Eng.& Tech. Journal, Vol.30 , No.15 , 2012

Prediction of the Best Electrode Geometry of Resistance Spot Welding RSW Theoretically by FEM and Experimentally

Khalil Ibrahim Abass
Engineering Collage, University of AL Mustansyria /Baghdad
Email: Khalil1969@yahoo.com

Received on: 27/12/2011 & Accepted on: 3/5/2012

ABSTRACT

The present research studies five spot welding electrodes (RSW) of different geometries. The design of each electrode considerers contacts shape and area of the welding spot. The considered welding electrodes are (Flat, Round, Project, Punch\Flat, Cross Flat). A simplified mathematical 2D-axisymmetric model is used to study the behavior of each electrode. It is solved numerically using Finite Element Method (FEM). The model describes the nature of welding contact in terms of contact locations, contact pressure and stress distribution. The model is validated by performing tensile shear tests on the welded specimens resulted from each electrode. Results show good agreement between the estimated behavior and the performed tests. The strength of welding appeared to be proportional to welding time for all five electrodes considered. The type (Project) gives the highest shear strength and the type (Punch\Flat) gives the lowest shear strength. The tests show that the electrode of the type (Punch\Flat) produces a hole in the welding area. This is caused by the electric spark in the gap between the upper electrode and the plate. The same defect is noticed in the type (Round). In both types, this phenomenon is attributed to the stress concentration in a narrow area which eventually causes the punch.

تخمين الشكل الهندسي الأمثل للألكترود في لحام المقاومة الكهربائية بالنقطة RSW(نظرياً بطريقة العناصر المحددة FEMوعملياً)

الخلاصة

في هذا البحث تم أختيار ودراسة خمسة أشكال هندسية مقترحة لألكترود لحام المقاومة بالنقطة – RSW, وقد صممت أعتماداً على شكل التماس ومساحة نقطة اللحام الى الأنواع:
(Flat, Round, Project, Punch\Flat, Cross Flat). وقد تم بناء نموذج مبسط ثنائي ألابعاد ومتماثل حول المحور 2D - Axis symmetric بطريقة العناصر المحددة - FEM حيث يظهر طبيعة التماس (مواقع التماس, قوة وضغط التماس, توزيع الأجهادات). كذلك تقييم شكل منطقة اللحام الناتجة ومساحتها والمنطقة المتأثرة باللحام ومصادقة النموذج النظري عن طريق أجراء أختبار الشد القصي عل العينات الملحومة وتقييم مقدار قوة اللحام الناتجة وبيان المقارنة بين الأشكال الهندسي الخمسة للألكترود. وقد أظهرت النتائج أن علاقة قوة اللحام تتناسب طردياً مع زمن اللحام ولكل أنواع الألكترودات مع ملاحظة أن نوع الألكترود (Project) كان الأعلى قوة قص. ونوع

https://doi.org/10.30684/etj.30.15.6
2412-0758/University of Technology-Iraq, Baghdad, Iraq
This is an open access article under the CC BY 4.0 license http://creativecommons.org/licenses/by/4.0

الألكترود (Punch\Flat) كان الأقل قوة. وهو نفس التخمين الذي قدمه نموذج الـ FEM. أما تقييم شكل اللحام فقد أظهر وجود ثقب في منطقة اللحام في نوع الألكترود (Punch\Flat) نتيجة وجود تفريغ كهربائي في الفجوة بين جزء الألكترود العلوي والصفيحة, وهو نفس العيب الذي ظهر في نوع الألكترود(Round) حيث تركز الأجهادات في منطقة ضيقة سبب خرق في وسط منطقة اللحام.

INTRODUCTION

Resistance Spot Welding (RSW) is a major bonding technique in the automotive industries Nowadays industries are using 30% of the total amount of spot weld to join a part of car. The advantages of resistance spot welding are high speed and suitability for automation and inclusion in high production assembly lines with other fabricating operations. In RSW process, two or three overlapped are welded together due to the heat created by electrical resistance. Spot welding may be performed manually, using robots, or by a dedicated spot welding machine and the process takes only few seconds. There are several variables to control in order to produce good quality weld like welding current (A), welding pressure (MPa) and time (Cycle), type of material, thickness, condition of electrodes and the surfaces. The profile of the electrode is important with respect to both the tip life and weld quality. Tips may be conical, truncated, flat, domed or cylindrical. Of these types the truncated cone and the dome predominate in case of welding carbon steel and Aluminium respectively. The most commonly recommended shape is the domed tip, the shape of which is more easily maintained in production than the truncated cone. The truncated cone tends to be used for commercial quality applications, mainly because electrode alignment is more critical and difficult to maintain consistently in production. Tip life, however, is markedly better, by a factor of two to three, than can be achieved with the domed electrode. Cone angles vary from 60° to 150° including an angle with a slight radius on the tip which aids in alignment and reduces marking of the sheet. [1]

The size of the electrode tip point controls the size of the resistance spot weld. Actually, the weld nugget diameter should be slightly less than the diameter of the electrode tip point. If the electrode tip diameter is too small for the application. The weld nugget will be small and weak. If, however, the electrode tip diameter is too large, there is danger of overheating the base metal and developing voids and gas pockets. In either instance, the appearance and quality of the finished weld would not be acceptable. [2]

A number of investigators have studied the spot welding process to obtain analytical and numerical solutions where:

Li. Baoqing, Shan Ping [3] represented an axis-symmetric contact finite element analysis (FEA) model of (RSW). It provided effective analysis of contact behaviour in the pre-squeeze stage. The numerical simulation results that the uneven contact pressure distribution on the Workpiece-Electrode interface is the reason of the contact pressure distribution on the faying interface. The contact behaviour is affected mainly by the electrode tip radius, work-piece depth and electrode force . A 2D axi-symmetric FEM model has been developed by **Thakur.A.G, Rasane.A.R [4]** to analyse the transient thermal behaviours of RSW process. The objective of this analysis is to understand physics of the process and to develop a predictive tool reducing the number of experiments for the optimization of welding parameters. During the welding cycles there is compressive stress in the contact area of faying surface, which is helpful for

PDF created with pdfFactory Pro trial version www.pdffactory.com

good metallurgical structure, forming a condensed weld nugget. Through the thermal histories and temperature distributions obtained from this analysis, the geometry and dimensions of the nugget can be calculated.

