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An Analysis of Resistance Spot Weld Growth on Mild and Stainless Steel with 1mm and 2mm Thicknesses

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***Abstract*— Resistance spot welding (RSW) is an essential welding technology today for joining two or more metals in various manufacturing industries. A statistic shows that one metal assembly out of five is joined using resistance spot welding mechanism, commercially. It uses traditionally two electrodes to hold the metal sheets and forces high current to pass through it. The growth of weld nugget is, at last obtained from a proper set up of its controlling parameters such as current, weld time, pressure of electrodes and also the tip size of electrodes. However, factors such as electrode deformation, dissimilar materials and materials with different thicknesses also affect weld growth. This paper looks into the effects of different thicknesses of two base materials .The materials that were used are mild steel and 302 authentic stainless steel with thicknesses of 1 mm and 2 mm. Mechanical tensile test and hardness test have been carried out to characterize the formation of weld nugget growth for different welding schedules. The results of the experiments showed that the growth of spot weld is strongly affected by the usage of materials with different thickness or types. The macrostructure of weld nugget also shows distinguishable differences in weld growth for the both mentioned cases. The tensile test was carried out on standard size samples but with different thicknesses and materials. It shows difference in yield strength for the same welding schedules. Meanwhile the hardness of welded materials varies from one another significantly but the hardness distribution along the welded areas seemed to almost same for each category of base metals.**

***Keywords*— Spot Welding of Mild Steel; Spot Welding of Stainless Steel, Spot Welding of Different Material and Thickness.**

I. 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 together and forces a high current to pass through it. The growth of weld nugget is determined by its controlling parameters i.e. the current, pressure, weld time, and electrode tips [2]. The other factors that influence the weld growth are electrode deformation, material properties, corrosion and gaps between work sheets [3]. Automotive industry is one of the main industries that use spot welds to weld its metal structures. To date, a car's body may contain an average of 3000-4000 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 body assemblies. So far many researches have been done on spot welding for various material such as low carbon steel, nickel, aluminium, titanium, copper alloy, stainless steel, austenitic stainless steel, galvanized low carbon steel, zinc coated steel, magnesium alloy and high-strength low alloy steel[1,2,4,8,9] but the mild and stainless steels are still widely preferred material for low cost metal assemblies. As such, this paper concentrates on the metallurgical study of the mild steel and the 302 authentic stainless steel and investigates the ability of producing sound welds using these metals. Welds were tested using tensile-shear [4,5] test and hardness test[7].

II. EXPERIMENTAL

The formation of weld is mainly influenced by controlling parameters of spot welding, as stated before. In this experiment, the pressure is kept constant at 3 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 of two different materials (mild steel and stainless steel). Table 1 shows the chemical composition properties of materials and table 2 shows the weld schedule that were used for this test.

TABLE 1 Chemical Composition

Mild Steel	
Element	Maximum wt%
C	0.23
Mn	0.90
P	0.04
S	0.05
302 Authentic Stainless Steel	
Element	Maximum wt%
C	0.15
Cr	17-19
Ni	8-10
Mn	2.00
Si	1.0
S	0.03
P	0.04

The test was primarily conducted to study the difference in growth of weld nuggets between these metals. We have varied the parameters from lower range of weld schedule (Pressure= 3 bar; current= 8 kA; time= 8 cycles) to higher range of weld schedule (Pressure= 3 bar; current= 12 kA; time= 12 cycles) to analyze the nugget growth as well as the weld strength. The sample size was maintained the same (25mm x 200mm) throughout the experiment but thicknesses and materials varied (Figure 1).

