THE PROPER ELECTRODE GEOMETRY OF RESISTANCE SPOT WELDING PROCESS

Khalil Ibrahim ABASS[1]

The main technique for assembly lines without slugs and good quality is Resistance Spot Welding, RSW. The quality of the welds has one of the major problems that should solve during the welding process. The electrode geometry effect on the tensile resistance and producing weld nugget quality of the mild low carbon steel plates is investigated using RSW. The design of four electrode geometries is studied considering the shape profile and the contact area. The evaluation of the spot welding process depends on the tensile strength of the welds, the welding zone shape, and what surrounded it. The highest strength was indicated at the cross-flat electrode while the lowest strength was of the punch flat and round electrode types with a punch hole in the welding area of both. The punch hole is referred to the electric spark at the interfaces between the plate surfaces and the direct electrode surfaces

Keywords: Resistance Spot Welding RSW, Electrode Geometry, Tensile Test.

1. Introduction

Resistance Spot Welding (RSW) is a welding technique that uses both pressure and electric current to make joints between flat parts in just a few seconds. The benefits of the process are insured by the automatic assembly lines. The welding process involves keeping the two components pressed with the help of two copper electrodes to locally concentrate the heat coming from the resistive effect of the electric current and to allow the formation of a melting point at the interface between the two surfaces in contact. The process may be performed manually or by using robots.

Resistance spot welding consists of a sequence of cycles, of short duration, which are shown in Figure 1 [1]:

1. Preparing the work piece;
2. Squeeze cycle, the upper electrode is carried in contact with the pieces by an applied force at the welding area;

[1] Asist. Prof., Mechanical Engineering Department, Faculty of Engineering, Mustansiriyah University,
P. O. BOX (46049), Al-Bab AL-Muadham, Baghdad, Iraq,
e-mail: khalil1969a@yahoo.com, k.i.abass@uomustansiriyah.edu.iq

3. Weld cycle, the electric current flows through the direct contact area of the plate section and the sheet/electrode interfaces, causing generates an electric resistance that produces the heat which is essential for creating a weld nugget;
4. Hold cycle, the electric current is switched off, and the complete weld nugget is formed;
5. Maintain contact, keeping under constant pressure for cooling and solidifying;
6. Off cycle, the electrode is raised up from the welded work pieces.

The parameters of the welding regime that directly influence the quality of the RSW assembly process are: welding time and pressing time (sec), welding pressing force (MPa), electric current (A). The secondary parameters are: training of the operators, the material and the geometry of the electrodes tip and their surface quality. Choosing the correct values for the parameters of the welding regime ensures a sufficient amount of heat for the formation of a melting point with the appropriate geometry and good aspect, the melting occurring only at the interface between the surfaces of the parts, where the contact resistance is the highest. Thus it is possible to reduce the number of metal spatter ejected from the molten core, reduce the cost and maintenance time of the machines.

A domed tip profile is the most electrode shape and may be conical, truncated conical, flat, or cylindrical profile as well [2, 3].

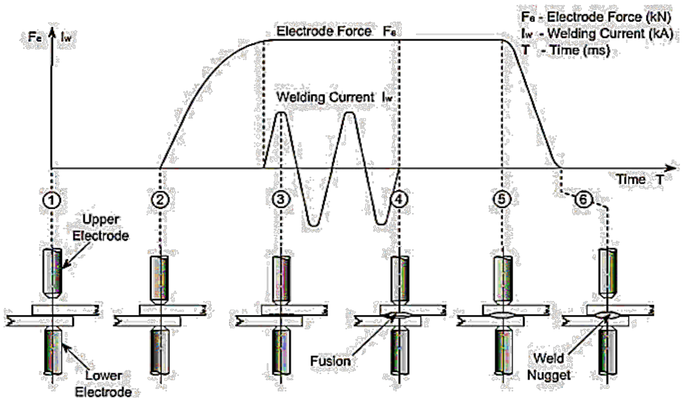


Fig. 1. Spot welding process and the main elements [1]

2. Literature Review

The main principle of the spot welding process is generating heat at the contact area due to passing the electric current and maintaining contact force for a limited time. The profile of the contact area involves the diameter and the geometry profile. The choice of improper values for the welding parameters determines effects like metal splashing from the molten core, offset of the melting zoom, or lack of fusion between the parts.

