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An Experimental Investigation on Spot Weld Growth on Dissimilar Joints of 304L Austenitic Stainless Steel and Medium Carbon Steel (Part 1)

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ABSTRACT

Carbon steels and stainless steels are more frequently welded joints than any other materials because of their weldability characteristics. So the spot welded joining characteristic of these two materials are discussed in this paper. The experiment was conducted on medium carbon steel and 304L austenitic stainless by varying the process controlling parameters; such as welding current, welding time and electrode pressing force. As such two sets of data were collected to characterize the formation of spot weld using pneumatic based 75kVA spot welder. The first set was made for the variation of welding time and current whereas the second was made for the variation of welding current and electrode force. The welded specimens are finally underwent the tensile test, hardness test and metallurgical test to characterize the weld growth. The weld nugget growth was noticed for the welding current and weld time increment except the electrode force. By increasing the electrode force, the process resistances were reduced and consequently the weld nugget was reduced. Moreover the effect of heat imbalance was clearly noticed in the weld nuggets due to different electrical and chemical properties.

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1. INTRODUCTION

Joining the dissimilar materials becomes very popular among mechanical assemblies, especially in the car assemblies. For an instance, the car doors assemblies are joined of DP600 and AISI 304 or DP800 and AISI 304. However the main structure of car bodies are made of DP 600 and DP800; supported with the use of AISI 304 materials for high mechanical strength. In this experiment the dissimilar joints of medium carbon steel and 304 stainless steels are experimented using pneumatic based spot welder [1]. This study may lead to the consideration of medium carbon steels in the car assembly which may offer high strength joints with low cost as compared to other materials. Technically considered, the spot weld growths are mainly developed due to the basic controlling parameters such as current, welding time, electrode force and electrode tips [2]. In this experiment: the welding current, welding time and electrode pressing force are all increased from lower range of weld lobe to higher range of weld for 1mm base metals while electrode tip remained unchanged.

2. RESEARCH METHOD

The base metals were rectangular in shape with equal size (200mm x 25mm x 1mm) as shown in figure 1 and its chemical properties are tabulated in table 1. A pair of water cooled copper electrodes with tip (truncated) diameters of 5 mm was used to join these base metals. A pair of test sample was initially placed on the top of lower electrode (tip) of the welder as overlaying 60mm on each other and then the initiating pedal was pressed. The heating process was started right after the squeezing cycles is ended. The welding current was immediately released then; in accordance with the given preset values. Thereafter the electrode pressing mechanism (pneumatic based) consumed some time for cold work and eventually returned to the home position of upper electrode. These process controlling parameters (welding current, weld time and electrode pressing force) are set before the welding process starts based on the ranges of weld lobe. The weld lobe was predicted by the spot welders' manufacturer and therefore the values were easily selected in this experiment (figure 2).

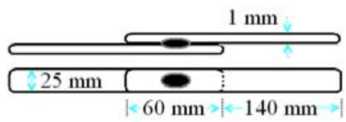

Figure 1. Test sample

Table 1. The material properties of medium carbon and 302 austenitic stainless steels

304L (2B) Austenitic stainless steel							
Element	C	Cr	Ni	Mn	Si	S	P
	0.048	18.12	8.11	1.166	0.501	0.006	0.030
Medium carbon steel							
Element	C	Cr	Ni	Mn	Si	S	P
	0.40			0.90	0.006	0.050	0.040

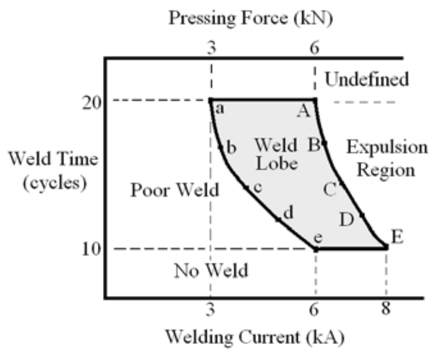

Figure 2. Weld lobe for 1mm sample sheets.

