Experimental Study of Resistance Spot Welding Technique on Dissimilar Steels

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Abstract— The experimental study of resistance spot weld deals between low carbon steel and austenitic CrNi stainless steel. The thickness of the welded dissimilar materials was 2 mm. A Delta Spot welding gun with a process tape was used for welding the dissimilar steels. Resistance spot welds were produced with various welding parameters (welding currents ranging from 7 to 8 kA). Light microscopy, micro hardness measurements across the welded joints were used to evaluate the quality of the resistance spot welds. The results confirm the applicability of Delta Spot welding for this combination of materials. Typically the sheets are in the 0.5 to 3 mm (0.020 to 0.118 in) thickness range. The attractive feature of spot welding is that a lot of energy can be delivered to the spot in a very short time (approximately 10–100 milliseconds). The properties of resistance spot welds of dissimilar steels have been studied and the influence of the welding parameters on the weld metal size has been evaluated.

Key words: Low Carbon Steel, Austenitic CrNi Stainless Steel, Welding Parameters, Resistance Spot Welding

I. INTRODUCTION

Welding requires skill. Determining "how to weld" requires knowledge regarding the materials being welded and welding process, among numerous other factors. Because of huge number of variables involved, the knowledge of the welding engineer and the skill of the welder need to be validated by a series of tests. All this information is documented on Welding Procedure Specification (WPS), Procedure Qualification Record (PQR), Welding Procedure Qualification Record (WPQR), and associated Test Reports. Welding is a field where everyone gets motivated and we are also attracted towards welding in sense of its working and its basic mechanisms. We are opted for spot welding.

Operation in which not less than two members are united in a body by heat, pressure, or both of them so that continuity can be obtained between the united two members. It is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing fusion, which is distinct from lower temperature metal- joining techniques such as brazing and soldering, which do not melt the base metal. Problem in welding is that it needs filler metal to weld materials.

By using resistance spot welding process we can weld the materials without filler metal. Resistance spot welding is a fusion welding process in which coalescence of metals is produced at the faying surfaces by the heat generated at the joint by the resistance of the work to the flow of electricity.

Main objective of the project is to join the materials without filler metal and to study the microstructure of the spot welds. The properties of resistance spot welds of dissimilar steels have been studied and the influence of the welding parameters on the weld metal size has been evaluated.

II. LIMITATIONS

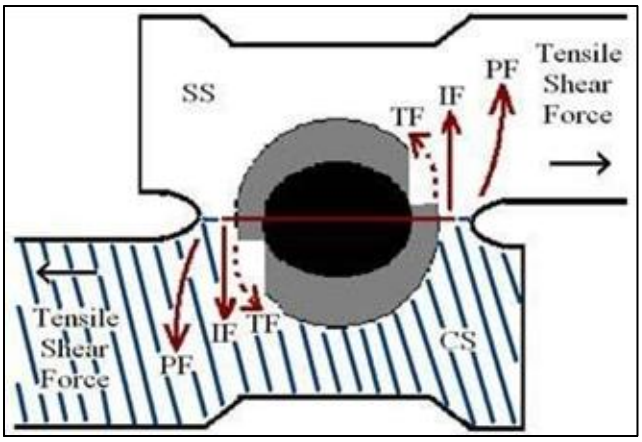

Fig 1.1 Failure modes

Having considered the failure modes (figure (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 (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 (c)) and; the shear force falls between 5.5 to 6.3kN. Here it commonly happened in the carbon steel sides.

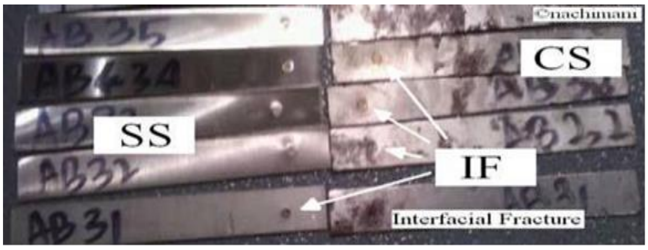

Fig. 1.2: Interfacial failures (IF) in group

Fig 1.3 Tear from one side (PF) failures in group

Various authors have looked into the spot weld parameter optimization for various materials or processes. Optimization method used for the austenitic stainless steel AISI 301L in RSW (Mr. Niranjan Kumar Singh et al, 2012). A two-dimensional model is utilized to predict temperature and stress fields during and after resistance spot welding process, increasing the applied welding voltage leads to an increase in the weld nugget size. Welding time has the same role, however, increasing the welding time causes to enhance heat transfer to surroundings and therefore less heat is consumed in formation of weld nugget.