The common effects of the surface occurring in industrial environments [4, 5, and 6] are follows:

1. The most common error in RSW is no centric and coaxial location of the electrode tips. As a result, the electrode indentations are irregular and the spot weld is not acceptable.
2. The electrode tip drops from the electrode holder because of the loose tolerances or due to the electrode tip brazing on the surface of the weld piece. In terms of the weld nuggets, the outcome is non-symmetric and has an inappropriate outer weld surface.
3. The incorrect setting of the electrode's tip, in this case, the heat flow is non-symmetric proportional to the electrode axis generating a non-symmetric nugget which; is often joined with a splash. Fukumoto et al. [5] studied the electrode life of RSW during maintaining all the conditions constant by the welds number criteria. The electrode life is important when considering replacing the electrode after 400-900 welds. The electrode/sheet areas are the appropriate surfaces for checking during the process while the increase of contact areas is causing the reduction in the current density. The result is indicated by undersized nugget formation and reducing the joint strength.

Charde [7] studied the weld zone and electrode alignment with its mushrooming profile effects on stainless steel metals. The results showed that the nuggets change from the truncated to dome-type weld due to electrodes misalignment that causes poor weld regions and expulsion state.

Kaisar et al. [8] investigated the electrode degradation effect on a defect, Zn-assisted Liquid Metal Embrittlement, LME cracking in resistant spot welding by creating 400 sequential welds of steel. The geometric profile degradation showed that the radius of the curve is the major influence affecting the LME cracking. The results indicated that increasing the welds number causes increase in the curvature and contact area of electrode-sheet contact.

Baoqing and Jinrui [9] started an axis-symmetric contact model of finite element analyses of RSW. In the pre-squeeze stage, they provided an effective analysis of contact behavior. The results of the numerical simulation showed the distribution of the uneven contact pressure on the workpiece-electrode interface is the cause for this situation on the interface. Electrode tip radius, electrode face, and workpiece depth has in an influence on the contact pressure and the shape of the distribution.

The finite element method FEM was used to model the influence of electrode geometry on the formation of nugget; this was investigated by Chang and Bohr [10]. They compared four electrode geometries which included standard domed-flat, new parabolic-shaped electrode (Para CapTM), and truncated ((ISO F-style). As a result, the shape of the electrodes influences the profile of the final shape and the development of the weld nugget. The Para CapTM of 6mm flat electrode gave a large weld current window at welding of 1.6 mm Dp 780 steel under the conditions examined. The temperature and the deformation of the electrode were arrounced at the domed-flat 4.8mm electrode. The ISO F-style of

6mm flat electrode can minimize the electrode and indentation heating of the steel. However, it did not supply a range of current as large as the Para Cap TM electrode. The current range of the truncated of 6mm flat electrode was similar to the ISO-style electrode, whereas nugget penetration was reduced.

The electrode pitting influence on the formation of weld nugget in RSW of the aluminum alloy was examined using FEM by both Chang and Zhou [11]. A pre-drilled hole of different durometers was assumed at the center of the tip surface of the electrode to simulate pitted electrodes. The results displayed that there is no detrimental effect on the nugget size performed by the small pitting hole. The actual area of the contact of the interface of the electrode/sheet did not vary considerably in the case of increasing the pitting hole diameter. However, the high pitting area of the electrode surface tip generated a raised contact area, which caused the current density at the sheet/sheet interface reduced; accordingly, this led to the forming of an undersized weld nugget. The numerical computation of the shape of the nugget and its dimensions showed good agreement with the experimental observance. The nugget size temperature commenced minimizing the diameter for the pitting holes larger than 3.0 mm diameter.

L.I. Hassan and H.D. Lafta [12] presented a comparative performance of the traditional electrode geometry with a non-traditional design. The research produced two groups of variables, the diameter, and the interior hole. The weld joint was tested by considering the current, welding time, and pressure. The torsion and tensile strength inspections are supported to examine the mechanical properties and the nugget profile size by macrograph consideration. The results showed that the torsion and shear tensile strength improved by about 150% and 140%, related to the traditional electrode geometry. Deng et al. [13] studied three types of electrode profile designs were explored a textured electrode and a multi-ring domed electrode with two-ring heights. They established; that there is no significant relationship between the electrode tip design and nugget diameter, and all Failure types were interfacial. However, the electrode tip profile influences the mechanical properties and microstructure.