Based on the weld lobe's limitation for upper and lower weldment; the weld schedules were developed (table2) to conduct the entire experiment to understand the basic parameter variation that cause the weld growth in 1mm- medium carbon and stainless steels. The combinations of the eighteen (18) weld schedules were developed for two conditions as for: a) the current and weld time variations and b) the current and force variations as shown in table 2. Seven samples were welded on each of the weld schedule; as tensile test used five, hardness test used one and metallurgical test used the balance-one [3].

Table 2. Weld schedule

Both				a) Current and Weld Time		b) Current and Force	
Sample No	Weld Schedule	Electrode Tip (mm)	Current (kA)	Time (cycle)	Force (kN)	Time (cycle)	Force (kN)
1-5	1	5	6	10	3	10	3
6-10	2	5	7	10	3	10	3
11-15	3	5	8	10	3	10	3
16-20	4	5	6	15	3	10	4.5
21-25	5	5	7	15	3	10	4.5
26-30	6	5	8	15	3	10	4.5
31-35	7	5	6	20	3	10	6
36-40	8	5	7	20	3	10	6
41-45	9	5	8	20	3	10	6

The welded samples of base metals were later undergone common strength tests that of the tensile shear tests in this experiment. Besides, the hardness test was also carried out to understand the hardness changes due to the solidification process at the welded areas and also its' surrounding areas [4]. The results of these two tests were insufficient to understand the nuggets characteristic and therefore the metallurgical study was carried out to complete the analysis in part 1.

3. RESULTS AND ANALYSIS

3.1 Tensile Test Results

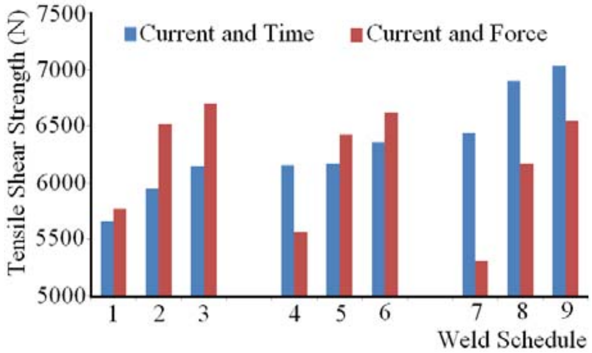

Figure 3. Tensile shear test results

The tensile-shear test (figure 3) was carried out using hundred kilo Newton (100 kN) capacity machine to determine the strength of spot welded samples of both ((current and weld time; current and force)) sets. The crosshead speed was maintained at 70 mm/min. The ultimate tensile strength (UTS) was taken as the maximum weld strength after which the weld joints have broken. Average strength values from the five samples were taken as the equivalent strength of that particular weld schedules. As for the weld schedules from 1 to 2 and 2 to 3 were analyzed; the strength increment was noticed due to the increment of welding current from 6 to 7 and 7 to 8 kA respectively. The similar increments were also noticed for the following weld schedules of 4, 5 and 6 as well as 7, 8, and 9. This obviously states that increase in current has caused increase in strength due to the increment of diameters, accordingly. Moreover the welded nuggets were seemed to be asymmetrical in shape and had two diameters to represent the mixed steel joints. The figure 4 shows the changes of diameters with respect to current; weld time and force changes on both sides. The stainless steel side nuggets seemed to be wider and higher as compared to carbon steel sides. However both sides have shown proportional changes. The currents increment was found on both sets. When the current and weld time incremental set is considered: the weld time increases the strength as it increases the diameters in fact. This fulfills the Joule's law of heating ($Q = I^2Rt$); where Q represents the heat developed; I represents the current; R represent the resistance and t represent the time given. By increasing either current or weld time; the heat supplied at the electrode tip is also proportionally increased and therefore the corresponding diameters increments are obtained. However when the current and force incremental set is considered: the force increment has caused drop in strength because of the drop of the static resistances. As for the increment of force from 3 to 4.5 and 4.5 to 6 kN; the tensile strength is reduced because the resistive components are reduced in the heating process which is another proportional coefficient of heat formula.

Thus: the resistance is reduced by producing high electrode pressing force as it does changes in length (ℓ) which is a proportional coefficient of resistive equation. The bulk resistance is computed as $R = \rho \ell / A$; where ρ is the resistivity (CS=1.611×10^{-7} Ω.m; SS=6.89×10^{-7} Ω.m); ℓ is the length (1mm) and A is the contact area (19.63 μm^2) of electrode. The electrode tips were not changed at all so that the resistance is mainly affected due to changes in bulk resistance with respect to material specific resistances. Similar types of changes have also seen in the tensile test result when the diameters of weld nuggets are reduced.

