EXPERIMENTAL STUDY OF WELDED JOINTS ON STEEL PLATE COLD-ROLLEDSHEET METAL USING DIFFERENT ELECTRODE TIPS

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ABSTRACT: Resistance spot welding is commonly used in the automotive industry, because it has advantages such as high speed, high-production assembly lines and suitability in automation. Welded joints are exposed to varying loads and pressure, as such, these conditions cause the joints to rupture. The objective of this paper is to study the different properties of welded joints in Steel Plate Cold-Rolled Coils, SPCC sheet metal by using different electrode geometries. The material used in this study was SPCC and selected welding tips: dome nose and flat nose as they are widely used in industrial applications. The findings indicated that weld nuggets of SPCC using the dome nose welding tip showed a value nearest to the theoretical value based on the America Welding Society, AWS's formula. The results for tensile testing were in accordance with weld nugget size, and the dome nose welding tip was 10% stronger than the flat nose. The difference in electrode geometries showed a significant impact on welded joint properties of SPCC metal for automotive applications.

KEYWORDS: *SPCC; Resistance Spot Welding; Dome Nose; Flat Nose*

1.0 INTRODUCTION

Resistance spot welding (RSW) is a process in which metal surfaces are joined in one or more spots by resistance to the flow of electric current through work pieces that are held together under force by electrodes [1]. The weld is made by a combination of heat, pressure, and time. The resistance spot weld nugget is formed when the interface of the weld joint is heated due to the resistance of the joint surfaces to electrical current flow. In all cases, of course, the current must flow so that the weld can be made. The pressure of the electrode tips on the workpiece holds the part in close and intimate contact during the making of the weld.The automotive industry is the major user of this welding process, followed by the appliance industry. Application of welded joint SPCC using RSW is employed in front fender and outer side panel in the automotive industry. Spot is employed to join overlapping strips, sheets or plates of metal in small areas. The pieces are assembled and placed between two electrodes, which must possess high electrical and thermal conductivity and retain the required strength at high temperatures. Therefore, they are made of pure copper for a limited amount of service, and of alloys of copper, of tungsten, or copper and chromium for continuous working [2]. Steel Plate Cold-Rolled Coils (SPCC) are extensively used as basic materials in the automotive industry.

Electrode is one of the major elements in the welding process. The functions of an electrode is to conduct welding current to workpieces, withstand and transmit the necessary force to the workpieces to produce a satisfactory weld and dissipate a part of the heat from the work to prevent surface fusion [3]. Dome nose and flat nose welding tips were selected as they are widely used in industrial applications. So far, very little attention has been paid to the properties of welded joints using different welding tips on SPCC metal. It is possible that failure in welded joints may occur. The spot weld nugget of the stiffened thin plate structure joint were asymmetric form due to the difference in electrical resistance of joined materials [8]. Current distribution as affected by electrode geometry. Electrode geomatery can affect wear and life through its influence on the local current distribution. Mathematical modeling and experimental developed to study the relationship but lack of study related to mechanical properties and electrode geometry [3].

The objective of the present study is to investigate properties of welded joints in SPCC metal using different electrode geometries. The findings of this study could assist in the selection of suitable electrode geometries to achieve optimum results for welded joints in SPCC sheet metal for the automotive industry.

2.0 METHODOLOGY

2.1 Types of welding tips

Table 1 and Table 2 show electrode geometry specifications for two different welding electrode tips in Figure 1 and Figure 2 below.

Table 1: Electrode geometry specifications

Type	Radius	Diameter
Flat nose	2 mm	10 mm
Dome nose	0 mm	10 mm

Table 2: Material composition of electrodes

Element	% of compositionDiameter
Copper	98.4%
Tellurium	0.5%
Nickel	1.1%

2.2 Resistance spot welding machine

A resistance spot welding machine, Multispot M80 was used in this experiment. Table 3 shows selected process parameters for this project.

Table 3 :Selected process parameters

No.	Process parameter	Range	Unit
1.	Current	12	KVA
2.	Electrode force	1800	Kg/cm2
3.	Welded cycle	5-6	Nil
4.	Thickness of SPCC metal	1.0	mm
5.	Electrode type	Straight	Nil
6.	Gap in electrode	0.5-1.00	mm
7.	Radius of electrode tip	Flat nose -2 ; Dome nose- 0	mm
8.	Shape ofelectrode tip	Dome & flat	Nil
9	Electrode material	Copper	Nil

2.3 Steel Plate Cold-Rolled (SPCC)

Figure 3 show Steel Plate Cold-Rolled Coils using in this experiment. Dimensions of SPCC steel measured 3.0 cm (width) by 10.0 cm (length). The thickness of the material was 1 mm. Table 4 and table 5 show mechanical material properties of SPCC steel used in this experiment.

