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STUDY THE EFFECT OF ADDITION COPPER LAYER FOR SPOT WELDING OF LCS-304LSS JOINTS

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ABSTRACT

The resistance spot welding of dissimilar materials is generally more challenging than that of similar materials due to differences in the physical, chemical and mechanical properties of the base metals. The influence of the primary welding parameters affecting the heat input such as; peak current on the morphology, micro hardness, and tensile shear load bearing capacity of dissimilar welds between Low Carbon steel and 304LSS joints and LCS-Cu-304LS joints investigated in this study. This study has been done in two stages: First, welding LCS -304LSS in weld parameters changed, after addition Copper sheet between LCS and 304LSS sheets in Optimum Parameters (8KA welding current, 20Cycle weld time and15.6N) force of electrode. Results shown that the increasing in Weld current, weld time and force of electrode led to increase of the mechanical properties for joints and the addition Copper layer between LCS and 304LSS led to reduce the mechanical properties for joints such as (the Maximum Load and Hardness)and the failure mode changed from pullout in LCS-304LSSjoints to Interfacial mode for LCS-Cu-304LSSjoints .

KEYWORDS: Resistance Spot Welding, Weldability, Low Carbon Steel, 304lstainless Steel Steel, and Copper Layer, Tensile-Shear Load, Welding Parameters, Mechanical Properties

INTRODUCTION

Resistance spot welding is one of the oldest of the electric welding processes in use by industry today. It came into use in the period 1900-1905 [1]. The principle of the resistance spot welding is that the strong current passes through two metal plates the electrodes, as shown in figure 1 The contact area is heated up for its contact resistance, which melts the metal plates and joins two metal plates together by the electrode force. Most of the heat concentrates on the contact surface because the resistance value is the largest in the contact area [2**].** The flow of current against the base metal resistance causes heat development and local melting of the metal sheets The heat generated, Q, is given by I2Rt, where I is the current, R is the resistance and t is the time for which current flows. Once the current flow has stopped the melted volume solidifies. The melted and solidified region of the base metals is referred to as the weld nugget. It consists of three zones: the fusion zone (FZ), the heat affected zone (HAZ) and the base metals (BM). The heat generated in the molten zone is dissipated by thermal conduction through the base metal, resulting in the formation of the heat affected zone. The weld nugget size is determined primarily by the welding current, welding time, electrode pressing force and electrode Tip diameter. These are the four main control parameters that enable a weld nugget to be formed that provides adequate joint strength for the planned application [3]. The growth of weld nugget is determined by its controlling Parameters (i.e., the current, force, and weld time).The other factors that influence the weld growth are electrode deformation, material properties, corrosion and gaps between work sheets. 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 studies have been done on spot welding for various materials such as low carbon steel, nickel, aluminum, titanium, copper alloy, stainless steel, austenitic stainless steel, galvanized low carbon steel, zinc coated steel, magnesium alloy and high-strength low alloy steel[4].

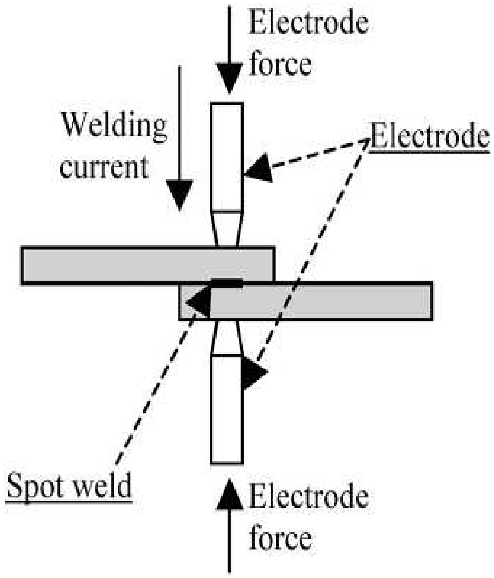


Figure 1: Illustration of Resistance Spot Welding

EXPERIMENT

The formation of weld is mainly influenced by controlling the parameters of spot welding, as stated before. In this experiment, the weld current, weld time and force of electrode) were varied. The test was conducted with a 1mm thickness of two different materials (Low Carbon Steel and 304LSS) and Copper sheet with thickness 0.45 mm. Table (1) shows the chemical composition of the materials. The test was primarily conducted to study the difference in weld strength and hardness between these metals. We have varied the parameters as in Table (2) below to analyze the weld strength as well as hardness. The sample size was maintained the same (80 mm ×30mm) with thickness of 1 mm as shown in figure 2. An average strength value of the 3 samples for each schedule was taken as shown in Table (2).