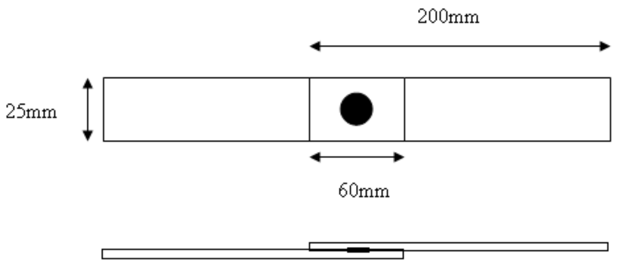

FIGURE 1 Test Sample

The tensile-shear (Figure 2) test was carried out to determine the yield strength of spot welded samples and also analyze the formation of weld nuggets. The ultimate tensile strength (UTS) was taken after which the breaking of weld occurred.

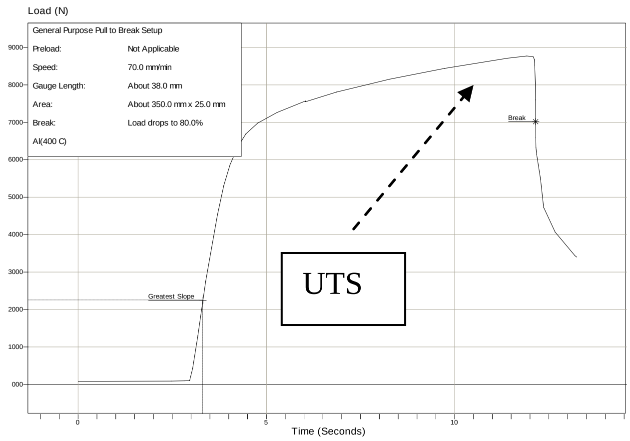

FIGURE 2 Tensile-Shears

The weld schedule was varied to analyze the weld formability on both the test materials. The samples are all welded using 50KVA spot welding machine. The pressure of electrodes was kept at 3bar; the current was increased for three level; 8 kA, 10 kA and 12 kA; the time cycle was also increased for three level; 8 cycle, 10 cycle and 12 cycle. Since the material is not coated, it does not require any pre-heating weld time to do so. Hence any additional set up was not made. Total of forty five (45) weld schedules were developed and 5 samples were considered for each weld schedule. An average strength value of the 5 samples was taken into account.

TABLE 2 Weld Schedule

Samples	**Materials (MS / SS)**	**Thickness (mm)**	**Pressure (Bar)**	**Current (kA)**	**Weld Time (Cycle)**
1-5	MS & SS	1 & 2	3	8	8
6-10	MS & SS	1 & 2	3	10	8
11-15	MS & SS	1 & 2	3	12	8
16-20	MS & SS	1 & 2	3	8	10
21-25	MS & SS	1 & 2	3	10	10
26-30	MS & SS	1 & 2	3	12	10
31-35	MS & SS	1 & 2	3	8	12
36-40	MS & SS	1 & 2	3	10	12
41-45	MS & SS	1 & 2	3	12	12

MS = Mild Steel ; SS = Stainless Steel ; mm = Mille Meters ;

kA =Kilo Amperes Bar = Bar and Cycle = Mille Seconds

The welded nuggets have also been analysed for hardness distribution along the welded zone and also the hardness of welded and un-welded areas. The hardness was measured for 5 repetitions along the diameter of nuggets using Rockwell Hardness Tester. Forty five samples were picked to do so. The results are graphically shown in Figure 6 and 7.

III. RESULT AND DISCUSSION

The entire weld schedule is divided into 3 groups; group 1, group 2, group 3 to show the weld time increment (8, 10&12 cycle). Each group shows the weld current increments from 8 to 10 and 10 to 12 kA as well. Each testing uses few samples to obtain an average of tensile strength.

For the 1mm-mild steel and referring to Group 1 (Figure 3), the tensile strength increases from the 1st weld schedule to the 2nd weld schedule and consecutively drops at the 3rd weld schedule. This is because from the 1st weld schedule to the 2nd weld schedule, weld current increases from 8 kA to 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 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 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 [1]. The similar pattern was also found for the other set of welding schedules; ie 2, 5 and 8 and also 3, 6 and 9. Comparison is done with the mild steel and stainless steel and referring again to Group 1. Same pattern of analysis for the mild steel was also seen on the stainless steel. However the weld strength achieved in stainless steel is greater than the weld strength achieved in mild steel. This is because the inherent materials properties of these steels where tensile strength of stainless steel is higher then mild steel [1, 6].

