IMPROVING HEAT BALANCE IN RESISTANCE WELDING

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Abstract

Resistance welding process is unique in terms of intimate physical contact between the parts and the welding electrodes. The electrodes provide a path for welding current that generates weld heat necessary for bond formation. In addition to supplying current, the electrodes also provide a means of applying forging force required to form the weld thus producing intimate contact between the parts and the electrodes. In some applications, the electrodes also act as a heat sink to regulate weld temperature while in some they actually generate a substantial portion of the weld heat and provide heat energy to the weld. In order to setup an optimized welding application where the right amount of heat is being generated at the right location, one has to understand the critical issue of heat balance. Heat balance is defined as the optimal distribution of heat generation across the weld in order to produce a robust welding process. A weld with good heat balance can also provide longer electrode life. Factors that affect heat balance include electrode material, electrode size, weld location, polarity, pulsation, and projection welding.

Keywords: Resistance Welding, Heat Balance, Projection, Polarity, Pulsation, Electrode Design.

Introduction

In resistance welding, the parts to be welded are supplied with electric current by means of direct contact between the parts and the welding electrodes. As the current flows through the parts, resistance to flow of electric current produces welding heat. Combination of welding force and heat produces a strong weld at the interface. Figure 1 shows a schematic of weld stack including two electrodes and two parts that are to be welded. The schematic also illustrates the number of resistances that are active in the stack during the welding process. These resistances include three contact resistances; two at the electrode/material interface and one at the weld interface. The four bulk resistances include the two parts being welded and the two electrodes. Under ideal circumstances, the welding process should generate heat primarily at the weld interface and partly in the bulk resistance of the parts being welded. However, in reality, generation of welding heat at the part/electrode interfaces and in the electrodes can not be avoided but has to be properly managed for good heat balance.

Heat Balance Techniques

There are many options to improve heat balance for a particular weld and include selection of electrode material, electrode size and shape, part design, polarity, and pulsation; the options are discussed below:

Electrode Material

There are many choices available for electrode materials ranging from very conductive copper (Class I) to Tungsten and Molybdenum which are quite resistive. Electrode materials that are good electrical conductors are also good conductors of heat. When welding resistive materials, one of the functions of the electrodes is to remove some of the excess heat from the electrode/material interface in order to keep it cool and hence a conductive copper electrode is well suited for welding carbon steels and stainless steels. On the other hand, welding of very conductive materials such as copper foils requires the electrodes to not only prevent any heat loss from the copper, but also to function as a source of heat; welding of conductive copper foils is best achieved with more resistive electrodes such as Tungsten and Molybdenum. For proper heat balance, one has to use a conductive electrode against a resistive alloy and a resistive electrode against a conductive alloy.

Figure 2 shows schematics of resistance welding stacks with options for electrode material combinations. The oval spot shows the "center of gravity" for heat generation for each stack. The electrode material combination in the center produces the right heat balance (oval at the weld interface) when the resistive electrode is against the copper alloy and a conductive copper electrode is against the steel.

Electrode Size

Size of electrode tip (cross-section) in contact with the material to be welded defines the current density flowing through the tip. In order to focus the weld energy at the weld interface, electrode sections have to be selected with a proper ratio. For example, when welding metal foils of dissimilar thickness, electrode tip size should be selected with a similar ratio so that the high current density is obtained at the weld interface as shown in Figure 3.

Electrode Shape

In addition to tip size, tip shape can be modified to suit heat balance. Common shapes are dome shaped and flat tip. If the nugget has to be shaped to draw the heat away from one of the interface so as to reduce any exterior marking on one of the surface of the weld, a combination of the electrode shapes can be used. Figure 4 shows a weld section between two pieces of 0.058" thick steel where one of the electrodes had a 5/8 diameter and a 6 inch tip radius and the other had a flat face with 2 inch diameter. As shown in the figure, the nugget is not symmetrical across the weld interface and is seen growing away from flat faced electrodes and drawn towards the radius tip electrode. Moving the weld nugget upwards helps reduce heating of the bottom surface and hence reduces the amount of visible indentation.

