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Effect Of Process Parameters On The Strength Of Aluminium Alloy A5052 Sheets Joint Welded By Resistance Spot Welding With Cover Plates

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ABSTRACT

Resistance spot welding (RSW) is the most popular joining technique used by automotive industries for the manufacture of automobile body structure. In automobile industries, the weight saving effect of replacing steel parts is an important factor in reducing fuel consumption and increasing speed and natural resources savings. In this study, A5052 aluminium alloy sheet having 1 mm thickness were welded using the RSW with cover plates. The process parameters namely welding current, welding time and electrode force considered for weld quality. The welded joints were subjected to tensile shear and hardness tests to determine the influence of welding parameters effect on the quality of spot welded joint. Also parameters effect on nugget diameter and failure modes were studied. The results showed that increase in welding current and weld time tensile shear strength and nugget diameter increased. While, increase in electrode force both nugget diameter and weld strength decreased. Hardness measurement results indicated that nugget diameter gave the lowest hardness value than base metal. The interfacial failure mode occurs for nugget diameter up to 5.81 mm and above this value nugget pullout failure mode observed. The result reveals that the technique is feasible to weld aluminium alloy.

Keywords **- Aluminium alloy, hardness, Nugget diameter, RSW, Tensile-shear load.**

I. INTRODUCTION

Resistance spot welding (RSW) is an efficient joining process widely used for the fabrication of sheet metal assemblies. RSW has excellent techno-economic benefits such as low cost, high speed and suitability for automation which make it an attractive choice for auto-body assemblies such as automobiles, truck cabins and rail vehicles. For example, a modern auto-body assembly needs 7000 to 12,000 spots of welding according to the size of a car, so the spot welding is an important process in auto-body assembly [1].

In automotive industries, weight reduction is strongly demanded for energy and natural resource savings. Due to low density, its recovery potential and significant mechanical properties, aluminium alloys have been adopted and are expected to be extensively used in the future, to partially replace steel that is primary construction material in automobile [2].

The quality weld spot weld in aluminum alloys is more sensitive to process variations than are similar welds is steels [9]. RSW of aluminium requires three to four times more welding current than the resistance of an equivalent thickness of steel. Aluminium has young's modulus is one third that of steel, aluminium is less resistance to surface indentation from electrode contact. Thermal balance in weld is difficult because surface oxidation changes the dynamic contact resistance characteristic at the workpiece interface. In RSW of aluminium alloy the problems occurring are short electrode tip life and surface oxidation [4].

Though the effect of the process parameters on the mechanical behavior of resistance spot welds on carbon and stainless steels is well documented, results from aluminium alloys continue to be scarce [5-6]. In the previous study, magnesium alloy sheets have been welded using the technique of RSW with cover plates and favorable joint has been achieved under the welding condition of low welding current [3]. In view of physical properties similarities between aluminium alloy and magnesium alloy, aluminium alloy was also welded by using this method in the present study.

In order to provide some foundational information for improving mechanical properties of the aluminium alloy joint, the availability of this method for aluminium alloy welding and the effect of welding parameters (welding current, weld time, electrode force) on the characteristics of the joint were investigated.

II. RSW WITH COVER PLATES

RSW is a joining process based on the heat source obtained from Joule's effect of resistance and electric current flow through the sheets held together by the electrode force, in which the coalescence occurs at the spot area in flying surfaces. Therefore in the process of RSW of aluminium alloy, enormously high electric current required because of low heat generation and high heat conduction of aluminium alloy. In this case, the utilization of enormously high welding current would reduce electrode tip life and require adopting larger capacity RSW machine. In order to enable the RSW of aluminium alloys sheets under relatively low welding condition, we proposed a technique of RSW with cover plate. Fig.1 and 2 shows the schematic diagram of this welding process, in which a cover plate was placed on both the side of aluminium alloy sheet. Here it is required that the cover plate was a metal sheet with relatively low electrical conductivity than aluminium alloy, so the higher heat generated in the cover plates as to be conducted from the cover plate to aluminium alloy sheet. Taking low cost and availability into account, we chose cold-rolled sheet SPCC as the cover plate. The cover plate 30×40×1 mm in size was adopted.

