Microstructure and Mechanical Properties of Dissimilar Joint of Cold Rolled Steel Sheets 1.8 SPCC-SD and Nut Weld M6 by Spot Welding

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Abstract— Resistance spot welding is one of welding methods which is most widely used especially in the medical equipment industry. Unfortunately, interfacial fracture and pullout fracture often occur. The aim of this research is to find optimum current and time of resistance spot welding process for the best micro structure and mechanical properties. This research combined two spot welding parameters of cold rolled steel sheets1.8 SPCC-SD and nut weld M6: current (49, 52, 55, 58, 61 Ampere) and time (14, 17, 20, 23, 26 *cycle*). Optical microscopic, Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD) were used to examine weld zone, heat affected zone (HAZ) and parent metal microstructure. The mechanical properties were investigated using universal tensile test and Vickers micro hardness. It was found that the lowest current and cycle result incomplete joining, while the higher current and cycle increase tensile strength and hardness. The micro structures tend to be ferritic with acicular, grain boundary and widmanstaten ferrite on the weld zone for all parameters. The best microstructure and mechanical properties occur at 14 cycle and 61 A of parameters combination.

Keywords— resistance spot welding, 1.8 SPCC-SD, Nut Weld M6, current, and time.

INTRODUCTION

Dissimilar metal joints are common in welded construction, and their performance is very important to the function of the whole structure. Dissimilar metal welding implicates the joining of two or more different metals or alloys. There are various types of dissimilar metal welds. Resistance spot welding of dissimilar metal usually does not use filler metal [1].

Resistance spot welding appears along with electrical energy which is increasingly easy to use. It is a form of arrest welding in which a weld is produced at a point on the work piece between the carrying current electrodes. The weld will have an area that is about the same size as the tip of the electrode, or as small as the tip of a different size of electrode [2]. Welded plates are clamped in joint place by a pair of alloy copper electrodes and then electrified with large current in a short time [3].

Resistance spot welding is a process of joining two or more metal parts by fusion at discrete spots at the interface of work pieces. Resistance to current flow through the metal work pieces and their interface generates heat. Therefore, temperature rises at the interface of the work pieces. When the melting point of the metal is reached, the metal will begin to fuse and a nugget begins to form. The current is then switched off and the nugget is cooled down to solidify under pressure [4].

Spot welding is widely used in industry, generally the automotive industry, household appliances, handicrafts, engineering spacecraft auto-body, truck cabins, and hospital equipments. The characteristics of the spot welds are very important to the durability and safety design of vehicles and others [1]. Quality and mechanical properties of spot welds importantly affect durability and crashworthiness of the vehicle [5].

Resistance spot welding is widely used because it is fast and easy to operate and it does not require special skills. Simplicity, low cost, high speed (low process time) and automation possibility are among the advantages of this process. The main constraint of this welding process is the work pieces being welded often do not stick strongly. It happens on dissimilar joint of cold rolled steel sheets 1.8 SPCC-SD and nut weld M6. It is caused by inappropriate setting of electric current and squeeze time variation.

Selection of too low electric current and squeeze time leads to low strength of the weld joint resulting in failure point interface (interfacial fracture/IF). On the other hand, selection of too high electric current and squeeze time will force spot welding joint that is too strong, exceeding the strength of plates. As a result, there is a failure on the plate (pullout fracture/PF). To assure the reliability of the spot welds during vehicle lifetime, process parameters should be set so that the pull out failure mode is guaranteed [6-7].

This study aims to find the optimum parameters of electric current and squeeze time to produce good quality of welded joints (defect-free).

EXPERIMENTAL PROCEDURE

The welded materials were cold rolled steel sheets 1.8 SPCC-SD (Figure 1A) and the nut weld M6 (Figure 1B). Composition test of welding material was conducted using spectrometer test equipment of composition. Both materials were welded using a Uto CHUO SPOT WELDER spot welding machine. Welding process was performed by varying electric current and cycle (Table 1).

After welding (Figure 2), specimens were cut into two parts using a chainsaw (Figure 3). Then both cut surfaces were polished using sandpaper. Sanding is done until the surface is completely smooth and scratch free. Then it was polished using a velvet cloth and autosol polish pasta until the surface is completely glazed. Microstructure was examined using optical microscopy and SEM. Hardness distribution test was conducted using Type: 38505 Karl Frank Gmbh, Wienheim-Birkenau Vickers Hardness with the test point as shown in Figure 4. The load was 200 gf and the emphasis time of penetrator was 5 seconds. Testing was conducted at five different points, initiated from the weld zone to the parent metal with the distance of each point was 0.5 mm.

Tensile strength of dissimilar joint of SPCC-SD 1.8 with a nut weld M6 was performed using the tensile test equipment TM-MD Controlab. Figure 1 shows the cold rolled steel sheets 1.8 SPCC-SD and the nut weld M6.