The effect of electrode cap geometry on nugget formation was modelled FEM and investigated by **Kevin R. Chan, John C. Bohr [5],** Four electrode geometries were compared, including standard domed-flat, truncated, (ISO F-style), and a new parabolic shaped electrode (Para Cap™). It was found that the shape of the electrodes had an influence on the development and final shape of the weld nugget. Where the (Para Cap™ - 6 mm flat) electrode yielded the largest weld current window when welding 1.6 mm DP780 steel for the conditions studied. Electrode temperature and deformation was found to be more pronounced when using the (domed-flat- 4.8 mm) electrode. The (ISO F-style- 6 mm flat) electrode while able to reduce the heating of the electrode and indentation of the steel. The (truncated- 6 mm flat) electrode showed a current range similar to the (ISO F-style), however nugget penetration was reduced.

The effect of electrode pitting on the formation of the weld nugget in RSW of an AL alloy was investigated using FEM was investigated by **B. H. Chang, Y. Zhou [6],** Pitted electrodes were simulated by assuming a pre-drilled hole of varying diameter at the centre of the electrode tip surface. The results showed that a small pitting hole would not have a detrimental influence on the nugget size. The actual contact area at the electrode/sheet interface did not change significantly when the diameter of the pitting hole was increased. However, a large pitted area at the electrode tip surface resulted in a greatly increased contact area and hence reduced current density at the sheet/sheet interface, which in turn led to the formation of an undersized weld nugget. The numerical calculation of the nugget shape and dimensions agreed well with experimental observations. The temperature and nugget size started to decrease for pitting holes greater than 3.0 mm in diameter.

Uğur Eşme [7] has presented an investigation on the optimization and the effect of welding parameters on the tensile shear strength of spot welded SAE 1010 steel sheets. Based on the ANOVA method, the highly effective parameters on tensile shear strength were found as welding current and electrode force, whereas electrode diameter and welding time were less effective factors.

Jianhui Xu and Xiuping Jiang [8] was employed to pre-join refractory alloy 50Mo–50Re sheet with a 0.127 mm gage. Five important welding parameters (hold time, electrode, ramp time, weld current and electrode force) were adjusted in an attempt to optimize the welding quality. It was found that increasing the hold time from 50 ms to 999 ms improved the weld strength. Use of rod-shaped electrodes produced symmetric nugget and enhanced the weld strength. Use of a ramp time of 8 ms minimized electrode sticking and molten metal expulsion.

THE FEM MODELLING OF RSW

A FEM model of contact analysis was developed using the university edition ANSYS software. Since the entire schematic arrangement of the RSW shown in figure (1-A) can model as an axi-symmetric model-2D, only one quadrant of the model was constructed for every geometry of electrodes (**Flat, Round, Project, Punch\Flat, Cross Flat)**. And the boundary conditions of the FEM model showed in the figure (1-A) where:

PDF created with pdfFactory Pro trial version www.pdffactory.com

I. The model is meshed using four elements; the element PLANE42 for electrodes, VISCO106 for sheets, the contact elements consisting of contact pair CONTA172 (contact element) and TARGE169 (target element). [9]
II. The upper electrode movable in y-axis direction only.
III. The lower electrode fixed in all directions.
IV. Two sheets movable in y-axis direction only.
V. Three contact areas: 1) Electrode\Sheet, 2) Sheet\Sheet, 3) Sheet\Electrode.
VI. The solving represented by von miss stress distributions and contact pressure at sheet\sheet interface as shown in the figure (1-B, C, D, E, F).

OPERATIONAL FRAMEWORKS

The operational framework for the experiment and data collection is shown in the figure (2) includes Design of electrode geometry, Prepare the specimen, Spot welding process, Tensile shear test and Data collection and analysis.

The Experimental Process

Starting with Selection of specimen to be weld, the basic component to select the specimen is the thickness and material. The mechanical properties and chemical composition of material (1008 - low carbon steel) list in tables (1, 2). A standard procedure needs to be followed to prepare the specimen. For this study, the standard used to prepare the specimen is IIS (Iraq Industrial Association) figure (3-F) [10]. This standard specifies the method for shear strength test of spot welded joint not more 0.5 mm in plate thickness, (t) and cut by the cutter to get standard dimension (100 x 23) mm, (L x W). The specimen should not be rusty, because it can affect the effectiveness of the experiment. For two sheet lap joint, the shape of test piece shall conform to Figure (3-F). This research used a single spot test piece.

And the procedure for prepare Electrodes. We select electrode made of copper and manufacture five different shapes as shown in Figure (3) with details and dimensions & Figure (4 - A, B, C, D, E) represents geometries of electrodes as follows:

Flat, (B) Round, (C) Project, (D) Punch / Flat, (E) Cross Flat.

In this research used three types of contact depending on:

I. Point: (round) electrode.
II. Line: a) Closed line (project) electrode,
b) Opened line (cross flat) electrode.
III. Area: a) Single area (flat) electrode,
b) Multi-area (cross flat) electrode,
c) Deferent area (punch\flat) electrode.

The figure (5) represents the shape of real contact area for each electrode and the values of these areas were calculated as shown in Table (3).