III. EXPERIMENTAL MATERIALS AND PROCEDURE

Aluminium alloy A5052 sheets of 1 mm thickness were used in this study. Cold rolled steel plates were used for cover plates. Resistance spot welding lap joints with cover plates were done on specimens of 100 mm × 40 mm × 1 mm in size Table 1. The nominal chemical composition of this alloy is given in Table 2. Fig. 1 and Fig. 2 show the geometry and dimensions of the welded specimens. Sheet surfaces were randomly abraded before resistance spot welding.

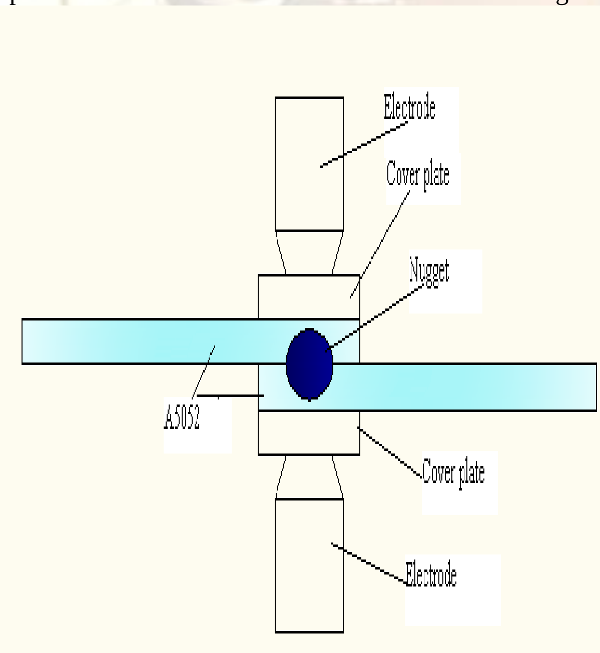

Fig. 1 Schematic diagram of resistance spot welding with cover plates

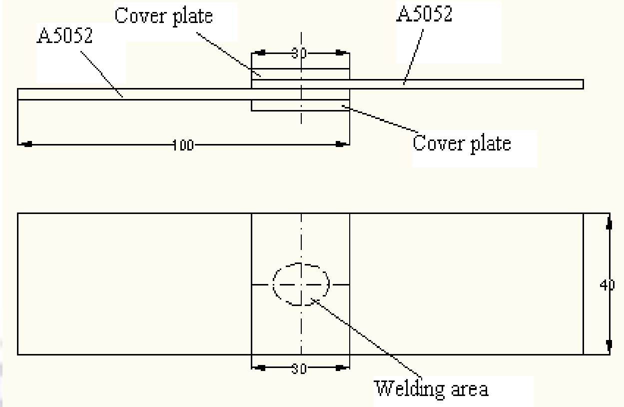

Fig. 2 shape and size of specimen for welding

Table 1 Dimensions of the work piece

Thickness(t) mm	Width (W) mm	Length (L) mm	Contact overlap mm
1	40	100	30

The specimens were welded using a stationary RSW machine as per welding condition in Table 3. Copper-chromium alloy electrodes with a tip diameter of 7 mm were used.

Table 2 Chemical composition of material

Alloying Element	**Wt. %**
Si	0.150
Mn	0.012
Cr	0.160
Ni	0.003
Cu	0.004
Al	97.000
Mg	2.400
Fe	0.240
Ti	0.010

All tests were performed at standard laboratory conditions. Tensile-shear strength is an important measure of welding quality of RSW. Therefore, in this research tensile-shear strength has been selected to describe the mechanical properties of spot weld.

All the tensile-shear tests were carried out at a crosshead speed of 2 mm/min on universal testing machine UTES-40. Set-1, Set-2, Set-3 and Set-4 total 22 spot welded specimens were tested on Universal Testing Machine for tensile shear load measurement. Tensile loading was applied till final failure of the weld specimens. Failure mode was determined from the failed samples.