The mode of AISI304 and DC 01 resistance spot welds is studied under tensile- shear test. We concluded that failure location for AISI 304 and DC 01 RSW in pullout failure mode is at HAZ, adjacent to the weld nugget Low fusion zone hardness to failure location hardness ratio increases the tendency of spot weld failure to occur in the interfacial failure mode during the tensile-shear test. Metallurgical characteristics of welds should be considered to predict and analyze the spot weld failure mode more precisely. With the help of tensile test, scanning electron microscopy we concluded that spot welds has good properties up to its optimum value for dissimilar steels (Austenitic CrNi Stainless Steel (AISI 304), Low Carbon Steel (DC 01)) when compare to similar steel metals.

III. Working Principle and Parameters Principle of Spot Welding

Spot welding operations involve a co-ordinate application of electric current and mechanical pressure of the proper magnitudes and durations. The welding current must pass from the electrodes through the work. Its continuity is assured by forces applied to the electrodes. The sequence of operation must first develop sufficient heat to raise a confined volume of metal to the molten state. This metal is then allowed to cool while under pressure until it is adequate strength to hold the parts together. The current density and pressure must be such that a nugget is formed, but not so high that molten metal is expelled from the weld zone. The duration of weld current must be sufficiently short to prevent excessive heating of the electrode faces. Such heating may bond the electrodes to the work and greatly reduce their life. The heat required for these resistance welding processes is produced by the resistance of the work pieces to an electric current passing through the material. Because of the short electric current path in the work and limited weld time, relatively high welding currents are required to develop the necessary welding heat.

A. Heat generation

In an electrical conductor, the amount of heat generated depends upon three factors:

1) The amperage
2) Resistance of the conductor (including interface resistance)
3) The duration of current.

These three factors affect the heat generated as expressed in the formula

$$E=I^{2}\times R\times T \text{ ……………………….. JOULES LAW} \quad (1)$$

Where,
E = Heat generated (joules) I = Current (amperes)
R = Resistance of the work (ohms) T = Duration of current (seconds)

The heat generated is proportional to the square of the welding current and directly proportional to the resistance and the time. Part of the heat generated is used to make the weld and part is lost to the surrounding metal. The welding current required to produce a given weld is approximately inversely proportional to the square root of the time. Thus if the time is extremely short, the current required will be very high. A combination of high current and insufficiently short time may produce an undesirable distribution of heat in the weld zone, resulting in severe surface melting and rapid electrode deterioration.

The secondary circuit of a resistance welding machine and the work being welded constitute a series of resistances. The total resistance of the current path affects the current magnitude. The current will be the same in all parts of the circuit regardless of the instantaneous resistance at any location in the circuit, but the heat generated at any location in the circuit will be directly proportional to the resistance at that point.

An importance characteristic of resistance welding is the rapidity with which welding heat can be produced. The temperature distribution in the work and electrodes, in the case of spot welding at least seven resistances connected in series in a weld that account for the temperature distribution. For a two thickness joint, these are the following:

1 and 7, the electrical resistance of the electrode material. 2 and 6, the contact resistance between the electrode and the base metal. The magnitude of this resistance depends upon the surface condition of the base metal and electrode force. This is a point of high heat generation, but the surface of the base metal does not reach its fusion temperature during the current passage, due to the high thermal conductivity of the electrodes (1 and 7) and the fact that they are usually water cooled.

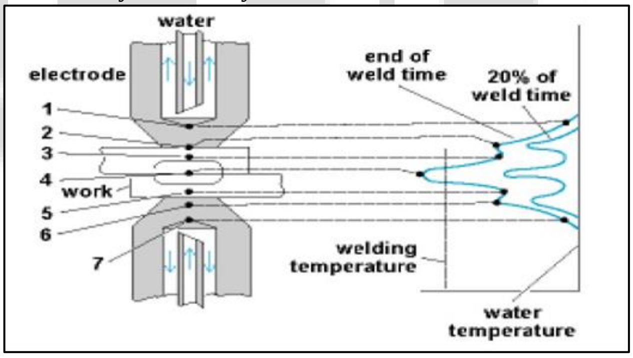

Fig. 3.1: Showing the resistance and temperature distribution

3 and 5, the total resistance of the base metal itself, which is directly proportional to the cross-sectional area of the current path. 4, the base metal interface at the location where the weld is to be formed. This is the point of highest resistance and, therefore the point of greatest heat generation. Since heat is also generated at points 2 and 6, the heat generated at interface 4 is not readily lost to the electrodes.Heat is generated at all of these locations is shown in fig 5.2, not at the base metal interface alone. The flow heat to or from the base metal interface is governed by the temperature gradient established by the resistance heating of the various components in the circuit. This is turn assists or retards the creation of the proper localized welding heat.