Li et al. [14] considered the effect of truncated electrode cone angle on weld nugget characteristics and electrode wear using finite element methods and experimental. The results showed an enhanced reducing the electrode temperature and needing a high current to adjust the heat wasted.

The paper presents a study on the effect of electrode surface geometry on welding quality, using four different types of electrode pairs for spot welding. Each profile electrode considered in its design the distribution of the contact area (point, plane, and line) of the welding spot. The welding electrodes which were considered were Flat, Punch/Flat, Round, and Cross Flat. The test applied included the welding process and tensile test. The nature of the welding contact was described by the model in terms of contact locations and contact pressure.

The welding process, the shape of the welding zone, and what surrounds are investigated. The experimental data are taken from tensile tests applied on the welded specimens for evaluating the effect of each electrode profile on the strength of the welded area.

3. Experimental Procedure

Operational layout: the data collection and experimental steps including the electrode geometry selection, Spot welding process, tensile test data collection, and the analysis of the results are shown in Figure 2.

Specimens selecting: the mechanical properties of AISI 1018 Mild/Low carbon steel components are listed in table 1. The mechanical test to which the welded parts were exposed was tensile shear, in order to evaluate the fracture behaviour. The tensile shear sample was 100 mm long (L) and 25 mm wide (W). The weld was made at the centre of the overlapping 35.35 mm region, and the plate thickness 0.5 mm (t), as shown in Figure 3.

Electrode preparation: the selected raw material was copper with four pairs of different electrode shapes, (Figure 4). The details and the electrode dimensions are shown in Figure 3.

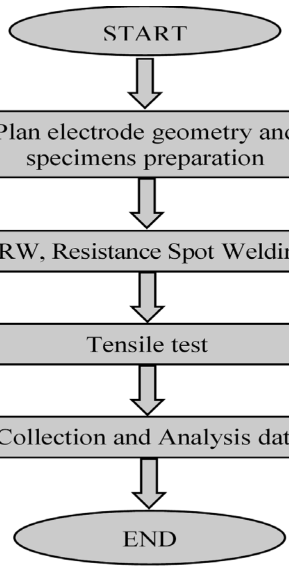


Fig. 2. Operational framework

Table 1

Material properties of AISI 1018 Mild/Low Carbon Steel

Mechanical properties	Tensile strength, MPa	Modulus of elasticity, GPa	Density, g/cm^3	Poisson's ratio
value	370	205	7.85	0.29

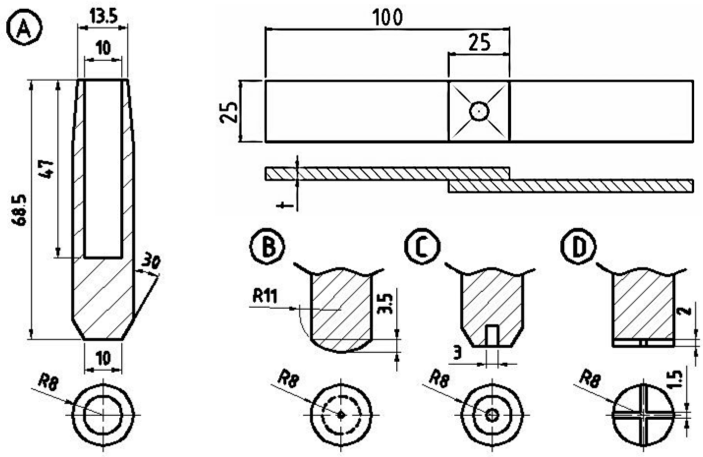
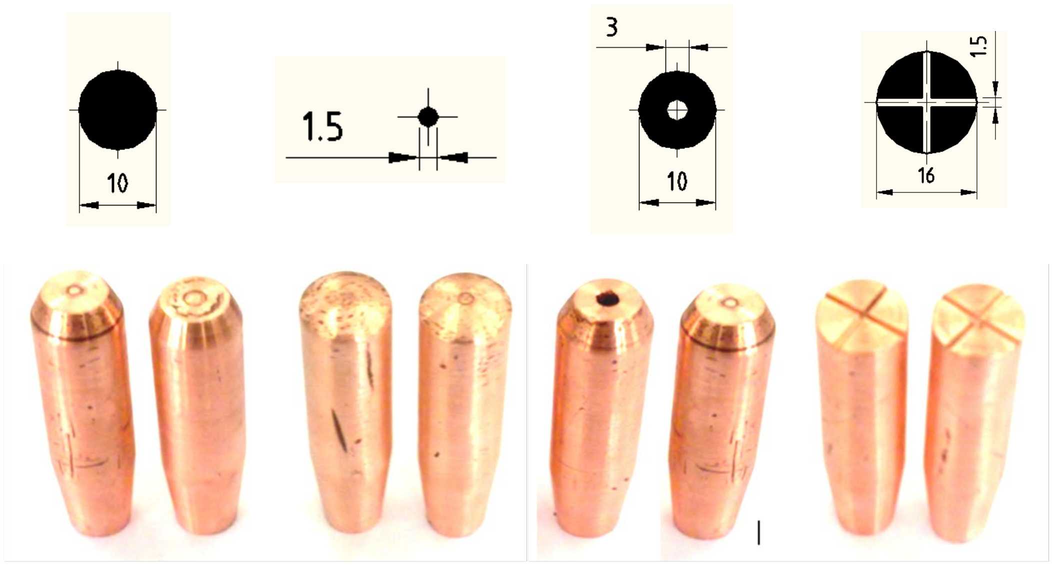


