Shear force analysis of Resistance Spot Welding of Similar and Dissimilar Material: copper and carbon steel

Imad M. Husain\textsuperscript{1}, Mursal Luaibi Saad\textsuperscript{2}, Osamah Sabah Barrak\textsuperscript{3}, Sabah Khammass Hussain\textsuperscript{4}, and Mahmood Mohammed Hamzah\textsuperscript{5}

\textsuperscript{1} Ministry of education / General directorate of vocational education/ Al-Najaf department of vocational education.
\textsuperscript{2} Technical Institute - Suwaira, Middle Technical University, Baghdad, Iraq.
\textsuperscript{3} Institute of Technology – Baghdad, Middle Technical University, Baghdad, Iraq.
\textsuperscript{4} Engineering Technical College, Middle Technical University, Baghdad, Iraq.
\textsuperscript{5} Ministry of Science and Technology, Central Laboratories Directorate.
E-mail: \textsuperscript{1}imadalsaffar707@gmail.com, \textsuperscript{2}Mursal673@gmail.com, \textsuperscript{3}usamah.barrak@yahoo.com, \textsuperscript{4}sabah.kh1974@yahoo.com (Corresponding author), \textsuperscript{5}mmhsh_1988@yahoo.com

Abstract. Resistance spot welding (RSW) is a complicated process, which involves the interaction of electrical, thermal, mechanical, and metallurgical phenomena. In this research we used two types of material (UNS G10050 carbon steel and UNS C10100 copper) and welded them in similar and dissimilar condition with four variables welding current, pressure, squeeze time and welding time. The results of the tensile-shear force were analyzed statistically by the Design of experiments (DOE) utilizing Taguchi method. Tensile-shear test used for counting the strength of the joint, maximum strength was found in similar joining condition for carbon steel, also it is interesting to note that the strength of dissimilar joint is stronger than copper joining in similar condition.

Keywords. Resistance spot welding, Similar and dissimilar welding, UNS G10050, UNS C10100, Tensile-shear force, DOE.

1. Introduction
Resistance spot welding (RSW) was invented in 1877 by Elihu Thomson and has been broadly utilized from that since as a process of manufacturing for joining sheet metal. The electrical resistance spot welding (RSW) is a complicated process, which comprises a method for joining of two materials at their common interface is an association interaction of electrical, mechanical, metallurgical, thermal, and surface phenomena. Figure 1 is a simplified illustration of the process, demonstrating some of the essential features of weld producing [1-3].

RSW is a significant process in the industry. In RSW, the overlapping work set between the water-cooled electrodes, and afterwards the heat is acquired by passing an enormous electrical current for a brief timeframe. RSW is might utilize the joining process for manufacturing sheet metal assemblies such as truck cabins, rail vehicles, automobiles, and home applications because of its feature in welding efficiency and appropriateness for automation [4-6]. For example, the modern auto-body gathering needs 7000 to 12000 spots of welding as approved by the size of a vehicle, so the welding of a spot is a significant process in the assembly of auto-body. Compared with the other processes of welding, for example, arc welding processes, the resistance spot is easily automated, quick, and easily maintained. In this process, the materials to be joined are positioned together under pressure by a couple of the electrodes and then a high electric current passed through the work-pieces between the electrodes.
Because of the Joule heating and the contact resistance, it leads to the form of a molten weld nugget in the work-pieces. The work-pieces are joined as occurs solidification of the weld pool. Moreover, the force is applied before, during, and after the electrical current application, to preserve the continuity of electric current and to supply the pressure important to form the weld nugget. The strength and quality of the welds are characterized by the size and shape of the weld nuggets. The size of the nugget has indicated the welding quality as described in the handbook provided by the Resistance Welder Manufacture’s association [7-11]. The most common disadvantages for this process are low strength in case of a discontinuous weld, high equipment cost, the thickness of the weld is limited, the explosion of metal near the weld site, cracks in the weld area, indented surface, and spattering.

The principles of (RSW), in the process of spot welding, two or three stacked or overlapped stamped segments are welded simultaneously as a result of the heat made by electrical resistance. This is afforded by the work-pieces as held together under the pressure between two electrodes, these electrodes are copper electrodes of water-cooled that provide basically of three functions:

1. Their low electric resistance equips a conduit to convey the high current to the work-piece without damages of huge the joule heating.
2. Its high thermal conductivity equips a process to control the formation of nugget and cool-down by conducting heat from the work-piece.
3. The electrodes apply a focused force on the surfaces of external materials to be joined.

