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Variation in the Properties of Spot Weldments of Cold Rolled Mild Steel Welded with Filler Metal by Preheating

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Abstract: Filler metal addition has been verified as an effective way to refine mechanical behaviour of cold rolled mild steel in resistance spot welding.Negligible quantity of filler metal if added to the spot weld is found to improve mechanical properties of spot weldments , if no variation in composition of base metal and filler metal is allowed.. Looking at practical applications, sensitivity of the Resistance Spot Welding process with filler metal to variation in preheating treatment were experimentally investigated.Filler metal quantity was from 30 mg to 70 mg and preheat heat treatment was kept between 20% to 60%.The material of the filler metal is same as that of base metal and was added at the centre of overlap in lap joint.The experimentation was carried out by spot welding of specimen varying filler metal from 30 mg to 70 mg maintaining preheating cycle constant at 20%.The experimentation was then repeated for different preheat cycles.For 20% to 60% of preheat cycle, maximum breaking point was found to be varying linearly with increase in preheat level. Overall improvement in load bearing and energy absorption capability was observed as majority of specimen fail under the button pullout mode.

Keywords: Spot welding, Filler metal, Failure mode, preheat, Cold rolled mild steel

I. INTRODUCTION

For selecting materials for cars, car designers today seek materials with best stiffness, mass reduction, safety performance, mass saving, formability, weldability, corrosion resistance, fatigue resistance, cost, and environmental factors. Spot welding is the preferential method of fabricating automotive structure components because of its less cost and maximum weld speed.

A vehicle's structural behaviour depends in part on the fabricated-joint structural uniformity. Mild steel is a good material for car body as it offers reduction in weight, renewed crash performance, good mechanical properties and good manufacturability.

Different techniques/methods are being verified to improve spot weld mechanical performance by improving microstructure and phases of the weldments, by changing welding techniques , welding of different metals as base metals and innovative welding designs. Spot welding of dissimilar base metals and resulting changes in microstructure and subsequent mechanical performance is being verified.

Effects of the filler metal and its quantity on failure mode is discussed on 1.5- mm-thick CRM steel [1].Newer material like advanced high strength steels (AHSS), offers the potential for improvement in vehicle crash performance without extra weight increase. Currently, two types of advanced high strength steels are being used in the automotive industry. One is the dual phase (DP) steel in which, mechanical properties are controlled by the martensite volume fraction and the ferrite grain size [2, 3]. Dual-phase steels and transformation-induced plasticity (TRIP) steels are finding increased use in automotive bodies due to a combination of high strength and high ductility and its weldability. Also, it has been stated that spot welding of AHSS steels has issues of weldability problems due to the relatively higher alloying level in these steels [4]. Resistance spot welding of TRIP steel yields inconsistent interfacial failure or partial interfacial failure modes indicating inferior mechanical performance [5].Weld behaviour of mild steel has been well explored, same cannot be said about advanced high strength steels. It has been proved that strength and crash-performance of traditional mild steel in spot welding can be enhanced with filler metal [1]. The performance of resistance spot welds in general can be enhanced by altering the microstructure by applying a pre-weld heat treatment. Thus a pre-weld heat treatment called preheating was introduced in weld cycle.Preheating is used to reduce cooling rate of the weld and base-metal thus reducing hardness of weld metal and heat affected zone.It also reduces shrinkage stresses and improve distribution of residual stresses. One of effort is investigated by varying filler metal to be added to spot weldments, varying preheating energy levels and verifying its response to mechanical testing.

II. EXPERIMENTAL PROCEDURE

The material i.e. Cold Rolled Mild Steel sheets used in this study is specifically for automotive body applications and selected sheet had 1.25-mm-thickness. The chemical composition of this material is shown in Table 1.

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Table 1 Composition of CR Mild Steel

Sample identity	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%
Cold Rolled Mild Steel Strips	0.047	0.011	0.25	0.0060	0.0181	0.036	0.0070	0.0286

Tensile testing of welded specimen was carried out to obtain tensile stress-strain curves of the CR MS sheets. A Resistance spot welder, K J Thermoweld make with specifications as mentioned in table 2 below was used to spot weld the specimen.

