A METALLURGICAL STUDY OF SPOT WELD GROWTH ON MILD STEEL WITH 1MM AND 2MM THICKNESSES

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ABSTRACT

Resistance Spot Welding (RSW) is an important welding technology for joining two or more metals in various manufacturing industries. For instance, to date a car may contain an average of 3000-4000 spot weld joints and the nuggets' joints are very important between metal sheets to ensure the aging factor of mechanical assemblies. As such the growths of spot welds create significance and it is determined by its' main controlling parameters such as: current, weld time and force. However factors such as electrode deformation, dissimilar materials, materials with different thicknesses and corrosions are also affect weld growth. This study was conducted to look into the effects of different thickness (1 mm and 2 mm) on weld nugget growth of mild steel. The tensile test and hardness test have been carried out to characterise the formation of weld nugget growth for different weld schedules. The results of the experiments showed that the growth of spot weld nuggets was affected by different thicknesses. The microstructures of weld nuggets have also shown distinguishable differences in weld growth for the both 1 mm and 2 mm thicknesses. The results have shown difference in yield strength as well, for the same welding schedules. This was happened due to the difference of resistive path of two thicknesses.

Keywords: *Mild Steel Weld Nuggets, Mild Steel Different Thicknesses*

1.0 INTRODUCTION

Spot welding process is a joining process that joins two or more metal sheets together through fusion at a certain point [1]. It is a simple process that uses two copper electrodes to press the work sheets or base metals together and forces a high current to pass through it. The growth of weld nugget is then determined by its controlling parameters i.e., the current, force and weld time [2]. The other factors that influence the weld growth are electrode deformation, material properties, corrosion, gaps between work sheets and what not [3].

Automotive industry is one of the main industries that have been using spot welding mechanism to join its metal structures for long time. To date, a car's body may contain an average of 3000 to 4000 spot weld joints which do not alter the weight of materials very much as compared to traditional arc welding. The other industries such as marine, bridge and road, high rise buildings and aircraft engineering are also primarily anticipating the spot welding process for its small scale metal assemblies. So far the researchers have done many researches on spot welding for various materials such as low carbon steel, nickel, aluminum, titanium, copper alloy, stainless steel, austenitic stainless steel, galvanised low carbon steel, zinc coated steel, magnesium alloy and high-strength low alloy steel [1-6].

This research was focused on the spot weld growth of the low carbon mild steel and investigates the ability of producing sound welds as the metal seemed to be very common and cheap as compared to others. The welded specimens were later tested using tensile-shear [3-4] test and hardness test [5-6] to characterise the formation of weld nuggets of low carbon mild steel.

2.0 EXPERIMENT

The formation of weld is mainly influenced by controlling-parameters of spot welding process, as stated before. In this experiment, the force is kept constant at 3 kN (2 Bar) and the other two important parameters (current and weld time) were varied for two different thicknesses to study the growth of weld nuggets. The test was conducted for two thicknesses (1 mm and 2 mm) of mild steel. Table 1 shows the chemical composition properties of materials and Table 2 shows the weld schedules that were used for this test.

Table 1: Chemical properties of mild steel

Element	Maximum wt %
C	0.23
Mn	0.90
P	0.04
S	0.05

Table 2: Weld schedule

Samples Number	Thicknesses (mm)	Force (kN)	Current (kA)	Weld time (Cycle)
1-5	1 and 2	3	8	8
6-10	1 and 2	3	10	8
11-15	1 and 2	3	12	8
16-20	1 and 2	3	8	10
21-25	1 and 2	3	10	10
26-30	1 and 2	3	12	10
31-35	1 and 2	3	8	12
36-40	1 and 2	3	10	12
41-45	1 and 2	3	12	12

We have varied the parameters from lower range of weld schedules (force = 3 kN; current = 8 kA; time = 8 cycles) to higher range of weld schedules (force = 3 kN; current = 12 kA; time = 12 cycles) to analyse the nugget growth as well as the weld strength. It yields three by three matrixes with constant force. The sample size was maintained at the same size (25 mm x 200 mm) except thicknesses (Figure 1). The tensile-shear (Figure 2) test was carried out to determine the yield strength of spot welded samples and also analyse the strength of weld nuggets. The Ultimate Tensile Strength (UTS) was taken into consideration after which the breaking of weld occurred (Figure 2).

