EVALUATION OF DYNAMIC RESISTANCE AS QUALITY CRITERION FOR RESISTANCE SPOT WELDING

by

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ABSTRACT

Resistance spot welding is being used extensively in the automobile electrical and consumer goods industries in our country. With high quality coupled with low cost demanded by many industries, it is important to adapt resistance welding controllers for assuring quality of spot welded joints. The present paper examines the dynamic resistance behaviour during resistance spot welding of low carbon steel and austenitic stainless steel with a view to study the applicability of dynamic resistance based controllers Low carbon steel sheet of 1 mm and austenitic stainless steel sheet of 0.5 mm were used for spot welding trials and tensile shear test is used for evaluation of joint quality. Nugget diameter and indentation were again measured. The details of instrumentation system for dynamic resistance measurement and method of computation are being discussed. Dynamic resistance values are computed for every weld trial and parameters such as current pressure and time are varied to study its influence on both dynamic resistance as well as tensile shear strength. It was found that there is good correlation between tensile shear load, nugget diameter and indentation with the percentage drop in dynamic resistance. This work suggests that the percentage drop in dynamic resistance can be used as criteria for ensuring the quality of the spot welded steel joints.

INTRODUCTION

Resistance spot welding is being used extensively in automobile, sheet metal industries and many other industries in our country. Today, with globalisation of economy, the demand for high product quality coupled with low cost is quite high. To meet this demand, extensive use of in process quality monitoring/control device for resistance welding is inevitable. The transition from resorting to extensive mechanical testing of sample lot for qualification of spot welded product quality to use of monitors / controllers is under progress. In this context, the present work examines the relationship between spot welding quality with the measurable parameter such as dynamic resistance.

EXPERIMENTAL PROCEDURE

For the present investigation, cold rolled low carbon steel sheet of 1.0 mm and austenitic stainless steel (AISI 304) sheet of 0.5 mm were selected for resistance spot welding trials. Welding was carried out in a 40 KVA poratable spot welding machine. The standard taper angle electrode of tip diameter 5 mm was used for carbon steel welding and 4 mm diameter electrode tip was used for stainless steel welding. For determination of spot welding quality, nugget diameter, penetration and tensil shear failure load were measured. For measurement of dynamic resistance during spot welding, an instrumentation system was specially designed and developed at Welding Research Institute, BHEL, Tiruchirapalli. This consists of toroid coil (for current measurement), pick up coil (for measurement of electrode tip voltage) and a two channel digital storage oscilloscope. The two inputs namely current, voltage during spot welding are sensed and digitised (8 bit) and stored as waveform in the oscilloscope. Subsequently, the stored waveform data is processed in 386 P.C./AT to calculate dynamic resistance for each half cycle using a special program written in 'C'. For dynamic resistance determination, R.M.S. value of both current and voltage were calculated as shown below and subsequently the dynamic resistance value was derived for each half cycle.

Squeeze time (Cycle)	Weld time (Cycle)	Load (kgf)	Current (Phase shift setting %)
10	4	250	16

$$\text{Current } I_{rms} = \sqrt{1/\Delta t \int_{T_K}^{T_{K+1}} i^2 (t)\, dt}$$

$$\text{Voltage } V_{RMS} = \sqrt{1/\Delta t \int_{T_K}^{T_{K+1}} v^2 (t)\, dt}$$

where T intergration interval for forming the half wave effective cycle.

I(t) instantaneous value of the welding current

v(t) instantaneous value of the welding voltage

T_K start of the Kth half wave cycle

T_{K+1} end of the Kth half wave cycle

After computing V_{RMS} and I_{RMS} for each half cycle, the dynamic resistance was computed using Ohms Law i.e. $R=V_{RMS}/I_{RMS}$. This approach is chosen as the other methods of determination is inaccurate [1-5].

STUDIES ON LOW CARBON STEEL WELDING

During resistance spot welding of 1 mm thick low carbon steel sheet, current and time were varied with respect to optimised welding parameter as given below :

The current was varied to 11% and 21% from the centre point value of 16% by keeping all other parameters (shown above) constant. Subsequently, the weld time was varied between two to six cycles by keeping the weld time of four cycles as centre point. In both the cases, the current and voltage waveform was recorded for every welding trial and dynamic resistance is derived.