The force of the electrode produces a positional deformation at the combined interface to situate the work-piece appropriately and to banquet good electrical contact before the flow of current. The necessary high current intensity (2000-15000 A) and low voltage (5-20V) for welding processes are acquired from transformers and the pressure is procured from hydraulic, pneumatic, and mechanic devices. A nugget is formed by the pressure and density of current, but not do high that molten metal is ousted from the weld zone. The duration of weld current should be sufficient short to prevent the excessive electrode faces heating. Spot welding might be performed robotically, manually, or by a committed of the spot weld machine. Low volume combinations are generally done manually, while the high volumes can be accomplished best by utilizing the robots or the welding equipment of dedicated [12-16].

Effect of welding time on the formation of heat, the squeeze time is the interval of time between the application of the initial electrode force on the work-piece and the initial application of current. It is requisite to delay the weld current until the electrode force has achieved the required level. After that, the weld time is estimated and adjusted in cycles of the line voltage similar to the all functions of timing. At the point when the electrode is removed promptly, the heat disperses and the contact surface becomes dark. After the operation of welding, the electrode ought to be applied to the sheet to
chill the weld. Hold time is important to permit the weld nugget to solidify before dismissal the welded parts, but it should not be excessively long because it may cause the prevalence of heat at the weld spot to the electrode and heat it [17-19]. The purpose of this work is to join the similar and dissimilar materials of copper with carbon steel (UNS G10050 with UNS C10100) by a Resistance Spot Welding process. The importance of this work is studying the effect of the welding parameters (welding current, electrode pressure, squeeze time & Welding time) on the shear tensile force. Moreover, a Minitab software was utilized to apply the design of experimental (DOE) technique to distinguish and analyse the effect of those parameters on the shear tensile force of the joint welding parameters.

2. Experimental studies
In this research, two types of metal (UNS G 10050 carbon steel and UNS C10100 copper) were selected and welded by electrical resistance spot welding by fixing electrode form, materials type, cooling water flow rate, and electrode force and changing welding current and time. All specimens were exposed to the tensile-shear strength test in order to determine the joint strength.

2.1. Material
The thickness of the two types for materials to be welded is 1mm and the dimensions are (25*100)mm as shown in figure 2. Its chemical composition is given in table 1, and the mechanical properties for the materials as shown in table 2. The fracture must be observed in welding zones of tensile-shear testing specimens. In addition, side effects should be prevented and minimum materials waste aimed. These factors were evaluated in designing the sizes of test specimens. A timer and current controlled electrical resistance spot welding machine having 120 KVA capacity and pneumatic application mechanism with a single lever was used in experiments. Weld time, hold time, and clamping time were adjusted automatically by the electronic device of the machine. The electrode profile was a dome shape with 6.5 mm circular contacting area RWMA Group A class 2 type B, made from a chromium-zirconium-copper alloy as AWS C1.1M/C1.1:2012 classification [20].

| Table 1. chemical composition for materials |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Element wt%     | C   | Si  | Mn  | P   | S   | Pb  | O2  | Cu  | Fe  |
| UNS G10050 (AISI 1005) | 0.22| -   | 0.25| 0.03| 0.035| -   | -   | -   | Bal |
| UNS C10100      | -   | -   | -   | 0.0002| -   | 0.0007| 0.0003| Bal. | -   |

| Table 2. the mechanical properties of the materials |
|-----------------|-----------------|-----------------|-----------------|
| Material Property | Yield Strength \( \sigma_y \) (MPa) | Tensile Strength \( \sigma_u \) (MPa) | Elongation EL, (%) |
| UNS G10050 (AISI 1005) | 302             | 433             | 36              |
| UNS C10100      | 196             | 232             | 24              |

Figure 2. dimension of the specimen
2.2. Experiments
The specimens are prepared as shown in figure 3. These parts were overlapped with 25mm spacing and welded. The variables in this research were current, pressure, squeeze time, and welding time as shown in table 3, all these conditions were designed in the Minitab program like as Design of Experiments (DOE) by the Taguchi approach way. In this study a twenty-four samples have been produced. The materials samples were welded in similar and dissimilar conditions, and eight welded samples were made for each welding condition depending on the machine program. The welded parts were subjected to the tensile-shear test in a testing machine in laboratory conditions, as shown in figure 4. The tensile speed test was constant during the test. The obtained values from the tensile-shear force are the maximum values read from the machine.