In addition, based on the basic component the variables such as time, current and electrode force are selected. The total time (welding and holding) selected as shown in Table (3), the effect of the current is changed with various shape (in this research was neglected) and a constant force was selected (450 N).

PDF created with pdfFactory Pro trial version www.pdffactory.com

The Procedure of Spot Welding Process

The several electrodes geometry (flat, round, project, punch\flat, cross flat) were tested and the figure (6-A, B, C, D, E) shows the nugget shape for all electrode types respectively. They are executes with deferent value of time cycle (2, 4, 6, 8, 10) sec for each electrode. In the beginning we start the experimental with these series of time in flat electrode, but at time (8, 10) sec appears some defects as shown in figure (6-F) therefore neglected.

The abstract of the calculations and measurements that resulted from this step tabulated in table (3). Which includes contact area value of the electrode, diameter of spot welding and heat affected zone diameter, describe of the weld nugget appearance and evaluation by the comparing between them.

Shear Tensile Test

From the shear tensile tests we get two types of curves as shown in Figures (7), (8) that represent the maximum force to joint two plates (specimen) where:

I. First zone: Represents primary welding deformation zone (where no fracture in material and no separate in welding zone) only deformation of specimen.

II. Second zone: Represents secondary welding deformation zone (where fracture in material or separate in welding zone).

III. Third zone: Represents welding fracture zone (where continuous of fracture in material or continuous separate in welding zone).

The table (3) represents the collection of data of these tests where shows generally the joint force increases with time as well as the project electrode have the greater force value of joint than that of other joints, especially at time 6 sec.

THE RESULTS AND DISCUSSION

The stress distribution indicator (von-misses) in the FEM model was estimated along all the contact area between the two electrodes and the two plates. It was also computed in the points of stress concentration as shown in Figure (1-B, C, D, E, F). This means that the metal in the pressure stage experiences a compression at these points higher than other points.

In other words; this means that the bounding force between the two plates was increased after the plastic stage happening in the welding process.

Another indicator is the area of contact pressure shown in Figure (9). The electrode (project) gives the maximum contact pressure distributed along contact area between the two plates; this demonstrates an excellent bonding of the metals of the two plates.

The results extracted from the welding samples were analyzed to find out the effects an: 1) The spot welding area. 2) The area of heat affected zone.
3) The general shape and appearance of the spot welding area.

The results were compared for electrodes of different shapes. Table (3) shows a review of these results. It can be deduced that the welding area increases with the increase of the welding time for all electrode types. The maximum welding area (Φ15 mm) was given by the electrode (project). The electrode (punch/flat) caused a punching in the middle welding area due to the electric sparking in the gap between the upper electrode and the plate Figure (6-D). The same punching phenomenon was seen in the electrode (round) Figure (6-B) as a result of the concentration of pressure

PDF created with pdfFactory Pro trial version www.pdffactory.com

in a narrow area where the spark commences. The high current passing through this narrow area highly increasers the rate of metal melting in the contact area.

The tensile shear test was carried out on all welding samples for all electrode types. The results in figure (10) show that the welding shear strength is proportional to the time spent in welding for all types of electrodes. The maximum bonding force (3.35 KN) in the welding area was given by the electrode (project) followed by the electrode (cross flat = 2.63 KN) then (flat = 2.58 KN). The bonding strength of the welding was so high that the metal surrounding the welding area was ruptured in the tension test and the welding bond itself remained intact. This was not the case with the electrode (punch/flat = 1.72 KN) where the fracture occurred at the welding bound itself.

CONCLUSIONS

1. The mathematical model solved by FEM gives satisfactory prediction of the value of contact pressure area at sheet\sheet interface and stress distribution in the welded area.
2. The result obtained from the squeeze stage shows that the contact behavior is affected mainly by the electrode geometry and electrode force. Also, the stress distribution varies from centerline of the model towards the edge of the electrode and the sheets.
3. The radius of faying interface depends on the electrode geometry and the contact pressure distribution shape is primarily affected by the electrode tip and electrode force.
4. Electrode geometry does affect the development and final shape of the weld nugget.
5. Increasing contact area between electrodes does not necessarily increase the shear force joining of the sheets.
6. The holes or spaces produced by electrode (punch\flat) cause a deformation in the welded area and weaken the force joining the sheets.
7. Increasing the welding time over 6 sec. causes a defect in the welded area due to the increase of molten quantity of the metal.

REFERENCES

[1] Gene, Mathers **“The welding of aluminium and its alloys”**, Published by Woodhead Publishing Limited, Abington Hall, Abington Cambridge CB1 6AH, England, 2002.

[2] **“Hand Book for Resistance Spot Welding”, Miller Electric Mfg. Co.,** An Illinois Tool Works Company, 1635 West Spencer Street, Appleton, WI 54914 USA, July 2005.

[3] Li. Baoqing, Shan Ping Lian Jinrui, Hu Shengsun ,**“ Study of Contact Behavior in the Pre-squeeze Stage of Aluminum Alloy Resistance Spot Welding”,** Tianjin University, Tianjin , P.R.C. 1992.

[4] Thakur,A.G, Rasane,A.R, Nandedkar,V.M, **“Finite Element Analysis of resistance spot welding to study nugget formation”**, international journal of applied engineering research, dendigul, Volume 1, No 3, 2010 p 483-490.

[5] Kevin, R. Chan[1], John C. Bohr[2], Ibraheem Khan[3], **“Effect of Electrode Geometry on Resistance Spot Welding of AHSS”,** [1]Kevin R. Chan, Nigel

PDF created with pdfFactory Pro trial version www.pdffactory.com

Scotchmer, Huys Welding Strategies Ltd., 175 Toryork Road Unit #35, Weston, Ontario, Canada, 2006.

