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OPTIMIZATION OF RESISTANCE SPOT WELDING IN ALUMINUM ALLOYS FOR LIGHT WEIGHT VEHICULAR STRUCTURES

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ABSTRACT

Resistance spot welding (RSW) is the most important process of welding low alloy steel sheets in automotive industry. Typically, RSW depends upon the amount of current passed, the resistance offered, length of the time the current is passed, applied load at joining points and quality of contact surface of copper electrodes. These conditions, commonly known as spot welding parameters are, weld current, ramp time, hold time, and electrode force used to optimize weld quality. Currently focus has been on the alternate material such as Aluminum and Magnesium to achieve fuel efficiency to reduce emission and fuel related expenditures. This study investigates the effect of important parameters to obtain high quality weld in Aluminum alloys and thereby achieve a light weight structure for desired vehicular solution. Reduction in vehicular weight an important factor in cost reduction on account of fuel saving creates a challenge for optimized spot welding involving complex structure . The study has analysed tensile test results, microstructure analysis and comparison with CT to obtain optimal solution.

INTRODUCTION

Optimization of spot welding parameters is the most important task required to obtain welded sheets with high quality and safety standards in vehicles and auto industry. Weight reduction in vehicular weight is identified as the most crucial factor in cost reduction on account of fuel saving [Sreenivasalu,2014] Apparently a very easy task, has multiple factors that create problem in aluminum to steel or aluminum to aluminum welding. In the past, efforts have been made to investigate effect of connected parameters to obtain high quality weld in aluminum alloys and thereby achieve a light weight structure [Manladan et al., 2017] for desired solution.

While Aluminum structures are sufficiently robust and inert due to their nature [Sun et al.,2015] and provide reasonable strength and safety against corrosion, austenitic steels offer structural rigidity, weldability, enhanced crash worthiness, fatigue resistance and maintain properties over wide range of temperatures. Although Aluminum structures provide appreciable strength and structural integrity but they are prone to oxidation and form hard and brittle inter metallic structures. The higher current and joining pressures are needed due to oxide layers that result in defective electrode tips. Furthermore, inherent structure of Aluminum alloys has tendency to develop brittle structures that might cause unwanted failure. In most cases, Aluminum alloys result with appreciable weight reduction because low, high strength and stiffness densities to weight ratio, demonstrate good corrosion resistance, enhanced electrical/thermal properties and good machinability. Aluminum alloys are therefore extensively used to join structures in vehicle body parts [Penner, 2013] panels, gear boxes and braking systems [Ambroziak, Korzeniowski. 2010].

Resistance spot welding is the main process used for joining Aluminum Alloys due to its acceptance as an ideal process for high speed production in auto welding. Hence forth the qualification of and

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acceptance of spot welds are pertinent to the mechanical properties and quality criteria. While these are readily achieved in RSW for alloy carbon steel, the RSW of Al-Al-Alloy present difficulties on account of higher thermal and electrical conductivity, presence of oxide layer on the surface, requiring higher welding currents and a solution for rapidly worn out electrode tips. In this case, an analytical study based on the comparison of joining process through riveting and RSW is presented to optimize the weld structures based on strength obtained through RSW.

Understanding fundamentals of RSW is of prime interest to compare the weld of Aluminum Alloys. In this case main steps involved[Jianhui et al.,2007] are squeezing “applying the pressure to weld piece”, welding “where the appropriate current passes through the joining surfaces for creating fusion” and holding “where the passage of current stops and weld force is maintained so that weld is allowed to forge and cool over. In short, two overlapping Aluminum sheets are placed on each other and clamped through pressurized electrodes to have a firm contact. The current is passed through the electrodes, which are cooled through circulating water for specified time. The resistance offered by the sheet to the flow of current results in a molten pool called as weld Nugget formed at two faying surfaces. The electrodes contact is maintained for some time so that Nugget is solidified. The process is governed by the equation $Q = I^2RT$ Where Q is Joules of heat input, I is current in Amperes, R is the resistance in ohms and T is time in seconds. The process is shown in Figure 1.