Fig. 3. Details and dimensions of the electrode geometries where,
A) Flat, B) Round, C) Punch / Flat, D) Cross Flat and the specimen.



A) Flat B) Round C) Punch/ Flat D) Cross Flat

Fig. 4. The geometries of electrode

Three types of contact area distributions are studied depending on point line and area:

1. Round, as a point.
2. Punch/Flat as a closed line, and Cross Flat as an opened line.
3. Flat as a single area, Cross Flat as a multi-areas, and punch/Flat as different areas.

Figure 4 and Table 2 present the geometrical shapes of the contact areas and their values based on the variables, such as electrode pressure, time, and current. The effect of electric current change with the various tip profile has been investigated at a constant pressure of 465 N.

The procedure of RSW: step by step RSW process is described below:

1. Turn on the power, spot welding machine, and cooling system; establish the initial value of the pressure variable;
2. Switch on the pressure and the weld button, the welding process will be done automatically;
3. Adjust the variables and repeat the same steps.

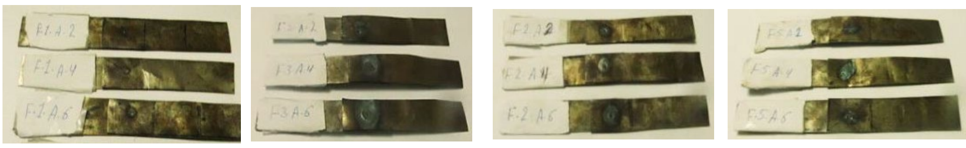
4. Results and Discussion

Calculation and measurement: the results are presented in Figure 5-A, B, C, D, which show the weld shapes, respectively. The welds were performed with different values of time cycle (2, 4, and 6 sec.) for each electrode, adding to the time cycles 8 and 10 sec., that produced some faults, as shown in Figure 6. Table 2 presents the measurements of the contact area, welding and heat zone diameter, and the description of the element properties and appearance, as shown in Figure 7.

2 sec

4 sec

6 sec



A) Flat B) Round C) Punch / Flat D) Cross Flat

Fig. 5. The welding specimens obtained using welding times of 2, 4, 6 sec

8 sec.

10 sec.

Weldment, less than 2 sec.

Fig. 6. The welding specimens obtained using welding times of 2, 8, 10 sec

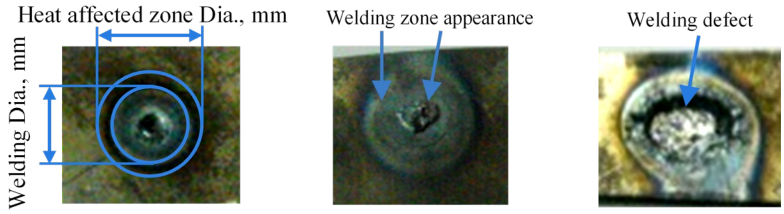


Figure 7. Specific zones of the spot welded joint: the welded zone (fused core), the heat affected zone around the molten core and a weld defect

The increase is practically in the welding region, and the heat-affected zone 'Diameter value, mm' of all electrode profile states with increasing the electric current, even with different contact area profiles (increase or decrease); in other words, the differences are irregular. The highest values are recorded at the welding diameter of 12.6 mm and heat affected zone diameter of 16.5 mm of the punch/flat electrode profile type at time; 6 sec. The lowest values are recorded at the welding diameter of 3.1 mm and heat-affected zone diameter of 6.2 mm of the flat electrode profile type at time; 2 sec, as shown in Table 2.