Weld Location

Increase in temperature at a weld is not only the function of energy input; it is also a function of heat loss from the weld area. Heat energy is lost from the weld primarily via conduction of heat by adjoining material and by the electrodes themselves which can act as heat sinks. Any change in volume of material available to act as heat sink will affect the weld. For example welds made in sheets of steel will behave differently when the weld is in the middle of the sheet as compared to a weld near the edge of the sheet; weld near the edge will by hotter since there is less volume of material around it for heat sinking. This change in heat balance because of change in welding location also affects welding of wires (Figure 5) where fine wires welded in mid-section have a weld stack height of 0.195” while the other weld on the right was made closer to the free ends of the wires and had a stack height of 0.185”. The weld on the right was hotter because it had less mass available for heat sinking.

Polarity

In resistance welding, I^2R (Joule heating) is majority source of welding heat but not the only one. Heat is also created, and even absorbed, when current flows across an interface/junction between two materials. Whether heat is released or absorbed depends on the direction of current flow; this effect is known as the Peltier effect [2]. Uniqueness of Peltier effect is that it can actually absorb heat at the interface. In majority of resistance welding power supplies including capacitor discharge, direct current, and inverter type units, current flows in only one direction throughout the welding cycle and hence the Peltier effect is consistent throughout the welding pulse. In alternating current (AC) welds of long duration, direction of current flow switches direction every 8.33 milli-seconds (at 60 Hz) and hence balances out any Peltier contribution. However, Peltier effect does play a role in short duration AC welds of a few cycles. Peltier effect heating/cooling plays an important role in short duration welds and with thinner components where interface heating will be dominant. Given the multiple interfaces and material junctions present in a weld, it is difficult to predict the direction of current flow that will be suitable for proper heat balance. Actual experimentation is usually required to establish the required direction of current flow.

<u>Pulsation</u>

Some power supplies can deliver the weld energy in the form of a series of short burst of energy that has the potential to alter the heat balance as compared to a single pulse [3]. As seen in Figure 1, resistance at the weld stack is composed of contact/interface and bulk resistances. In order to focus the weld heat at the interfaces, pulsation mode can be used. It is the cooling between pulses that allows time for the bulk material to cool thus changing the ratio between the interface/contact and bulk resistances. Thus when the next pulse of energy is delivered, the ratio of contact to bulk resistance is higher than it would have been with a single wide pulse, and hence heat generated during the next pulse is more focused at the interfaces. Such a strategy has been successfully used to weld parts that are dissimilar in terms of size and metallurgy but where changing part geometry is not an option.

<u>Projection</u>

In resistance welding, material across the weld interface should reach an equivalent temperature at the same time. However, in applications where one of the parts is much bigger that the other, the bigger part acts like a giant heat sink and hence it is very difficult to generate heat in the bigger component resulting in the thinner section component getting too hot but still not producing a good weld. In order to improve heat balance, a projection is usually formed/machined/coined/stamped in the bigger component. The projection focuses welding current at the interface and increases current density that leads to rapid heating of material at the weld interface. Projection design has to be chosen such that temperature rise across the interface, both in the bigger component with the projection and the smaller component without projection occurs in the same time frame. However, there are limitations to using projection design. First of all, a projection is a special feature formed and requires an extra machining step and cost associated with it. Secondly, welding with projections requires a weld head that has the ability to provide fast follow-up so that the electrode is able to maintain good contact between the electrode face and the component surface.

Discussion

Techniques discussed above provide a wide variety of choices for the weld engineer to improve heat balance and process robustness. Additionally, two or more techniques can be combined for further improvement; for example polarity and electrode shape can be combined to produce the desired results. Except for projection welding, none of the other techniques discussed require the weld engineer to change the part design and hence are easier to implement. Even though adding a projection requires significant changes in part design and can be expensive, projection welding remains one of the most popular methods of improving heat balance and process robustness.

In spite of the fact that the techniques are widely used, there are limitations that an engineer has to be aware of. For example, if one of the parts is plated, the plating alloy and its reactivity with electrode material can limit available choices for electrode material and may be in conflict with the choice selected based on earlier discussion. Weld location can often be a process variable that cannot be easily controlled. In those situations, any variation in weld location may have to be compensated for with the use of welding modes.

Summary

Proper heat balance is the key to producing a robust welding process. There are multiple methods to improving heat balance including electrode material, size, shape, polarity, pulsation, and projections. Improving heat balance by such varied methods is unique to resistance welding and perhaps the reason for popularity of resistance welding as a method of choice in industry. These methods can be combined to suit the needs of a particular weld application. Even though the choices are plenty, there are also limitations that the engineer has to take into account before selecting a particular option.

