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Article

Joining of Dissimilar Metals using Resistance Spot and Friction Stir Spot Welding for Automotive Applications: A Review

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A B S T R A C T

In automobile industry the demand of lightweight material is increasing extensively to reduce an environmental damage. Use of aluminium alloys and high strength steel serves the purpose of automotive applications but integration of these dissimilar metals has brought some advance challenges for achieving acceptable joints. This study reviews the different joining processes for the basic understanding of processes, properties, structure and limitations of dissimilar metal by Resistance Spot Welding and Friction Stir Spot Welding. RSW is commonly used joining process in the industry because its ability to join wide range of metals efficiently. The RSW has significant interest in automotive manufacturing processes due to its main benefits of high speed and low cost of operation. Friction Stir Spot Welding (FSSW) is a recently developed solid state joining method for joining difficult-to-weld dissimilar metals. FSSW is consequent friction stir welding technology; its major benefits are low cost joining, lower welding temperature and shorter welding time than conventional welding methods. The main interest of this study to review the metallurgical characteristics, hardness–microstructure correlation and mechanical performance of the dissimilar metals by Resistance spot welding and Friction stir spot welding method.

Keywords: Automotive, Dissimilar Metals, RSW, FSSW, Micro-structure

Introduction

In automotive industry to reduce the environmental damage caused by the vehicles use of light weight metals are preferred. This improves the fuel efficiency significantly.[1] To achieve improvement in the fuel economy and safety of the passenger's reduction in the mass of the vehicle body structure is achieved by substituting conventional steel material with light weight dissimilar aluminium and high strength steel alloys. An extensive use of aluminium alloys are conditioned by the welding assembly with steel grades.[2] The components of vehicle body are made of thin metal sheets which are connected by spot welding. Spot welding is an important joining process used for production of automobiles. Various advanced spot welding methods such as gas tungsten arc spot, laser spot and friction stir spot welding process, the conventional Resistance Spot Welding (RSW) is the major process in sheet metal joining mostly in automotive industry.[3]

Resistance welding is the oldest of the welding processes used in industry. RSW is the leading welding technique used for joining of metals. It is a fusion welding process in which the flow of a localised electrical current induced heat by the resistance of the parts being welded. The weld is prepared by a combination of heat, pressure and time. Pressure is applied to confirm proper contact between the parts being welded. Copper alloy electrodes are used apply the welding current and force to the work pieces, which are shaped to deliver the necessary current density and pressure at the point of welding.[4]

The interface of metal work piece generates heat due to the resistance to current flow through work pieces resulting temperature rise at the interface of the work pieces. Metal will start to fuse at the melting point and nugget initiates to form and self-generated fusion weld is made between the work pieces. The nugget is cooled down to solidify under pressure after switching off the current.[4-5] Interaction between the physical and metallurgical properties of the material welded were complex in RSW. A thorough understanding of the process is required to achieve a weld nugget with adequate size and consistent mechanical properties.[4] The fundamental understanding of the RSW process and the evolution of the structure and properties essential to be combined to attain defect free, structurally sound and reliable weld joint.[6]

Friction Stir Spot Welding (FSSW) is comparatively new process that has received substantial attention from the automotive, aerospace and other industries.[7] This technique allows to spot join the so called hard-to-weld light alloys or advanced high-strength steels, which are very communal materials in automotive or aerospace industries, with over 90% in power saving and 40% in equipment saving against Resistance Welding (RW) or Resistance Spot Welding (RSW). FSSW is a solid-state welding development in which a specifically intended rotating cylindrical tool with variable end geometry and a probe pin is first leapt into the upper sheet. Then, the heated and softened material together to the tool deforms plastically, and a solid-state bond is organized between the surfaces of the upper and lower sheet.[8] The special feature of the FSSW is that carrying the heat is abetted by the plastic flow of the substrate close to the rotating tool.[9] Heat and plastic flow coming from tool rotation govern significant microstructural modifications causing the local modification of material characteristics around the joint.[8]