Table 2

The electrode profile and the time effect on the welding zone properties

Electrode profile	Time, sec.	Contact area, mm^2	Welding Diameter, mm	Heat affected zone Diameter, mm	Welding zone properties	Welding zone appearance
Flat	2 4 6	78.50	3.1 4.2 6.4	6.2 7.2 7.53	Regular diameter and good shape	Good surface finish
	8 10		---- ----	---- ----	Defects in welding zone	
Round	2 4 6	start with point to 1.767	6.6 7.2 8.3	9.15 11.2 14.35	Regular diameter and very good shape	Very good surface finish
Punch \ Flat	2 4 6	78.50 + 71.47	6.1 8.2 12.6	9.15 13.25 16.5	Increase diameter with time	Not good surface finish relative to round shape
Cross Flat	2 4 6	38.84*4	5.1 9.2 10.3	9.2 11.4 12.3	Increase diameter with time	Not good surface finish relative to round shape.

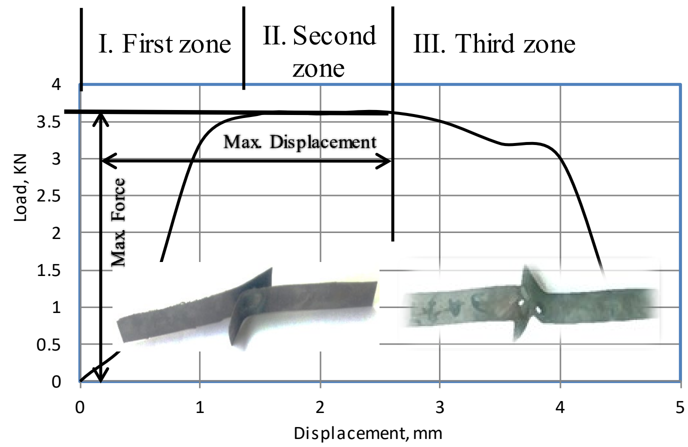
Tensile test: two types of curves indicate the highest joint force, as shown in Figure 8, where:

I. First zone: the primary welding zone, where no fracture and no separation appear.

II. Second zone: the fracture or the separation occurs in the welding zone. A good tensile strength is observed before breaking begins.

III. Third zone: continuous tear or separation in specimen material at the welding zone, where, reducing the load applied with increasing the displacement is recorded.

Tensile resistance is reflecting of contact force depending on the period and distribution of welding time. At any contact process between two pieces, the contact resistance depends on the contact area distribution. Therefore, the longer displacement represents higher contact resistance.



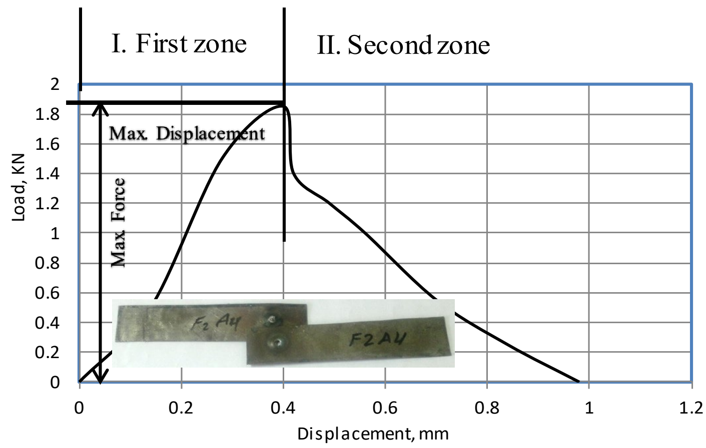


Fig. 8. The displacement-load relationship of tensile test on the welded specimen pair

Assuming that the pressure force is the same and the electrode profile is different, the contact area will vary. Therefore, more contact (integrated) areas are supposed to be more resistant to shear tensile. This assumption is true when there is no welding or fusion of metal between the two workpieces surfaces. In case the electrode shape profile is different, the shape of the weld will differ, and the force that the weld can withstand will vary - applying the stress law, force/area shows the difference.