Nugget diameter was measured after tensile shear test fractured specimen achieved. Sometimes due to oval shape of the weld nugget geometry diameter measured in both the directions and average value of both was taken. Here set-1, set-2, set-3 and set-4 total 22 specimen's nugget diameters were measured. All specimens nugget diameter was measured by the travelling microscope.

Table 3 Resistance spot welding condition for each specimen series

	Specimen series code	welding current (KA)	Welding time (cycles)	Electrode force (N)	cover plates (Y/N)
Set-1	S-1-1	6.3	15	2050	Yes
	S-1-2	7.3	15	2050	Yes
	S-1-3	8	15	2050	Yes
	S-1-4	8.8	15	2050	yes
	S-1-5	9.8	15	2050	Yes
Set-2	S-2-1	8	5	2050	Yes
	S-2-2	8	10	2050	Yes
	S-2-3	8	15	2050	Yes
	S-2-4	8	20	2050	Yes
	S-2-5	8	25	2050	Yes
	S-2-6	8	30	2050	Yes
Set-3	S-3-1	8	15	1658	Yes
	S-3-2	8	15	2050	Yes
	S-3-3	8	15	2443	Yes
	S-3-4	8	15	2835	Yes
	S-3-5	8	15	3228	Yes
	S-3-6	8	15	3621	Yes
Set-4	S-4-1	6.3	15	2050	No
	S-4-2	7.3	15	2050	No
	S-4-3	8	15	2050	No
	S-4-4	8.8	15	2050	No
	S-4-5	9.8	15	2050	No
Set-5	S-5-1	6.8	15	2835	Yes
	S-5-2	8	15	2835	Yes
	S-5-3	9.8	15	2835	Yes
Set-6	S-6-1	8	5	2835	Yes
	S-6-2	8	15	2835	Yes
	S-6-3	8	25	2835	Yes
Set-7	S-7-1	8	15	2050	Yes
	S-7-2	8	15	2835	Yes
	S-7-3	8	15	3621	Yes

The hardness of the welds was measured on the parallel to the interface using a Vickers hardness tester. Set-5, set-6 and set-7 total 9 spot welded specimens were tested on Vickers hardness tester. Testing was performed with a 5 kgf indentation load and with a hold time of 15 second. Hardness measurements were carried out both the side from the weld nugget centre and average hardness values of both the sides of similar points was taken.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A. Tensile-shear load

The influence of the weld current on the tensile-shear load is illustrated in Fig. 3 for set-1. A significant increase in the tensile-shear load with increasing weld current was observed, even for the maximum current studied (9.8 kA). Increasing welding current value T-S load increased with also small expulsion of material was occurred. Welding current values at 8.8 and 9.8 KA splashing of material from weld nugget was observed. The reason for this behavior is that the increase in current heat input is increased as per the joule's equation.

The effect of the weld time on the tensile shear load is shown in Fig. 4 for set-2. A significant increase in the T-S load was observed with increasing weld time. With increasing welding time 5 cycles to 30 cycles T-S load increasing 2.25 KN to 3.98 KN.

