Proc. of Int. Conf. on Advances in Robotic, Mechanical Engg. and Design, ARMED

Microstructure Analysis of Resistance Spot Welding of Commercial Low Carbon Steel using WC Micro-Powder

B K Samantaray [1], N.Hota[2] and B.B.Pani[3]
[1]Department of Mechanical Engineering, IIT, Bhubaneswar, Odisha, India
Email: bikashcallu2@gmail.com
[2]Department of Mechanical Engineering, GIET, Bhubaneswar, Odisha, India
Email: nhota@gietbbsr.com
[3]Department of Mechanical Engineering, VSSUT, Burla, Odisha, India
Email: bibhuti89@yahoo.co.in

***Abstract*—The present work is an investigation towards making the spot welding joint reliable by improving the quality of a welded joint for a commercially available low carbon steel of BIS 513:2008 standard. The focus is to analyze the microstructure of spot welded low carbon steel using tungsten carbide powder. Tensile shear strength was employed to check the failure of such joints. The verification was done through the experimentation using optimized combination of levels for parameters. Tensile tests were performed using instron type UTM machines to give accurate results. Finally, an attempt was made to outline modes of failure for different sets of experiment and preventing them to strength the welded joint making them reliable. The investigation proved the nature of failure in relation with the microstructure of welded component during the loaded condition.**

***Index Terms*— Resistance spot welding, UTM, microstructure , mechanical characterization, low carbon steel.**

I. INTRODUCTION

The growing demand of fuel efficient and light vehicles has compelled the automobile industry to ponder new techniques for manufacturing. Whether it may be advanced materials or welding techniques the area of research has widen in the recent scenario. The automobile or aerospace industries have broadened their area of interest especially in joining or fabrication techniques to achieve properties such as higher strength to weight ratio, enhance safety and crashworthiness keeping the cost factor in mind. Welding is the most crucial fabrication technique of joining in the automobile industry, and its condition plays a vital role in end result i.e. the mechanical properties of the joint. The heat input from welding heat source creating a large temperature gradient on workpiece could certainly affect the microstructure in turn the mechanical properties of steel. It is therefore of prime importance to characterize the microstructure and its influence on final mechanical properties during welding. With rising popularity of resistance spot welding (RSW) due to high production rate, low skilled worker with added advantage of being an economic process, its area of application has increased with passage of time. The strength of the joint is commonly characterized by the

Grenze ID: 02.ARMED.2018.7.509

modes of failure it undergoes, may it be plug pullout type, partial pullout type or interfacial type.
The minimum size of the spot weld was formulated as