Table 1. The coding of welding specimen

Time (cycle) / Current (A)	14	17	20	23	26
49	a1	a2	a3	a4	a5
52	b1	b2	b3	b4	b5
55	c1	c2	c3	c4	c5
58	d1	d2	d3	d4	d5
61	e1	e2	e3	e4	e5


(A)


(B)

Figure 1. A. SPCCSD 1.8 plate B. Nut weld M6

Figure 2. SPCCSD 1.8 plate and Nut weld M6 after welding

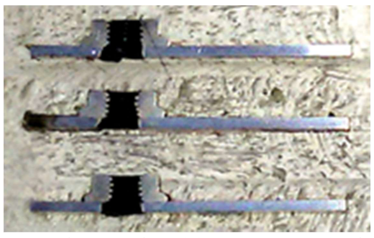

Figure 3. Cut surfaces of welding material after welding

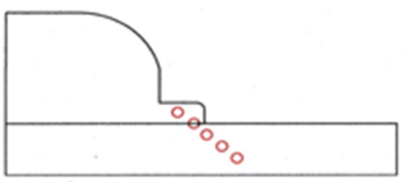

Figure 4. Test points of hardness testing

RESULT AND DICUSSION

The chemical composition of the plate and nut can be seen in Table 1.

Table1. Chemical composition of test materials (%wt)

Element	C	Si	Mn	Al	Cr	S	P	N	Fe
SPCC-SD 1.8	0.03	0.01	0.21	0.02	0.02	0.01	0.01	0.02	Bal
Nut weld M6	0.25	0.18	0.49	0.02	0.03	0.01	0.02	0.08	Bal

Table 1 shows that SPCC-SD 1.8 and Nut weld M6 contain 0.03 wt% C and 0.25 wt% respectively. Even though there is a prominent difference between the C levels of SPCC-SD 1.8 and Nut Weld M6, both of the materials are still classified as low carbon steel.

Differences in levels of C cause differences in thermal conductivity and electrical resistivity which lead to an asymmetrical weld nugget in the dissimilar metal joints [8]. Besides, differences in levels of C and Mn cause strength differences which also affect the strength of weld joint.

a. Microstructure

Generally, microstructures which are formed on the welding process depend on the chemical composition of the parent metal and filler metal, the previous process and techniques used. The dominant microstructure that is formed in the parent area, heat affected zone and weld zone after the welding process is ferrite. Ferrite is the softest structure, which appears white under an optical microscope. Figure 5C shows that the parent metal microstructure of welding materials is full ferrite. The difference lies in the grain size which is greater at higher levels of C because this area is not affected by the heat of the welding process. Differences in microstructure are caused solely by differences in C levels.

HAZ area microstructure (Figure 5B) is almost the same as the parent metal microstructure. The difference is the HAZ region has a finer microstructure than the parent metal. Grain boundary ferrite visible in the HAZ has larger size than the grain boundary ferrite contained in the weld zone. At the same time, the higher current results larger grain size of ferrite and grain boundary ferrite in the HAZ region.

In the welding area (Figure 5A) a considerable amounts of acicular ferrite are visible and scattered randomly. Widmanstatten ferrite which is smoother and fewer than acicular ferrite is also present. At 14 cycle and 49 Ampere, SPCCSD 1.8 plate and Nut weld M6 have not integrated well. Welding parameter combination is too small.

At 20 cycles and 52 Ampere, beside acicular ferrite structure which is scattered randomly, quite a lot of widmanstaten structure and several grain boundary ferrites appear. At 20 cycles and 55 Ampere a smaller amount of acicular ferrite structure is formed. There is also the same amount of grain boundary ferrite and shorter widmanstaten ferrite.

At 14 cycle and 61 Ampere, a small amount of acicular ferrite appears because cooling process takes place rapidly. In this variation, the predominant structures are ferrite and grain boundary ferrite while widmanstatten ferrite structure is of the least amount.

At the same time, it appears that at low currents, microstructure is dominated by acicular ferrite and several widmanstatten ferrite. At higher current, widmanstatten ferrite is increasingly dominant. This happens because the acicular ferrite is formed at lower temperature than widmanstatten ferrite. Acicular ferrite is formed at 650°C, while widmanstatten ferrite is formed at 500°C.

