INDEPENDENT JOURNAL OF MANAGEMENT & PRODUCTION (IJM&P)
http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

JOINING OF DISSIMILAR ALLOY SHEETS (AL 6063&AISI 304) DURING RESISTANCE SPOT WELDING PROCESS: A FEASIBILITY STUDY FOR AUTOMOTIVE INDUSTRY

Reddy Sreenivasulu
Department of Mechanical Engineering
R.V.R. & J.C.College of Engineering (Autonomous)
Chowdavaram, Guntur, AndhraPradesh, India
E-mail: rslu1431@gmail.com

Submission: 10/05/2014
Revision: 24/05/2014
Accept: 25/05/2014

ABSTRACT

Present design trends in automotive manufacture have shifted emphasis to alternative lightweight materials in order to achieve higher fuel efficiency and to bring down vehicle emission. Although some other joining techniques are more and more being used, spot welding still remains the primary joining method in automobile manufacturing so far. Based on the literature survey performed, venture into this work was amply motivated by the fact that a little research work has been conducted to joining of dissimilar materials like nonferrous to ferrous. Most of the research works concentrated on joining of different materials like steel to steel or aluminium alloy to aluminium alloy by resistance spot welding. In this work, an experimental study on the resistance spot weldability of aluminium alloy (Al 6063) and austenitic stainless steel (AISI304) sheets are lap joined by using a pedestal type resistance spot welding machine. The weld nugget diameter, force estimation under lap shear test and T – peel test were investigated using digital type tensometer attached with capacitive displacement transducer (MIKROTECH; BANGALORE; Model: METM2000ER1). The results shows that joining of Al 6063 and AISI 304 thin sheets by RSW method is feasible for automotive structural joints where the loads are below 1000N act on them, it is also observed that by increasing the

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

spots per unit length, then the joint with standing strength to oppose failure is also increased linearly in case of interfacial failure mode and nonlinear for pullout failure mode.

Keywords: Dissimilar alloys, Resistance Spot Welding, Failure mode, Al 6063 alloy sheet, AISI 304 sheet.

1. INTRODUCTION

Materials for motor vehicle applications are required to maintain the integrity of the structure (i.e. to be sufficiently robust to withstand their service environment) and to be inert (i.e. corrosion resistant). Stainless steels are used in motor vehicle applications because they are resistant to corrosion and high temperature oxidation, offer energy absorption properties and maintain their mechanical properties over a wide temperature range (ETAL, 2012).

During recent years, the use of joints between dissimilar materials has considerably increased. Conventional structures made of steel have been replaced by lighter materials, capable of providing high mechanical strength, lower volume of material and good corrosion resistance. In the developing of new technologies for the aerospace industry, these junctions are of great importance, because they allow the systems, subsystems and components manufactured in stainless steel and aluminum alloy to be structurally united.

The difficulties in the welding of aluminum alloy with stainless steel by fusion welding processes have been a great challenge for engineering, because they result from hard and brittle intermetallic phases that are formed between aluminum and steel at elevated temperatures (KHAN; KUNTZ; ZHOU, 2008).

Spot welds made by resistance welding are the primary method of joining in automobile industry, quality of resistance spot welds is one of the major concerns. In resistance spot welding overlapping sheets of metal are joined by applying electric current and pressure in the zone to weld with copper electrodes, as illustrated in Figure1, copper is used for electrodes because it has low electrical resistance and high thermal conductivity.

Spot welding operation is composed of three steps that are the squeezing, welding and holding stages. Squeezing consists of applying the weld force to the

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

work-pieces in order to obtain the appropriate amount of pressure, prior to welding. During welding, the electric current passes through the work-pieces, while the welding force is maintained, generating heat (SHAMSUL; HISYAM, 2007).

In the course of the holding stage current is switched off and weld force maintained, allowing the weld to forge and cool under pressure. Although some other joining techniques are more and more being used, spot welding still remains the primary joining method in automobile manufacturing so far.