IV. Materials Used

1mm of Low carbon steel (DC 01) and 1mm of Austenitic CrNi stainless steel (AISI 304).

A. Procedure

Spot welding involves three stages; the first of which involves the electrodes being brought to the surface of the metal and applying a slight amount of pressure. The current from the electrodes is then applied briefly after which the current is removed but the electrodes remain in place for the material to cool. Weld times range from 0.01 sec to 0.63 sec depending on the thickness of the metal, the electrode force and the diameter of the electrodes themselves.The equipment used in the spot welding process consists of tool holders and electrodes. The tool holders function as a mechanism to hold the electrodes firmly in place and also support optional water hoses that cool the electrodes during welding. Tool holding methods include a paddle-type, light duty, universal, and regular offset. The electrodes generally are made of a low resistance alloy, usually copper, and are designed in many different shapes and sizes depending on the application needed.The two materials being welded together are known as the workpieces and must conduct electricity. The width of the workpieces is limited by the throat length of the welding apparatus and ranges typically from 5 to 50 inches (13 to 130 cm). Workpiece thickness can range from 0.5mm to 3mm.

After the current is removed from the workpiece, it is cooled via the coolant holes in the center of the electrodes. Both water and a brine solution may be used as coolants in spot welding mechanisms.Electrodes are brought together against the overlapping work pieces and pressureapplied so that the surfaces of the two work pieces under the electrodes come in physical contact after breaking any unwanted film existing on the work piece.Welding current is switched on for a definite period of time. The current may be of the order 3000-11500 A for a fraction of second to a few seconds depending on the nature of the material and its thickness. As the current passes through one electrode and the work pieces to the other electrode, a small area where the work pieces are in contact is heated. The temperature of this work zone is approximately equal to recrystallization temperature of material.

To achieve a satisfactory spot weld, the nugget of the coalesced metal should form with no melting of the material between the faying surfaces. At this stage, the welding current is cut off. Extra electrode force is then applied or the original force is prolonged. This electrode force or pressure forges the weld and holds it tighter while the metal cools down and gains strength.The electrode pressure is removed from the spot welded work pieces.

Fig. 3.2: Resistance Spot Welding Machine

V. SELECTION OF SPOT WELDING ELECTRODES

Spot welding electrodes are subjected to the most service of any current carrying member of the resistance process. These electrodes must transmit both the welding current and the welding force through the same area of contact, which is the weld area.

Selection of the proper electrode material is very important to assure correct current carrying capability. Some other factors, which affect spot welding material selection, are resistance to electrode pick-up and sticking. The severity of these conditions can reduced through proper electrode selection and proper welding machine set-up.

VI. EFFECTS OF PARAMETERS

A. Effect of welding current

In the formula, $E=I^2 \times R \times T$, current has a greater effect on the generation of heat than either resistance or time. Therefore, it is an important variable to be controlled. Two factors that cause variation in welding current are fluctuations in power line voltage and variations in the impedance of the secondary circuit with AC machines. Impedance variations are caused by changes in circuit geometry or by the introduction of varying masses of magnetic metals into the secondary loop of the machine. Direct current machines are not significantly affected by magnetic metals in the secondary loop and are little affected by circuit geometry.

In addition to variations in welding current magnitude current may vary at the weld interface. This can result from shunting of current through preceding welds and contact points other than those at the weld. And increase in electrode face area, or projection size in the case of projection welding, will decrease currant density and welding heat. This may cause as significant decrease in weld strength.