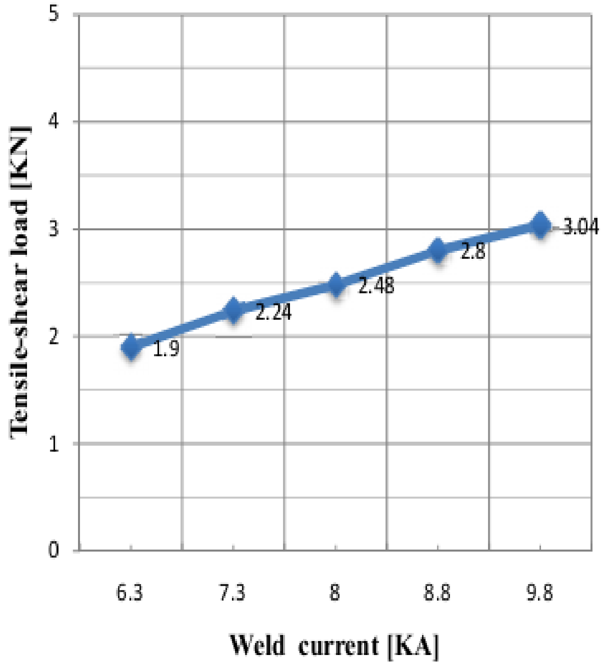

Fig. 3 Effect of welding current on Tensile-shear load

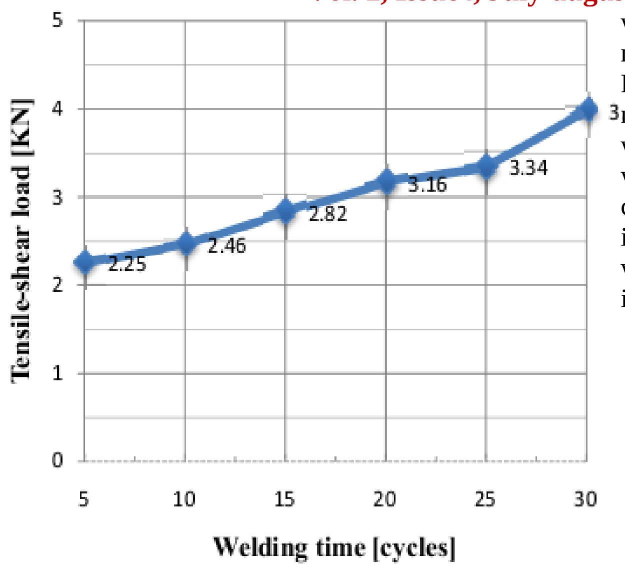

Fig. 4 Effect of welding time on Tensile-shear load

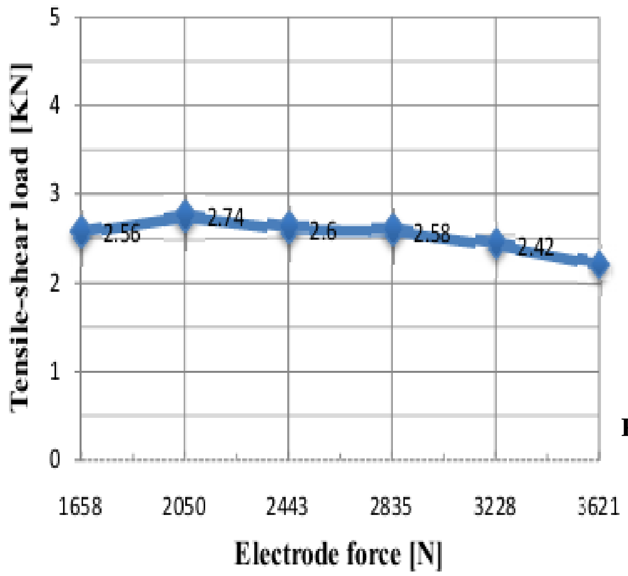

Fig. 5 Effect of electrode force on Tensile-shear load

The effect of the electrode force on the T-S load is shown in Fig. 5 for set-3. A minor decrease in the T-S load was observed with increasing electrode force. At 2050 electrode force maximum tensile shear load value achieved after this it is decreased. With increasing electrode force 1658 N to 3621 N T-S load decreasing 2.56 KN to 2.20 KN. The reason behind is increasing electrode force value increase contact resistance due to that decreasing electric resistance and also heat input.

B. Nugget diameter

The effect of the variation of weld current on nugget diameter is shown in Fig. 6 for set-1. The nugget diameter increases continuously with weld current up to the maximum intensity that we have tested. Initially 6.3 KA to 7.3 KA nugget diameters increased rapidly after minor effect observed. Such kind of behavior can be attributed to the increase in heat input with increasing current and it agrees well with results observed by other authors in welds in magnesium alloy [3].

Fig.7 shows the effect of welding time effect on the nugget diameter of the joints welded under the welding conditions of set-2. This demonstrates that welding time has similar effect as studied in welding current effect. The nugget diameter of the joint increase with increasing the welding time increase with increasing the welding time increase with increasing the welding time.