Table 2-Spot Welder Specification [1]

Machine Model K J THERMOWELD	**Unit**	**TSP 30**
Rating KVA @ 50% duty cycle	**KVA**	**30**
Max. available current (short circuit) @ Throat Depth : 460 mm.	**K.Amp**	**15**
Optimum Weldability{@ 460 Throat Depth}:		
Minimum	**mm**	**0.3 + 0.3**
Maximum	**mm**	**1.5 + 1.5**
Machine Dimensions (Approx.L x W)	**mm**	**1020 x 520**
Height		**1500**
Net Wt. (For 460 mm Throat) (+30 Kg. for 200 mm Throat (Approx)	**Kgs.**	**450**
Shipping Wt. (For 460 Throat) (+ 30 Kg. for 200 Throat) (Approx)	**Kgs.**	**525**

Fig 1-Resistance spot welder

The cycle in the spot welder can be controlled with the help of parameters as mentioned in table 3.The machine was microcontroller based and energy levels were programmable.

Table 3-Spot welder parameters and setting variables

	Indication	**escription**	**Parameter**
Squeeze Time		**cle**	
Preheat Time		**cle**	
Energy Level		**programmable**	
Cool (I) Time		**cle**	
Slope for W2		**le**	
Weld Time		**cle**	
Weld Energy (% Heat Setting)		**programmable**	
Cool (II) Time		**cle**	
Anneal Time		**cle**	
Energy Level		**programmable**	
Hold Time		**cle**	
Off Time		**cle**	

The dimensions of spot weld specimen were 70 mm by 25 mm. The thickness of CRMS sheet as mentioned was 1.25 mm thick. The electrode material was made C15000 (copper alloy) and it had a face diameter of 5 mm. The coolant i.e. water flow-rate in the electrode was at 4 lit/min.

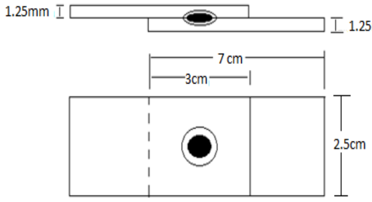


Fig 2 Test coupon

The spot welding schedules and parameters for experimentation is shown in Table 3.The purpose of experimentation was to determine effect of preheating on addition of filler metal in relation to mechanical behaviour. The composition of filler metal was same as that of base metal and it was added at the centre of overlap.

The extent of filler metal added in experimentation was from 30 mg to 70 mg for each preheating energy level from 20% to 60%.The schedule followed is mentioned in table 3 and was maintained unchanged with addition of filler metal and varying preheating energy level. Specimens were tested in tensile tests and load displacement curve were plotted to obtain breaking capacity. The failure mode was also observed and was interpreted by visual inspection. Some of the spot weld specimens were sectioned through the cross section perpendicular to the length direction and mounted for macrostructure and microstructure observations following standard metallographic procedures.

III. RESULT AND DISCUSSION.

Investigations are carried out by adding small quantity of filler metal from 30 mg to 70 mg in spot weldments.The preheating is done from 20% to 60%.At 20% and 30% preheat, addition of 40 mg of filler metal lead to maximum breaking strength followed by gradual reduction in breaking strength. At these preheat, failure energy of joint is maximum for 40 mg addition of filler metal. At 40% and 50% preheat, addition of 50 mg of filler metal lead to maximum breaking strength and failure energy followed by gradual reduction. Increasing preheat to 60% shifted peak load and failure energy of joint to 60 mg of filler metal (Fig 4). Two distinct failure modes are observed during static tensile testing: interfacial fracture and nugget pullout (Fig 6).Load carrying capacity and energy absorption capability for these welds was found to be more as majority weldments fail under the button pullout model.As mentioned earlier with increase in preheat energy, ability of the weldments to accommodate filler metal is found to be increasing linearly.

At 20% preheating, the nugget diameter was maximum for 30 mg of filler metal, but was near to 40 mg of filler metal offering maximum strength. There is subsequent increase in nugget diameter in association with increase in strength with increase in preheat and filler metal. Marked increase in uniformity in nugget diameter is clearly observed with preheating. Nugget growth appeared to be slower and more even with preheating. It provides a smooth transition from the unheated state to the molten weld state.