Influence of welding parameters on dynamic resistance

Table I summarises the results obtained by varying welding current during experimentation. The results include the nugget diameter, penetration, tensile shear test load and percentage drop in dynamic resistance. **Fig. 1** shows the typical dynamic resistance curves obtained at various phase shift settings. It is found that the peak dynamic resistance value for 11% phase shift occurs at fourth half cycle and for 21% phase shift it occurs at second half cycle. Therefore, it is clear that as phase shift angle increases (i.e. current increases) the peak dynamic resistance value reaches at an earlier period. The percentage drop in dynamic resistance is 16.1% for 11% phase shift setting and increases to 64.5 for 21% phase

Table I : Results of spot welding of low carbon steel sheet thickness : 1 mm + 1 mm (effect of phase shift)

Weld time : 4 cycles | **Load 250 kgf**

SL. No	Phase Shift %	Current KA	Nugget Diameter mm	Indentation %	Tensil load kgf	Mode of failure	% drop D.R.	Remarks
1	11	5.7	3.14	7	-	IF	18.6	BAD
2	11	5.8	-	-	450	-	16.1	BAD
3	16	6.5	4.51	10.6	-	PS	26.6	GOOD
4	16	6.5	-	-	580	-	27.6	GOOD
5	21	7.7	4.73	35	-	PS	64.5	SPLASH
6	21	7.4		-	550	-	57.7	SPLASH

I.F. : Interface Failure along the weld **P.S.** : Pulled Slug Failure **D.R.** : Dynamic resistance shift. So, the percentage drop in dynamic resistance value also increases with increase in phase shift.

The dynamic resistance values alongwith tensile shear load, nugget diameter as a function of time are tabulated in **Table II**. It is observed that the drop in dynamic *resistance increases from a value* of 3.8% in 2 cycles to a value of 63.6% in 6 cycles time. As the cycle time increases, the percentage drop in dynamic resistance value also increases. The increase in weld time has got significant effect in the percentage drop in dynamic resistance. The dynamic resistance curve reveal that the drop in dynamic resistance is high for the high cycle time *i.e.* 6 cycles. At the end of last one period in the 6 cycles, the drop is steep at which expulsion was observed. The steep fall can be clearly seen in the **Fig. 1**.

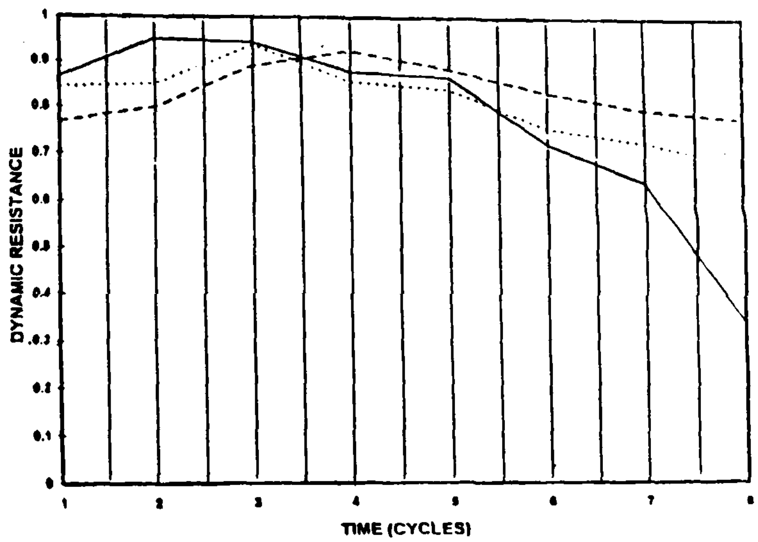

Fig. 1 : Effect of Phase Shift Setting on dynamic resistance in Low Carbon Steel

— — — — 11% Phase Shift
.... 16% Phase Shift
———— 21% Phase Shift

Influence of welding parameters on nugget diameter and indentation

Tables I & II show the relationship between the nugget diameter & indentation with time and current (phase shift setting). The nugget diameter increases for increase in time as well as increase in current. For the increase in time, it increases from 2.1 mm for 2 cycles to 4.6 mm for 6 cycles. For the increase in phase shift setting, it increases from 3.1 mm at 11% phase shift to 4.6 mm for 21% phase shift. The relationship between nugget diameter and the percentage drop in dynamic resistance can be seen from the table of values. The percentage drop in dynamic resistance increases with increase in nugget diameter. It increases from 4.2% for a nugget diameter of 2.1 mm to 60.3% for a value of the nugget diameter of 4.6mm. The percentage of indentation again increases from 3.2% for 2 cycles to 33% for 6 cycles weld time. Further, the increase in phase shift setting from 7 to 11%, resulted in increase in the percentage of indentation from 7% to 35%. Therefore, like that of nugget diameter, the increase in current or time results in increase in percentage of indentation.