Table 1: Chemical Composition LCS and 304 Lsteels and Copper

Element% Steel	C	Fe	Si	Mn	Cr	Ni	Mo	V	Nb	Cu	Pb	Bi
LCS	0.015	99.0	0.01	0.273	0.0319	0.203	0.022	0.0066	0.0273	0.0466	0.025	
AISI304L	0.09	68.6	1.66	1.3	18	8	0.394	0.04	0.059	0.408	.0327	
Pure copper										99.9	0.005	0.001

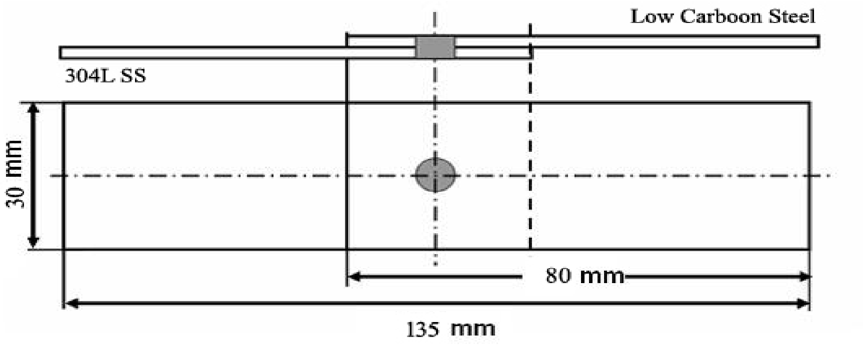


Figure 2: The Dimension of the Sheets

Table 2: Weld Schedule

Sample No.	Material	Electrode Tip(mm)	Current (KA)	Weld Time	Electrode Force (N)
1-3	LCS-304LSS	5	5	10Cycle	11.5
3-6	LCS-304LSS	5	6	10	11.5
6-9	LCS-304LSS	5	7	10	11.5
9-12	LCS-304LSS	5	8	10	11.5
12-15	LCS-304LSS	5	8	15	11.5
15—18	LCS-304LSS	5	8	20	11.5
18-21	LCS-304LSS	5	8	20	13.6
21-24	LCS-304LSS	5	8	20	15.6
24-27	LCS-Cu-304LSS	5	8	20	15.6

RESULTS AND DISCUSSIONS

3-1Tensile –Shear test of Welds for LCS-304LSS and LCS-Cu-34LSS Joints.

Figure 3 shows the effect of welding current on the shear strength of welds which indicate that generally increasing welding current led to increase the bearing load capacity. In other word increasing weld current from (4-to-8KA) respectively is caused increase in Maximum load and Shear strength), due to the increasing in welding current results in higher heat generation at the faying interface resulting in formation of larger fusion zone and increases the overall bonding area according to 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 equivalently increased and therefore the corresponding diameters increase. However, at high heat input welding condition (beyond 9KA), peak load is reduced due to expulsion at the faying interface [5, 6]

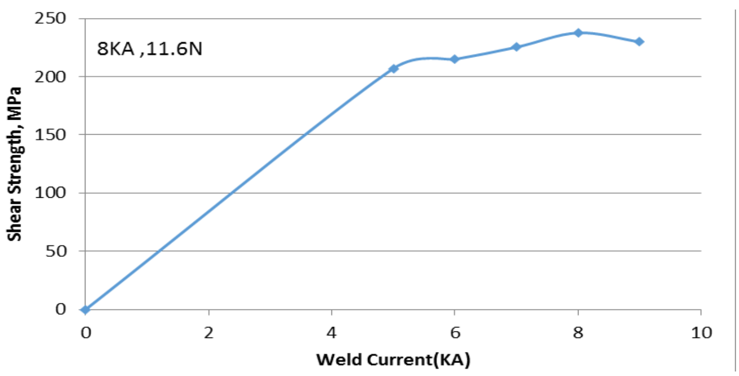


Figure 3: Effect the Weld Current on the Shear Strength of LCS/304 LSS Joints

Also the increasing in weld time and force of electrode led to similar results when increased welding current and Figure 4.

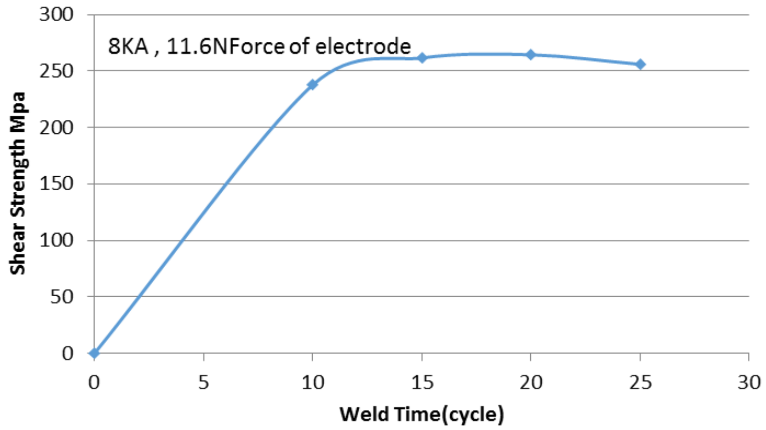


Figure 4: Effect the Weld Time on Shear Strength of LCS/304LSS Joints

The increasing of electrode force has caused drop in peak load because of the drop of heat when the electrode force beyond 90psi.the Max load is reduced because the resistive components were 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 shown in figure 5.