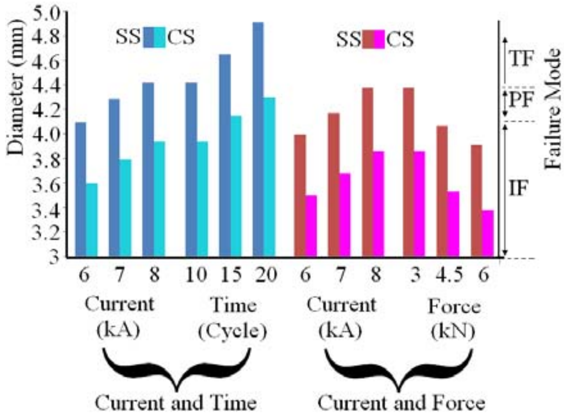

Figure 4. Diameter of weld nuggets and failure modes

3.2 Failure Modes

Having considered the failure modes (figure 5(a)) of tensile test of dissimilar joints; we have noticed that the breaks happened in accordance with weld types. A poor weld has interfacial fracture (IF) (figure 5(b)) and the shear-force seemed to be falling below 5.5kN for 1mm base metals. The breaks are happened in the weld nuggets due to poor joint. A moderate-good weld has tear from either side of base metal (PF) (figure (5c)) and; the shear force falls between 5.5 to 6.3kN. Here it commonly happened in the carbon steel sides. Furthermore a good weld (figure (5d)) has better bounds between sheets and therefore it requires higher shear force to break the joints. In this case it was just above 6.3 kN and tear was button pullout (TF).