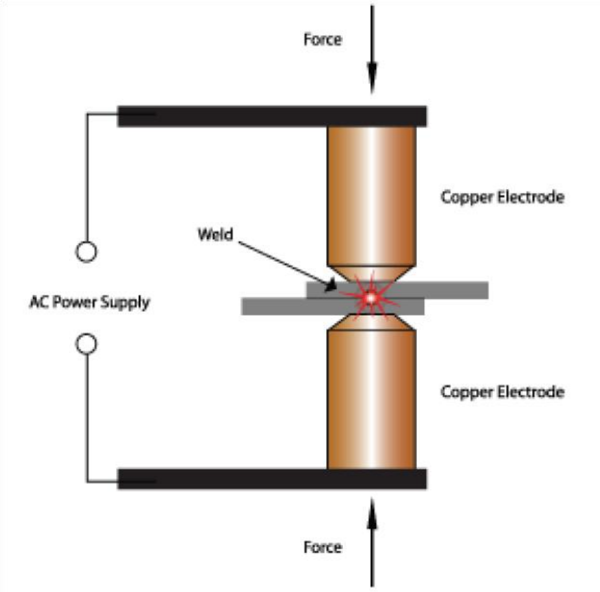

Figure 1: Spot welding process description showing the passage of high value current and formation of nugget

In comparison to low alloy steel sheets,where improper spot weld parameter of high current causes folding interface in HAZ between welded sheets [Liu et al., 2010] presence of an oxide layer over the surface of Aluminum sheets results in high contact resistance severely degrading electrode tips which needs to be cleaned mechanically or chemical methods. Consequently production of Aluminum oxide layer over the surface of electrode restricts the number of additional weld to barely few in number afterwards. It may be added that introduction of greater air pressures for electrode force, small rotation to the plates during operation or low current preheating [Han et al., 2010] improve conditions in Aluminum welding.

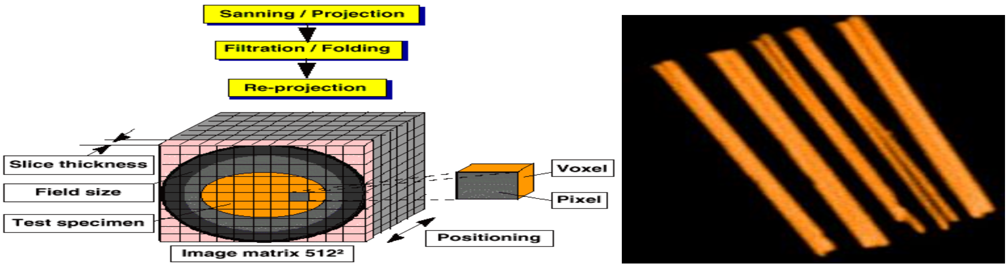

Figure 2: Computed Tomography for analysis of defects in structures and CT shots of samples

CT has proven as good indication of quality in developmental and series production(Figure 2).Spot welding samples are subjected to CT analysis for determination of defects that may result in failures. While any CT scanner reconstructs an image matrix showing two dimensional cross section image of material distribution within the test specimen based on the fact that X rays will lose intensity and attenuate in line with set values against any specimen. This is exploited in samples made from composites used in aerospace structures and results can be evaluated for reliability.

EXPERIMENTAL SET UP

The important consideration in case of Aluminum welding is the presence of oxide layer,uneven rough surface and presence of oil or lubricant layer.The purpose of this experimentation is to study the behavior of spot welding action and shear analysis to estimate the force required for loading. Al 2024 sheets with thickness of 1,1.5 mm and Al 5056 sheets with thickness 3 mm are used in this study. Sample size is taken as per standard ANSI/SAE/D8. As the main concern is to analyze the failure of metal sheets and attain maximum shear values at which the interfacial failure occur therefore the RSW for selected sample is optimized for the results at which ideal condition for the weld are defined and maximum nugget diameter is obtained. A pedestal type RSW machine with a multi ring domed electrode (Figure 3) instead of standard 45 ° conical electrode is used with 28 mm face diameter welding current is kept at 75-90 KA, electrode pressure at 6 bar and weld time for 70-80 cycles and hold time of 30-42 cycles. The tensile shear test was performed with UTS machine Sintech with cross head speed of 2mm/min with a tensometer. Failure mode through sheet test specimen was recorded. In order to optimize the results, micro structure analysis through 500 x microscope and SEM were recorded for Base metal, Fusion zone and columnar growth pattern