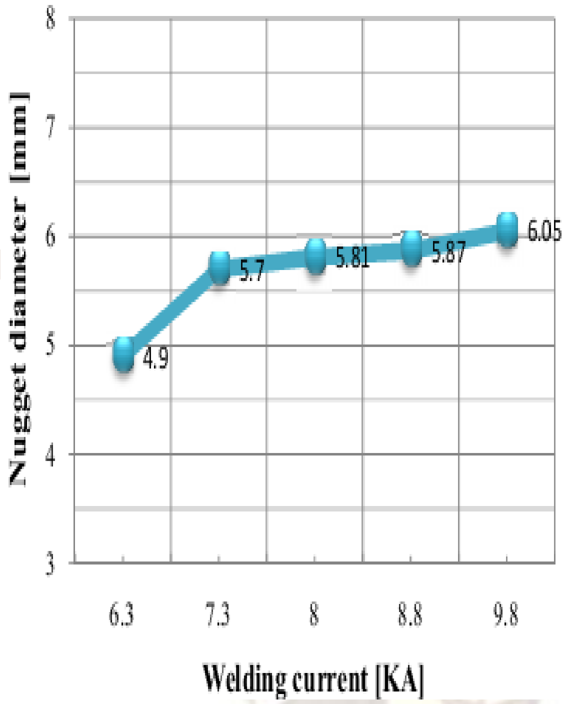

Fig. 6 Effect of welding current on nugget diameter

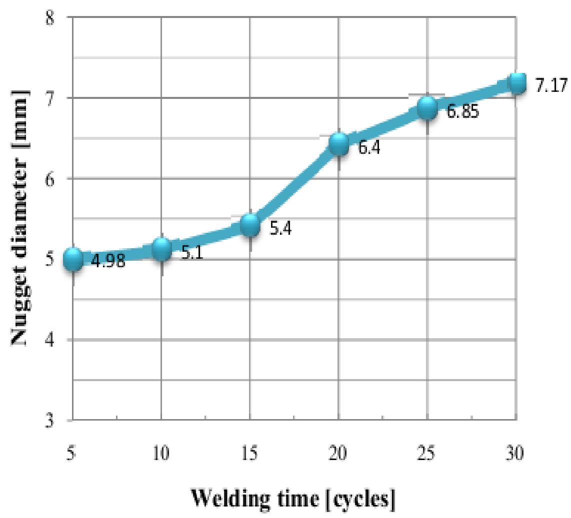

Fig.7 Effect of welding time on nugget diameter

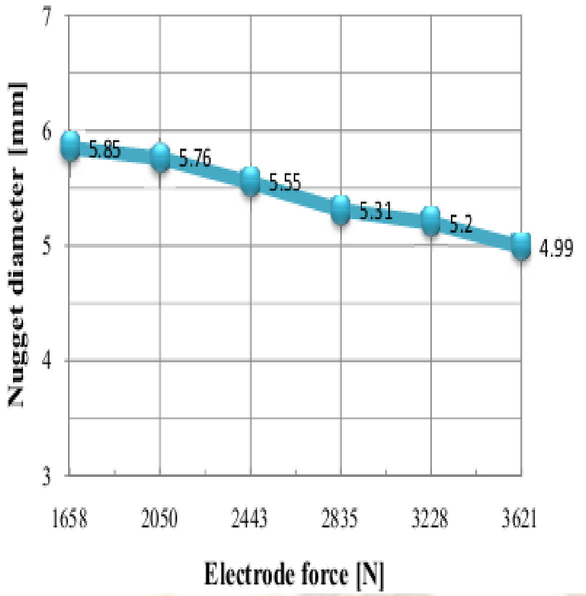

Fig. 8 Effect of electrode force on nugget diameter

Fig.8 illustrates the effect of electrode force on nugget diameter in the welds for set-3. Minimum electrode force value nugget diameter is 5.85 mm. With increasing electrode force value the nugget diameter reduced. The increase in the electrode force value can significantly improve the contact between the faying surfaces. It also decreasing electrical resistance and heat input so that this may be reason for the nugget diameter decrease with increasing the electrode force.