Table 4: Mechanical material properties of SPCC steel (%wt) [3]

C (wt%]	Si[wt%]	Mn [wt%]	P [wt%]	S [wt%]
≤ 0.12	-	≤ 0.50	≤ 0.040	≤0.045

Table 5: Mechanical material properties of SPCC steel [3]

Yield strength [MPa]	Tensile Strength [MPa]	Elastic Modulus [GPa]	Elongation [%]
144	278	186	41.25

3.0 RESULTS AND DISCUSSION

3.1 Weld nugget measured using a Vernier calliper

The findings revealed that weld nugget size using dome nose welding tip achieved the nearest value of the critical diameter size as shown in Table 6. The resistance spot weld nugget that was formed when the interface of the weld joint was heated due to the resistance of the joint surfaces to electrical current flow was compared.

Based on America Welding Society, AWS's formula is $d = 4\sqrt{t}$ where t is the thickness of the plate in millimeters [4]. This formula was used to calculate critical diameter size. In this study, the thicknesses of the SPCC (overlap region) was 2.04 mm, thus the critical diameter that should be obtained was around 5.71mm assuming that the specimens had gone through a good combination of heat, pressure and weld time in the resistance spot welding process.

The weld nugget size for SPCC using the dome nose welding tip and the flat nose welding tip was 5.73 mm and 5.62 mm, respectively. The findings suggested that if the full length of the electrode was made of the same cross-section, it would be too weak to withstand the pressure exerted on it and could also cause high electric resistance. The electrode tip diameter had a bearing on the weld nugget size formed because it correlated with a reduction in the contact area of the electrode on the SPCC sheet metal. On top of that, higher electrode-worksheet interface angles were shown to yield more uniform current distributions at the electrode face. This effect reduces localized heating at the face periphery. The more uniform heating may contribute to more wear, with higher angles promote more rapid mushrooming of the tips. Also, more uniform current distribution were shown to require lower current values to produce nominal size welds [3].

Table 6: Weld nugget of SPCC using dome nose and flat nose welding tips

Sample	Weld nugget diameter (mm) using dome nose	Weld nugget diameter (mm) using flat nose
SPCC-1	5.72	5.63
SPCC-2	5.84	5.67
SPCC-3	5.64	5.57
SPCC-4	5.70	5.60
SPCC-5	5.75	5.65
Average	5.73	5.62
Critical diameter size	5.71	5.71

3.2 Liquid Dye penetrant

Liquid penetrant examination is one of the most popular non-destructive examination (NDE) methods in industry. It is economical, versatile, and requires minimal training when compared to other NDE methods. Liquid penetrant exams check for material flaws open to the surface by flowing very thin liquid into the flaw and then drawing the liquid out with a chalk-like developer. After the SPCC was joined by resistance spot welding using dome nose and flat nose electrodes, the samples were taken for dye penetrant testing to check whether the joint obtained had porosity or flaws due to unsuitable parameters of the spot weld.

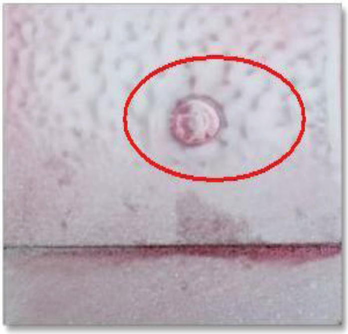

Figure 2: Dome nose

Figure 3: Flat nose

A dwell (soak) time was observed to allow the penetrant to permeate into cracks and voids. This typically lasted 5 to 30 minutes. Figure 2 and Figure 3 show that there are no signs of flaws or porosity on the joint part. A developer was applied which acted as a blotter to draw the penetrant from the flaws creating an indication on the surface of the joint part. However, in this case there was no indication of flaws or porosity on the surface. It can be said that the process of resistance spot welding on the specimens was conducted satisfactorily using the correct procedure with the right parameters or else, this type of surface indications would not be obtained.

3.3 Universal tensile test machine

A universal tensile test machine, Instron 5969 was used to determine the Shear strength of welded joints using dome nose and flat nose welding tips. The results were consistent with the data obtained in Table 7 which showed that, the join using dome nose welding tip was 10% stronger than the joint using flat nose electrode. The strength of any spot welding component depends on the nugget formed in between the joining plate [5]. These results were in agreement with the weld nugget diameter in which it was larger using the dome nose as compared to the flat nose. Dome nose geometry would provide greater mechanical strength and larger sink at the tip than the flat nose. 90 degree contact angle which provides the uniform current will result in mechanical strength and current uniformity [4].