Table 4 Results obtained with filler metal addition and preheating

Specimen No.	Filler material by weight mg (mg)	Breaking load kN	Preheat variation %	Type of failure	Displacement at max load mm mm	Nugget Diameter mm
85	30	10.7	20%	Button pull out	3.7	4.71mm
86	40	10.72		Button pull out	3.65	4.45 mm
87	50	10.6		Button pull out	3.6	4.3mm
88	60	10.31		Button and interfacial	3.4	4.43mm
89	70	10.2		Button and interfacial	3.4	4.21mm
95	30	10.8	30%	Button pull out	3.73	4.81mm
96	40	10.83		Button pull out	3.69	4.7mm
97	50	10.61		Button pull out	3.6	3.98mm
98	60	10.29		Button and interfacial	3.36	3.4mm
99	70	10.16		Button and interfacial	3.3	3.25mm
110	30	10.8	40%	Button pull out	3.67	4.8mm
111	40	10.82		Button pull out	3.7	4.81mm
112	50	10.91		Button pull out	4.1	4.91mm
113	60	10.8		Button pull out	4.0	4.78mm
114	70	10.75		Button and interfacial	3.9	4.56mm

115	30	10.61	50%	Button and interfacial	3.7	4.1mm
116	40	10.81		Button pull out	3.7	4.87mm
117	50	10.94		Button pull out	4.1	5.1mm
118	60	10.9		Button pull out	3.9	4.9mm
119	70	10.76		Button and interfacial	3.87	4.87mm
125	30	10.45	60%	Button and interfacial	3.7	4.2mm
126	40	10.67		Button pull out	3.67	4.32mm
127	50	10.91		Button pull out	3.9	4.98mm
128	60	10.92		Button pull out	4.1	5.2mm
129	70	10.8		Button and interfacial	3.89	4.9mm

Fig 3 Few welded and tested specimen

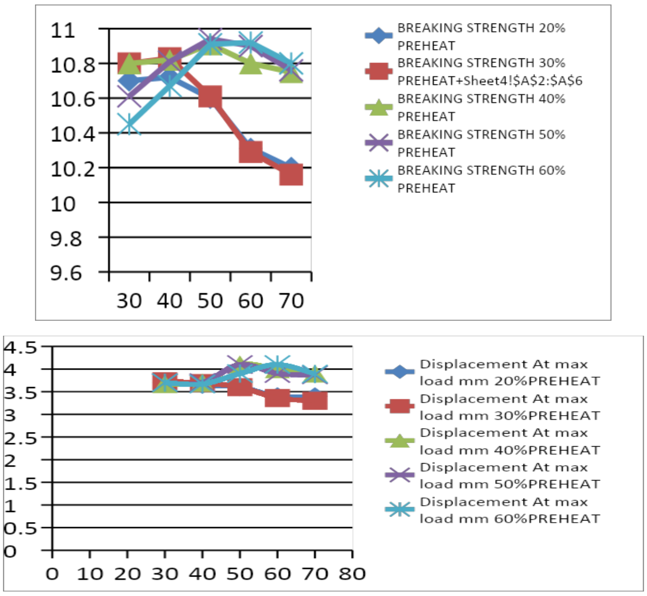
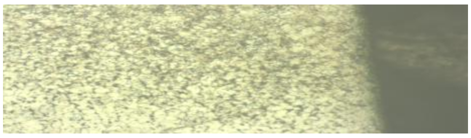


Fig 4 Variation of displacement at max load(mm) and average breaking strength(kN) on Y-axes with filler metal quanity (mg) on X-axes at 20-60% preheatinging energy level

IV. EFFECT OF ANNEALING ON PHASES IN MICROSTRUCTURE OF WELDMENTS WITH FILLER METAL

In the present study ,filler metal from 30 mg to 70 mg was added with preheat from 20% to 60%.It is observed that preheating did decrease the violence and speed of nugget formation. It also changed the pattern of heat distribution. The joint region consists of three distinct structural zones: (i) fusion zone (FZ) or weld nugget, (ii) heat affected zone (HAZ), and (iii) base metal (BM). The Heat Affected Zone (HAZ) experienced more uniform and slower cooling rate due to preheat [6]. The HAZ microstructure near the fusion boundary consisted of less martensite and ferrite. With increase in preheat energy, the quantity of filler metal accommodated for peak load and energy was observed to be increasing. The HAZ was found to be more stress free due to preheating and phase transformations more homogeneous due to preheating [7]. The microstructure of the region away from fusion boundary consisted of ferrite and pearlite. When the duration of the preheat is increased, the nugget may begin to form before the initiation of the weld current.