$$D = K\sqrt{t}$$

Where D denoted as the nugget diameter of weld in mm and t is minimum sheet thickness in mm whereas K is process dependent constant and value ranges from 3 – 6. Zhang et al. inferred that strength of joint is mostly concern with fusion zone, especially pullout mode of failure is due to increase in size of fusion zone.
Resistance spot welding utilized the copper electrode to impinge upon the workpiece material to which the resistance to flow of current through the interface leads to local heating of the overlapped surface. Bouyousfi et al. studied the effect of spot welding process parameters (welding current, welding duration, and applied load) on the mechanical properties and characteristics of spot welded join between two stainless steel sheet (304ASS) having same thickness. This investigation revealed micro hardness and tensile test results have revealed weld resistance is depends upon the process parameters especially load. Applied load being a major factor compared to welding time and current. Similarly, Esme et al. studied the optimization of process parameters involved in welding of SAE 1010 using Taguchi method. This investigation is related to welding current and electrode force as prime factor in determination of welding strength. He concluded that Taguchi method is quite reliable optimization technique. He also focused on the use of ANOVA to emphasize on the level of contribution of each factor, concluding welding current and electrode force being highly effective parameter on tensile shear strength compared other factors. Khan et al. considered the amount of carbon at joints which is related to fusion zone (FZ) hardness. Upon increase in carbon content, hardness of FZ increases. Similar studies were conducted related to welding parameters on RSW of DP600 automobile steel sheets . Pouranvari and Marashi investigated upon mechanical performance of dual – phase DP600, DP780, DP980 grade sheets. Their research was mostly related to microstructure of welded portion, focusing upon heat affected zone which plays a crucial role in mechanical strength of DP steels with high fraction of martensite. Eshraghi et al. studies regarding the finite element analysis indicating current density as the major factor on the sizes of fusion and heat affected zone. Basically, current density is indirectly related to pressure of contact. The microscopic study reveals there is only contact between peaks at lower pressure as a result lesser area comes in contact increasing the current density to compensate for the decrease in flow of electric current. Marashi et al. found the strength and size of fusion zone was directly related to type of failure whether pull out or interfacial. The other aspect of the RSWed portion is the development of residual stresses, Anastassiou et al. found the residual stresses are responsible for decrease in fatigue and fracture strength of structure. So, priority was given to selection of appropriate process parameters. This could only be achieved through optimization techniques as discussed by various authors. Khanna and Long added that it was the electrical resistance that electrode force imposes upon during heating and cooling that affects the residual forces. Lindh and Tocher for the first time studied the residual stresses through 2D finite element model to predict these stresses in 5mm thick titanium alloys. Studies were extended to low carbon steel sheets by Popkovskii and Berezienko . The research was conducted for non – ferrous material e.g. aluminium which has high electrical and thermal conductivity, thermal expansion and forming oxide making it less suitable for RSW compared to steel which is highly conducive due to its robustness, reliability and cost effectiveness. These factors were studied by Partick et al. . Similarly, Zhang and Taylor have optimized the position of two spot welds in tensile specimen. Chae et al. focused upon the two-spot weld location and its optimization under static and impact loading condition. Their research was concentrated on maximizing safety factors of spot weld joints. Besides, with increase in spots, the strength also increases but abiding to the appropriate location of these spot welds. Rui et al. used an optimization algorithm to minimize the stress intensity factor of spot welds, these were solely for the purpose of fatigue life of the structure. A.G. Thakur and V.M. Nandedkar studied the optimization of galvanized steel sheet using taguchi method to using L18 orthogonal array to improve quality of weld.Vignesh, K., A. Elaya Perumal, and P. Velmurugan studied the effect of various control parameters like electrode tip diameter, welding current, and heating cycle on the nugget size and tensile shear strength of dissimilar metal spot welding of 2-mm-thick AISI 316L austenitic stainless steel and 2205 Duplex Stainless Steel sheets.
Although this was a rare study but to the best of my knowledge neither of them have studied the importance of squeeze time, weld time and hold time in relation to electrode force. The purpose of the present research is to emphasize upon the microstructural study of spot welded joint for commercially available low carbon steel

for various set of experiments in relation with the strength of the joint. It also involves the analysis during transformation through air cooling during spot welding joint.

II. EXPERIMENTAL DETAILS

Cold rolled sheets were cut to the dimension of 100mm length and 25 mm width for three thickness 0.8mm, 1.2mm and 1.5mm. Prior to resistance spot welding, it was cleaned with ethanol to make it free of oil and dust.The samples were spot welded to 25mm x 25mm. The standard spot-welded samples are shown in the figure 1.

The chemical composition and mechanical properties of the specimen are summarized in Table 1 and 2 respectively.

TABLE I. CHEMICAL COMPOSITION OF CR3 MILD STEEL (IS 513: 2008)

ElementContent %		**Content (%)**
Fe	Bal.	99.18-9.62 %
C	0.10	
Mn	0.45	0.30-0.60 %
S	0.030	≤0.050 %
P	0.025	≤0.040 %

TABLE II. MECHANICAL PROPERTIES OF CR 3 MILD STEEL (IS 513: 2008)

Sample	UTS (MPa)	YS (MPa)	EL %	Hardness (HRB)
Base Metal	350	220	34	57

Fig. 1. Standard spot welded sample

Fig 2. Spot welder model SS-35-450

Fig 3. 3382 floor type UT

The experiment was performed on a mechlonic-made SS-35-450 model 35kVA pedestal type spot welding machine and throat depth of 450mm using pointed type copper-chromium electrode of cap 16mm and tip diameter 6.5mmcontrolled by microprocessor based resistance control system shown in figure 2. The experiment was conducted for each different thickness of 0.8mm, 1.2mm and 1.5mm. The welding current was kept constant throughout the operation at 75 % duty cycle. Tensile shear strength was considered as response characteristics to determine the strength of RSWed joint. Tensile testing was carried out on an Instron – built 3382 floor type universal testing machine at a constant strain rate of 0.5mm/min. The peak loads were recorded through blue-hill lite software package inbuilt to the system. The UTM machine is shown in the figure 3.