[6] Chang[1], B. H. Y. Zhou[2], I. Lum[2] and D. Du[1] **"Finite element analysis of effect of electrode pitting in resistance spot welding of aluminium alloy",** Science and Technology of Welding and Joining, 2005, Vol. 10, NO. 1, p61-66.

[7] Uğur Eşme **"Application of Taguchi Method for The Optimization of Resistance Spot Welding Process"**, The Arabian Journal for Science and Engineering, Volume 34, Number 2B, October 2009, p 519-528.

[8] Jianhui Xu [a], Xiuping Jiang [a], Qiang Zeng [a], Todd Leonhardt [b], John Farrell [c], Williams Umstead [c], Michael P. Effgen [c] **, "Optimization of resistance spot welding on the assembly of refractory alloy 50Mo–50Re thin sheet**", Journal of Nuclear Materials 366, 2007, p 417–425.

[9] **Ansys**, User's Manual, Version 11, 2010.

[10] Mona kidder abass **"Study affect the oldness and other factors on spot welding joints for some aluminium alloys"**, M.Sc., 1986.

Table (1): material properties of (1008 - low carbon steel) specimen blank.

Properties of material	Values
Young's modules, E	361 GPa
Density, ρ	7980 kg/m^3
Yield stress, σy	216 MPa
Poisson's ratio, ν	0.3

Table (2): chemical composition of (1008 - low carbon steel) specimen blank.

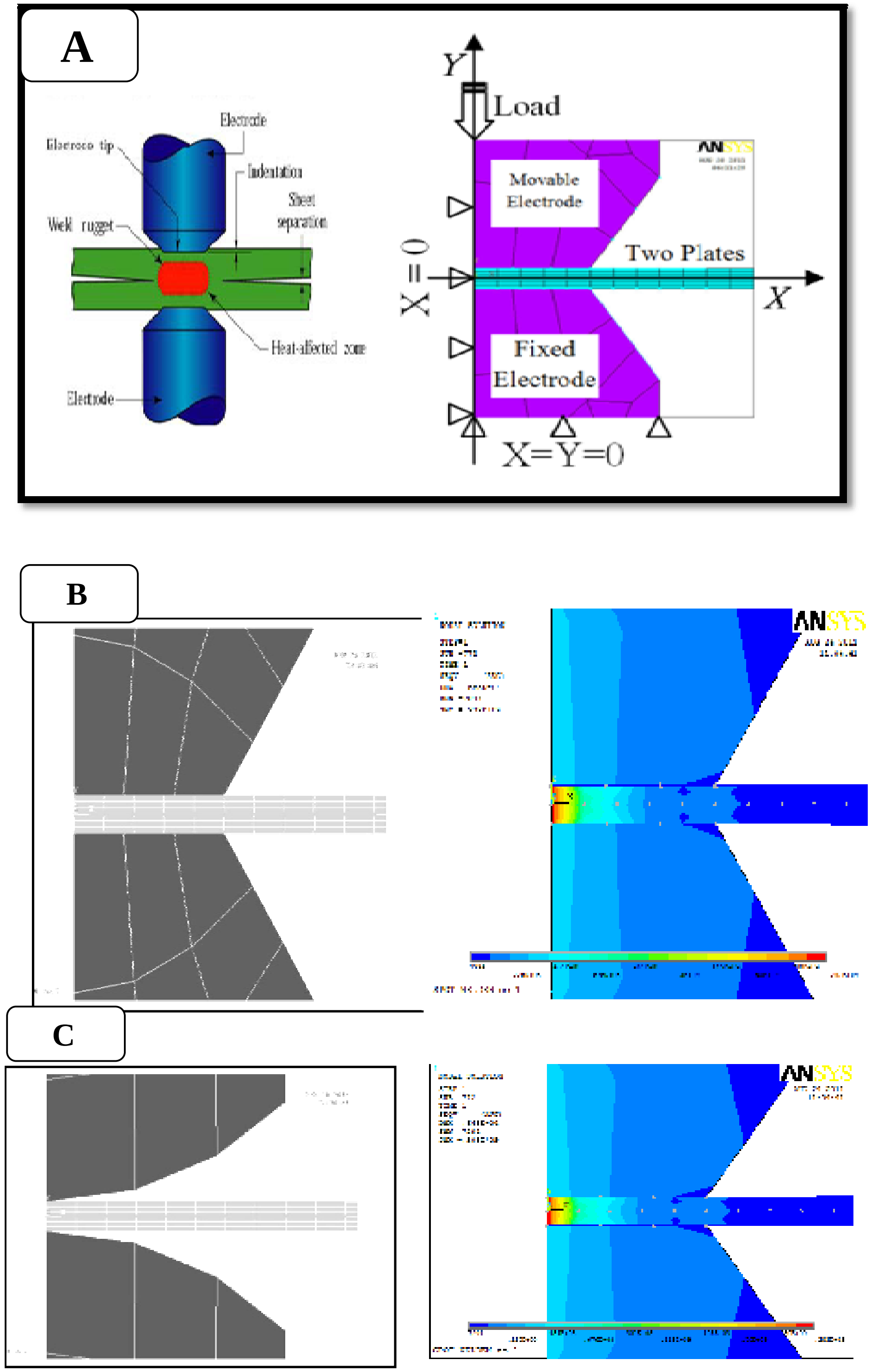
Element	C	Si	Mn	S	Cr	Ni	Mo	Cu	Ti	V
Wt %	0.06	0.003	0.31	0.037	0.021	0.077	0.005	0.052	0.008	0.002

PDF created with pdfFactory Pro trial version www.pdffactory.com

Table (3): the properties of spot welding zone and the effect of(time, electrode geometry) on the force value (max. Shear force) at constant force (450N).