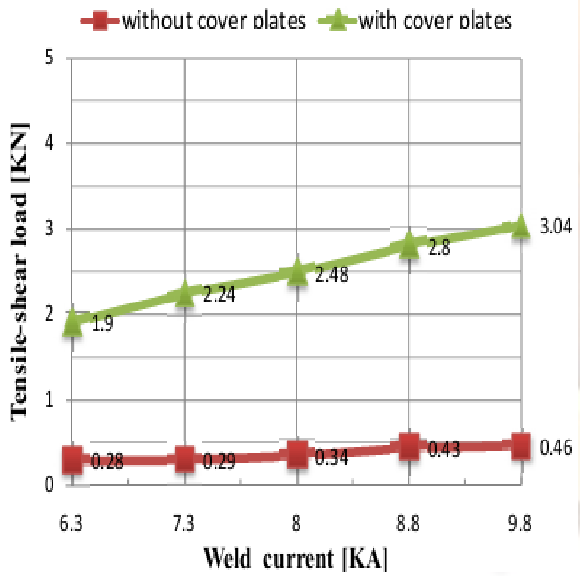

Fig. 9 welding current effect on tensile-shear load

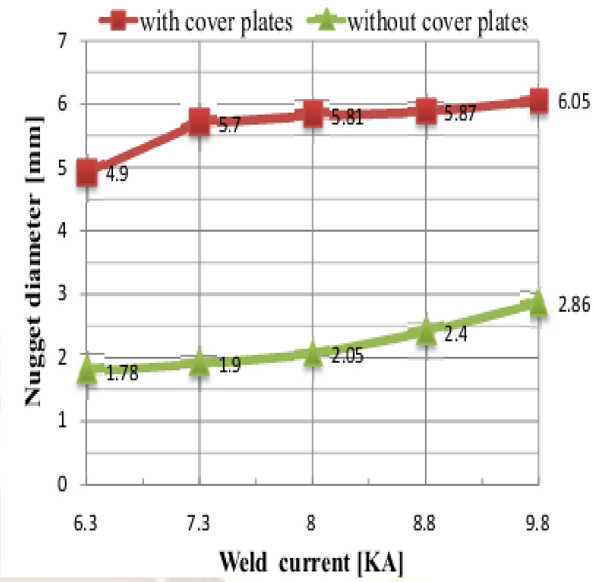

Fig. 10 welding current effect on nugget diameter

Generally, welding current has effects on the tensile shear load and nugget diameter of joint. Fig.9 and Fig.10 shows the effect of welding current on the tensile shear load and nugget diameter of the joints welded under the welding conditions of sets 1 and 4. In the case of RSW with cover plates, the nugget diameter and tensile shear load of the joints increased with the increasing of the welding current. The maximum tensile shear load of 3.04 KN and the nugget of 6.05 mm in diameter was obtained at the welding current of 9.8 kA. While without cover plates tensile shear load 0.46 KN and nugget diameter 2.86 mm at the welding current of 9.8 KA.

C. Hardness

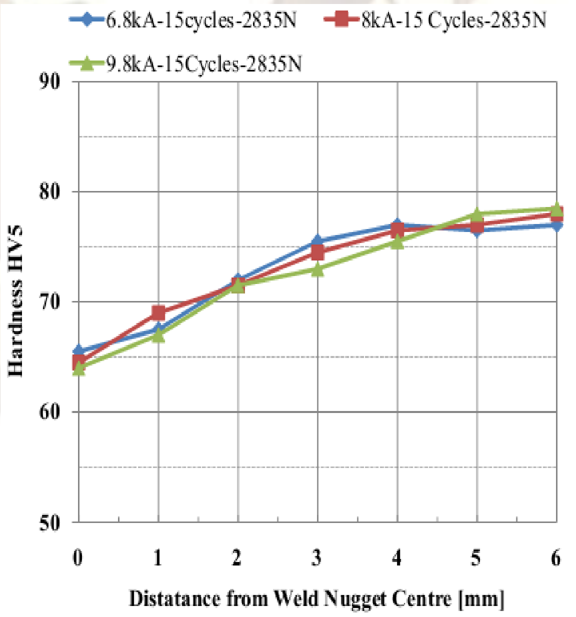

Fig. 11 Hardness values of spot welded specimen at different welding current condition