The results that were extracted for identifying the effects on the welding samples depended on analyzing the following:

1. The direct welding area.
2. The affected welding area.
3. The welding zoom properties and appearance.
4. Time-Force relationship practically of electrode types.

The results compared four electrode profiles, as shown in Table 2, where detected at any increases in the direct welding area causes increasing in the electrical current.

The appearance of the punching when using the Punch/Flat electrode, is due to generated the electric spark at the electrode-plates interfaces, Figure 5C. As well, the same defect was produced in the Round electrode, Figure 5B.

The metal melting of the direct contact area increases directly with the electric current that depends on the area profile and the value.

The heat affected diameter percentage ratio is expressed as: *heat affected zone diameter - welding diameter / welding diameter*. The percentage ratios are decreased for flat, punch/flat and cross flat electrode profile types with different levels and a crossing ratio state. While the ratio increased for the round electrode profile type with an increase in the electric current from 2 to 6 seconds. The increasing and the decreasing were irregular and nonlinear ratios, even regular increments of the electric current are used, as shown in Figure 9. The welding time is not a sufficient condition for improving the contact resistance (increasing the welding time means continuous current flow and generating the temperature at the applied pressure). The area-time relationship is affected as well.

The results presented the relationship between the resistance force (bonding force during shear) of the welded area (KN) and the welding time (Sec), as shown in Figure 10.

The maximum bond force recorded at the welding area is 2.85 KN referring to the Cross Flat electrode type, as well as followed by the values of Flat and Round electrode types, 2.78 KN and 2.75 KN respectively.

The bonding region of the welding area resisted the applied force of all the electrodes types, except the case of the Punch/Flat electrode, 1.95 KN, which ruptured at the welding bonding area itself.

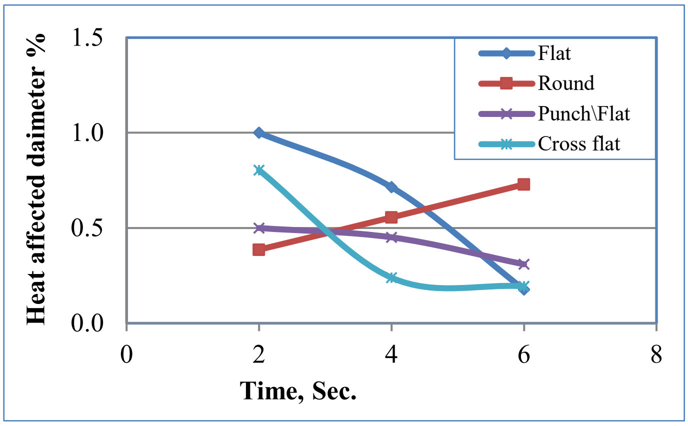


Fig. 9. Diameter % relationship,
A) Flat, B) Round, C) Punch / Flat, D) Cross Flat

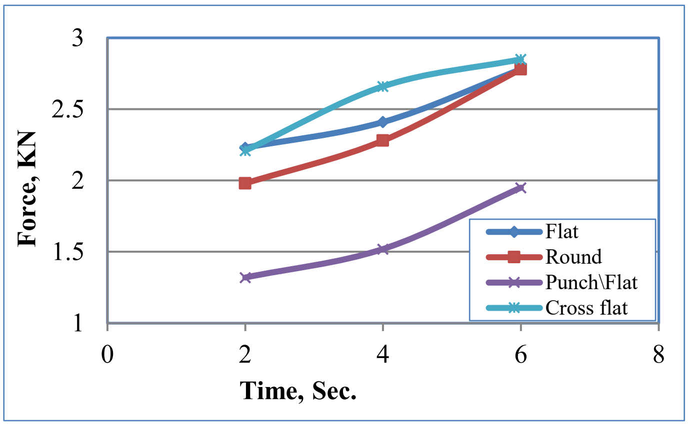


Fig. 10. Time - force relationship,
A) Flat, B) Round, C) Punch / Flat, D) Cross Flat

5. Conclusions

The results confirmed that a good prediction is obtained and the strength of the welding region is proportional to welding cycle time for all the electrode profiles that have been studied.