The Shape	Total Time "sec"	Area of Contact "mm²"	Pressure Applied N/m²	Dia. of Spot Welding "mm"	Dia. Average of Heat Zone "mm"	Max. Shear Force in Tension "KN"	Appearance of Spo Welding zone
FLAT	2 4 6	(78.53*2)	5.73.E +06	3 4 6	6 7 7.5	1.95 2.2 2.58	1. The dia. is regular and the shape is good. 2. The surface is good.
	8 10	(78.53*2)	5.73.E +06	---- ----	---- ----	---- ----	1. The defects in welding zone. 2. The surface is not good.
ROUND	2 4 6	start with point to (1.767)	2.55.E +08	6.5 7 8	9 11 14	1.75 2.48 2.54	1. The dia. is regular and the shape is very good. 2. The surface is very good.
PROJECT	2 4 6	rings (18.85+ 42.41)*2	7.35.E +06	10 12 15	15 17 20	1.82 2.8 3.35	1. The dia. is regular to both zones. 2. The surface is good at all times.
PUNCH \ FLAT	2 4 6	71.47 + 78.53.	6.30.E +06	6 8 12	9 13 16	1 1.2 1.72	1. The dia. is increase with time. 2. The surface is not good relative round shape.
CROSS FLAT	2 4 6	(38.84*4) *2	2.90.E +06	5 9 10	9 11 12	1.6 2.44 2.63	1. The dia. is increase with time. 2. The surface is not good relative to round shape.

PDF created with pdfFactory Pro trial version www.pdffactory.com



PDF created with pdfFactory Pro trial version www.pdffactory.com

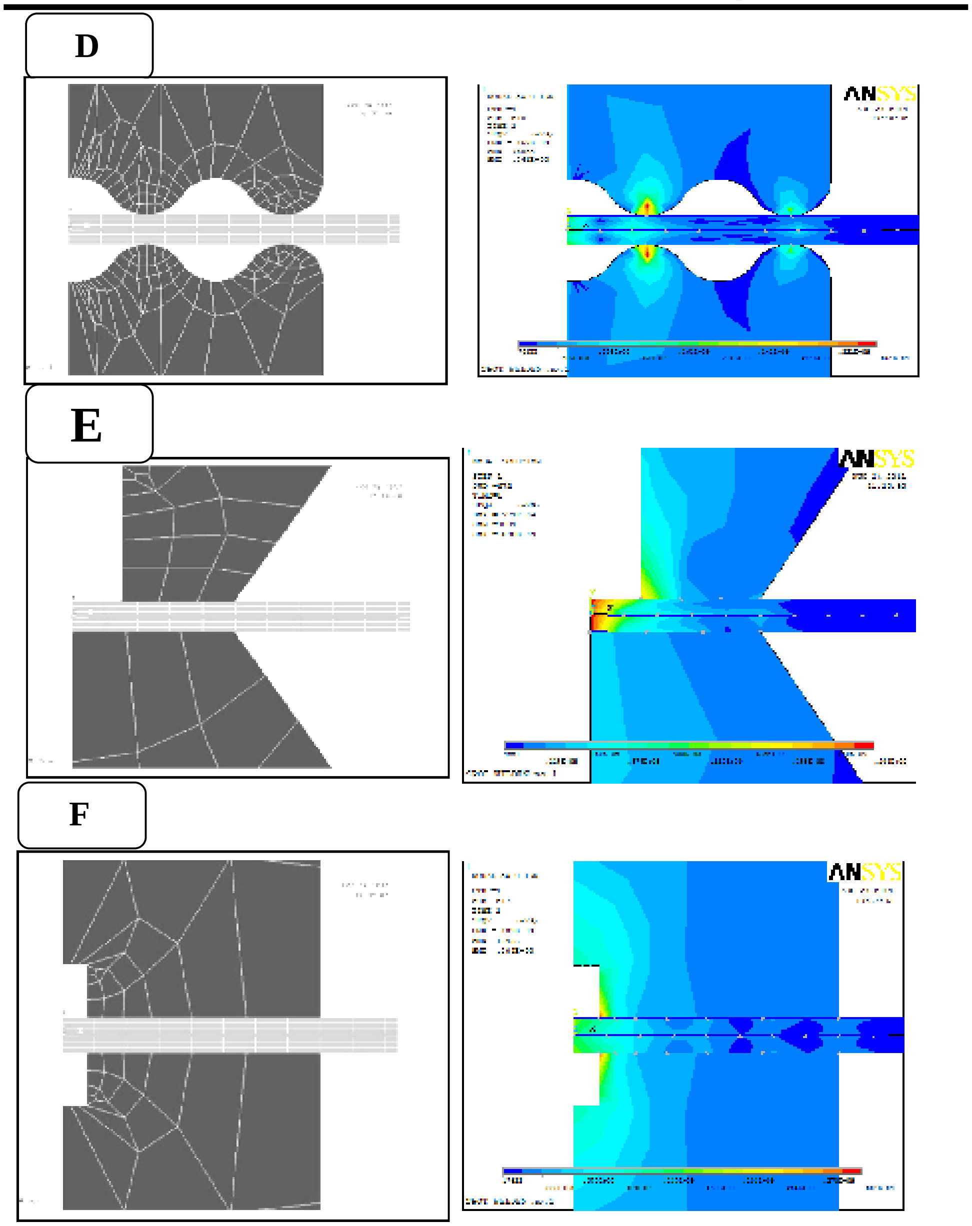


Figure (1): Represents the FEM model of RSW, where:
(A) Axi-symmetric model and boundary conditions,
(B) Flat, (C) Round, (D) Project, (E) Punch / Flat, (F) Cross Flat.