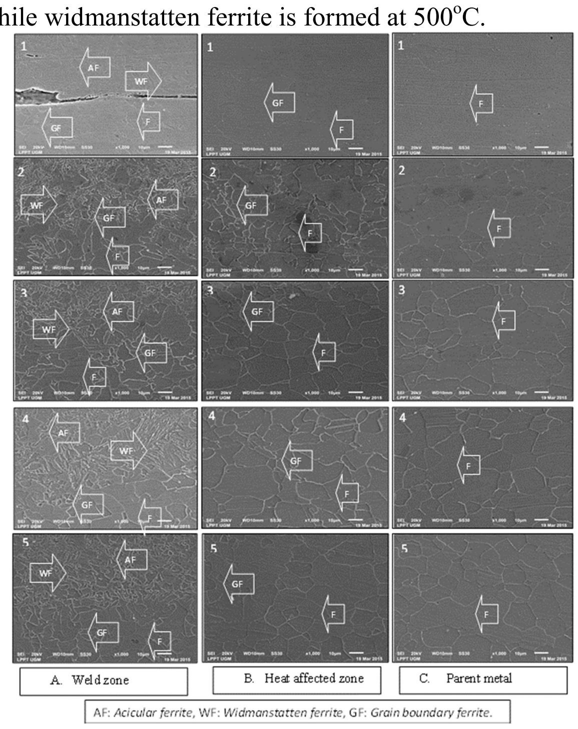

Figure 5. SEM Microstructure of welding materials

b. Hardness

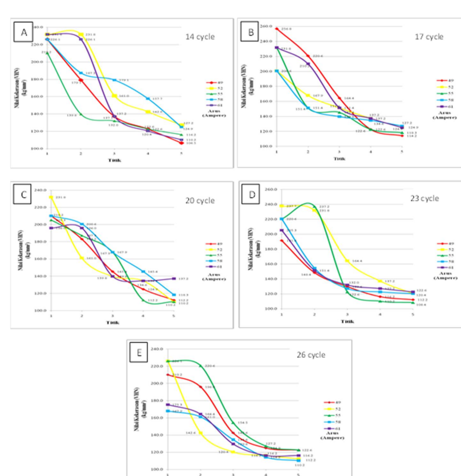

Figure 6. Vickers hardness distribution of welding materials

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Figure 6 shows the hardness distribution of 14 welding cycle in 5 current variations. There is a similar pattern on figure A, B, and C. Point 1 is the welding area, which has higher hardness than point 2 (fusion zone). Point 3 is the heat affected zone on which its hardness declines drastically and continues to decline with smaller gradient until parent metal (point 4 and 5). Figure D and E have similar pattern until point 3. However, from point 4-5 the hardness is stable because this area is not affected by the heat. On figure A, it can be seen that at 49 Amperes the hardness values at point 1, 2, and 3 are 226.1 kg/mm², 179.1 kg/mm^2 going down 20.79%, and 137.1 kg/mm2 respectively. It means there is a decrease of 20.79% from point 1 to 2, and 23.45% from point 2 to 3.

Impairment hardness from point 1-5 also occurs in other current variation (52-61 amperes), as well as on the specimen with other variation of time and current. The farther away from the weld metal, hardness value gets smaller due to the welding area which is formed during the heating and cooling process after welding. Thus, the ferrite structure transforms into acicular ferrite, Widmanstatten ferrite and grain boundary ferrite structures. Acicular ferrite is formed at below 650^{o}C which inhibits the rate of crack propagation. Compared to other structures, acicular ferrite is a structure that has the highest hardness value. Widmanstatten ferrite is formed at 500^{o}C – 750^{o}C and it decreases the ductility and toughness. Grain boundary ferrite is formed at 650°C-1000^{o}C which has lower toughness and ductility. The parent metal and HAZ area have more ferrite than the weld area. The number and grain size of the ferrite greatly affect the hardness of materials. If emphasis time (cycle) increases, the average value of hardness increases.

c. **Tensile Strength**

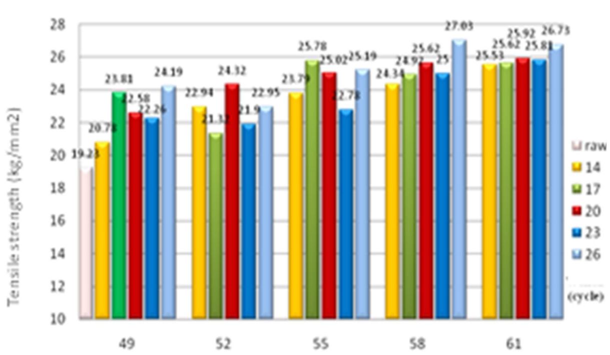

Figure 7. Tensile strength of dissimilar joint SPCCSD 1.8 plate and Nut weld M6

Figure 7 shows that the highest tensile strength is 27.03 kg/mm^2 which occurs at 26 cycle and 15Ampere. Quality of the joining between SPCCSD 1.8 plate and Nut weld M6 on this combination welding parameter is the most excellent. The form of damage after the tensile test shows that joining of the plate and nut is perfect.

The lowest tensile strength occurs at 14 cycle and 49 Ampere. Figure 5a1 shows that the plate and nut are not integrated well. Overall the higher the current and cycle are, the higher the tensile strength is. It reaches its maximum at 26 cycles and 15 Ampere. This is in accordance with the microstructure which indicates that the weld zone has a ferrite accicular dominant structure whose hardness value is the highest compared to other structures.

CONCLUSIONS

1. Microstructure formed on weld zone area is acicular ferrite, widmanstatten ferrite and grain boundary ferrite. The HAZ area consists of ferrite and grain boundary ferrite, while the parent metal area consists of ferrite.
2. The highest hardness (237.7 VHN) after welding occurs at 52 Ampere and 23 cycle on the weld metal area because the structure of the ferrite transforms into acicular ferrite, Widmanstatten ferrite and grain boundary ferrite.
3. The highest tensile strength (27,03kg / mm^2) occurs at 26 cycle and 58 Ampere.

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