Influence of welding parameters on tensile shear load

Tables I & II show the tensile shear load as a function of current setting and time respectively. It is observed that the tensile shear load increases for the increase in weld time.The tensile shear load is 380 kgf for the weld at 2 cycles and increases to 610 kgf for the weld at 5 cycles. It again falls at 6 cycles to 480 kgf. For the change in current, it increases from 450 kgf for 11% phase shift to 580 kgf for 16% phase shift and then falls to 550 kgf for 21% phase shift setting. The tensile shear load increases with increase in percentage drop in dynamic resistance. The tensile shear load is maximum for 32.5% drop in dynamic resistance. Further, upto 25% drop in dynamic resistance, the weld failure took place at the interface of the weld. Between 25% to 35% drop in dynamic resistance, the failure is of pulled slug type. After this range, eventhough the percentage drop in dynamic resistance value is quite high, the tensile shear load is reduced. This is due to expulsion of metal from weld region under splashed condition.

Discussion

From the **Fig. 1**, it is found that the dynamic resistance increases in the initial stage till it reaches maximum. Subsequently, the value gradually reduces and exhibits drooping characteristics. This is similar to the observations made by earlier researchers [5-6]. The rise in the dynamic is due to the rise in temperature and hence the characteristic curve reaches a peak value on the basis of Alov's theory of the heat development and abstraction [7]. As per the model, the initial development of a zone intensive heating takes place around the circumference of the electrodes. The subsequent softening after fitting makes metal to metal contact in the weld region. Therefore, the heat generation near the sheet to electrode becomes less. Also the electrode is water cooled. So, the subsequent heating will take place at the weld interface and this results in the development of the heat zone at the interface. The resulting temperature rise causes an increase in the resistance. The molten nugget is formed before the peak value. The dropping dynamic resistance characteristic from the maximum value can be explained as follows :

$$R = \rho l / A$$

where R is the resistance of a conductor length l, measured in ohms, p is the electrical resistivity of the conductor measured in microohm per meter and A is the area of conductor measured in mm^2.

The above expression can be used to explain the influence of the nugget diameter and identation on the drop in dynamic resistance behaviour. As the nugget diameter increases the area of contact increases and hence the dynamic resistance R decreases. After certain time due to the softening of the metal.

Table II : Results of spot welding of low carbon steel sheet thickness : 1 mm + 1 mm (effect of weld time)

Phase shift : 16%								Load : 250 kgf.
SL. No.	Weld Time Cycle	Current KA	Nugget Diameter mm	Indentation %	Tensil load kgf	Mode of failure	% drop D.R.	Remarks
1	2	6.2	-	-	380	IF	3.8	-
2	2	6.3	2.1	3.2	-	-	4.2	-
3	3	6.4	-	-	425	IF	14.5	-
4	3	6.5	3.2	6	-	-	-	-
5	4	6.5	-	-	580	PS	26.6	GOOD
6	4	6.5	4.5	10.6	-	-	27.6	GOOD
7	5	6.8	-	-	610	PS	37.6	GOOD
8	5	6.9	4.6	22	-	-	32.5	GOOD
9	6	7.5	-	-	480	IF	60.3	SPLASH
10	6	7.7	4.6	33	-	-	63.6	SPLASH

I.F. : Interface failure along the weld **P.S.** : Pulled slug failure
D.R. : Dynamic Resistance

indentation of the electrode takes place and hence the conducting path l is reduced. As a consequence, dynamic resistance reduces. Therefore, dynamic resistance value reduces both due to enhancement of nugget diameter as well as due to indentation. This trend is clearly seen in **Tables I & II**. From the table, it can also be seen that for a two cycle period the dynamic resistance drop is caused by the nugget diameter than by percentage indentation. In the six cycle

Table III : Results of spot welding of austenitic stainless steel (thickness : 0.5mm + 0.5mm)