III. RESULTS AND DISCUSSION

In the experiment microstructure analysis was carried out on an optical microscope. Basically, it reveals three distinct zones in spot welded portion. These are

1. Welded / Fusion zone
2. Heat affected zone
3. Base metal

The low carbon steel is represented by an AISI/SAE 1010 steel, as carbon content increases, the amount of pearlite increases. Pearlite is about 100% at carbon percent of 0.8%. Below 0.8% C, the microstructure is fully ferritic which is exactly the specimen used in the given experiment as shown in the figure6. This structure in the micrograph consists of numerous individual ferrite grains separated by grain boundaries shown by dark borders of each grains. These grains are BCC crystal structure. Basically, these are polygonal, equiaxed grains. Beside this it has very less pearlite and carbon inclusions in spherical form.

It is evident from figure 4 and 5,tungsten carbide powder has been introduced at the interface of joint. Carburizing phenomenon takes due to the introduction of carbide powder, where hardness is only imparted at the joint surface due to diffusion of carbon from the carbon rich WC powder. It may be a case of "pack carburizing". Due to diffusion of carbon, there is a possibility of different microstructure within and outside the dendrites. Also, due to fast cooling process, there is also cases of decarburization by the reaction with atmospheric oxygen resulting in large oxidized crack and internal oxidation along a small crack.

The spot-welded zone using tungsten carbide the interface. The first figure shows the distinctseparation between the base metal and fusion zone separated by carbon diffusion layer. Excess powder getting expelled out at corner of weld. Large void could be seen at the nugget portion which may be due to incomplete fusion and solidification or contamination with atmospheric air. Thin thread like patterns could be seen in the weld zone, it may be probably due to improper fusion between particles of tungsten carbide powder.

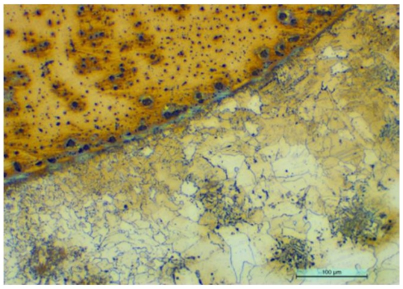

Fig.4 Microstructure of spot welded joint using WC powder

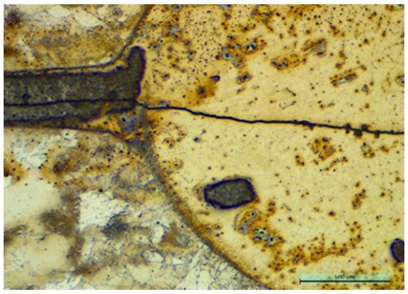

Fig. 5 Fusion and Heat Affected Zone

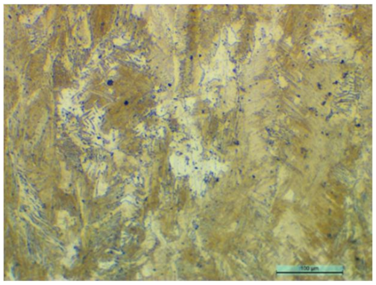

Fig. 6 Fusion Zone of RSW without WC Under Optical Microscope

During static load testing, tension shear testing is most common criteria used in determining weld strength. During the loading, the weldment tends to rotate to align the gripped ends with the welded joint. With increase in loading, sheet separation increases and heat affected zone is clearly visible.

Failure is spot welding occurs in two modes:

1. Pull out failure (PF)
2. Interfacial failure (IF)

Pullout failure is tensile in nature and driving force for pullout failure mode is tensile stress. Due to certain amount of rotation, the tensile stresses formed around the nugget causes plastic deformation in sheet thickness direction. These are visible at heat affected zones in the base metal where necking occurs. This necking is more severe in one of the sheets than other.

Likewise driving force for interfacial failure mode is shear stress. High shear stress is created at the interface which exceeds nugget shear strength and prior to tensile stresses that causes necking around nugget, failure occurs at the interface. Interfacial failure mode occurs certainly with a shear mechanism in the shear tensile test.

While using WC powder at the interface of the spot-welded joint, the expulsion of powder with corrosion of the base metal due to high heat generation during welding was observed.

It is concluded that with increase in tensile shear stress, pullout type failure is dominant with few minor exceptions.

The tendency of pullout type failure occurs at lower pressure and decreases with increase in pressure. Studies reveal that as pressure increases, the area of contact between overlapping surface increases as a result current density decreases which in turn reduces the nugget diameter. Interfacial failure which is due to shear failure acts prior to necking causing shear failure This is quite clear from the specimens depicted in figure 7.

Fig. 7 (a) Pull out failure (b) Interfacial failure (c) failure interface with WC

IV. CONCLUSIONS

The present study on the experimental research of Optimization of process parameters of RSW joint and its effects on the strength of spot welded joint of CR3 low carbon steel can be concluded with following results.