References

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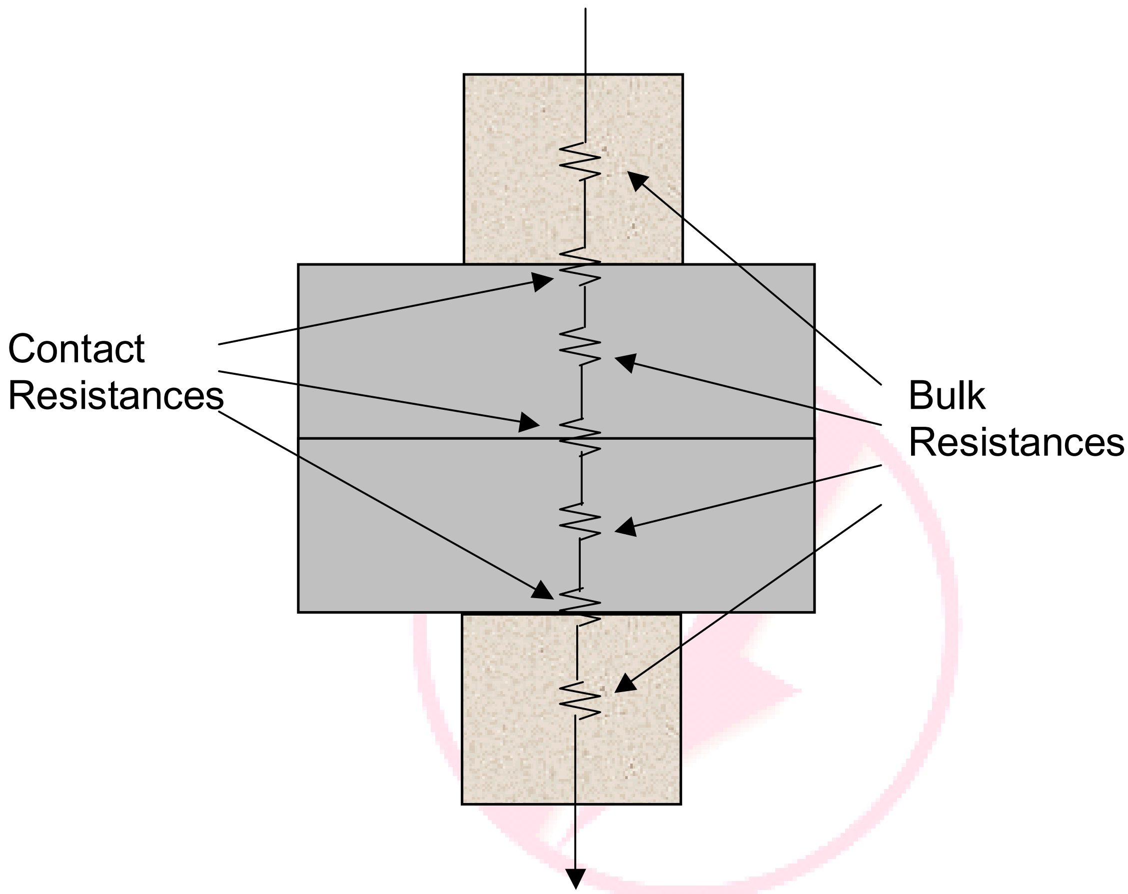

Figure 1. Schematic showing a typical resistance welding stack with two electrodes on top and bottom pinching the parts to be welded. Also shown are four bulk resistances and three contact resistances.

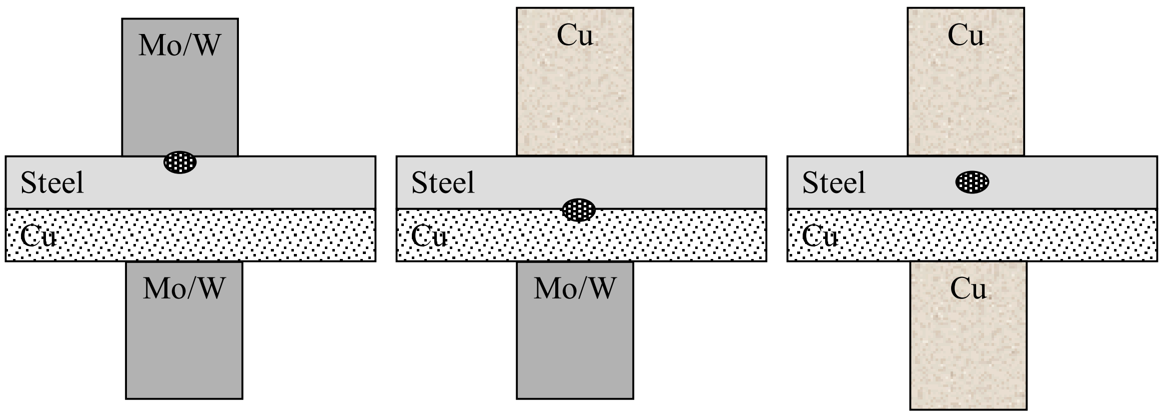

Figure 2. Schematic of weld stack showing choice of electrode material and the resultant shift in heat balance. A resistive electrode against a conductive part and vice-versa usually works well for heat balance.