Sl. No	Phase Shift %	Load Kgf	Weld time cycle	Current KA	Nugget Diameter mm	Indentation %	Tensile load kgf	Mode of failure	% drop D.R.	Remarks
1	10	190	4	6.3	-	-	310	P.S	27.1	*
2	10	190	4	6.2	3.3	19	-	-	29.5	*
3	4	235	5	5.3		-	140	I.F	19.7	*
4	4	235	5	5.4	-	-	180	I.F	17.6	*
5	4	235	5	5.4	2.3	6.5	-	-	18.5	*
6	4	235	2	4.9	-	-	100	I.F	12.5	*
7	4	235	2	4.9	-	-	80	I.F.	11.9	*
8	4	235	2	4.8	1.8	4.5	-	-	10.0	*
9	16	235	2	7.3	-	-	270	I.F.	23.8	**
10	16	235	2	7.3	-	-	270	I.F.	20.6	**
11	16	235	2	7.3	3.4	19.5	-	-	22.2	**
12	16	235	5	7.7	-	-	300	P.S.	37.6	**
13	16	235	5	7.9	-	-	280	P.S.	32.6	**
14	16	235	5	7.8	3.6	23.5	-	-	37.7	**
15	16	140	5	7.8	-	-	320	P.S.	48.6	**
16	16	140	5	7.9	-	-	300	P.S.	43.5	**
17	16	140	5	7.9	3.9	28.7	-	-	46.6	**
18	4	140	2	5.1	-	-	190	I.F.	18.4	*
19	4	140	2	4.9	-	-	200	I.F.	18	*
20	4	140	2	5.0	2.4	7.7	-	-	17.4	*
21	16	140	2	6.4	-	-	280	I.F.	30.5	**
22	16	140	2	7.0	-	-	280	I.F	29.4	**
23	16	140	2	7.0	3.4	21.5	-	-	28.2	**
24	4	140	5	5.4	-	-	250	I.F.	20.8	*
25	4	140	5	5.4	-	-	240	I.F	19.5	*
26	4	140	5	5.3	3.0	11.5	-	-	20.7	*

P.S. : Pulled slug failure
I.F. : Interface failure along the weld

* no splash
** splash

time period it seen that the precentage indentation has more significant contribution than the nugget diameter for the increase in dynamic resistance drop.

STUDIES ON DYNAMIC RESISTANCE BEHAVIOUR OF AUSTENITIC STAINLESS STEEL

For austenitic stainless steel spot welding of 0.5 mm + 0.5mm, guide parameters from the AWS recommendations are used and extensive trials were conducted. The peel testing of joints was carried out to check the extent of nugget formation. The following optimum parameter combination is finally arrived at :

Squeeze time (Cycle)	Weld time (Cycle)
8	4
Load (kgf)	**Current (phase shift setting %)**
190	10

With this centre point, three parameters namely current, weld time and load were varied at two levels to study the influence of these parameters on nugget diameter, tensile shear load and dynamic resistance drop.

Influence of weld parameters on dynamic resistance

The results of this experimentation is summarised in **Table III.** For a phase shift of 16% and load of 235 kgf, it is found that the percentage drop in dynamic resistance increases from 22.2% at 2 cycles to 32.6% at 5 cycles. This shows that the percentage drop in dynamic resistance increases with increase in weld time. Likewise, the percentage drop in dynamic resistance increases from 12.5% for 4% phase shift to 22.2% for 16% phase shift. By keeping the phase shift and time constant, load was varied to study the influence on percentage drop in dynamic resistance. When the load is decreased from 235 kgf to 140 kgf, the percentage drop in dynamic resistance increases from 32.6% to 46.6%. Therefore the reduction of electrode load leads to increase in dynamic resistance drop.

Influence of weld parameters on nugget diameter and indentation

The nugget diameter under varied welding conditions is summarised in **Table III**. From the table, it is found that with increase in weld time from 2 cycles to 5 cycles, the nugget diameter increases from 2.4 mm to 3.9 mm. Likewise, as the current (i.e. phase shift setting) is increased from 4% to 16%, the diameter increases from 1.8 mm to 3.6 mm. The percentage of indentation again increases from 3.2% for two cycles to 33% for 6 cycles. Further, the increase in phase shift setting from 7 to 11% resulted in increase in the percentage indentation from 7 to 35%. Therefore, like that of nugget diameter, the increase in current or time results in increase in percentage indentation. Hence, both current and time increase result in increased nugget formation. This can be explained by the basic heat generation equation $Q = I^2Rt$ where I is current in kA, R is contact resistance & time in second. With increase in current or time, heat generation at the contact surface is more and this results in more nugget growth as revealed by high nugget diameter as well as by high percentage of indentation.