Table 7: Shear strength of SPCC using dome nose and flat nose welding tips

Sample	Tensile strength for dome nose (MPa)	Tensile strength forflat nose (MPa)
SPCC-1	66.28	58.34
SPCC-2	66.65	61.51
SPCC-3	67.43	59.78
SPCC-4	67.50	60.20
SPCC-5	66.70	59.45
Average	66.9	59.9

4.0 CONCLUSION

This study set out to examine the relationship between properties of welded joints on SPCC sheet metal and electrode geometries. This study has identified that dome nose electrodes show significant properties impact as compared to flat nose electrodes for welded joints on SPCC sheet metal. The main findings can be summarized as follows, weld nugget size using dome nose tip attained the nearest value - a critical size diameter of 5.73 cm. Liquid penetrant showed no signs of porosity on welded joints for both electrode tips and that tensile strength using dome nose welding was 10% stronger than joints using flat nose welding tip.

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REFERENCES

[1] Z. Han, J. Indacochea, C.H. Chen and S. Bhat, "Weld Nugget Development and Integrity in Resistance Spot Welding of High-Strength Cold-Rolled Sheet Steels," *Weldingjournal*,Vol 72,no.5,pp.209-216,1993.

[2] P.G.Harsh and J.P.Navnit, "A Review on Study and Analysis of Various Parameters Affecting Nugget Formation in Resistance Spot Welding Using FEM," *International Journal for Scientific Research & Development*, vol 11, no.2, pp.108-111, 2015.

[3] R.J. Bowers, C.D. Sorensen and T.W. Eagar, "Electrode Geometry in Resistance Spot Welding," *Journal of Welding Research*,pp.45-51,1990.

[4] H.Y. Hsiu and N.Q. Nguyen, "Spot weld Property Testing and Simulation Modeling with Failure Criteria," *Applied Mechanis and Materials*, vol 248, pp.198-203, 2013.

[5] P.R. Rajanarender, "Analysis of Spot Welding Electrode," *International Journal of Mechanical and Industrial Engineering*, vol 2, no.2, pp.56-61, 2012.

[6] P.G. Harsh and P.J. Navnit, "A Review on Study and Analysis of Various Parameters Affecting Nugget Formation in Resistance Spot Welding Using FEM," *International Journal for Scientific Research & Development*, Vol.11, no.2, pp.108-111, 2015.

[7] O. Mitsuhiro, O. Yuki, S. Tatsuaki ,E.T. Shuhei, O. Hiroaki and S.Tetsuro, "Mechanical properties of SPCC low carbon steel joints prepared by metal inert gas welding," *Materials Science & Engineering A*, vol 560,pp. 643–652,2013.

[8] T. Yono, P. Yustiasih and C. Ikmal, "Critical Nugget Diameter of Resistance Spot Welded Stiffened Thin Plate Structure," *Modern Applied Science*, vol 7, pp.1913-1852, 2013.

[9] M. Zhou, S.J. Hu and H. Zhang, "Critical Specimen Sizes for Tensile-Shear Testing of Steel Sheets," *Welding Journal Research Supplement*, vol. 78, pp.305-313, 2010.

[10] Z. Weihua, S. Daqian, H. Lijun and L. Yongqiang,"Optimised design of electrode morphology for novel dissimilar resistance spot welding of aluminium alloy and galvanized strength steel," *Materials and Design*, Vol 8, pp.461-470,2015.

[11] Z. Yu, L. Zhen, L. Yang, L.M. Zu and H.Y. Zun, "Microstructure characterization and tensile properties of Mg/Al dissimilar joints manufactured by thermos-compensated resistance spot welding with Zn interlayer," *Materials and Design*, Vol 75, pp.166-173, 2015.

[12] D. Xiang, Z. Hongtao, L. Jihou and F. Jicai, "Microstructure and properties of Mg/Al joint welded by gas tungsten arc welding-assisted hybrid ultrasonic seam welding," *Materials & Design*, Vol 77, pp.65-71, 2015.

[13] Q. Ranfeng, S. Shinobu and I. Chihiro, "Effect of interfacial reaction layer continuity on the tensile strength of resistance spot welded joints between aluminum alloy and steels," *Materials & Design*, Vol.30, pp.3686-3689, 2009.

[14] N. Pathak, K. Bandyopadhyay, M. Sarangi and P.K. Sushanta, "Microstructure and Mechanical Performance of Friction Stir Spot-welded Aluminum-5754 Sheet," *Journal of Material Engineering andPerformance*, Vol.22, pp.131-144, 2013.

[15] S.K. Khanna and X. Long, "Residual Stresses in resistance spot welded steel joints," *Science and Technology of Welding and Joining*, Vol 13, pp.278-282, 2008.