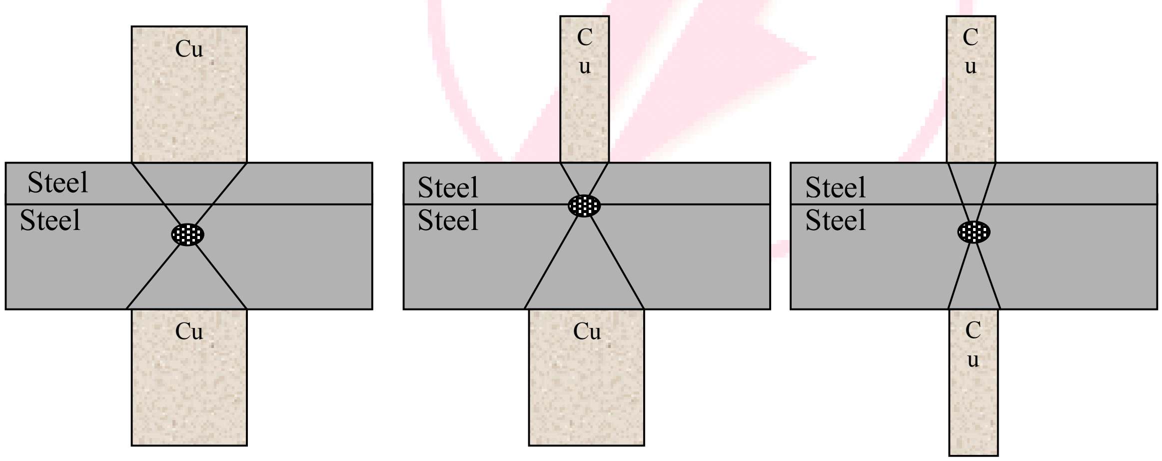

Figure 3. Schematic of weld stack showing effect of electrode size on heat balance. Matching electrode size to thickness of part helps to focus weld heat the weld interface.