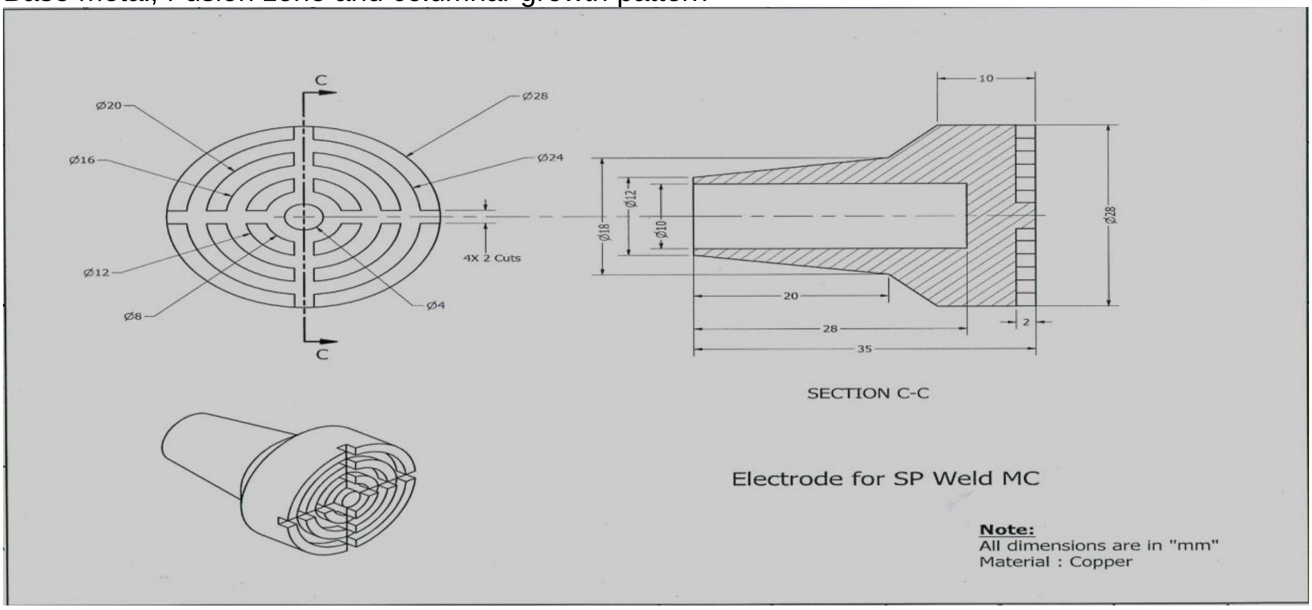

Figure 3.The spot welding multi ring electrode used in the experimental set up

The spot welding samples were tested through Instron tensile testing machine(Figure 4). The test speed was kept at 2 mm/min to have ideal test results.Standard metallographic analysis techniques were adopted and metallic surfaces after etching were subjected to polishing with grit stone. Standard microscope having magnification of 500x was adopted for microstructure analysis.

Figure 4.The samples and Tesile testing machine used in the experiment set up

Experimental Details

The experimentation involved resistance spot welding of two samples of each with size 100 x25x2 mm from Aluminum alloy of Al 2012 and 5056. The two plates were placed over each other (Figure 5) with an over lap of 25 mm.