PDF created with pdfFactory Pro trial version www.pdffactory.com

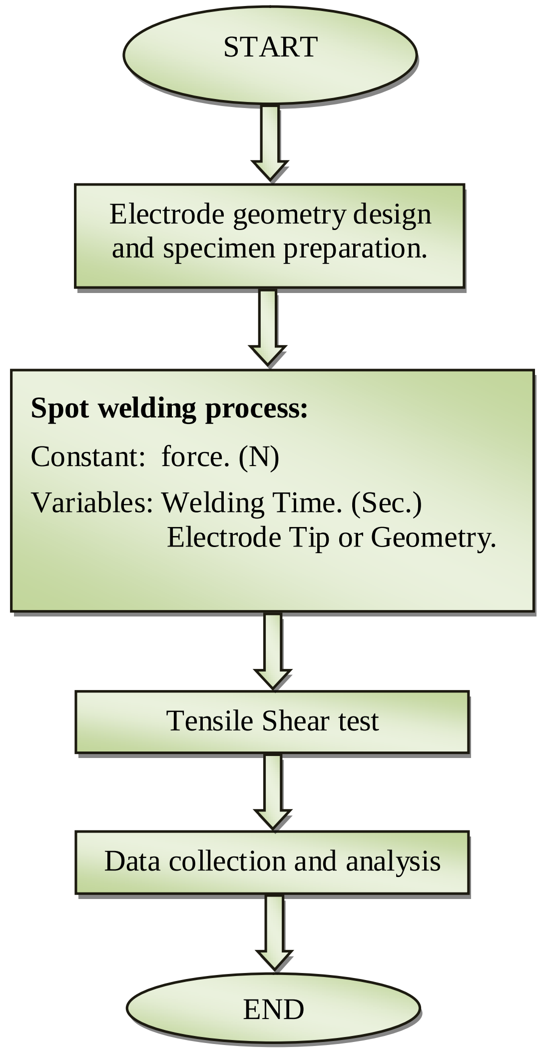


Figure (2): Flow chart illustrating the experimental procedure.

PDF created with pdfFactory Pro trial version www.pdffactory.com

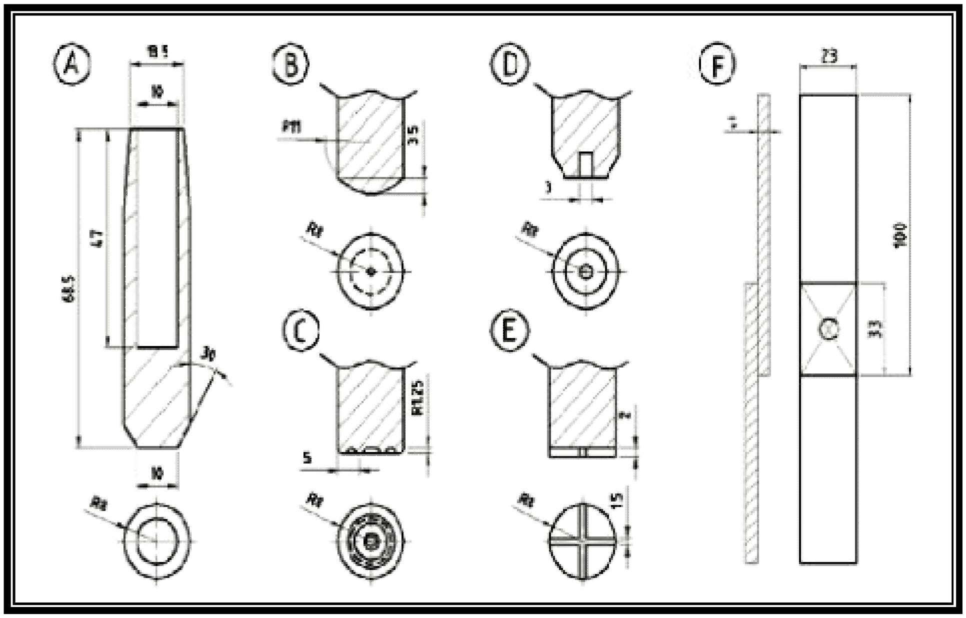


Figure (3): Represent the geometries of electrode and specimen with detailsand dimensions where: (A) Flat, (B) Round, (C) Project, (D) Punch / Flat,(E) Cross Flat.(F) The Tensile Shear Specimen, IIS (Iraq Industrial Association).

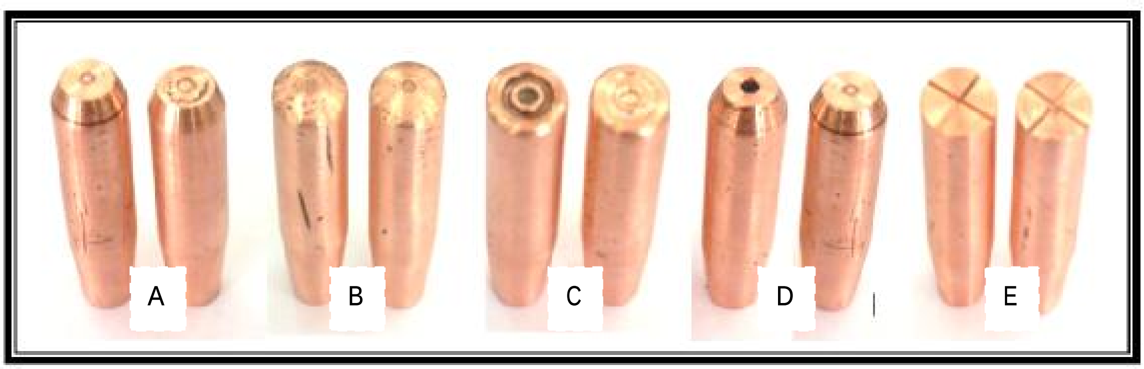


Figure (4): Represent real electrodes, where the geometries of electrode are,
(A) Flat, (B) Round, (C) Project, (D) Punch / Flat, (E) Cross Flat.