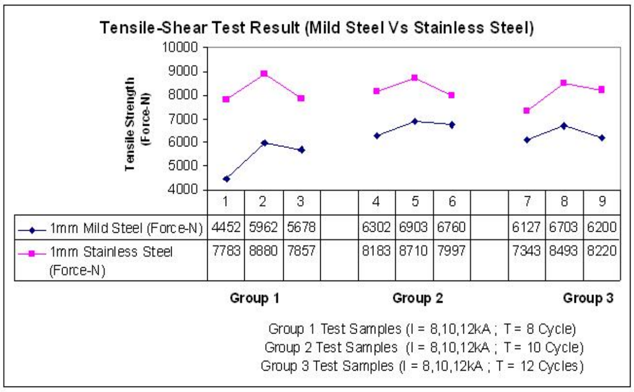

FIGURE 3 Tensile Shear Force Vs Weld Samples (1mm)

Further test was carried out on the 2mm mild steel and stainless steel as shown in Figure 4. For the 2mm mild steel and referring to Group 1, the tensile strength increases from weld schedule 1 till weld schedule 3. This is because of the increase in weld current from 8 kA to 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), weld schedule 3 shows a reduction in strength with 1 mm thickness due to expulsion. However with 2 mm thickness, expulsion was avoided because the current supplied was not sufficient to cause overheating at the weld zone [1, 6].

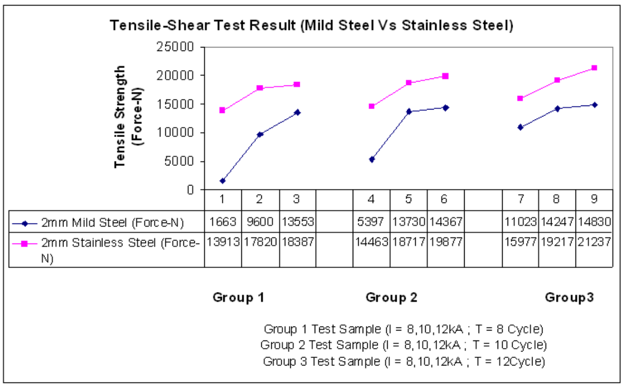

FIGURE 4 Tensile Shear Force Vs Weld Samples (2mm)

In general an increase in weld strength was noticed for the 2mm thickness compared to the 1mm 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. However at high current and weld time, the amount of heat supplied was sufficient to produce a sound weld. Mathematically the heat generated by electrode is given by

$$E = I^2_{rms} \cdot R \cdot T_s = I^2_{rms} \cdot \frac{\rho \ell}{A} \cdot T_s$$

Where,

I^2_{rms} is the true rms welding current; R is the sheet resistance; ρ is the sheet electrical resistivity; ℓ is the total sheet thickness; A is the spot area and Ts is the total welding cycle.

Since total sheet thickness is proportional to heat generation, strength achieved in 2mm thickness sheets was higher than 1 mm thickness sheets. Similar observation was also discussed by Oikawa(2007)[11]

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, in this case. 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 centre of welded area [12]. 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 [12]. Figure 5 shows the different weld failures of test samples.

FIGURE 5 Tensile Tested Samples

Hardness test was done using the Brinell-Rockwell Tester to study the hardness of weld obtained for both mild steel and stainless steel.

Hardness of welded area versus un-welded area yields a distinguishable difference on hardness values for both materials. The welded area has higher hardness compared to the un-welded. This might be because of the melting at the weld zone to produce weld nugget that has caused work hardening [10] as shown in Figure 6 and 7. However the hardness distributions along the welded areas were not constant at all. It fluctuates without any relationship between them. These have been graphically shown on figure 6 and 7.