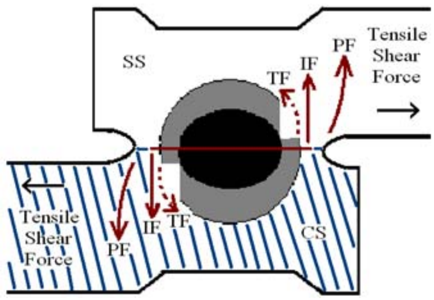

Figure 5(a). Failure modes

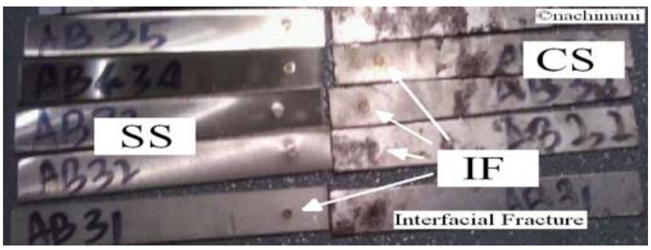

Figure 5(b). Interfacial failures (IF) in group

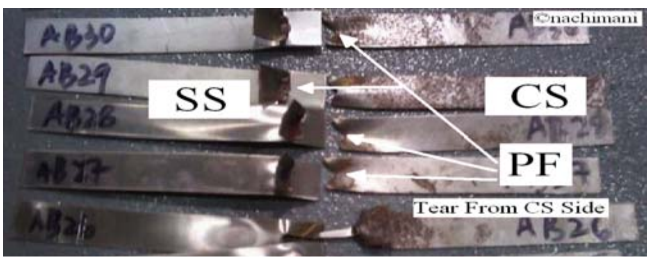

Figure 5(c).Tear from one side (PF) failures in group

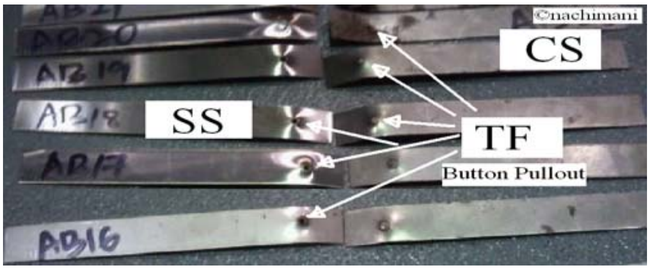

Figure 5(d). Tear from either side or button pullout (TF) failures in group

3.3 Hardness Test Result

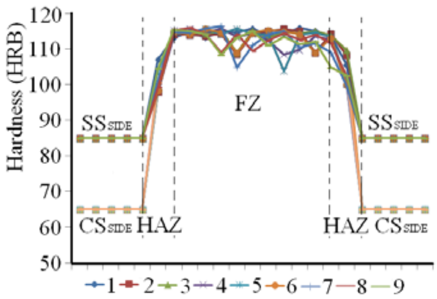

Figure 6. Hardness of dissimilar joint (weld schedule 1-9)

As for the hardness test, the fusion zones (FZ) seemed to be asymmetrical joints. It has been slightly hardened at stainless steel side (from 86 HRB to 115 HRB); and almost doubled (from 65 HRB to 115 HRB) at carbon steel side due to the solidification process. However once the contacted areas of both metals are molten; it becomes dissimilar region. The heat affected zones' (HAZ) hardness was slightly lower (95 HRB at CS; 105 HRB at SS) than the fusion zone but higher than the base metals. However the half-oval shape of heat affected zones was easily noticeable in carbon steel sides because of thermal conductivity. Similar region (HAZ) was not seen in any stainless sides but the chances are high if the welding process is prolonged. Besides, the HAZ was not seen in all side of carbon steel but some. The hardness has been measured for all the nine weld schedules (figure 6).

3.4 Metallurgical Study

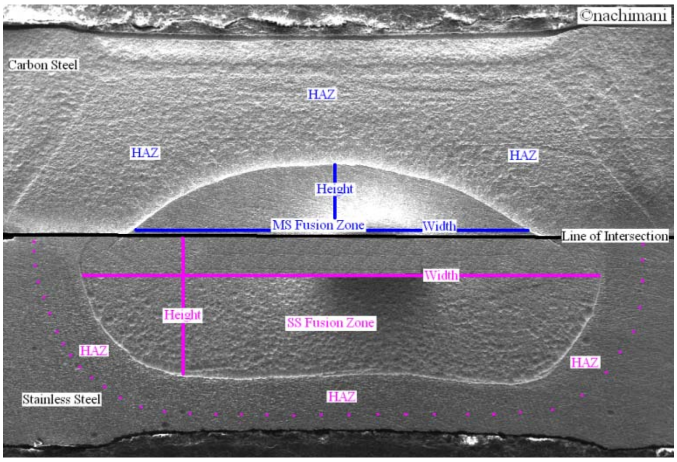

Figure 7. Dissimilar joint's macro view

The metallurgical test was conducted to view the micro and macro structural changes. Actually such test easily helps to predict the exact size of fusion and heat affected zones [5]. The typical outlook of the fusion zones seemed to be coarse grains while the heat affected areas seemed to be finer grains. The macrographs of these types of patterns have been noticed throughout the experiment and shown on figure 7, for instance. The parameters changes have directly influenced the grains at both: the fusion zones and the heat affected zones. However the heat affected areas are not clearly visible in many welds and also vary from one weld schedule to another. A typical macrograph of weld nugget is shown figure 7 to identify the weld zones and corresponding diameters. The thermal conductivity coefficients are higher in carbon steels as compared to stainless steels; therefore wider ranges of heat affected zones (HAZ) were noticed. But the thermal expansion coefficient rate is lower which alters the chemical properties; so that the width and height of fusion zone was shorter. On the other side, the stainless steel seemed to have higher thermal expansion coefficient but lower thermal conductivity. So the heat affected zones (HAZ) was smaller but the fusion zone was wider as compare to mild steels. Technically this phenomenon is called as heat imbalance. Table 3 lists some values for carbon and stainless steels.