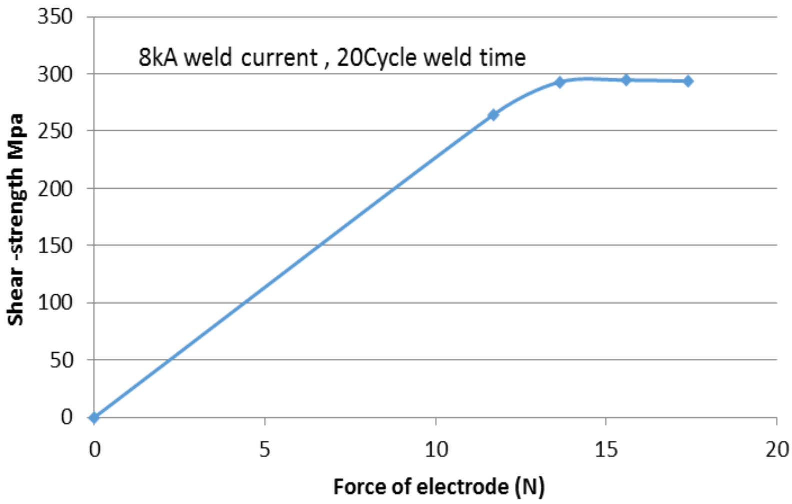


Figure 5: Effect the Pressure Electrode on Shear Strength of LCS/304L SS RWS

When the dissimilar joints LCS/AISI304L tested under tension -shear with add the copper sheet between the LCS and AISI304L in the optimum parameters(8KA, 20 Cycle and 15.6NForce of electrode), the peak load is equal to 4.62KN. In other words the Maximum load is reduced compared to the joints LCS/AISI304L, becausethe copper is element solubility limited in steel ,So poor bounding in welding joint. Results that is reduced the mechanical properties for the joint.

Microstructure of the Dissimilar LCS/304LSS RWS

A typical macrostructure of LCS/304LSS RWS reveals three distinct zones, fusion zone (FZ), heat affected zone(HAZ) and base metal(BM),as shown in figure 6.

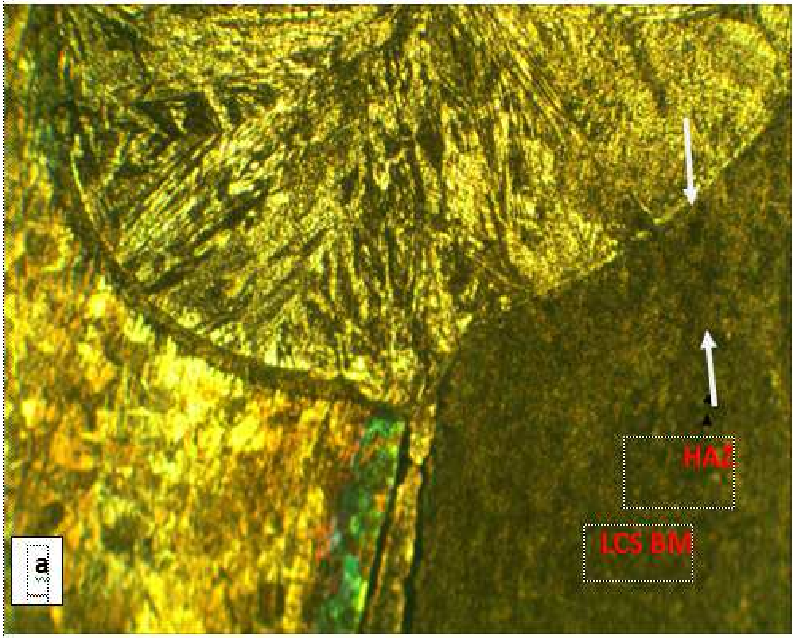


Figure 7a: Optical Micrograph of LCS/304LSS after RWS

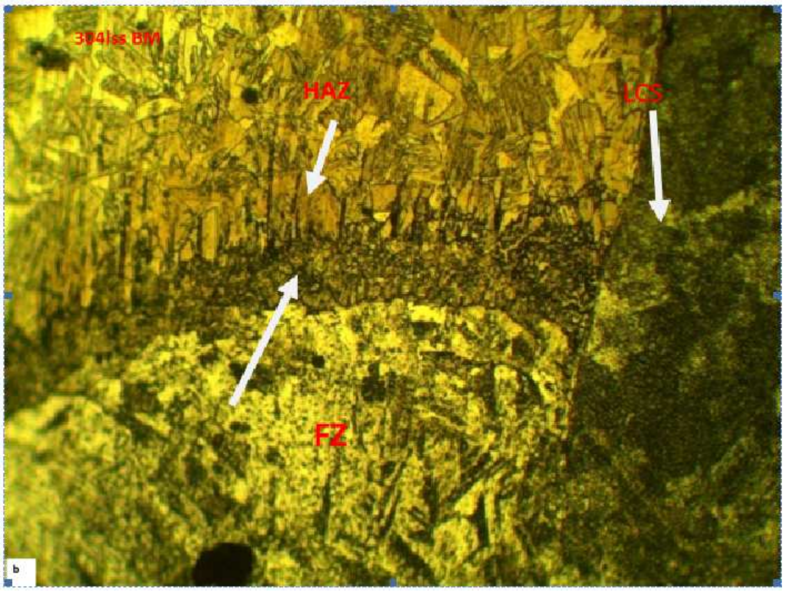


Figure 7b: Optical Micrograph of LCS/304LSS after RWS

Optical microscopes were used to examine the micro -structural variations as shown in figure 7. Figure 8 shows that the microstructure in the base metal basically consists of fully ferrite from low carbon steel side and austenitic from 304LSS side. Twins also shows in the structure of 304LS due to plastic deformation of austenitic stainless steel.