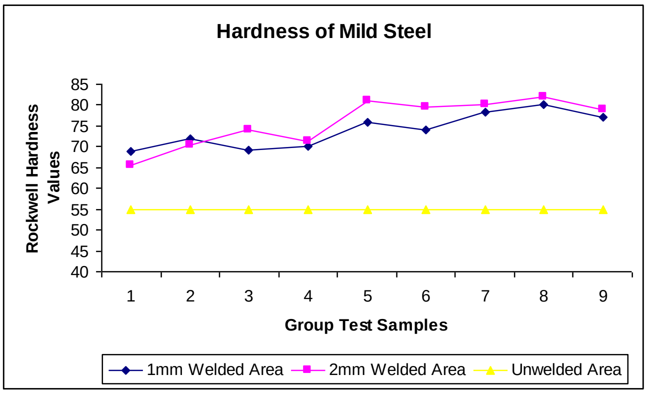

FIGURE 6 Rockwell Hardness (HRB) of Mild Steel

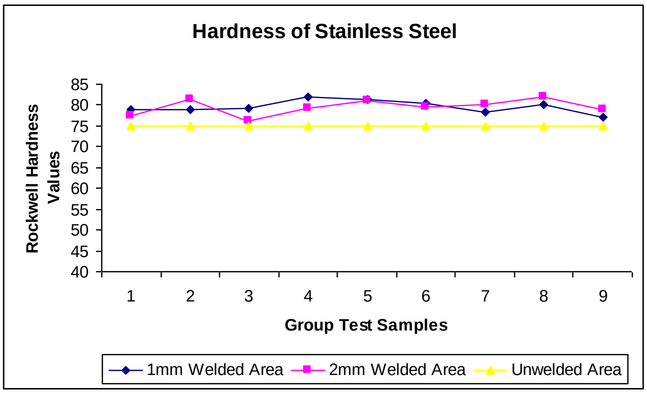

FIGURE 7 Rockwell Hardness (HRB) of Stainless Steel

The metallurgical studies have shown thorough details about the nugget formations and expansions. Macro structures of nuggets were observed for 1mm and 2mm but only few included here to show the nugget growth. The conditions of nuggets formation were described below at the macro structures.

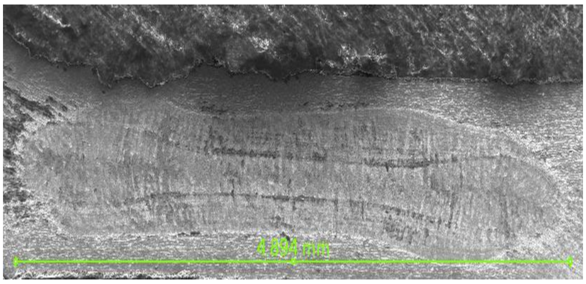

FIGURE 8 MS-1mm (Improper Weld because of insufficient current and time)
(**8kA**, 10Cycle, 3Bar – 4.094mm)

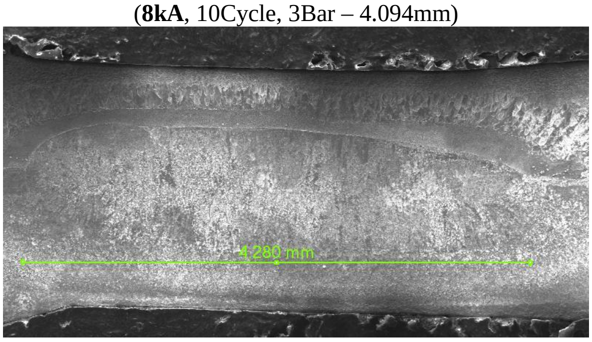

FIGURE **9** MS-1mm (Better Weld due to sufficient current and time)
(**10kA**, 10Cycle, 3Bar – 4.280mm)