The highest binding strength value performed by the Cross Flat electrode type and the lowest value by the Punch/Flat electrode type

The same type of defect is noted when using the Punch/Flat and Round electrode types. The defects detected in the welding area appear like holes, because of the electric spark at the interfaces between the workpiece surfaces and the contacted electrode surfaces.

Increasing the contact areas between the electrode tips in RSW does not necessarily improve the shear strength of spot welded joints. In other words, the distribution of points, lines and contact areas can increase or decrease the shear strength of the joint.

The presence of holes or spaces in the electrode profile causes the deformation in the welding zone and then weakness at the binding force of sheets.

REFERENCES

[1] *M. Brijesh, M. Desai, M.P. Parmar, P. Student*, "Optimization of process parameters for Resistance Spot Welding process of Austenitic SS 304 using Response Surface Method – A Review", International Journal For Technological Research In Engineering **vol. 1**, iss. 9, 2014, pp. 646-650.

[2] *R.S. Tabar, K. Wärmefjord, R. Söderberg*, "Evaluating evolutionary algorithms on spot welding sequence optimization with respect to geometrical variation", 15th CIRP Conference on Computer Aided Tolerancing – CIRP CAT 2018, Procedia CIRP, **vol. 75**, 2018, pp. 421–426.

[3] *H.K. Hussein, I.R. Shareef, IA. Zayer*, "Prediction of spot welding parameters using fuzzy logic controlling", Eastern-European Journal of Enterprise Technologies, **vol.** 5, no. 2, 2019, pp. 57-64.

[4] *D. Bračun, I. Polajnar, J. Diaci*, "Indentation shape parameters as indicators of spot weld quality", International Journal of Materials and Product Technology **vol.** 27, no. 3-4, 2006, pp. 247-257.

[5] *S. Fukumoto, I. Lum, E. Biro, D. R. Boomer, Y. Zhou*, "Effects of electrode degradation on electrode life in resistance spot welding of aluminum alloy 5182", Welding Journal, **vol. 82,** iss. 11, 2003, pp. 307-312.

[6] *I. Lum, E. Biro, Y. Zhou, S. Fukumoto & D. R. Boomer*, "Electrode pitting in resistance spot welding of Aluminium alloy 5182", Metallurgical and Materials Transactions, **vol. 35**, iss. 1, 2004, pp. 217-226.

[7] *N. Charde*, "Effects Of Electrode Deformation on 304 Austenitic Stainless Steel Weld Geometry of Resistance Spot Welding", Journal of Mechanical Engineering and Sciences (JMES), **vol. 3**, 2012, pp. 261-270,

[8] *K. Mahmud, S.P. Murugan, Y. Cho, C. Ji, D. Nam, Y. Park*, "Geometrical degradation of electrode and liquid metal embrittlement cracking in resistance spot welding", Journal of Manufacturing Processes, **vol. 61** 2021, pp. 334-348.

[9] *L. Baoqing, S.P. Jinrui, H. Shengsun*, "Study of Contact Behavior in the Pre-squeeze Stage of Aluminum Alloy Resistance Spot Welding", Tianjin University, Tianjin , P.R.C 2002.

[10] *K.R. Chan, N. Scotchmer, J.C. Bohr, I. Khan, M.L. Kuntz, Y. Zhou*, "Effect of electrode geometry on resistance spot welding of AHSS", in: SMWC XII Session 7-4, Livonia, MI, 2006.

[11] *B.H. Chang, Y. Zhou, I. Lum, D. Du*, "Finite element analysis of effect of electrode pitting in resistance spot welding of aluminium alloy", Science and Technology of Welding and Joining, **vol.** 10, iss. 1, 2005, pp. 61-66.

[12] *L.I. Hassan, H.D. Lafta*, "The Effect of Electrode Geometry and Pre-heating Treatment on Resistance Spot Welding Strength", Engineering and Technology Journal, **vol.** 41, no. 07, 2023, pp. 1-9.

[13] *L. Deng, Y. Li, B. Carlson, and D. J. W. J. Sigler*, "Effects of electrode surface topography on aluminum resistance spot welding", Welding Journal, **vol.** 97, 2018, pp. 120-132.

[14] *Y. Li, Z. Wei, Y. Li, Q. Shen, Z. J. Lin, M., "*Transfer, Effects of cone angle of truncated electrode on heat and mass transfer in resistance spot welding", Int. J. Heat Mass Transf., **vol**. 65, (2013, pp. 400-408.