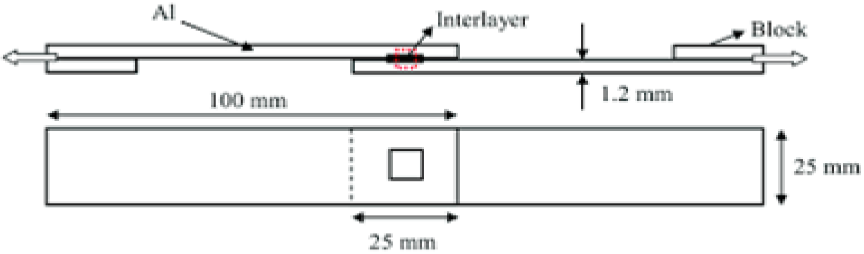

Figure 5. Dimensional details of spot welding samples and formation of nugget

The universal 100 KVA spot welding machine was used with a setting of desired current and varying weld time to spot weld the samples. The welded samples were subjected to shear tensile testing with universal Tensile testing machine instron in compliance with E8 "Standard Test Methods for Tension Testing of Metallic Materials".The tensile shear testing was selected as it offers a convenient way of holding spot welded samples and realistic values for shear loads are obtained. The purpose of the test was to measure the value of tensile shear load values at spot weld interface. The values of shear load were recorded for maximum values of partial or full interfacial failure to obtain optimized value of current time.The welded plates were subsequently prepared for microstructure analysis by immersing for 20 seconds through Kellers etchant(Nitric acid 5ml, hydrochloric acid 3ml, hydrofluoric acid 2ml and distilled water 190ml) and mounting these samples for microstructure analysis through Leica optical microscope with 500x magnification to study the micrographs of Base Metal(BM) , Heat Affected Zone (HAZ)and welded bead or Fuzed Zone(FZ) of welded samples.The microstructure study was restricted to the optimized spot welded samples as the microstructure analysis was compared with published literature to verify the results

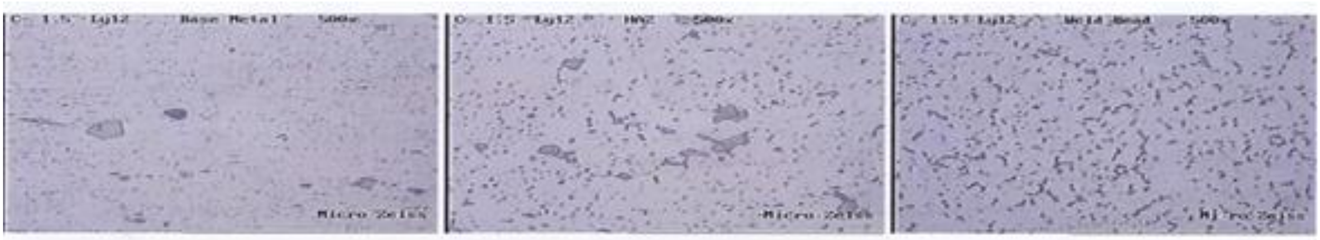

Figure 6 Micrographs showing the Microstructure of(BM,HAZ,FZ) 1.5 mm, 2024 Aluminum

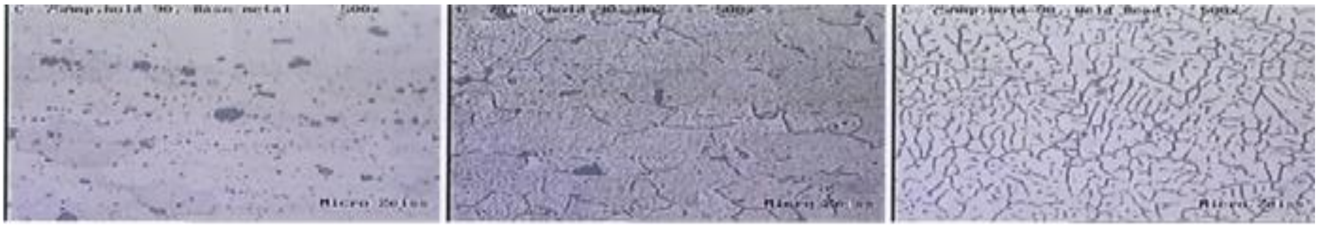

Figure 7 Micrographs showing the Microstructure of(BM,HAZ,FZ) 1.5 mm, 2024 Aluminum