B. Effect of welding time

The rate of heat generation must be such that welds with adequate strength will produce without excessive electrode heating and rapid deterioration. The total heat developed is proportional to weld time. Essentially, heat is lost by conduction into the surrounding base metal and electrodes; a very small amount is lost by radiation. These losses increase by increase in weld time and in metal temperature, but they are essentially uncontrollable During a spot welding operation, some minimum time is required to reach melting temperature at some suitable current density. If current is continued, the temperature at plane 4 in the weld nugget will far exceed the melting temperature, and internal pressure may expel molten metal from the joint. Generated gasses or metal vapor may expel together with minute metal particles. If the work surface are scaly or pitted, gasses and particles may also be expelled at planes 2 and 6. Excessively long weld time will have the same effect as excessive amperage on the base metal and electrodes. Furthermore, the weld heat-affected zone will extend farther into the base metal.

C. Effect of welding force

The resistance R in the heat formula is influenced by welding force its effect on contact resistance at the interface between the work pieces. Welding force is produced by the force exerted on the joint by the electrodes. Electrodes force is considered to be the net dynamic force of the electrodes upon the work, and it is the resultant pressure produced by this force that affects the contact resistance.

Pieces to be spot welded must be clamped tightly together at the weld location to enable the passage of current. Everything else will be equal, as the electrode force or welding force is increased, the amperage will also increase up to some limiting value. The effect on the total heat generated, however, may be the reverse. As the force is increased, the contact resistance and the heat generated at the interface will decrease. To increase the heat to the previous level, amperage or weld time must be increased to compensate for the reduced resistance.

VII. Implementation and Results

The implementation here is done on lap joint and cross joint of plain sheets of Cr Ni austenitic stainless steel and low carbon steel.

A. Description of Joints

1) LAP Joint

When the two members to be connected together by overlapping then the joint is called lap joint .A single bolted lap joint and a double bolted lap joint are shown in figure respectively.

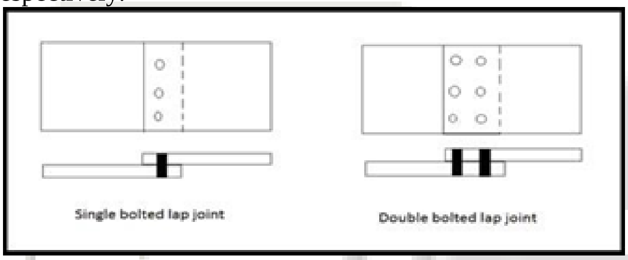

Fig. 4.1: Lap joint

B. CROSS Joint

The main difference between this and the basic half lap is that the joint occurs in the middle of one or both members, rather than at the end. The two members are at right angles to each other and one member may terminate at the joint, or it may carry on beyond it. When one of the members terminates at the shin, it is often referred to as a Tee lap or middle lap. In a cross lap where both members continue beyond the joint, each member has two shoulders and one cheek.

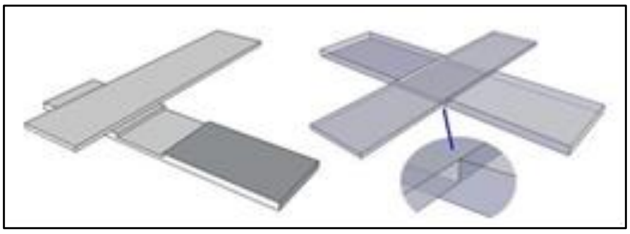

Fig. 4.2: Cross lap joint

VIII. Explanation of Key Functions

A. Dimensioning of lap joint

Both the sheets of CrNi stainless steel and low carbon steel are cut in 100mmX60mm. This plates are then marked 3mm both horizontally and vertically throughout the plates. Now we can see the points on each plate having 3mm space between them.Now if we the sheets are placed one on other, points come into contact.so overlap the sheets at edges and spot weld them

Fig. 4.3: Spot welding of lap joint of sheets

B. Dimensioning of cross joint

Both the sheets of CrNi stainless steel and low carbon steel are cut in 150mmX60mm. This plates are den marked 2.5mm along length and 2mm along breadth throughout the plates.

Now if we place the plates in cross position the points get intersected. Now the intersected points must be spot welded.

Fig. 4.4: Spot welding of cross joint of sheets

IX. Method of Implementation

A. Tensile test on universal testing machine

A universal testing machine (UTM), also known as a universal tester, materials testing machine or materials test frame, is used to test the tensile strength and compressive strength of materials. The "universal" part of the name reflects that it can perform many standard tensile and compression tests on materials, components, and structures.