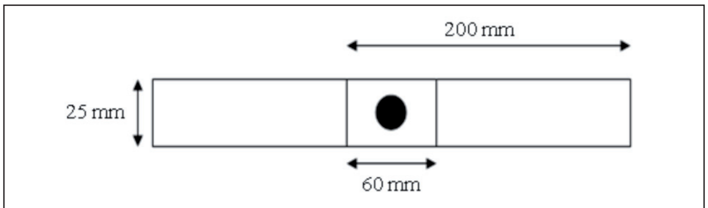


Figure 1: Test sample

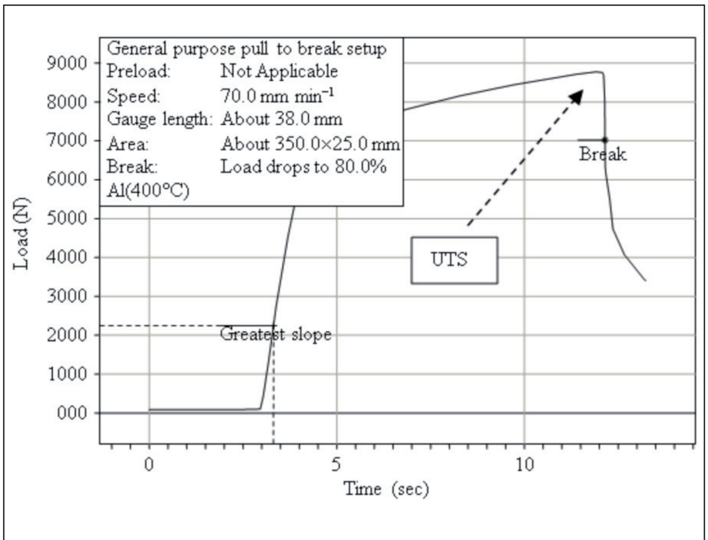


Figure 2: Tensile shear curve

The specimens are all welded using 50 KVA spot welding machine with an electrode tips of 5 mm (round) in diameter. The weld schedule was specifically increased by two parameters that of, firstly the current (8, 10 and 12 kA); secondly the time cycle (8, 10 and 12 cycles) while a constant force was maintained during the welding process takes place. As such a combination of 45 samples was developed with 5 samples in each weld schedule (Table 2). An average tensile strength value of the 5 samples was taken into account. Moreover the welded nuggets have also been analyzed for hardness distribution along the welded zone (heat affected zone, fusion zone) and also for the hardness of un-welded areas. The hardness was measured for 5 repetitions along the diameter of nuggets using Rockwell Hardness Tester using HRB scale. All the forty five samples were picked to undergo hardness test. The results are graphically shown in Figure 5.

3.0 RESULTS AND DISCUSSION

3.1 Tensile Shear Test

The entire weld schedule is divided into 3 groups; as, group 1, 2 and 3 to show the weld time increment (8, 10 and 12 cycle). Each group shows the weld current increments from 8 to 10 and 10-12 kA. Each testing uses 5 samples to obtain an average of tensile strength and hardness. As for the 1 mm-mild steel and referring to weld schedule 1 (Figure 3), the tensile strength increases from the 1st weld schedule to the 2nd weld schedule (4452kN to 5962kN) and then drops at the 3rd weld schedule (5962kN to 5678kN). This is because from the 1st weld schedule to the 2nd weld schedule, weld current increases from 8-10 kA. Therefore more heat is supplied at the weld zone which produces a stronger weld. However further increase in current (12 kA) causes expulsion which reduces the weld strength [1]. For the same 1 mm mild steel, comparing weld schedule 1, 4 and 7 where the welding current is maintained at 8 kA but the weld time increased from 8 cycles to 12 cycles, the weld strength initially shows an increase (4452kN to 6302kN) due to sufficient time given for the weld to develop.

However, at longer weld time (12 cycles), overheating causes the molten metal to expel from the weld zone therefore causing a reduction in weld strength (6302kN to 6127kN). The similar pattern was also found for the other set of welding schedules; i.e., 2, 5 and 8 (5962kN to 6903kN and to 6703kN) and also 3, 6 and 9 (5678kN to 6760kN and to 6200kN) [2].

Furthermore, to 1 mm specimens; the 2 mm mild steel and referring to weld schedule 1, the tensile strength increases from weld schedule 1 till weld schedule 3 (1663kN to 9600kN to11355kN). This is because of the increase in weld current from 8-12 kA which causes an increase in heat that is supplied to the weld zone. Comparing the weld pattern for 1 mm thickness and 2 mm thickness (Group 1 or 8 cycles weld time), weld schedule 3 shows a reduction in strength for 1 mm thickness due to expulsion. However with 2 mm thickness, expulsion was avoided because of the thickness (high resistance) of the mild steel path which was unable to cause overheating at the weld zone [1]. This is how the 1 and 2 mm mild steel showed difference in strength.