Table 3. Electrical properties of carbon and stainless steel

Properties	Stainless steel	Carbon steel
Density	8.00 g/cm^3	7.85 g/cm^3
Melting Point	1400-1450°C	1426- 1538°C
Electrical Resistivity	6.89 x 10^{-7} Ω.m	1.611 x 10^{-7} Ω.m
Thermal Conductivity	16.2 W/m.K (min)	54 W/m.K (min)
Thermal Expansion	17.2 x 10^{-6} /K	12 x10^{-6} /K

Further to these macrographs analysis for diameters, the experimentation was also extended to understand the chemical and micro structural changes[6]. The chemical mixtures that existed at welded areas versus the base metals (carbon and stainless steels) were analyzed using energy disperse X-ray system (EDX-System). The results are graphically shown in figure 7 (a, b and c). Figure 7(a) determines the chemical properties at welded nucleus while figure 7(b) does it at the stainless steel side and figure 7(c) does it for carbon steel side.

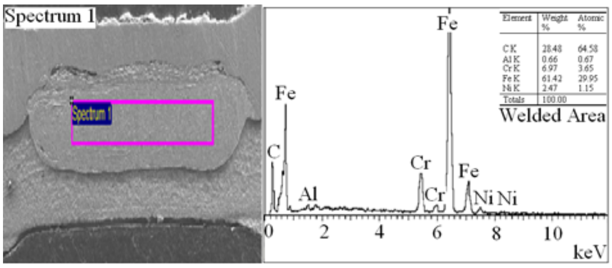

Figure 7(a). Chemical properties at the dissimilar steels' fusion zones

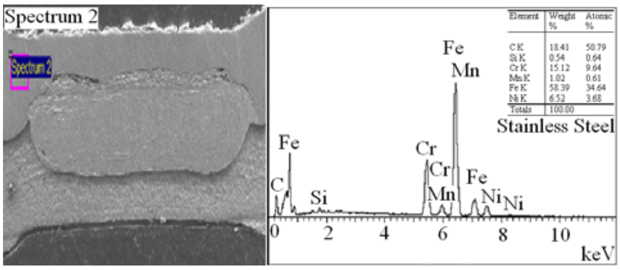

Figure 7(b). Chemical properties at the stainless steel sheets

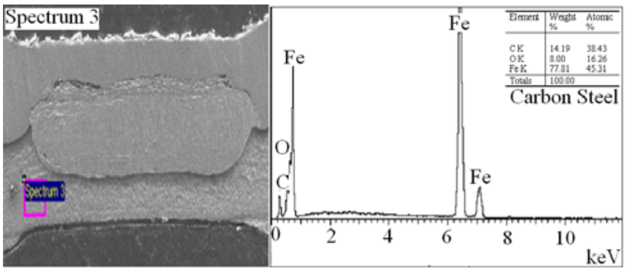

Figure 7(c). Chemical properties at the carbon steel sheets

The solidification process of the molten base metals causes the micro structural changes. The carbon content is significantly increased (28.48%) at the fusion zones after compared with stainless (18.41%) and mild steel (14.19%) sides. The fusion process adds all the carbon contents of both base metals and also dissipates some of the other chemical compositions in heating process. So the final carbon content of fusion zone was seemed to be slightly increased in percentage as compared to the base metals. Besides the chromium content from stainless steel side (15.12%) is also reduced to 6.97% and the nickel content is from 6.52% to 2.47%. However the primary content of Iron (Iron -Fe) occupied the zones with major percentage. Figure 8 shows the typical zones' orientation in the mixed steel joints.