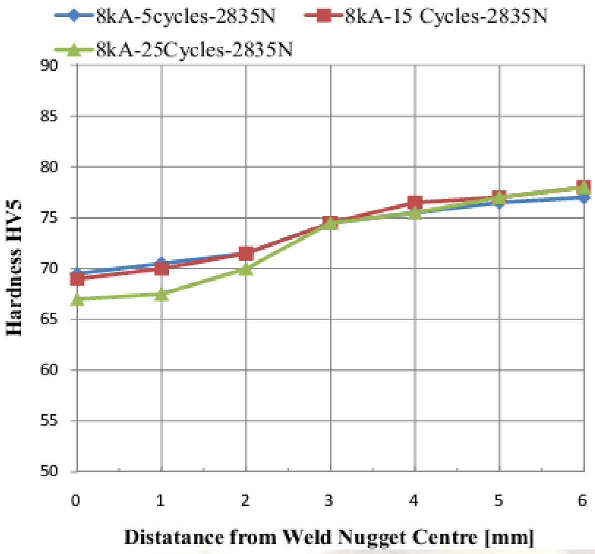

Fig. 12 Hardness values of spot welded specimen at different weld time condition

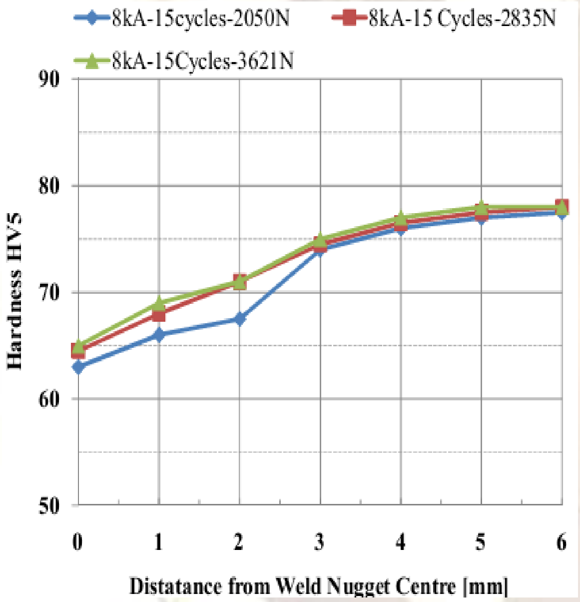

Fig. 13 Hardness values of a spot welded specimen at different electrode force condition

Fig. 11 shows the effect of welding current on the hardness of the spot welded joints for set-5, illustrating that an increase in the welding current the joints are stronger leads to a reduction in the hardness value. The reason behind may be the increase in the amount of heat developed. Increasing weld current value from 6.8 to 9.8 in the nugget area hardness values minor decreased. After 3 mm away from the weld nugget centre hardness value almost constant. The loss of alloying elements from the weld pool that may result in a reduction in strength [7].

The effect of welding time on the hardness of the spot welded joints for set-6, see Fig. 12. The figure indicates that increasing the welding time stronger joints achieved leads to a reduction in the hardness. This reason behind is to the increase in the amount of heat developed. This heat anneals and removes the residual stresses from the spot welded joints and consequently reduces the hardness. After 3 mm away from the weld nugget centre hardness value nearest same due to away from weld nugget no more effect observed.

The effect of the electrode force on the distribution of hardness in the welds is illustrated in Fig. 13 in transverse direction of the spot welded joints for set-7.The figure shows that an increase in the electrode force the joints found as weaker that leads to an increase in the hardness. Up to nugget diameter and heat affected zone hardness values slightly varies. This may be attributed to the reduction in the amount of heat developed, due to the reduction in the sheet resistance associated with the increase in electrode force.