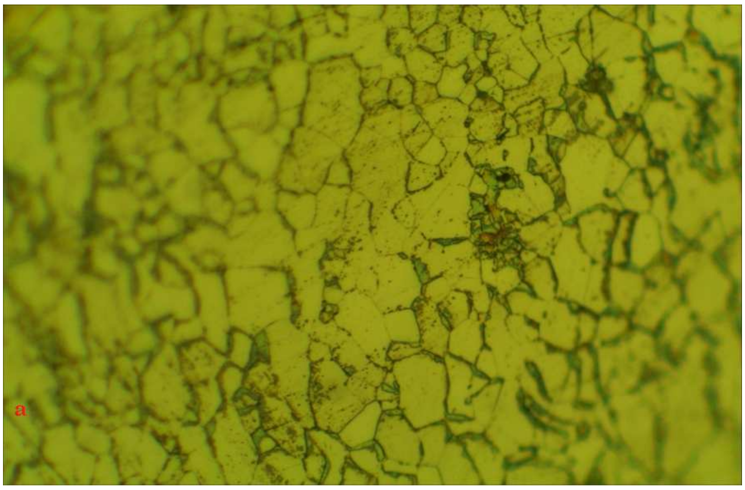


Figure 8a: Optical Micrograph Base Metal Microstructure of LCS

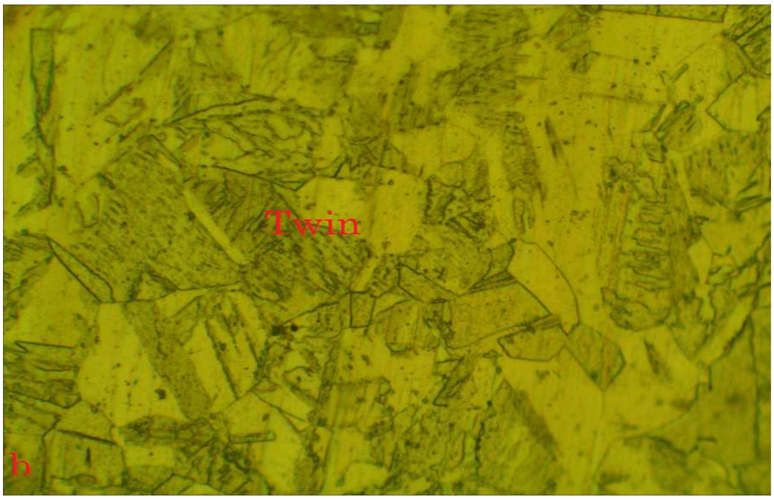


Figure 8b: Optical Micrograph Base Metal Microstructure of 304Lss

In fusion zone, phase transformation occurs. When the temperature is high (above melting points of the base metals), liquid phase formed and this liquid consist of the elements of two metals and may be one liquid. During cooling after welding process, solidification occurs and then solid state transformation occurs. Due to applied pressure during welding process (thermo mechanical), some changes take place in the microstructure in fusion zone. Applied high pressure on the metals causes squeeze the weld metal and induce phase transformation. Grains refine during thermo mechanical process during welding. Defects also formed during solidification such as porosity, segregation, etc. presence pressure works rearrangement of atoms and inclusions and refine the grains.

Microstructure of fusion zone of LCS/304LSS joint can be predicted using constitution diagrams (Schaeffer diagram), Figure 9. According to this diagram, the microstructure is nearly martensite, when dilution (defined as low carbon steel to 304Lstainless steel volume ratio in the weld nugget) is 50%.

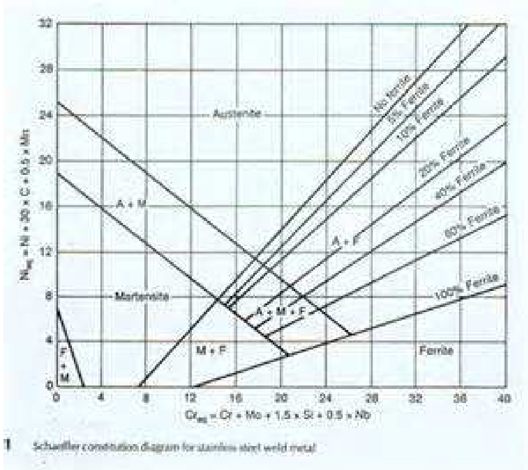


Figure 9: Schaeffer Diagram, Fusion Zone Microstructure Prediction, when Dilution is 50%

Also the Figure 10 shows that the microstructure at center of the FZ consists of marten site phase when Optical microscope. Phase transformation occurs during spot welding during heating and cooling of the joint materials, it is known very low carbon steel is low hardening during quenching from austentic temperature and 304L also has single phase called austenitic and this phase is stable at all temperatures. This stability of this phase due to alloys elements especially Ni element. Cold work or strain hardening induce austenitc phase to transform to martenstic structure of 304 L. Serve deformation during applied electrode force causes this phase transformation. This behavior of spot welding may be not occurs in such process of other fusion welding of 304LSS.