Figure 3. Specimen joined by RSW, a) similar UNS G10050, b) similar UNS C10010, c) dissimilar material

Table 3. The conditions of the welding

| No. | Current (A) | Pressure (bar) | Squeeze time (c.) | Welding time (c.) |
|-----|------------|----------------|-------------------|-------------------|
| 1   | 10000      | 25             | 15                | 5                 |
| 2   | 10000      | 25             | 15                | 8                 |
| 3   | 10000      | 35             | 25                | 5                 |
| 4   | 10000      | 35             | 25                | 8                 |
| 5   | 12000      | 25             | 15                | 5                 |
| 6   | 12000      | 25             | 15                | 8                 |
| 7   | 12000      | 35             | 25                | 5                 |
| 8   | 12000      | 35             | 25                | 8                 |

Figure 4. Schematic of Tensile Strength Test
3. Results and discussion

3.1. Effect of the variables of tensile-shear strength

It can be seen for us obtained from the diagram, as shown in figure 5, the best result for the tensile-shear strength appeared in this research when we welded carbon steel (UNS G10050) in similar condition by 10000 A welding current, 35 bar pressure, 25 cycle squeeze time and 8cycle welding time and that as result for sufficient heat input to weld zone and extending weld nugget, however when compared to other conditions its preferable to apply more welding current, pressure, squeeze time and welding time for joining copper as shown in figure 4 (12000 A, 35 bar, 25 cycle squeeze, 5cycle welding time) and that as a reason for the behaviour of copper because of its high thermal conductivity which causing heat sink from the weld zone as the welding time set to 8cycle, the strength drops as a result for increasing the heat concentration to make the nugget resulting much weaker than before, while in dissimilar welding samples the maximum conditions are more applicable to obtain the best results as shown in figure 5 and that as a result for the different between two materials like thermal conductivity and melting temperature. Generally, the maximum shear force reached up to 4.5 KN shear force for joining carbon steel in similar condition and next 3.5 KN shear force for joining dissimilar condition and the weaker joining was in copper joining by 2.35 KN shear force.

![Figure 5. Results of tensile-shear strength for the all specimens](image)

3.2 Effect each variable on the tensile-shear strength

Depending on the Taguchi analysis, the effective variables for the strength are shown in figure 6, in case of similar materials condition for (UNS G10050 = AISI 1005) the strength increased when the all variables increased except the welding time when its increased the strength decreased and that leads to know that the formation of nugget needs more heat input with short period of welding time to reduce heated effect zone and allows the carbon to return inter to the atoms and without having the chance to form free Graphite that may decreases the strength.
In another similar welding condition with copper (UNS C10010), it was noticed that all variables behave like the same manner in case of carbon steel but weaker as shown in figure 7.

But in case of dissimilar condition it was found that the squeeze time behaves inversely with strength as shown in figure 8, and that leads to know that the two materials require a shorter cooling time to allow joining happened especially for the copper as compared to carbon steel alloy and that needs more time for welding.
3.3 Contour Plots
To estimate approximately results for tensile-shear strength under different conditions for joining these materials an approximate simulation was made for these three conditions as shown in figures 9, 10, and 11. In joining UNS G10050 carbon steel in similar joining condition, and gave these variables; welding time 6 cycles and current 11200 A and fixed another variable, it will be found that the tensile-shear strength is between 3 and 4 KN, et cetera.

Figure 8. Main effects of dissimilar condition

Figure 9. Contour plots for similar UNS G10050
Figure 10. Contour plots for similar UNS C10010

Figure 11. Contour plots for dissimilar joining

4. Conclusion

The maximum tensile-shear strength value was obtained for welding carbon steel in similar joining condition by using 10000 A welding current, 35 bar pressure, 25 cycles squeeze time and 5 cycles welding time, while the tensile-shear strength for joining copper was weaker than for joining carbon steel with copper in dissimilar joining condition. Dissimilar joining condition needs high current, pressure and welding time while needs less squeeze time for best results unlike the similar joining condition which needs less welding time and much current, pressure and squeeze time.
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