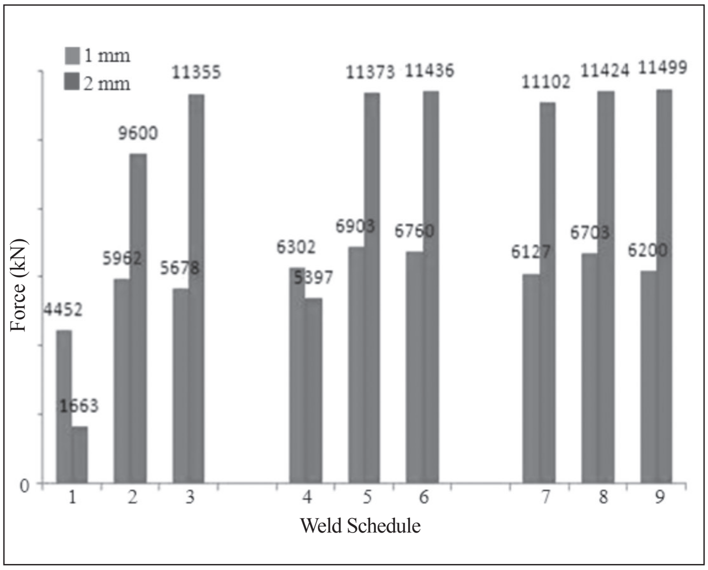


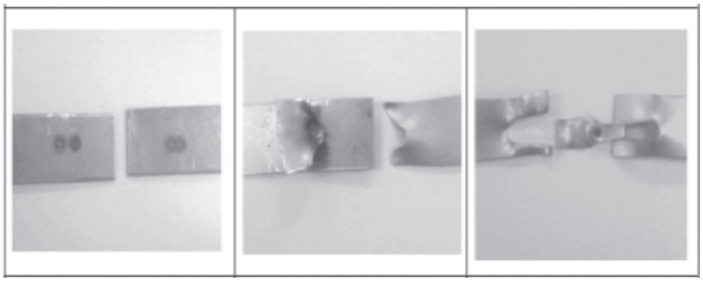
Figure 3: Tensile test result (1 and 2 mm)

In general an increase in weld strength was noticed for the 2 mm thickness compared to the 1 mm thickness except for welding schedule 1 and 4. These welding schedules were done with the lowest weld current (8 kA) and probably the current was not sufficient to create melting at the given welding time due to thickness. However at high current and weld time, the amount of heat supplied was sufficient to produce a sound weld. This is because the increase of thickness of welded sheets. Mathematically the heat generated by electrode is given by:

$$E = I^2_{ms} \cdot R \cdot T_s = I^2_{ms} \cdot \frac{\rho \ell}{A} \cdot T_s \quad (1)$$

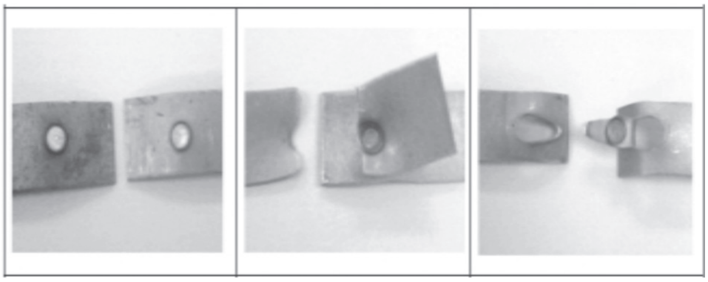
Where: I^2_{rms} = The true rms welding current; R = The sheet resistance; ρ = The sheet electrical resistivity; ℓ = The total sheet thickness; A = The spot area; T_s = The total welding cycle.

Since total sheet thickness is proportional to heat generation, strength achieved in 2 mm thickness sheets was higher than 1 mm thickness sheets mathematically. Similar observation was also discussed by Oikawa *et al.* (2007). By physical observation of the tensile-tested samples, three different weld failures were noticed. Firstly interfacial fracture (a), Secondly tear from edge of one side of metal sheet (b) and thirdly tear from both side of metal sheet (c). It was seen that the interfacial fracture occurred because of the insufficient supply of weld time and current, here. The tear from edge of one side of metal sheet occurred because of the gradual thermal distribution along the Heat Affected Zone (HAZ) and therefore the HAZ produces lower strength than the welded area. That's why the break occurred at the HAZ rather than the center of welded area. Lastly, tear from both side of metal sheet occurred because of the over-thermal gradient at the heat affected zone on which the tear off easily happens when pull out force is applied [8-10]. Figure 4 shows the different weld failures of test samples.