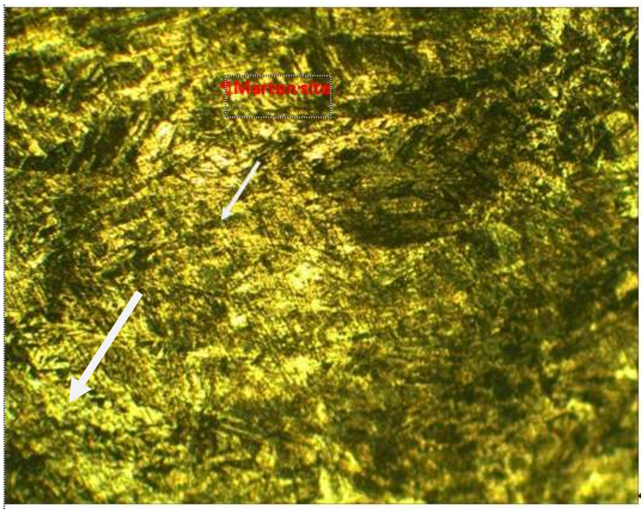


Figure 11: Optical Micrograph Weld Nugget Microstructure of Dissimilar LCS/304LSS RWS; Fusion Zone of Low Carbon/304LSS

The HAZ, near to FZ is often experiences solid state phase but no melting. The microstructure gradient (BM, HAZ and FZ) in LCS side from joint LCS/304LSS is shown in Figure 12 The HAZ in the near region from LCS side the temperature ranges fromA_{C3} and A_{C1}. The microstructure in this region is ferrite and Under A_{C1} the microstructure of HAZ consist of deform of ferrite by thermo- mechanical treatment and the grains size was changed.

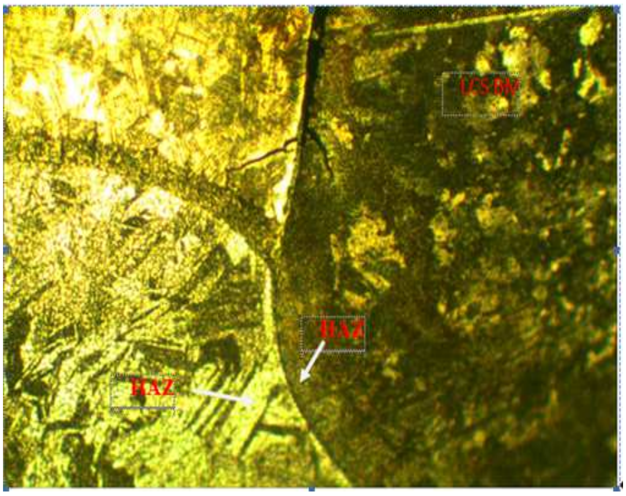


Figure 12: Optical Micrograph of HAZ Microstructure of LCS/304LSS RWS in LCS Side

On the other hand, for 304lSS side the microstructure at this region may be full austenite, during cooling no transformation occurred and the final microstructure remained austenite. Martensite is not observed in this region as shown in figure 13.

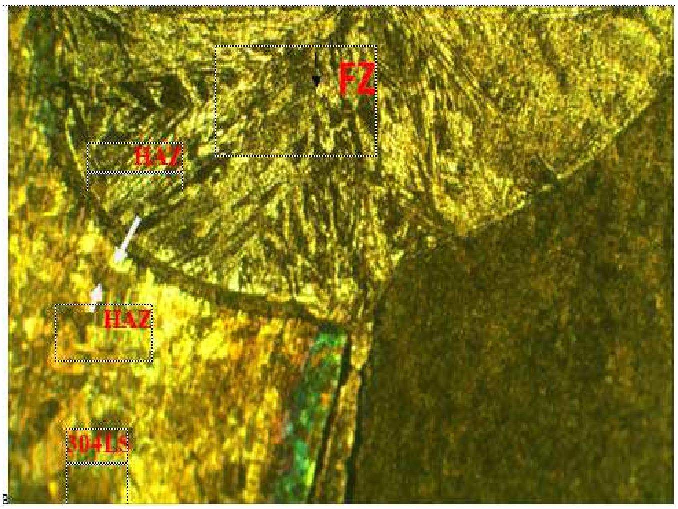


Figure 13: Optical Micrograph of HAZ of Dissimilar LCS/ 304LSS from 304LSS Side

The microstructure for dissimilar LCS/304LSS joints when added the copper sheet, may be it will be martensite and copper which is a binary eutectic system because the copper has a limit solubility in steel and the non-homogenous distribution of copper in mixture steel due to the copper is meta nonferrous and steel is ferrous metal, this led to weaking in mechanical properties of weld joint as shown in figure 14 .

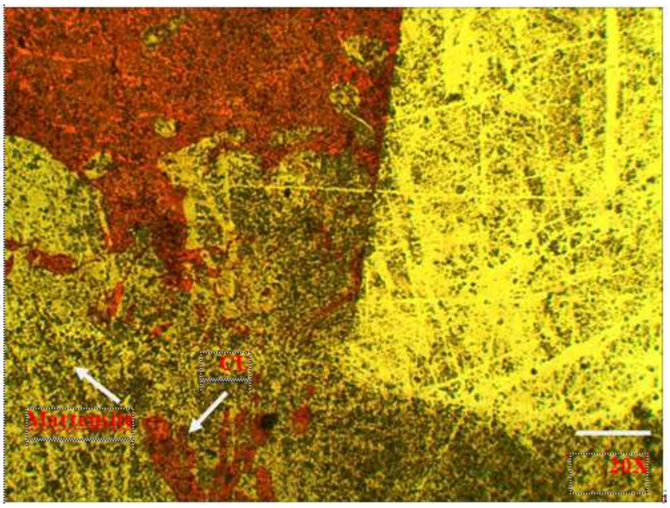


Figure 14: Optical Microstructure of LCS/CU/304LSS RWS

When adding copper will occur reaction between Copper, LCS and 304LSS in the form of waves and semi-coating process for FZ as shown figure (15)