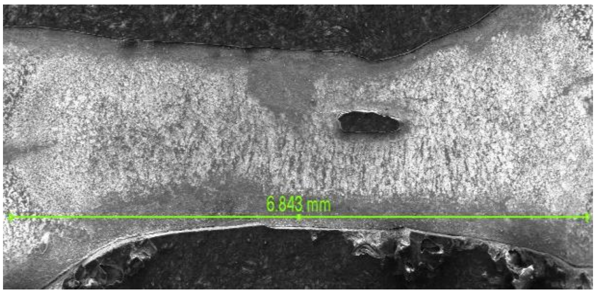

FIGURE **10** MS1mm (Thickness was reduced due to expulsion. So deformed-outlook)
(**12kA**, 10Cycle, 3Bar – 6.843m)

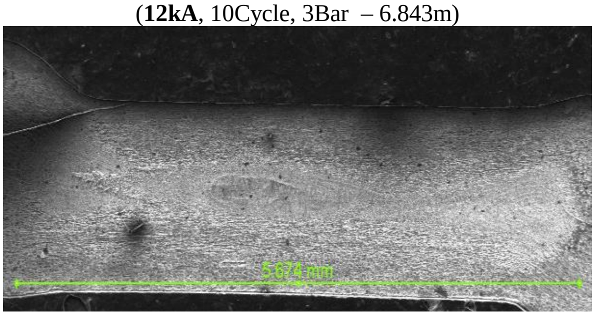

FIGURE 11 SS-1mm (Improper Weld because of insufficient current and time)
(**8kA**, 10Cycle, 3Bar – 5.674mm)

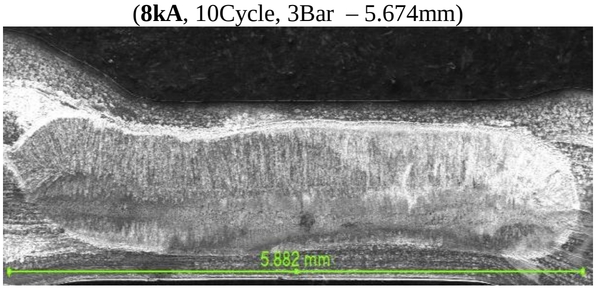

FIGURE 12 SS-1mm (Better Weld due to sufficient current and time)
(**10kA**, 10Cycle, 3Bar – 5.882mm)

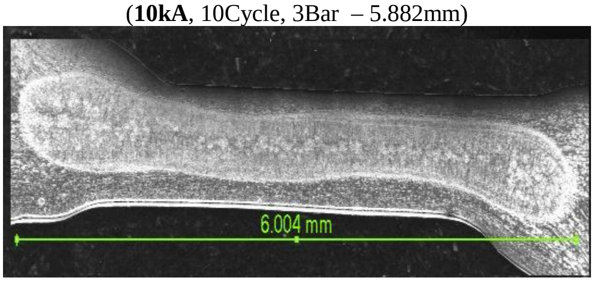

FIGURE 13 SS-1mm (Thickness was reduced due to expulsion. So Thickness reduced)
(**12kA**, 10Cycle, 3Bar – 6.004mm)

The figure 8, 9, and 10 are showing the microstructure for 1mm mild steel nuggets' growth from insufficient parameters' case (figure 8) to an expulsion case (figure 10). The following figures 11, 12, 13 are showing the same situation (as how mild steel was developed) for 1mm stainless steel.

IV. Conclusions

This paper looks into the RSW characteristic of mild and stainless steel of 1 and 2mm of thickness. It concludes that:

1) Increase in current and weld time showed almost proportional increment in strength until expulsion limit occurs.
2) Higher thicknesses of materials had produced higher tensile strength due to strong bounding.
3) Proportional diameter increments have been found on the welded areas while increasing the weld schedules for both materials.
4) Stainless steel had offered higher tensile strength as compared to mild steel because of the martensite properties.
5) Mild steel had produced rapid increments of hardness at the welded areas as compared to stainless steel

Acknowledgment

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