(1 mm Samples)

(a) (b) (c)



(2 mm Samples)

(a) (b) (c)

Figure 4: Tensile tested samples.
(a) Interfacial fracture (I = 8 kA; T = 8 cycle);
(b) tear from edge of one side of metal sheet (I = 10 kA; T = 10 cycle);
(c) tear from edge both side of metal sheet (I = 12 kA; T = 12 cycle)

3.2 Hardness Test

Hardness test was done using the Brinell-Rockwell Tester to study the hardness of weld obtained for both 1 mm and 2 mm mild steel. Hardness of welded area versus un-welded area yields a distinguishable difference on hardness values. The welded area has higher hardness compared to the un-welded. This is because of the heat treatment characteristics of mild steel. The hardness of mild steel can be increased by heat treatment. As such the welded areas are giving higher hardness values as compared to unwelded areas. However the increment of weld schedules with respect to hardness distribution along the welded areas, seemed not proportional. It fluctuated along the areas of weldment (Figure 5). This observation seemed true for both 1 and 2 mm thickness sheets.

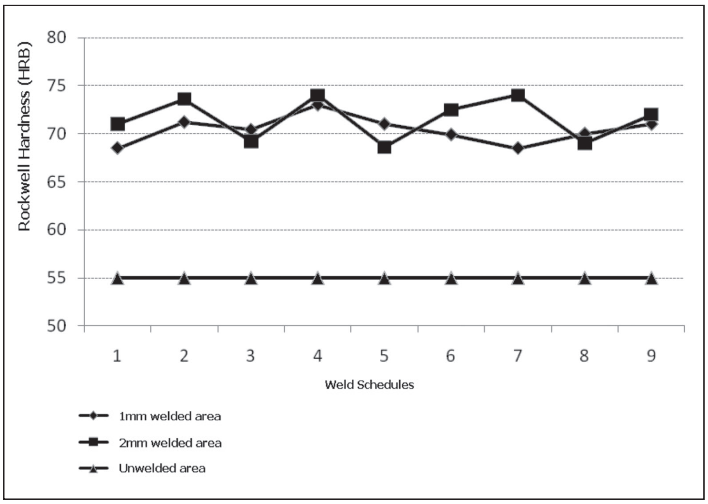
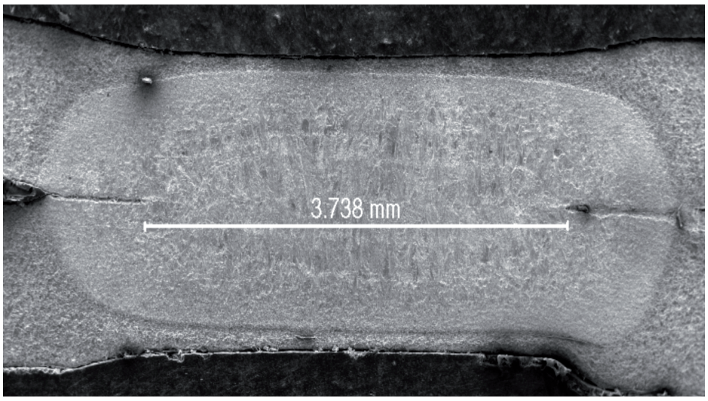
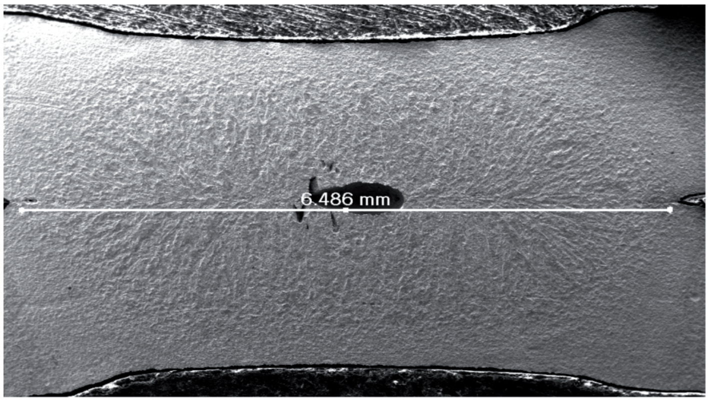
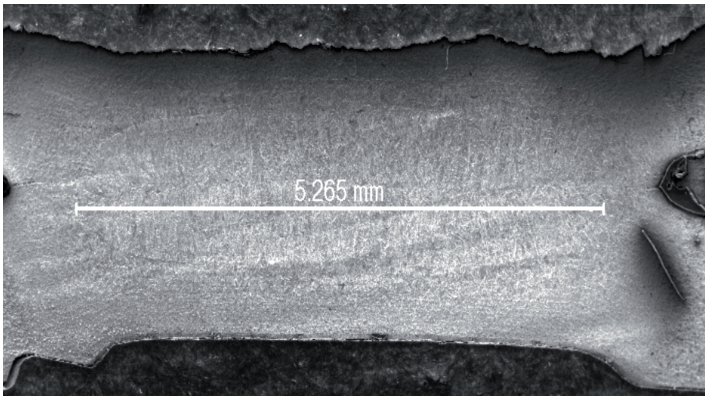
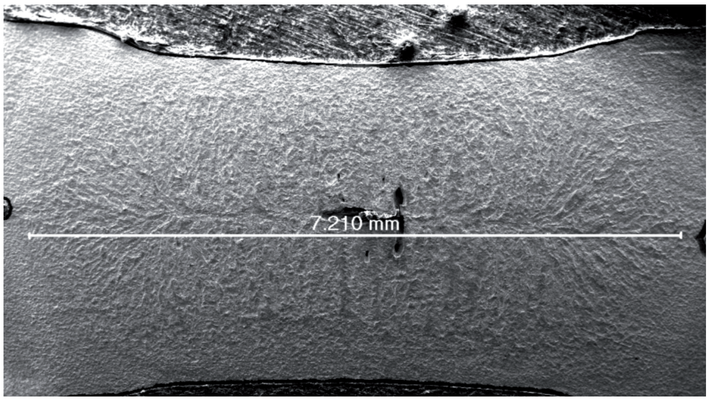
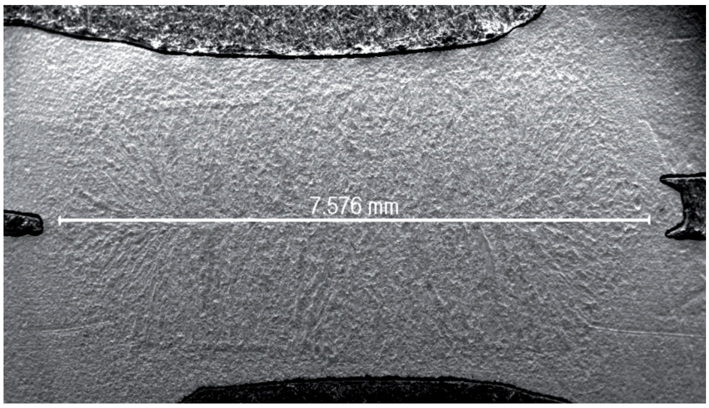