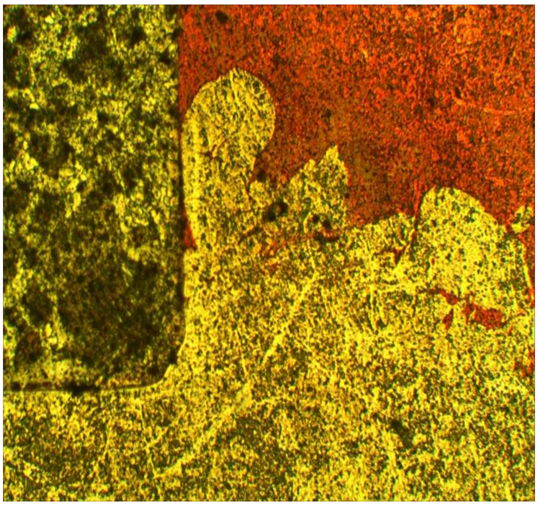
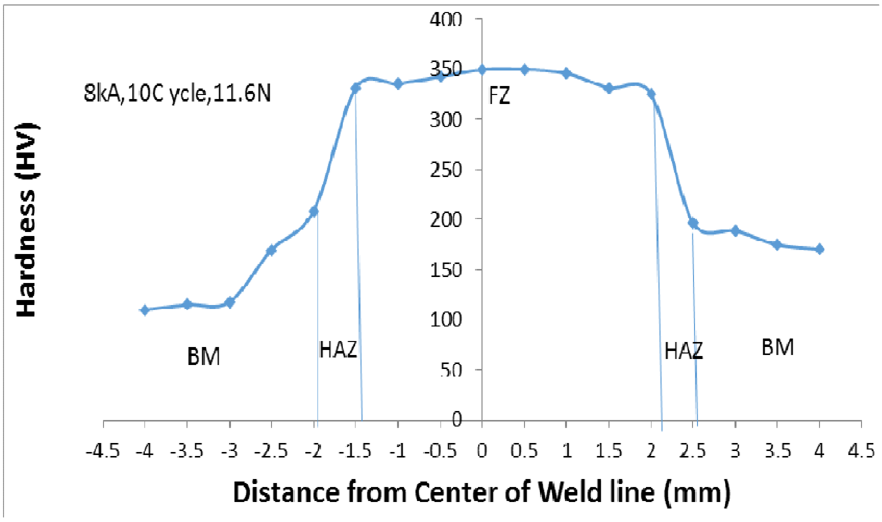


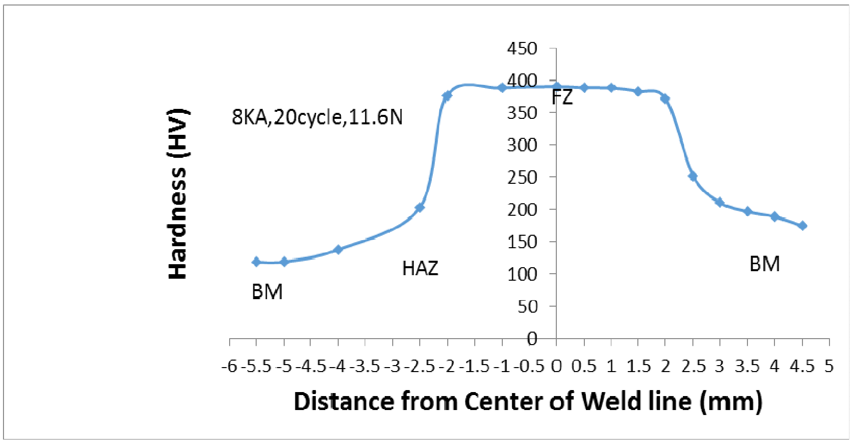
Figure 15: Optical Microstructure of LCS/Cu/304LSS RWS

Hardness Profile and Microstructure Characteristics of Dissimilar Weld Joints

Hardness profiles of LCS/304LSS combinations are shown in figure 15. It is observed that FZ hardness higher than of the base metals and heat affected zone. Martensite phase has a higher hardness and formation at FZ during fast cooling during welding and presence high alloying elements and pressures (plastic deformation). When is used (8KA current weld, 10 Cycle time weld and the force electrode11.6N). the hardness value Fusion zone is max (350HV̆). Furthermore the hardness of heat affected zones(HAZ) was lower than the fusion zones but higher than the base metals Max(120HV). From low carbon steel side about the hardness of HAZ is Max (210HV) while the h hardness of HAZ is Max(265HV) from 304lss side. In other words the hardness value in the process was increased when increasing weld current, weld time and force electrode as shown in figure (4.15a, b and c).