The special feature of the FSSW is that carrying the heat is abetted by the plastic flow of the substrate close to the rotating tool.[9] Heat and plastic flow coming from tool rotation govern significant microstructural modifications causing the local modification of material characteristics around the joint.[8] Problems arising from the fusion welding of aluminium alloys, such as solidification cracking, liquation cracking and porosity, are removed with FSW, due to the solid-state nature of the process.[9] The complexity of the resistance spot welds depends on Spot welds do not show identical microstructure. Various features of a typical macrostructure of resistance spot weld are shown in Figure 2. Due to the weld thermal cycle, three dissimilar microstructural districts are fashioned in the weld and its surrounding.[10] Fusion zone (FZ) or weld nugget is melted and re-solidified during welding process. Macrostructure of the weld nugget involves of columnar grains. Fusion zone size which is the width of the weld nugget at the interface in the longitudinal direction is the most significant factor in defining quality of spot welds.[10] Heat Affected Zone (HAZ) which is not melted but experiences microstructural changes during welding. The properties of HAZ can expressively affect the performance of spot welds.

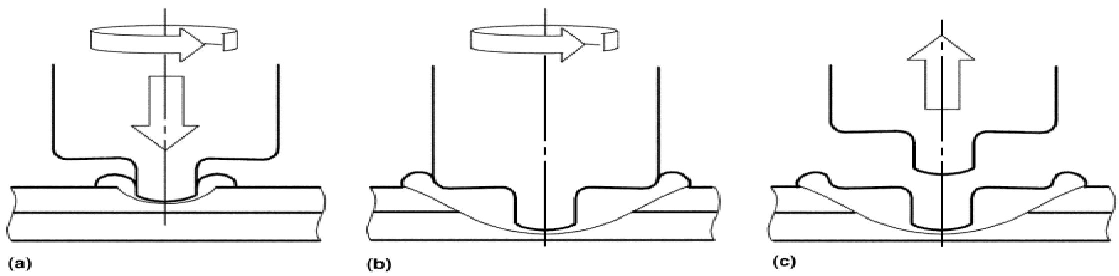

Figure 1.(a) Plunging; (b) Bonding; (c) Drawing out

Figure 2.Typical macrostructure of resistance spot welds

Base Metal (BM) does not show any metallurgical modifications. Since investigation of the spot weld failure needs the characterisation of the failure, strain hardening and the strain rate sensitivity properties of the FZ and HAZ, microstructural heterogeneity further obscures the failure analysis and prediction of the failure mode.[11] Failure mode and failure mechanism of spot welds are complex phenomena. They mostly depend on the complex interaction between weld geometry, FZ/HAZ/BM properties, test geometry and the stress state in the weld. Therefore, failure mode and failure location are not known in advance.

Substantial efforts have been made to understand a complete understanding of physical and motorized metallurgy connecting in RSW and FSSW. The objectives of this study are to detail and compare the microstructure and static mechanical properties of RSW and FSSW process.[11-15]

Nomenclature

RSW	Resistance Spot Welding
FSSW	Friction Stir Spot Welding
HAZ	Heat Affected Zone
TMAZ	Thermomechanically Affected Zone
SZ	Stir Zone
BM	Base Material