Influence of weld parameters on tensile shear load

From **Table III**, the relationship between the tensile shear load and various weld parameters such as current, time and load can be seen. As the weld time is increased from 2 to 5 cycles, the tensile shear load increases from 190 to 300 Kgf. Likewise, when the current is increased from 4% to 16% phase shift setting, the tensile shear load increases from 190 Kgf to 280 Kgf. Therefore, increase in both current and time results in increase of tensile shear strength. Further, increase in electrode load from 140 to 235 Kgf results in decrease in tensile shear load from 320 to 280 Kgf. This is expected, as increase in electrode load results in more contact area at the weld interface and in turn reduced contact resistance. Reduced contact resistance reduces the heat generation at the weld interface and hence the reduced nugget growth and low tensile shear load as observed in the present experiment.

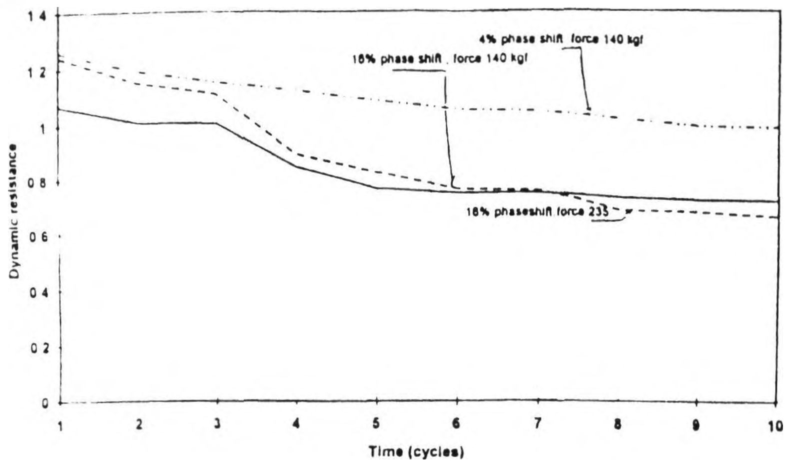

Fig. 2 : Influence of weld parameters on dynamic resistance in austenitic stainless steel.

——————— Series 1

---------------- Series 2

— -- — -- Series 3

Discussion

From **Fig. 2**, the dynamic resistance curve for austenitic stainless steel follows a drooping characteristic. This is same as the welding done in low current condition. In carbon steel a peak value followed by a drooping characteristic was observed. In the case of stainless steel only drooping characteristics was observed and there is no rise in the dynamic resistance value. This is similar to the dynamic resistance curve generated by Andrews, Bhattacharya and Peter Kuy [2,5,8]. Andrews has found steep fall in dynamic resistance curve is due to initiation of melting in the case of the stainless steel [5]. In the carbon steel the peak rise of the curve is the change of period from softening to melting. Carbon steel has a high melting voltage than softening voltage and so there is a rise in the resistance value. But stainless steel has a low melting voltage than softening voltage. So the transition period from the softening to the melting voltage resulted in a fall of dynamic resistance unlike carbon steel. This is in agreement clearly with our observation.

CONCLUSION

Based on the work carried out on spot welding of low carbon steel and austenitic stainless steel, the following conclusions can be drawn.

1. With increase in current and time, the percentage drop in dynamic resistance increases for both the materials.
2. The nugget diameter and tensile shear strength increases with respect to current and time upto a certain level.
3. There is a very good relationship between percentage drop in dynamic resistance to both nugget diameter and tensile shear load of spot welded joints.
4. The percentage drop in dynamic resistance can be taken as a quality control criterion for spot welding of both low carbon steel and austenitic stainless steel.
5. The dynamic resistance increases initially to a maximum, followed by dropping of its value for low carbon steel welding. Whereas in austenitic stainless steel, it exhibits continuous dropping of its value from beginning to end throughout the welding period without any maximum.

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