A: The Hardness Distribution of 1mm Weld, Joints



B: The Hardness Distribution of 1mm Weld Joints

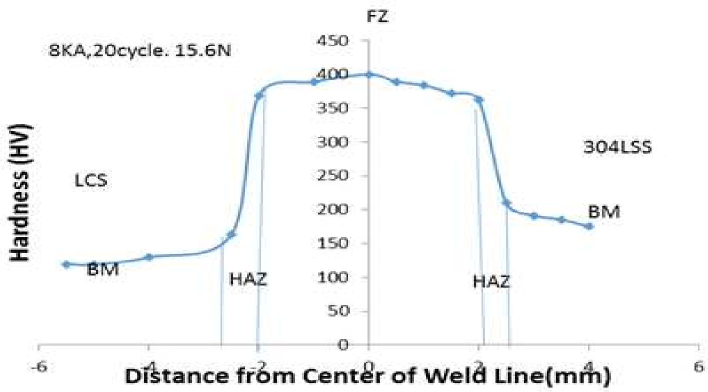


Figure 15a,b and c : The Hardness Distributions of 1mm Weld Joints

As can be seen in figure 15, the hardness increases of LCS/304LSS. The difference in FZ hardness of dissimilar joints combinations is influenced by the chemical composition and the microstructure of the FZ. The chemical composition of the FZ is a mixture of the composition of each of the BMs. Hence, the FZ hardness is affected by the mixing /dilution degree of the BMs. The FZ chemical composition of a dissimilar composition can be estimated by averaging the LCS and 304LSS BM.

The hardness value of dissimilar LCS/304LSS joint when addition the copper layer between base metals is reduced to (350HV) shown in figure 16. While the hardness value for this joint without copper is (400HV). Reduced in the value of hardness due to that copper is more ductile and plastic deformation than carbon steel and 304LSS.The presence of copper in weld pool play to dissipate the heat from the weld zone to base metal due to higher thermal conductivity of copper. Limited solubility of copper in the steel, which that reduced the solid solution strengthening of the weld zone

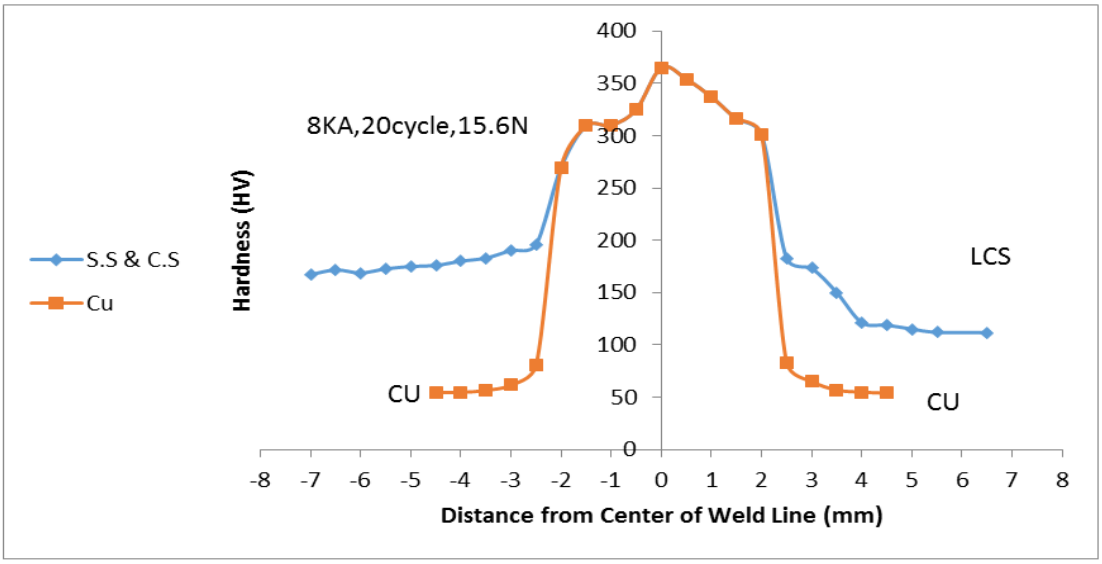


Figure 16: The Hardness Distribution of LCS/Cu/304lssjoint

Failure mode of LCS/AISI304L

The specimens that failed in the tensile-shear test showed three main fracture modes as shown in the figure 17. Poor welds (low fracture force and small nugget diameter) were Characterized by interfacial fracture (IF) – through the nugget in the junction plane between the faying sheets. A poor weld has interfacial fracture (IF) and the shear-force seemed to be falling between 4 to 5kN for 1mm base metals. Moderate to good welds showed tearing on either side of the nugget in the base metal (partial-tearing-failure - PF). The shear force falls between 5 to 8kN.Very good welds were strongly bonded to both sheets and therefore its tear on both sides (TF) or a perfect button pull out will results.