Physical and Metallurgical Characteristics

Resistance Spot Welding: Microstructure

The strength of a spot welded joint is frequently related to the joint's weld characteristics as Weld nugget or FZ size D which is the furthermost important factor in defining the quality of spot welds.[10] Fusion zone size governs the overall bonding area of the joint is controlled by parameters such as welding current, welding time and electrode force. Penetration depth is the width of melted zone in through thickness direction. Fusion Zone Voids: voids are formatted in weld nugget by expulsion and solidification shrinkage. The expulsion of liquid substantial from the weld pool can lead to an absence of material to block the weld nugget upon solidification. The expansion of void after cooling be contingent on the electrode force. If the electrode force is high enough, the weld nugget will be incessant and no cavities or pores will be left after cooling. Without expulsion, the occurrence of large cavities and pores after the formation of an RSW joint is caused by the solidification of molten material. The solidifying weld metal tends to contract because of both solidification shrinkage and thermal contraction. Consequently, tensile stresses develop in the solidifying weld metal. The existence of shrinkage voids and solidification cracks in the weld nugget has been stated by various researchers. HAZ size: The HAZ size is determined by heat transfer from FZ into the surroundings. It is reported that HAZ size can affect the ductility of the spot welded joints. Hardness and material properties of FZ and HAZ: Hardness and material properties of FZ and HAZ are measured by the interaction of weld thermal cycle, chemical composition and the initial microstructure of the BM. Babuet. al.[12] used the analytical model to study the micro constituents in FZ of spot welds developed by Ion et al.[13] and numerical model of Bhadeshia[14] In the approach used by Bhadeshia, a thermodynamic method used to consent the expectation of phase transformation from chemical composition of the steel concerned. Khan etal.[15] investigated the correlation between FZ hardness and chemical composition for a range of AHSS resistance spot welds. They found that the exclusive use of carbon content is not sufficient in calculating FZ hardness and the effect of differing alloying substances must be taken into account. L. Liu et.al.[16] Studied the microstructure & mechanical properties of 2 mm thick AZ31 magnesium alloys by RSW for a range of current. They found that alloys produced two zones with different microstructural features in the nugget i.e., Columnar Dendritic Zone [CDZ] and Equiaxied Dendritic Zone [EDZ] resulting, the fracture toughness of AZ31-SA welds is relatively higher compared with AZ31-SB welds. Also the micro hardness of AZ31-SA is relatively higher. They also commented that as welding current increases, the width of CDZ near the notch decreased linearly and became shorter and finer. D.Q. Sun et.al[17] investigates microstructures, crack features and mechanical properties of resistance spot welded magnesium alloy joints.

Figure 3, shows optical micrograph of resistance spot welded magnesium alloy joint. The joint consists of weld nugget and heat-affected zone (HAZ) surrounding the nugget. Their experimental consequence shown that the weld nugget size was associated to the welding current. They found that with a rise of welding currents from 15 kA to 23 kA, the joint strength increases which is allied with increasing the nugget diameter.

Properties of RSW Joints

A comparison of mechanical properties of EN AW 5005 aluminium alloy material by RSW and FSSW were performed by M. K. Kulekci.[18] They concluded that the pin length is a major factor influencing the tensile strength of material and higher strength is found in joint made by FSSW. Also the hardness and plastic deformation found increasing in the FSSW joint. Fatih Hayat[19] Investigate the joining ability of magnesium AZ31 alloy sheets and aluminium 1350 alloy sheets with the help of resistance spot welding. Effect of various current values on the nugget geometries of Mg-Al specimens has been recorded using Scanning Electron Microscopy (SEM). He made the observations as the current is directly proportional to the nugget diameter and the nugget diameter and indentation depth on the Al alloy side was found greater. For the high current value pull out type fracture and for low current value partial interfacial mode fracture of weld specimen were found. LadislavKolarik[20] analyse the properties of 2 mm thick low carbon steel and austenitic CrNi stainless steel by FSW. Found that the HAZ of the low carbon steel sheet was broader than the HAZ of the austenitic stainless steel. The fracture characteristics and the microstructure of the welded A5052/DP 600 joint was studied by Scanning Electron Microscopy (SEM) and Electron Back-Scattered Diffraction (EBSD) by Jianbin Chen et al.[21] M. I. Khan et al[15] examines mechanical properties and microstructure of resistance spot welded joints of AHSS including 590R, DP600, DP780 and TRIP780. The microstructural observations and hardness testing has been shown harder microstructures within the FZ of the AHSS.