Figure 5: Rockwell hardness results (HRB values Vs group samples)

3.3 Micro Structures

The metallurgical studies have shown thorough details about the nugget formations and expansions. Macro structures of nuggets were observed by varying current and force but only some (current based) of it included here for simplicity. Finally it supports the tensile and hardness test results by showing increment in diameters (Table 3).

Table 3: Micro structures of weld nuggets

Base Metal (1 mm)	**Base Metal (2 mm)**
MS-1 mm (**8** kA, 10 cycles, 3 bars)	MS-2 mm (**8** kA, 10 cycles, 3 bars)
	
MS-1 mm (**10** kA, 10 cycles, 3 bars)	MS-2 mm (**10** kA, 10 cycles, 3 bars)
	
MS-1 mm (**12** kA, 10 cycles, 3 bars)	MS-2 mm (**12** kA, 10 cycles, 3 bars)
	

4.0 CONCLUSIONS

This experiment looks into the RSW characteristic of low carbon mild steel of 1 and 2 mm of thickness. It concludes that:

1. Increase in current and time resulted increment in tensile strength until expulsion limit occurred.

2. Increasing the thickness of base metal caused strong bounding between base metals and consequently increased tensile force is required to break the nuggets.

3. The diameter of nuggets was increased with increase in current and time which supports the tensile strength increment on tensile tests.

4. The hardness values of welded area were increased (from 55 to 72 HRB in average) due to the electrical and thermal conductivity of mild steel.

5. When the thickness of nuggets was reduced due to expulsion it also resulted in reduced tensile strength.

6. Macro structure of nuggets exhibits the coarser area (fusion zone), fine area (heat affected zone) and base metal clearly.

5.0 ACKNOWLEDGEMENTS

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PROFILES

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