Weld Metal



Heat Affected Zone (HAZ)

Fig 5- Weld Metal and HAZ of Specimen No 86 (Preheat 20%, Filler Metal 40 Mg) - Weld Metal Shows Widmanstatten Ferrite, Normal Ferrite (Whitish) and Pearlite (Blackish),HAZ Shows Martensite (Black) and Ferrite Investigation into effect of addition of filler metal with preheat on mechanical properties of resistance spot weldments

At 20% and 30% preheat level, maximum breaking strength is obtained at 40 mg of filler metal. It means at these preheat levels, failure energy of joint was maximum for 40 mg addition of filler metal.Increase in preheat energy level is compensated by additional optimal accommodation of filler metal.e.g addition of 50 mg of filler metal at 40% preheat level lead to maximum breaking strength and failure energy. Following same relationship increase in preheat to 60% shifted peak load and failure energy of joint to 60 mg of filler metal. Thus with increase in preheat energy, ability of the weldments to accommodate filler metal is found to be increasing. This fact can be credited to enhanced diffusion process of the filler metal into the base metal due to slower solidification of weld metal. But this diffusion process shall be optimum for a combination of filler metal and preheat energy, otherwise overheating and insufficient heat to preheat may affect diffusion process resulting in inferior mechanical properties [8]. Failure modes observed during static tensile testing are: interfacial fracture and nugget pullout, as shown in Fig.6 . Load carrying capacity and energy absorption capability for these welds is found to be more as majority weldments fail under the button pullout mode ensuring marked uniformity in energy absorption and load carrying capacity. Thus preheating contributed in improving energy absorption capability of weldments with slight reduction in breaking strength.

Fig 6 – Failure modes in spot specimens: Button pull out and interfacial

Investigation into the changes in nugget diameter with addition of filler metal with preheat in resistance spot weldments

Nugget growth appeared to be slower and more even with preheating. It provides a smooth transition from the unheated state to the molten weld state. Heat flow is very important to the nugget formation process. Although the power required to form the nugget is virtually the same, long-time/low-current welds invariably produced more uniform nuggets than short-time/high-current welds. In the long-time welds, heat generation is slower and more homogeneous. This more even heating generates more uniform nugget geometry. As mentioned earlier with increase in preheat energy, ability of the weldments to accommodate filler metal is found to be increasing linearly. Invetigations are carried out by adding small quantity of filler metal from 30 mg to 120 mg in spot weldments.The preheating is done from 20% to 60%.At 20% preheating, the nugget diameter is more for 30 mg of filler metal than 40 mg of filler metal offering maximum strength. Increase in nugget diameter with increase in preheat and filler metal is visible.More uniformity in nugget diameter is clearly observed with preheating. At a given current in a cycle, filler metal can be accommodated optimally, the quantity of which depends on plate thickness.Thus, addition of 30 mg of filler metal contributes in fusion zone and resulted in increase in fusion zone size and penetration. Once the filler metal melts, it penetrates by diffusion through the base metal during welding. This trend is in accordance with the results obtained by Hasanbasoglu and Kacar [8] Increasing the nugget size indirectly widened the load-bearing area in welded joint, and thus increased the failure load of the joint. It has been suggested that there is a direct correlation between joint tensile shear load and nugget diameter in the case of the [9]. Expulsion of metal may begin then due to excess availability of filler metal, resulting in weak joint and higher areas of stress concentration. But no expulsion of metal was visible in present experimentation

V. SUMMARY AND CONCLUSION

The microstructure and the mechanical behaviour of spot welded cold rolled mild steel was successfully modified by adding filler metal and utilizing preheat heat treatment cycle in resistance spot welding . The main results in this study are listed as follows;

1. Experimentation is carried out with preheating and is observed that it reduces dynamics of nugget formation and HAZ, thus improving homogeneity in phases existing in weld metal and HAZ.The martensite formation was less stressfull and hence plasticity is observed to be more uniform due to preheating.
2. The failure mode was predominantly button pull out in all cases with preheating. Thus preheating have contributed in improving load carrying capacity and energy absorption capability of spot weldments irrespective of filler metal addition.
3. A linear relation between preheating and filler metal is found to be existing .With increase in preheating, filler metal that can be accommodated is found to be increasing linearly for the given strength. Marked consistency in breaking strengths is visible though found to be varying with preheating and filler metal.

4. Preheating seems to control dynamics of phase formation whereas nugget diameter is controlled by addition of filler metal. Thus properties of joint is found to be the function of filler metal and preheating treatment.

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