Friction Stir Spot Welding: Microstructure

It is well-known that macroscopic appearance of FSSW joint is affected by temperature and material plastic deformation. Besides, welding parameters such as rotation speed, dwell time, plunge depth, and plunge rate etc. decide the friction heat during welding. Hence, macroscopic appearance changes with the change of welding parameters. The microstructural evolution during friction stir welding of Al alloys has been studied in sufficient depth. R. Nadan et.al.[22] Described the joint region which can be divided into four different zones as stir zone or weld nugget: The area where the microstructure is affected by strong plastic deformation and high temperature resulted in dynamic recrystallization, thermo mechanically affected zone: The area where experienced high plastic deformation by the material rotational flow without undergoing the dynamic recrystallization, HAZ: The area where the microstructure of the material has evolved due to experiencing a thermal cycle without undergoing plastic deformation. BM: The area where the microstructure of the materials is remained unchanged after welding process.

For joints of galvanized steel, white layer was found at the top sheets in all samples S. Baek etal.[23] explained it to the phase transformation of galvanized steel or the reaction between the tool and steel sheets. Zhang et al.[24] found under friction heat and stirring, SZ shows fine equiaxed grains due to recrystallization and Sizes of grains in SZ increased with the increase of rotation speed. The TMAZ experienced both frictional heat and deformation which resulted in highly deformed grains. Yin et al.[25] reported that SZ of AZ91-AZ31 FSSW weld contained dissimilar intermingled AZ31 and AZ91 lamellae, which had similar chemical compositions with those of the AZ31 and AZ91 sheet materials prior to spot welding. Also, diffusion of aluminum at boundaries of AZ91 and AZ31 could be seen by EDS.

Property of FSSW Joints

Yuan et al.[26] shown that the rotation speed and plunge depth were the important factors for tensile-shear strength. Zhang et al.[24] reported that joint strength was influenced by rotation speed while it was not affected significantly by dwell time. Morphology of the tool has influence on the weld. Badarinarayan et al.[27] directed that strength of weld made with the triangular pin double that of weld made with the cylindrical pin, which was attributed to the grain size as well as tensile failure mode. Q. Chu[28] studied probe less FSSWing of AA2198-T8 aluminum-lithium alloy showing that the width of stir zone is controlled by shoulder diameter, and the ratio of the width to shoulder diameter approaches 0.9. It can be summarized that the dwell time and rotation speed have significant effects on the tensile/ shear strength and HA of the probe less FSSWed joints. Prakash and Muthukumaran[29] investigated refill FSSW of Al-Mg-Si aluminum, in the study, joint that had higher strength than the joint made by conversational FSSW because refilling process increased effective cross-sectional area of the nugget. Tran et al.[30] investigated

