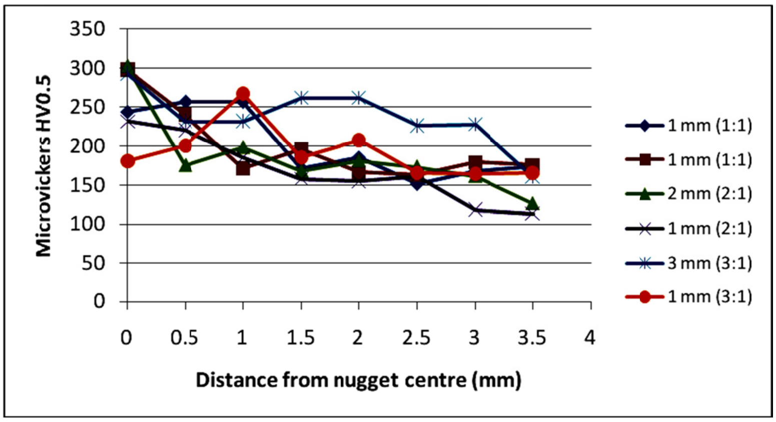


Figure 3. Microhardness distribution

The hardness of weld nugget, heat affected zone (HAZ) and raw materials in both side of joined sheet is shown in Figure 3. The microhardness of weld nugget was found to be higher than that of HAZ and raw material. The highest hardness of the unequal thickness weld nuggets was almost 300 HV0.5 which was observed on the bottom of nugget. It was more affected by strain hardening due to indentation of electrode. As known pressure on the electrodes was maintained for a hold or forging time while the weld solidified during the processes of spot weld. When the current was switched off automatically the weld solidified under pressure. During this period, stress hardening takes place in the welding zone due to the rapid cooling of weld metal (Hasanbasoglu & Kacar, 2007).

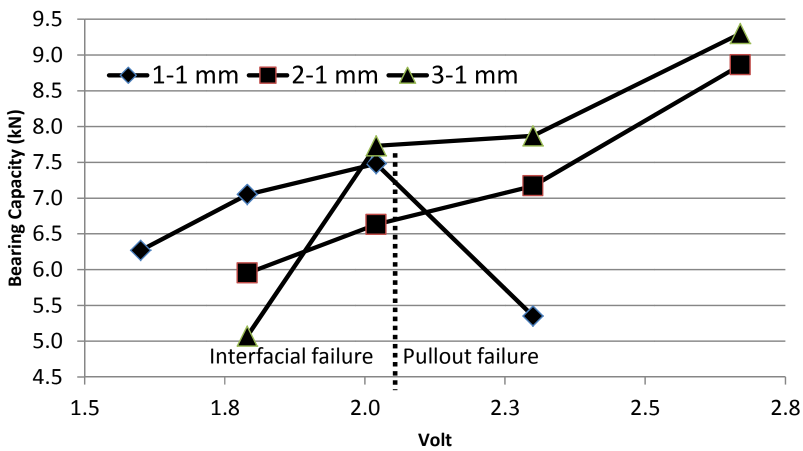


Figure 4. Effect of voltage on the bearing capacity of RSW joint

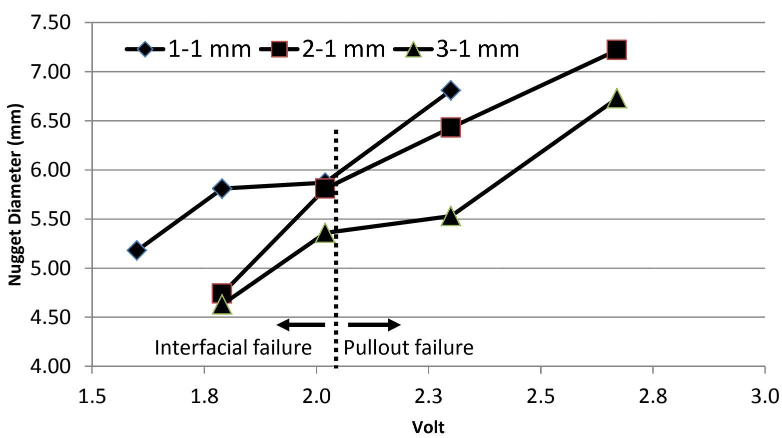
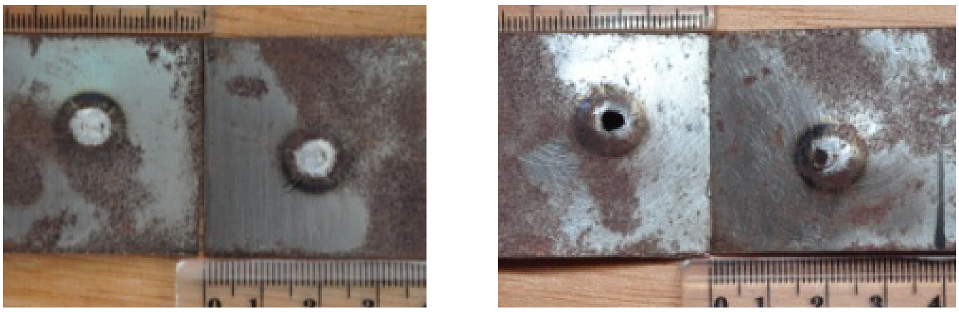