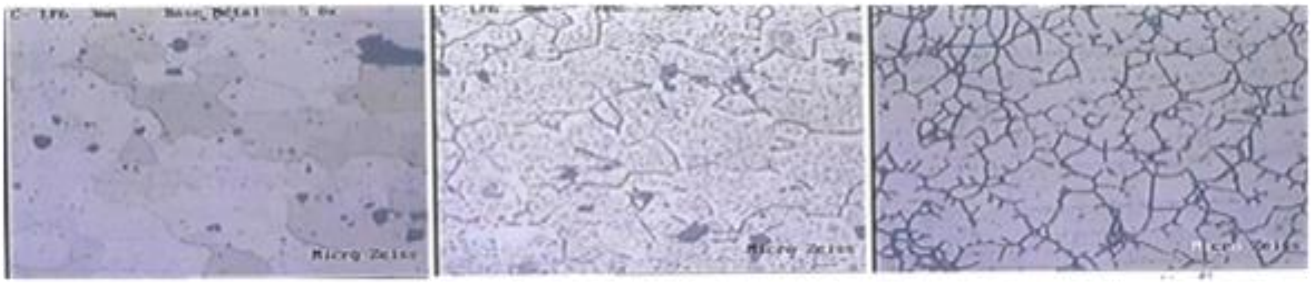

Figure 8 Micrographs showing the Microstructure of(BM,HAZ,FZ) 1 mm, 5056 Aluminum

First three micrographs(Figure 6) pertains to 1 mm 2024 Aluminum sheets with grain of Aluminum solid solution alongwith particles of $Cu\,Al_2$ in annealed state are observed in first micrograph with precipitates in second due to HAZ and third showing the interdendritic network of un dissolved $Cu\,Al_2$ in bead (FZ). In the next three micrographs (Figure 7) 1.5 mm 2024, Aluminum sheets in supplied state,grain of Aluminum solid solution with greyish particles of Cu,Fe,Mn and fine particles $Cu\,Al_2$ was observed,while $Cu\,Al_2$ precipitates due to HAZ with network of un dissolved eutectic of $Cu\,Al_2$ in weld bead observed in last two micrographs.In next three micrographs (Figure 8) 3 mm 5056 Aluminum sheets in supplied state having grain of Aluminum solid solution with precipitates of $Mg_2\,Al_3$, and particles of $Mg_2\,Si$ in first micrograph and heavy precipitates of $Mg_2\,Al_3$ in second due to HAZ with third micrograph showing the equiaxed dendrites of Mg_2Al_3 with fine precipitates at dendrite boundaries

Five samples were prepared for CT analysis after having Aluminum spot welding in case of strips of Al 2024 1.5 mm sheets. The parameters for the CT analysis were set in accordance with standard process and experimentation was performed in Lab.

RESULTS

	Si	Mn	Ni	Fe	Ti	Mg	Cu	Cr	Zn	Al
Al 2024 T3	0.4	1.0	-	0.4	0.15	2.6-3.6	0.1	0.3	0.2	Balance
Al 2024 1mm	0.23	0.51	0.016	0.34	0.04	1.47	4.27	-	0.12	-do-
Al 2024 1.5 mm	0.21	0.52	0.014	0.34	0.04	1.46	3.97	-	0.12	-do-
Al 5056 3mm	0.053	0.59	-	0.32	0.054	6.29	-	0.041	0.006	-do-

Table 1 : Nominal composition values of Aluminum High strength sheets(Wt %)

Young's Modulus	Yield Strength	Ultimate Tensile Strength	Elongation	Density
73 G Pa	280 M Pa	400-430 M Pa	10-15 %	2.78 g/cm³