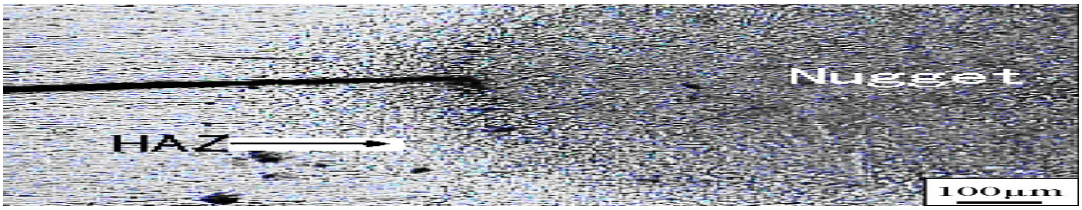

Figure 3.Optical Micrograph of Spot Welded Joint

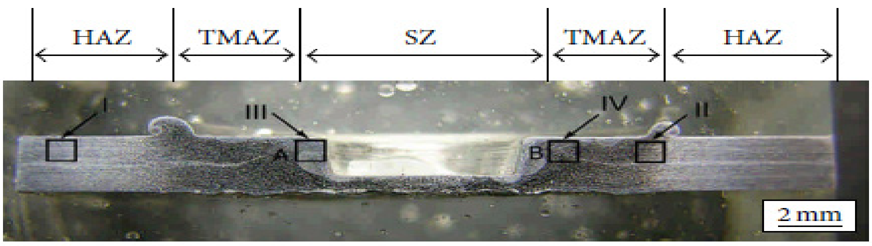

Figure 4.A Typical Micrograph of the Cross-section of a Friction Stir Spot Weld

that failure mode of the 5754-7075 welds in lap shear specimens, under quasistatic loading conditions, crack propagated along the nugget circumference, under cyclic loading conditions, crack propagated in the width direction of the specimen, and the left part of the lower sheet was eventually separated.

Summary

RSW, the critical joining process, appears a relatively simple in automotive industry. With the increasing demand for lightweight materials, joining three sheets of similar and dissimilar metals by RSW is an increasing trend. In this paper, the understanding of process, microstructure and properties relationship in RSW of automotive steel is reviewed. The sophisticated designed microstructure of material is destroyed in the FZ and HAZ during RSW, which required detailed investigations of microstructure advancement during welding process. The success of these techniques is mainly depended on precisely regulating the welding parameters, temperature distribution during pre-/ post-heat treatment by using advanced numerical modelling and in detailed understanding of metallurgical response of FZ and HAZ.

In present scenario FSSW process has one of the most ideal processes in substituting the conservative resistance spot welding and joining of lightweight structural metals, such as aluminium, magnesium alloys and AHSS etc. Besides the ideal process the FSSW has experience some challenges that can be revealed by further detailed investigations such as the indentation or keyhole effect. It leads to corrosion in the weld joint that should be addressed by advancements in the process such as refill FSSW, Probe less or pin less FSSW and other new processes. In the research scope of the FSSW materials should be enlarged besides aluminium, magnesium and its alloys. Some resent advanced high strength material as well as engineering plastics need to be investigated using FSSW. Lastly for the industrial production, the flexible, multipurpose, economical and reliable FSSW equipment should be industrialized.

References

1. Xia M, Tian Z, Zhao L et al. Fusion zone microstructure evolution of Al-alloyed TRIP steel in diode laser welding, Material Transactions, 2008; 49: 746-753.
2. Donders S, Brughmans M, Hermans L et al. Tzannetakis, The effect of spot weld failure on dynamic vehicle performance, Sound & Vibration 2005; 39: 16–25.
3. A. De: ‘Spot welding’, *Sci. Technol. Weld. Join.*, 2008; 13: 213-214.
4. Williams NT, Parker JD. Review of resistance spot welding of steel sheets: Part 1 – Modelling and control of weld nugget formation, International Materials Reviews, 2004; 49: 45-75.
5. Zhang H, Senkara J. Resistance welding: fundamentals and applications’; 2005, London, Taylor & Francis CRC Press.
6. David SA, Debroy T. Current issues and problems in welding science, Science 1992; 257(5069): 497-502.
7. Hancock R. Friction welding of aluminum cuts energy cost by 99%. *Welding Journal* 2004; 83(2).
8. Fanelli P, Vivio F, Vullo V. Experimental and numerical characterization of Friction Stir Spot Welded joints. *Engineering Fracture Mechanics* 2012; 81: 17-25.
9. Cam G, Gucluer S, Cakan A et al. Mechanical properties of friction stir butt-welded Al-5086 H32 plate, Materialwissenschaft und Werkstofftechnik, 40 (2009), 638–642.
10. Pouranvari M, Asgari HR, Mosavizadch SM et al. Effect of weld nugget size on overload failure mode of resistance spot welds, Science and Technology of Welding and Joining, 12 (2007): 217–225.
11. Yang YP, Babu SS, Orth F et al. Integrated computational model to predict mechanical behavior of spot weld, *Science and Technology of Welding and Joining* 2008; 13: 232–239.
12. Babu SS, Reimer BW, Santella ML et al. Integrated thermal-microstructure model to predict the property gradients in resistance spot steel welds, Proc. 8th Sheet Metal Welding Conf., Detroit, (1998)
13. Ion JC, Easterling KE, Ashby MF. A second report on diagrams of microstructure and hardness for heat-affected-zones in welds. ActaMetallurgica, 1984; 32: 1949–1962.
14. Bhadeshia HKDH, Svensson LE. Mathematical modeling of weld phenomena, London, Institute of Metals 1993; 109–180.
15. Khan MI, Kuntz ML, Biro E et al. Microstructure and Mechanical Properties of Resistance Spot Welded Advanced High Strength Steels, *Materials Transactions*, 2008; 49(7): 1629 – 1637.
16. Liu L, Xiao L, Feng JC et al. Resistance Spot Welded AZ31 Magnesium Alloys, Part II: Effects of Welding Current on Microstructure and Mechanical Properties, Metallurgical and Materials Transactions A, 2010; 41: 2642-2650.
17. Sun DQ, Lang B, Sun DX et al. Microstructures and mechanical properties of resistance spot welded magnesium alloy joints. *Materials Science and Engineering A* 2007; 460-461.
18. Kulekci MK, Ugur Esme, Onur Er. Experimental Comparison of Resistance Spot Welding And Friction-Stir Spot Welding Processes For The En Aw 5005 Aluminum Alloy, *Materials and technology* 2011; 45 (5): 395–399.
19. Hayat F. The effects of the welding current on heat input, nugget geometry, and the mechanical and