Figure 5. Effect of voltage on the nugget diameter

It is difficult to characterize the spot weld joint in its strength due to the limitations of nugget area measurement methods. The bearing capacity is usually used to express the characteristics of the welded joints. It is the quantity that states the ability of spot weld joint to continue load between joined parts. The experimental results indicated that welding voltage had a significant effect on the shear load bearing capacity of the spot welds under tensile-shear static test. As can be seen in Figure 4, for all pairs of sheet thicknesses, increasing welding voltage made the shear load bearing capacity of RSW joint increase. It was primary due to increasing nugget area and shown by Figure 5. It is well known that increasing RSW's parameters such as welding current, welding voltage and holding time make nugget area increase. Figure 5 shows that increasing welding voltage led to increasing nugget diameter. Special case was occurred in 1-1 mm specimens, due to sheet damage under over voltage, the peak load decreased in the voltage of 2.3 V although its nugget area increased. In this condition, thin plate underwent excessive deformation and became thinner than initial thickness at the end of the nugget. Failure would lead from this area and the strength of the RSW joint was very low. On the contrary, if the welding current was lowered so thin plate was not damaged, fusion of joined plate would be imperfect, and the joint strength would be also very low.



(a) (b)

Figure 6. (a) Interfacial failure (IF) mode, (b) pullout failure (PF) mode

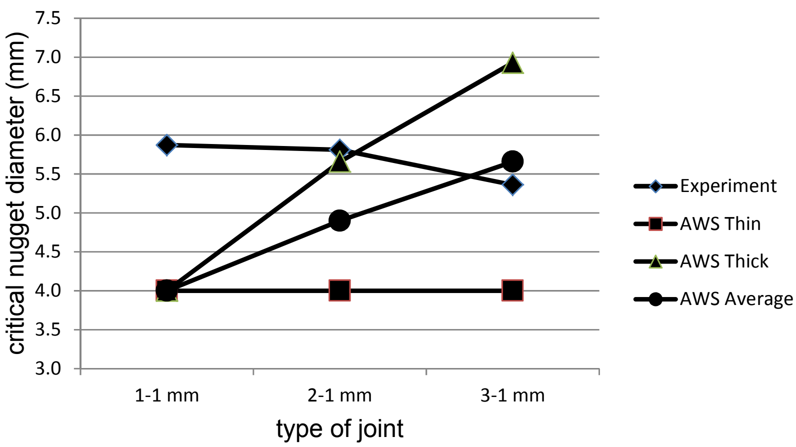


Figure 7. Comparison of the AWS's critical nugget diameter and experiment results

Shear and tensile load combination will be occurred when lap joint was exposed load. In this condition, two modes of failure were occurred during static tensile-shear testing: interfacial failure (IF) and nugget pullout failure (PF) as shown in Figure 6. Failure mode has a significant influence on the bearing capacity of spot welds. Figure 4 shows that bearing capacity of pullout specimen was higher than that of interfacial specimen. In the pullout failure, the bearing capacity increased if the thickness of joined materials increased. The small load component in the through thickness direction due to the increased stiffness and decreased rotation is the main reason (Nordberg, 2006). There was transition condition in which interfacial failure (IF) turned into pullout failure (PF). It was called critical condition and commonly determined by the critical nugget diameter. Spot weld joints which had smaller nugget diameter than the critical nugget diameter would fail in IF mode whereas the other would fail in PF mode.

Based on the experiment result, it was found that critical nugget diameter of the spot weld joint would decrease due to the increasing plate thickness. It did not agree with AWS formula stated that $d = 4\sqrt{t}$ where t is the thickness of the plate in millimeters. The experimental critical nugget diameter was higher than the AWS nugget diameter. Figure 7 shows the comparison of the experimental critical nugget diameter and the nugget diameter determined by using AWS formula. If it used the thinnest plate in AWS formula, constant nugget diameter of 4 mm would be obtained for all pairs of sheet thickness. The AWS nugget diameter would increase if it used the thickest or the average of sheet thickness. As can be seen in Figure 7, if AWS formula was used in 1-1 mm and 2-1 mm joints, it would fail in interfacial failure (IF) mode and have low bearing capacity. AWS formula with the thickest plate or average plate thickness guaranteed pullout failure (PF) in 3-1 mm joint. It indicated that AWS formula should be used carefully in the unequal sheet thickness joint of the stiffened thin plate structure.

4. Conclusions

The spot weld nugget of the stiffened thin plate structure joint were asymmetric form due to the difference in electrical resistance of joined materials. Increasing welding voltage made the shear load bearing capacity of RSW joint increase. In the pullout failure, the bearing capacity increased if the thickness of joined materials increased. Due to the interfacial failure, in the lower voltage range, increasing thickness decreased both nugget diameter and bearing capacity. The experimental critical nugget diameter to ensure pullout failure mode in the unequal sheet thickness joint of the stiffened thin plate structure decreased if the sheet thickness of joined materials increased. It was higher than nugget diameter obtained by AWS formula. AWS formula should be used carefully in the dissimilar sheet thickness joint of the stiffened thin plate structure.

Acknowledgments

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