1. Microstructural analysis was carried using various metallographic technique. Primary study was carried out under Optical Microscope. It reveals that base metal is primarily composed of ferrite grains with distinct boundary marked by dark border. Also, the same microstructure reveals a region surrounding each area of martensite and retained austenite called “new “ferrite that is formed during cooling that is the new ferrite grew into the austenite regions. This new ferrite is considered as a simple extension of the ferrite already present and is thus referred to as epitaxial ferrite because it is formed epitaxially on existing ferritic lattice.

   Martensite has a distorted body-centered cubic (BCC) lattice. The amount of distortion and therefore the properties of martensite are a strong function of carbon content. For low-carbon steels (less than 0.2 wt%) the lattice structure of the martensite is very close to BCC and it is less brittle.
2. With the use of **WC,** it was a clear case of carburization may be “pack carburization” type. In this case, tungsten carbide powder has been introduced at the interface of joint. Carburizing phenomenon takes due to the introduction of carbide powder, where hardness is only imparted at the joint surface due to diffusion of carbon from the carbon rich WC powder. Due to diffusion of carbon, it may produce different microstructure within and outside the dendrites. Also, due to slow cooling process, here is also cases of decarburization by the reaction with atmospheric oxygen resulting in large oxidized crack and internal oxidation along a small crack.

3. Regarding modes of failure, joint is considered reliable if it fails due to tensile stress i.e. pull out type.

   It can also be concluded that interfacial failure occurs when joint is subjected to lesser tensile stresses. The aim should be to achieve pull out type of failure shown in table 13 with each experimentation done for optimized combination of levels show Pullout failure. (PF)
4. With increasing in thickness, pressure and welding time, the tensile stresses also increase.
5. Higher welding time upto a certain limit, shows pullout type of failure whereas interfacial failure occurs at low welding time but subjected to the pressure conditions whether low or high.

REFERENCES

[1] D. Cornette,T. Hourman, O. Hudin,J.P Laurent,.A. Reynaert,"High Strength Steels for Automotive Safety Parts". *SAE Trans. J. Mater. Manuf.* **2001**, *110*, 37–47

[2] A. Ramazani, K. Mukherjee, A Abdurakhmanov, U. Prahl, M. Schleser, U. Reisgen, W. Bleck, Micro-Macro Characterisation and Modelling of Mechanical Properties of Gas Metal Arc Welded (GMAW) DP600 Steel. Mater. Sci. Eng. A 2014, 589, 1–14.

[3] H. Zhang, J. Senkara, Resistance Welding: Fundamentals and Applications; Taylor and Francis CRC Press: Boca Raton, FL, USA, 2006.

[4] Ugur Esme, "Application of Taguchi method for the optimization of resistance spot welding process", The Arabian Journal for Science and Engineering, Vol. 34, No. 28, pp. 519 – 528, 2009

[5] M.I. Khan, M.L. Kuntz, E. Biro, Y. Zhou, "Microstructure and Mechanical Properties of Resistance Spot Welded Advanced High Strength Steels". *Mater. Trans.* **2008**, *49*, 1629–1637.

[6] F. Hayat, S. Ibrahim, "The Effect of Welding Parameters on Fracture Toughness of Resistance Spot-Welded Galvanized DP600 Automotive Steel Sheets." *Int. J. Adv. Manuf. Tech.* **2011**, *58*, 1043–1050.

[7] Eshraghi, Mohsen, et al. "A Parametric Study of Resistance Spot Welding of a Dual-Phase Steel Using Finite Element Analysis." *PRICM: 8 Pacific Rim International Congress on Advanced Materials and Processing*. John Wiley & Sons, Inc., 2013.

[8] M. Pouranvari, et al. "Influence of fusion zone size and failure mode on mechanical performance of dissimilar resistance spot welds of AISI 1008 low carbon steel and DP600 advanced high strength steel." Materials & Design 32.3 (2011): 1390-1398S.B Chin., J.J Foo., Y.L Lai., . T.K.K Yong, "Forced convective heat transferenhancement with perforated pin fins", Heat Mass Transfer 49 (2013) 1447–1458.

[9] A. Thakur, and V. Nandedkar. "Optimization of the Resistance Spot Welding Process of Galvanized Steel Sheet Using the Taguchi Method." *Arabian Journal for Science & Engineering (Springer Science & Business Media BV)*39.2 (2014).