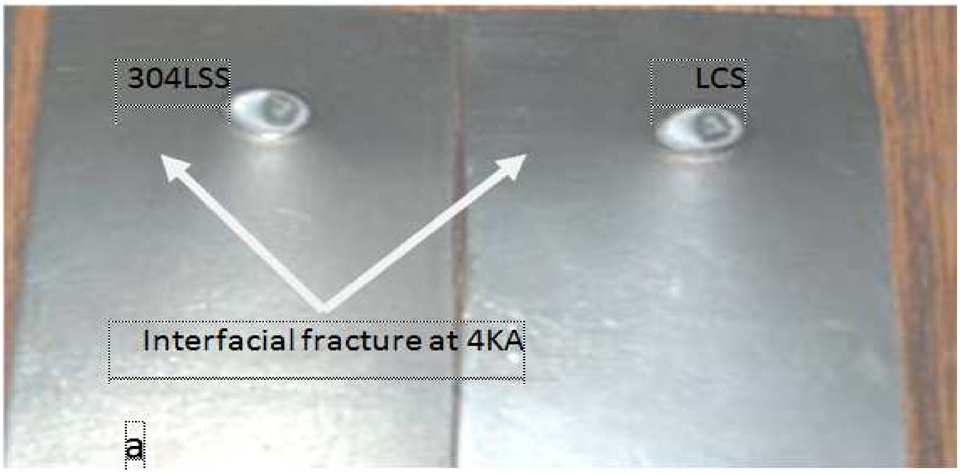


Figure 17 A

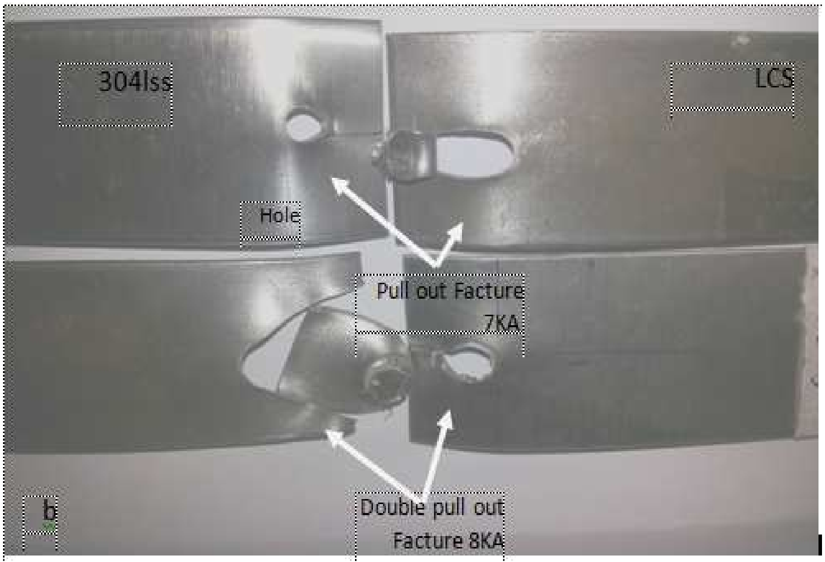


Figure 17A: Interfacial Fracture Modes, (B): Pull Out Fracture Mode, Double Pullout Fracture Mode of LCS/304LSS RWS

The effect of the welding current on the failure mode is shown in Table (3).A pullout mode failure was indicated in which the nugget was pullout from LCS. The failure appears to be initiated near the middle of the nugget circumference by in the LCS sheet, and then propagated by necking /shear along the nugget circumference until the upper sheet is turn off. It's well-known that necking occur at the reign that has lower hardness; due to its lower resistance to plastic deformation. Therefore, it is concluded that the spot weld strength in the pullout failure mode is controlled by the strength and FZS of the LCS side. Figure 18 shows the failure modes of LCS/304LSS RWS.

Table 3: The Effect Welding Current on the Failure Mode

Welding current(KA)	Failure mode
4	IF
5	PF
6	PF
7	PF
8	PF

Figure 18a: Effect the Weld Current on the Failure Modes, (B): Effect the Weld Time on Fracture Mode, (C): Effect the Force Electrode on the Fracture Mode of LCS/304LSS RWS

Failure mode was changed from interfacial (IF) to pull out failure mode (PF) by increasing the weld current, weld time and force electrode [7].

The failure mode for joints LCS/Cu/304LSS was interfacial fracture mode, because of the presence of copper which is given ductility for joints, and observed that the fracture is started from 304lss side .due to the absence of a strong association between copper layer and 304lSS due to the copper is limited solubility in steel as shown in (19).

Figure 19: Interfacial Fracture Mode for Joints LCS/Cu/304LSS

CONCLUSIONS

The analysis of dissimilar spot welded joints of Low carbon Steel and 304Lstainless steels concluded that:

- Increase in (weld current and weld time and force of electrode) resulted increment in tensile strength until expulsion limit occurred.
- The diameter of nuggets was increased due to increase the heat generated with increase in (Current, time and force of electrode) which supports the tensile strength increment on tensile tests.
- The hardness value of welded area for LCS/304LSS joints was increased from (350HV to 400HV) when increased the welding parameters from(8KA,10Cycle and 11.6N) to (8KA, 20Cylce and15.5N) due to the heat

generated in weld nugget which is increased the overall bound area caused by fusion zone size.

- The maximum load is same the parameters of LCS/304LSS joints during tensile- shear test is higher than of LCS/Cu/304LSS joints.
- The PF failure of LCS/304LSS joints initiated from the base metal of LCS, but in LCS/Cu/304LSS joints the failure initiated from 304LSS base metal.
- Increasing (welding current, welding time and force of electrode) transforms the failure mode from interfacial to pullout.
- Martensite observed the microstructure of FZ in the both LCS/304LSS joints, in addition martensite, the microstructure of LCS/Cu/304LSS joints contain copper a non –homogenous distribution in weld zone of LCS /Cu/304LSS joints.
- Ferrite observed the HAZ area near the base metal LCS, the change in the size of grain of ferrite in HAZ not appear.
- Austenite grains observed in the HAZ near the 304LSSbase metal, the grain growth in grain size or change not observed.
- The microstructure of HAZ in the LCS/Cu/304LLSS showed a diffusion layer of copper and pushed in the weld zone like-copper coated fusion zone.

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