Table 2: Nominal Main Mechanical Properties and Values of Aluminum Alloy 2024

Sample No	Current KA	Squeeze Time(Sec)	Weld Time(Sec)	Hold Time (Sec)	Shear load (Al 2024 1mm)	Nugget Dia (mm)
1	70	1.0	0.12	0.5	2.6	17
2	70	1.2	0.1	0.6	2.9	17.5
3	70	1.3	0.12	0.7	2.9	18
4	75	1.3	0.14	0.7	3.1	18
5	75	1.2	0.14	0.7	2.9	19
6	75	1.5	0.14	0.75	2.9	19
7	80	1.4	0.16	0.7	3.1	20
8	80	1.4	0.16	0.75	3.0	20
9	80	1.4	0.15	0.7	3.1	20.5
10	85	1.6	0.15	0.8	3.2	21
11	85	1.5	0.16	0.75	3.3	21
12	85	1.7	0.16	0.8	3.2	21.5

Table 3: Results of study Al 2024 1.5 mm sheet shear Testing at varying current and Weld time

Sample NO	Current KA	Squeeze Time(Sec)	Weld Time(Sec)	Hold Time (Sec)	Shear load (Al 5056 3 mm)	Nugget Dia (mm)
1	75	1.2	0.14	0.6	2.7	17
2	75	1.1	0.1 3	0.55	2.8	17
3	75	1.2	0.13	0.65	2.9	17.5
4	80	1.4	0.14	0.7	3.9	18
5	80	1.4	0.16	0.7	4.0	19
6	80	1.4	0.15	0.7	4.1	19
7	85	1.5	0.16	0.75	4.5	21
8	85	1.6	0.16	0.8	4.5	21
9	85	1.5	0.16	0.75	4.5	21
10	90	1.6	0.17	0.8	4.3	22
11	90	1.7	0.16	0.85	4.9	22
12	90	1.8	0.17	0.8	4.3	22

Table 3: Results of study Al 5056 3 mm sheet shear Testing at varying current and Weld time

DISCUSSION

The surface morphology suggests that for an ideal nugget formation, it is desired that current and weld time is optimised through experimentation.Furthermore the size of the nugget increases with increase in welding current .Shear test of the RSW samples involves application of tensile load, resulting in failure at nugget interface. As the load is increased,necking of the sheet metal occurs and ultimately the structure fails at the partial or full interface. Highest tensile shear load occurs around the optimized values of current and weld time. In 1.5 mm Al 2024 sheets, minimum tensile load is 2.7 KN with weld time of 0.12 sec at 70 KA with nugget diameter of 17 mm, whereas maximum tensile load recorded for the same samples is 3.2 KN with weld time of 0.16 sec at 85 KA and nugget diameter of 21.5 mm. The results of Al 2024 1 mm sheets are generally similar as 1.5 mm sheets therefore these are not discussed here. In Al 5056 3 mm sheets, minimum tensile shear load is 2.7 KN at 70 KA at weld time of 0.14 sec and nugget diameter of 17 mm, while maximum tensile load is 4.9 KN at 90 KA with weld time of 0.16 sec and nugget diameter of 22 mm.

The nugget size is recorded for weld quality. In case of irregular nugget, the sizes are averaged out for maximum and minimum size.The Values for riveted structures in Al 5056 with thickness of 3 mm were recorded for shear test. The values averaged around 7.8 KN, significantly higher than RSW in case of Aluminum spot weld. While it is a good option considering high strength values for rivted structures , however riveting in case of small thickness sheets of 1.5 mm in Al 2024 there is strong doubts as regards to its sustainability over a longer life cycle , there fore industry will have to adopt RSW of small thickness Aluminum sheets for light weight and economical solutions.

The samples prepared for CT analysis showed that a clear fused line where Aluminum was properly welded, however structure which had lack of proper fusion had dark shaded line of varying thickness.There is a good indication for further experimentation that shall establish clear standard for CT acceptance criteria in case of RSW.

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