The tensile test is most applied one, of all mechanical tests. In this test ends of test piece are fixed into grips connected to a straining device and to a load measuring device. If the applied load is small enough, the deformation of any solid body is entirely elastic. A CEN deformed solid will return to its original from as soon as load is removed. However, if the load is too large, the material can be deformed permanently. The initial part of the tension curve which is recoverable immediately after unloading is termed. As elastic and the rest of the curve which represents the manner in which solid undergoes plastic deformation is termed plastic. The stress below which the deformations essentially entirely elastic is known as the yield strength of material.

In some material the onset of plastic deformation is denoted by a sudden drop in load indicating both an upper and a lower yield point. However, some materials do not exhibit a sharp yield point. During plastic deformation, at larger extensions strain hardening cannot compensate for the decrease in section and thus the load passes through a maximum and then begins to decrease. This stage the "ultimate strength"' which is defined as the ratio of the load on the specimen to original cross-sectional area, reaches a maximum value. Further loading will eventually cause 'neck' formation and rupture.

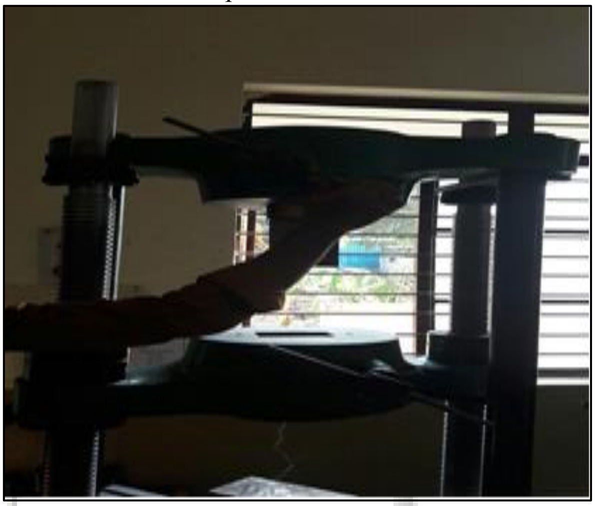

Fig. 4.5: universal testing machine

X. Result Analysis

The value obtained in the tensile test of spot welded sheets of Cr Ni stainless steel and low carbon steel by UTM = 245.5 mPa

The value of tensile test of spot welded sheets of MS by UTM = 521 mPa

S.no	Force N	No. of welds	Shear stress mPa	Tear stress mPa	Comparative stress
1	2700	9	10.61	15.92	31.84
2	5400	9	21.23	31.85	63.78
3	8100	9	31.84	47.78	95.56

Table 1: Spot Weld for Single Shear Load Stress

XI. Calculations

A. Force = 2700 N No. of welds = 9

Diameter of welds = 6mm Thickness of sheets = 1mm Coefficient of weld for shear = 0.65 Coefficient of weld for tear out = 0.5

Shear stress = (4X2700)/ (9X3.14X36) =10.61 MPa Tear stress = 2700/ (9X3.14X6X1) = 45.92 MPa

Comparative stress = max (10.61/0.65, 15.92/0.5) = 31.84 MPa

B. Force = 5400 N No. of welds = 9

Diameter of welds = 6mm Thickness of sheets = 1mm Coefficient of weld for shear = 0.65 Coefficient of weld for tear out = 0.5

Shear stress = (4X5400)/ (9X3.14X36) = 21.23 MPa Tear stress = 5400/ (9X3.14X6X1) = 31.85 MPa

Comparative stress = max (21.23/0.65, 31.85/0.5) = 63.7 MPa

C. Force = 8100 N No. of welds = 9

Diameter of welds = 6mm Thickness of sheets = 1mm Coefficient of weld for shear = 0.65 Coefficient of weld for tear out = 0.5

Shear stress = (4X8100)/ (9X3.14X36) =31.84 MPa Tear stress = 8100/ (9X3.14X6X1) =47.78 MPa

Comparative stress = max (31.84/0.65, 47.78/0.5) = 95.56 MPa

XII. Conclusion

With the help of tensile test, scanning electron microscopy we concluded that spot welds has good properties up to its optimum value for dissimilar steels (Austenitic CrNi Stainless Steel (AISI 304), Low Carbon Steel (DC 01)) when compare to similar steel metals.

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. With the help of tensile test, scanning electron microscopy we concluded that spot welds has good properties up to its optimum value for dissimilar steels (Austenitic CrNi Stainless Steel (AISI 304), Low Carbon Steel (DC 01)) when compare to similar steel metals.

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