fractural properties of resistance spot welding on Mg/Al dissimilar materials. Materials and Design 32 (2011) 2476-2484.

20. Kolarik L, Sahu Ml, Kolarikova M et al. Resistance Spot Welding of dissimilar Steels. Acta Polytechnica 2012; 52(3).
21. Chen J, Yuan X, Zhan Hu et al. Microstructure and mechanical properties of resistance-spot-welded joints for A5052 aluminum alloy and DP 600 steel, Materials Characterization 2016; 120: 45–50.
22. Nadan R, DebRoy T, Bhadeshia HKDH. Recent advances in friction-stir welding – process, weldment structure and properties, *Progress in Material Science* 2008; 53: 980-1023.
23. Baek S. Microstructure and mechanical properties of friction stir spot welded galvanized steel. *Materials Transactions* 2010; 51(5): 1044–1050.
24. Zhang ZH, Yang XQ, Zhang JL et al. Effect of welding parameters on microstructure and mechanical properties of friction stir spot welded 5052 aluminum alloy, *Materials & Design* 2011; 32(8-9): 4461-4470.
25. YinYH, Sun N, North TH et al. Microstructures and mechanical properties in dissimilar AZ91/AZ31 spot welds, *Materials Characterization* 2010; 61(10): 1018-1028
26. Yuan W, Mishra RS, Webb S et al., Effect of tool design and process parameters on properties of Al alloy 6016 friction stir spot welds. *Journal of Materials Processing Technology* 2011; 211(6): 972-977.
27. Badarinarayan H, Yang Q, Zhu S. Effect of tool geometry on static strength of friction stir spot-welded aluminum alloy. *International Journal of Machine Tools and Manufacture* 2009; 49(2): 142-148.
28. Chu Q , Li WY, Yang XW et al. Study of process/structure/property relationships in probe less friction stir spot welded AA2198 Al-Li alloy, *Weld World*, 2017; 61: 291-298.
29. Prakash SJ, Muthukumaran S, Refilling probe hole of friction spot joints by friction forming, Materials and Manufacturing Processes 2011; 26(12): 1539-1545.
30. Tran VX, Pan J, Pan T. Fatigue behavior of spot friction welds in lap-shear and cross-tension specimens of dissimilar aluminum sheets. *International Journal of Fatigue* 2010; 32(7): 1022-1041.