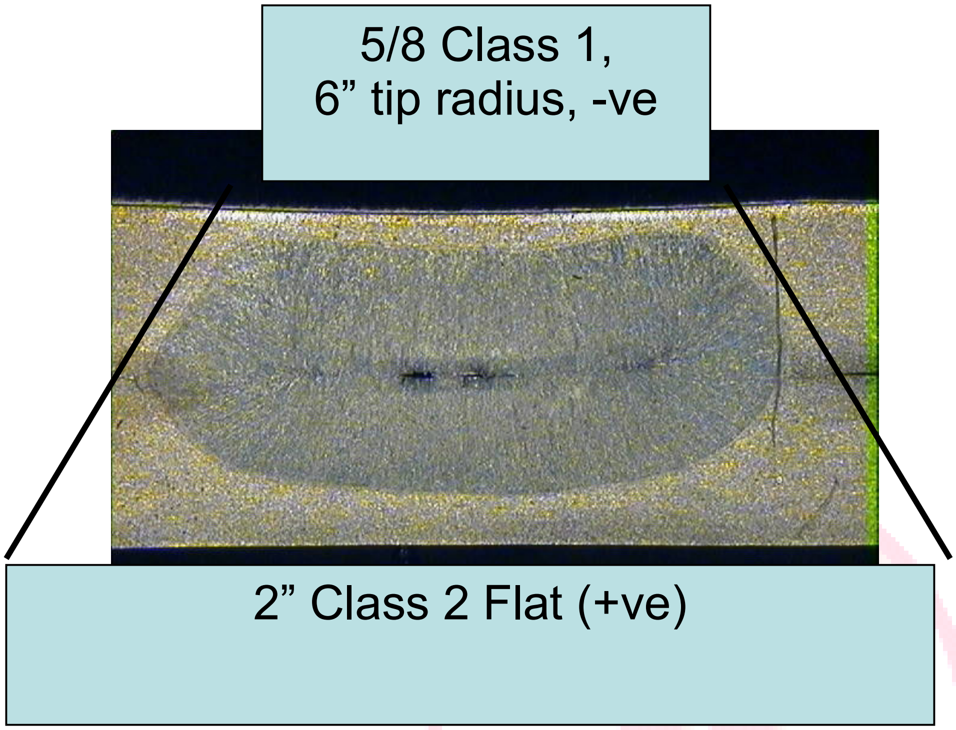

Figure 4. Photomicrograph of a weld section between two sheets of steel formed with electrodes of differing tip shapes shown schematically on either side. The difference in electrode tip shapes has helped pull the weld nugget towards the upper sheet leaving the lower sheet surface with practically no indentation.

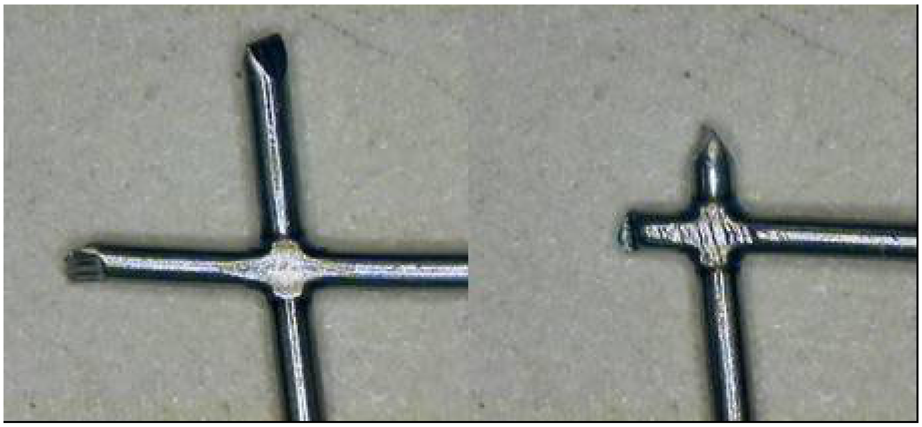

Figure 5. Photos of welds showing effect of weld location in welding of two 0.010" Ni wires. Weld on the left made away from the wire ends had an after weld stack height of 0.0195"; weld on the right near the wire ends had a stack height of 0.0185" indicating a hotter weld at the same weld settings.

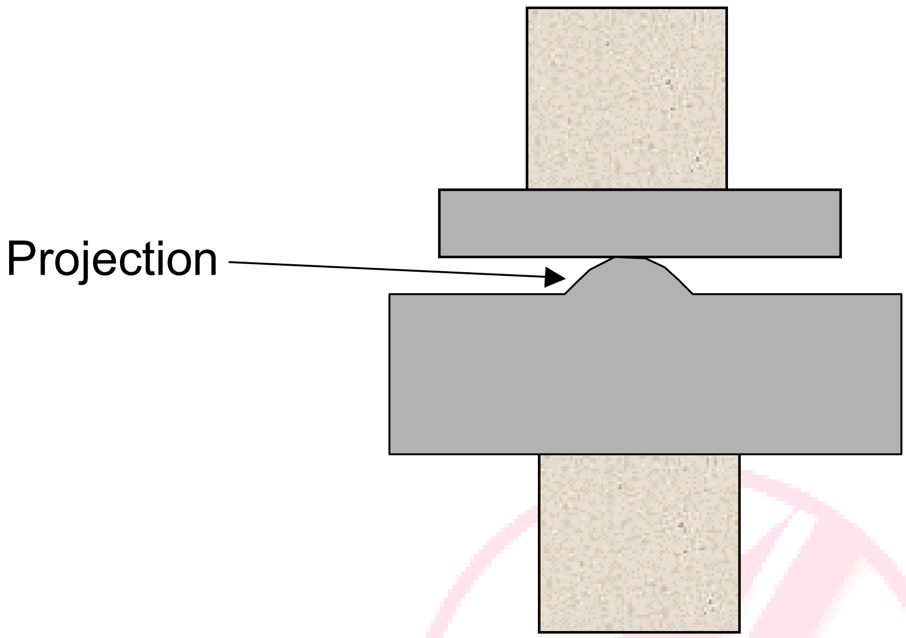

Figure 6. Schematic shows a weld stack with a projection in the bigger component to improve heat balance. If parts are of similar size, projection should be made in the more conductive component.