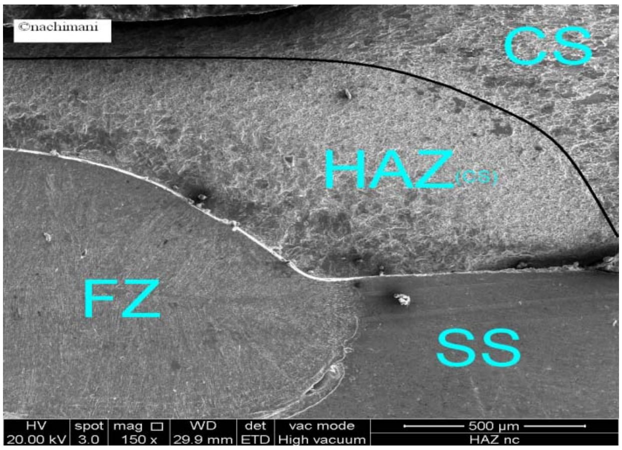

Figure 8(a). Macrograph of weld zones

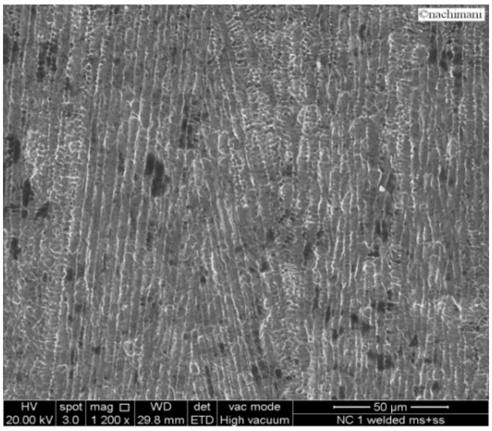

Figure 8(b). Weld nuggets' structure (austenitic-ferritic mixture)(FZ)

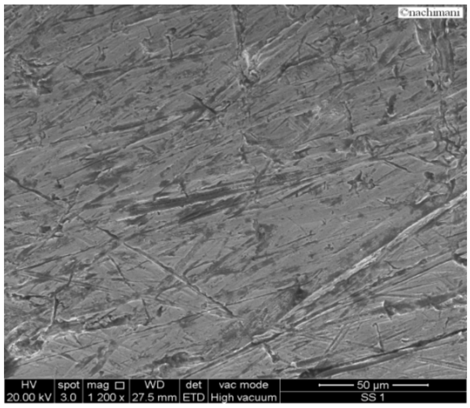

Figure 8(c). Stainless steel side (SS)

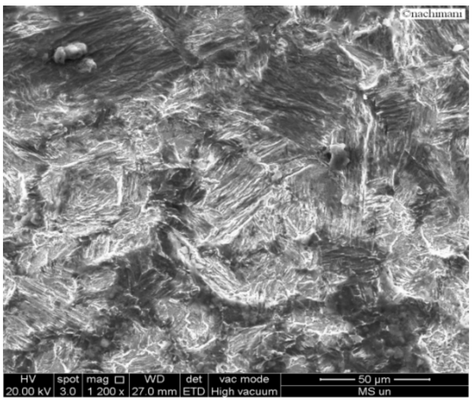

Figure 8(d). Carbon steel side (CS) (Coarse grains)

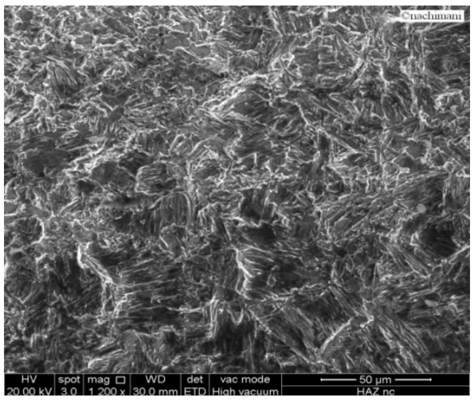

Figure 8(e): HAZ of carbon steel side (HAZcs Refined grains)

Figure 8(a) shows the boarder orientation of metals grains; Figure 8(b) shows welded areas structure which contained the austenitic-ferritic rich mixture [7]. Figure 8(c) shows the original grain matrix of stainless steel whereas figure 8(d) shows the original grain matrix of medium carbon steel. Figure 8(e) shows the refined grains of heat affected zone of medium carbon steel.

4. CONCLUSION

The analysis of dissimilar spot welded joints of medium carbon and stainless steels of 1mm sheets conclude that:

1. The parametric changes (current and time) have resulted proportional changes in tensile strength regardless of base materials. Both current and weld time have caused diameters increments which increases bonding strength of weld pairs.
2. The parametric changes (current and force) have resulted proportional changes in tensile strength for current but inversely proportional for force regardless of base materials. Force increment has caused diameters decrement which decreases bonding strength of weld pairs.
3. The hardness of welded areas has been increased regardless of materials but the hardness distributions along the welded areas are fluctuating and instable.
4. The fusion zones of carbon steel are shorter than the stainless steel but the heat affected zones are wider than the stainless steel.

Asymmetrical views of nugget growths were seen due to the nature of the materials; particularly the electrical and thermal characteristics.

ACKNOWLEDGEMENTS

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