PDF created with pdfFactory Pro trial version www.pdffactory.com

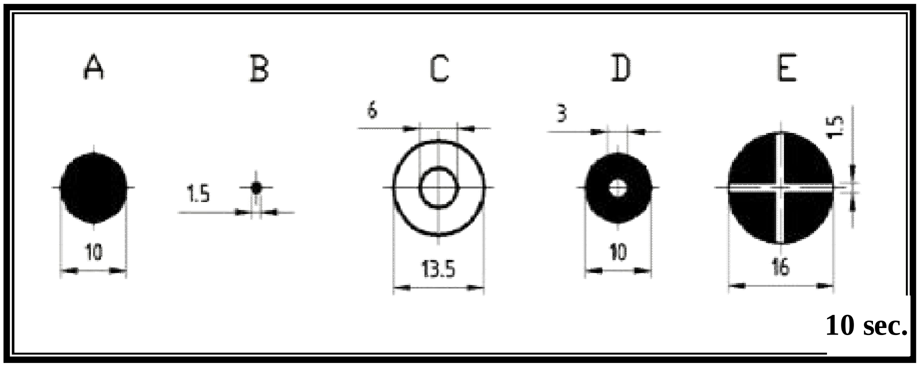


Figure (5): Represents contact areas of the electrodes, where the geometries are, (A) Flat, (B) Round, (C) Project, (D) Punch / Flat, (E) Cross Flat.

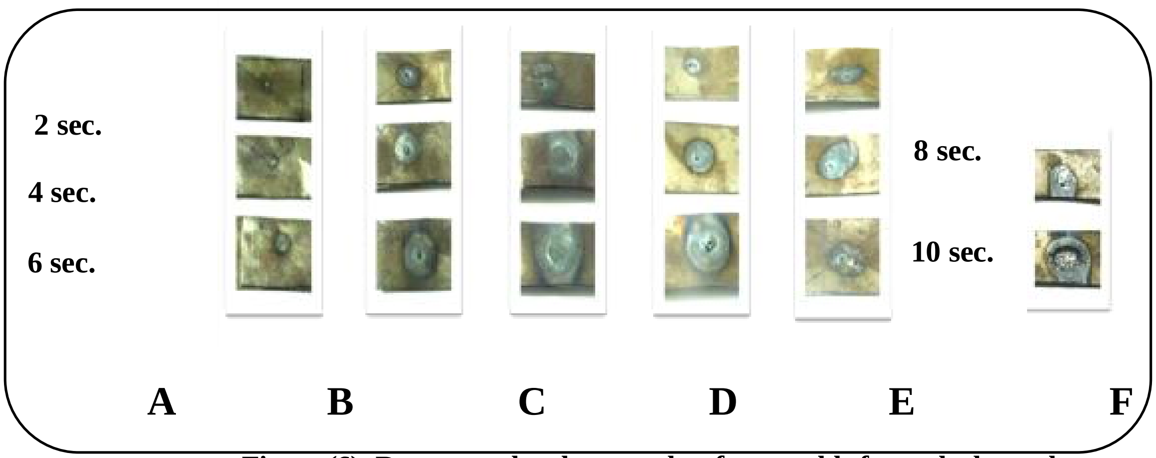


Figure (6): Represent the photographs of spot welds for each electrode at time 2, 4, 6 sec. and constant force = 450 N.(A) Flat, (B) Round, (C) Project, (D) Punch / Flat, (E) Cross Flat.(F) The defects in welding zone at time 8, 10 sec. are Surface splash (Flat electrode).

PDF created with pdfFactory Pro trial version www.pdffactory.com

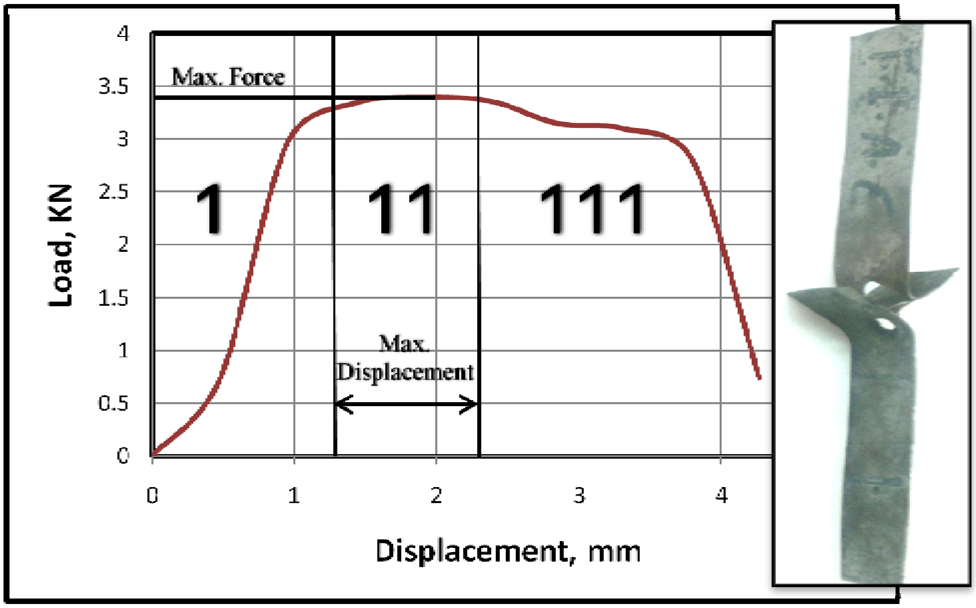


Figure (7): Represents the relationship between the displacement and force when applied tensile shear test on the welded specimen at welding variables: Project Electrode, Time = 6 sec., constant force = 450 N.