D. Failure mode

Fig.15 shows the relationship between the weld nugget diameter and the tensile shear load, from the results of the tensile shear tests. Fig.14 shows two different types of failure modes observed. An approximately linear relationship was observed between nugget diameter and tensile shear load.

The interfacial failure mode occurs for nugget diameters up to 5.81mm while above this value nugget pullout failure mode was observed. Currently, in order to guarantee the reliability of the welds, the welding parameters should be adjusted so that pullout failure mode is obtained during testing. The result revealed that the tensile shear load increased with the increasing of the nugget diameter.

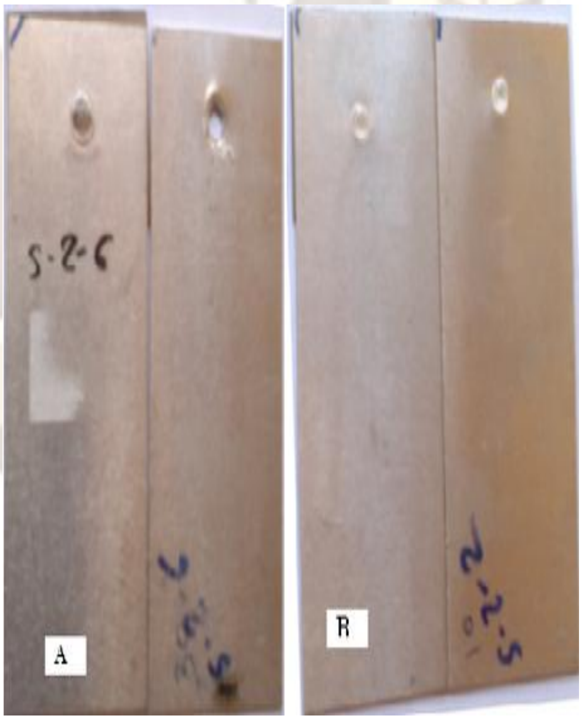

Fig. 14 RSW failure modes: (A) Pull out mode and (B) Interfacial mode

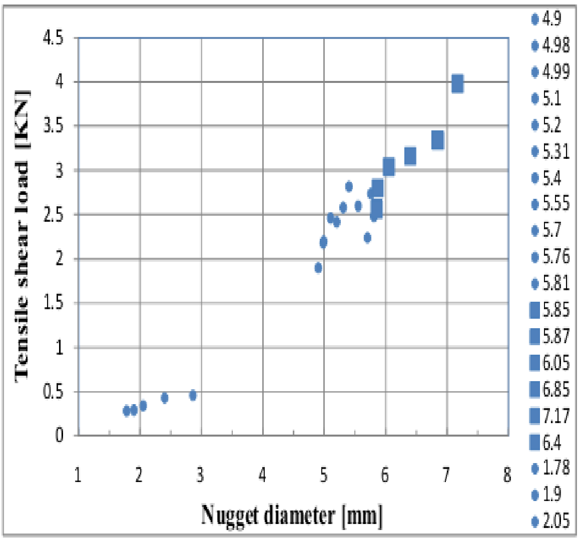

Fig. 15 Relationship between weld nugget size and tensile shear load (for pull out failure and for interfacial failure mode)

V. Conclusion

It is feasible to weld aluminium alloy sheet via a RSW method using cover plates. The joint with larger nugget diameter and higher tensile shear load was obtained under relatively low welding condition.

With increasing welding current and time a significant increase in tensile shear load was observed, due to augmentation of the nugget diameter. Beyond critical nugget diameter the failure mode changes from interfacial failure mode to pullout mode.

Process parameters have minor effect on the hardness value. The increase in the weld current and time minor decrease in hardness value in nugget while increasing electrode force minor increase in hardness in the nugget and heat affected zones of the welds.

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The interfacial failure mode observed up to nugget diameter 5.81 mm and above this value pullout failure mode observed. Use of cover plates for resistance spot welding of A5052 sheets is feasible.

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