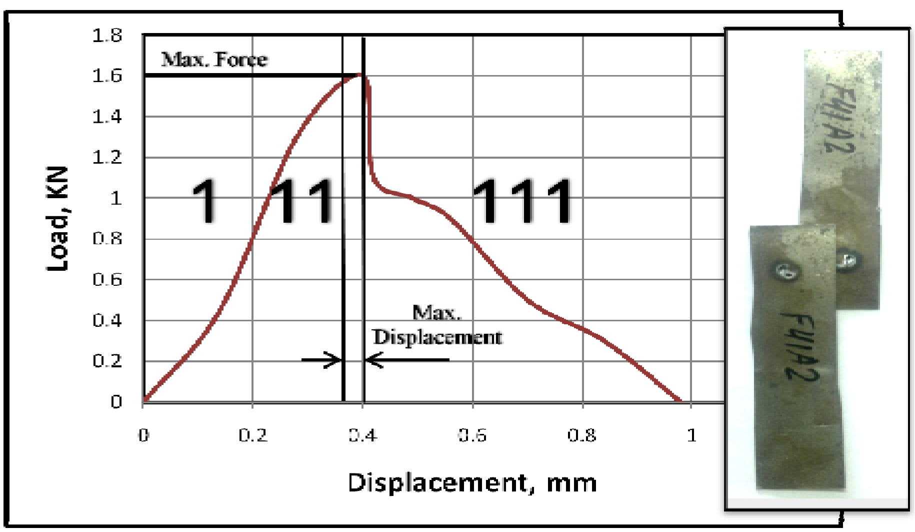


Figure (8): Represents the relationship between the displacement and force when applied tensile shear test on the welded specimen at welding variables: Punch\Flat Electrode, Time = 2 sec., constant force = 450 N.

PDF created with pdfFactory Pro trial version www.pdffactory.com

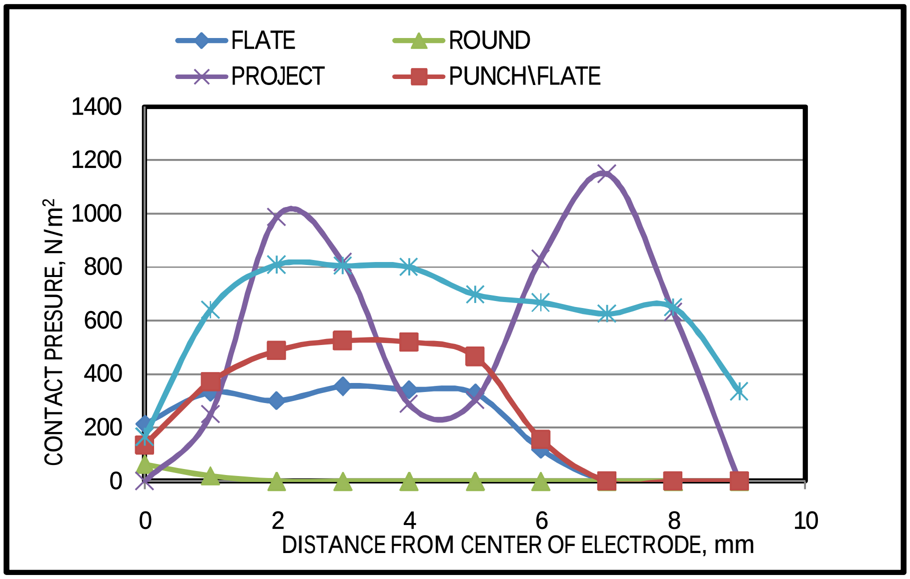


Figure (9): Represents the contact pressure distributions in sheet\sheet interface of all electrodes in FEM modeling analysis at constant force = 450 N. (A) Flat, (B) Round, (C) Project, (D) Punch \ Flat, (E) Cross Flat.

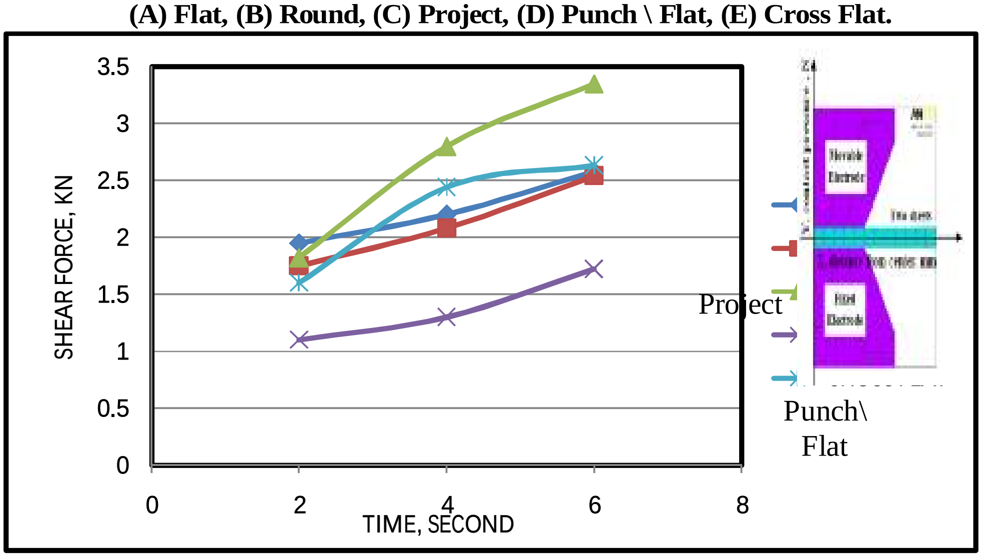


Figure (10): Represents the relationship between shear force and time practically of all specimens at Constant force = 450 N of electrode types, (A) Flat, (B) Round, (C) Project, (D) Punch / Flat, (E) Cross Flat. at constant welding Pressure = 450 N.

PDF created with pdfFactory Pro trial version www.pdffactory.com