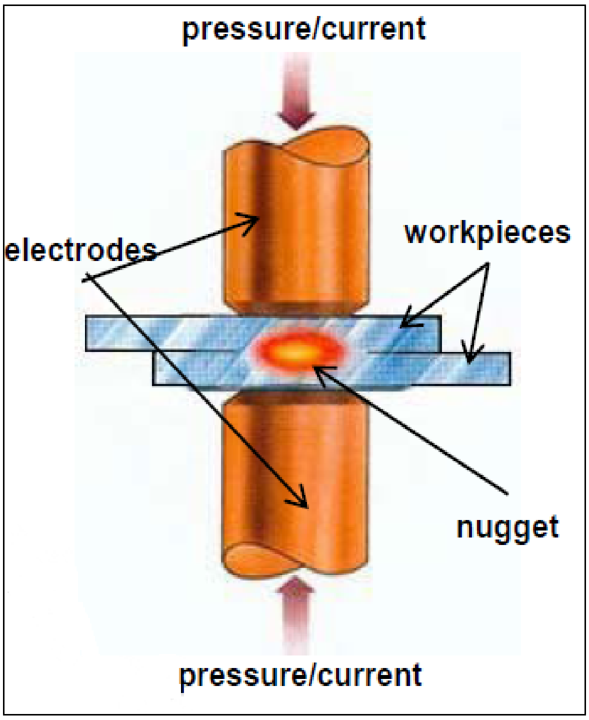


Figure 1: Principle of Resistance Spot Welding
Source: Shamsul and Hisyam (2007)

1.1. Relation between Welding Current and Time

Heat developed during welding is proportional to time and to square of current. Though both parameters are responsible for heat generation, the weld heating rate is determined only by current, because heat lost to the work-piece and to copper electrodes increases with weld time.

Heat lost to the work-piece increases heat affected zone and thermal distortion, while heat in the electrodes can degrade them, all being undesirable effects. The level of current required for any metal tends to be inversely proportional to its electrical and thermal resistivity’s (POURANVARI, et al., 2008).

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

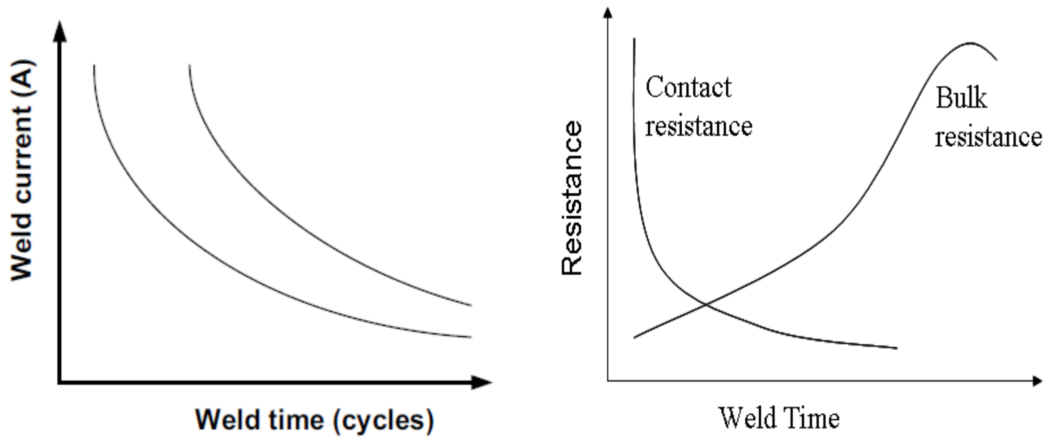


Figure 2: Schematic representation of current-time relationship and change in resistance during RSW
Source: Pouranvari, et al. (2008)

1.2. Failure Modes in RSW

There are two types of failure modes possible in resistance spot welds while doing static tensile-shear test. They are NUGGET PULLOUT and INTERFACIAL FRACTURE. When the welding current is varied failure mode changes. During tensile-shear test, the shear stress at the sheet/sheet interface is the driving force for the interfacial mode, and the tensile stress at the nugget circumference is the driving force for the pullout failure mode (MAJID, 2011).

Each driving force has a critical value and the failure occurs in a mode when its driving force reaches its critical value, sooner. The Fusion zone size is the governing parameter determining stress distribution. For small weld nuggets, the shear stress reaches its critical value before the tensile stress causes necking; thus, failure tends to occur under interfacial mode. Therefore, there is a critical weld Fusion Zone size beyond which, the pullout failure mode is expected (KAH; MARTIKAINEN, 2012).

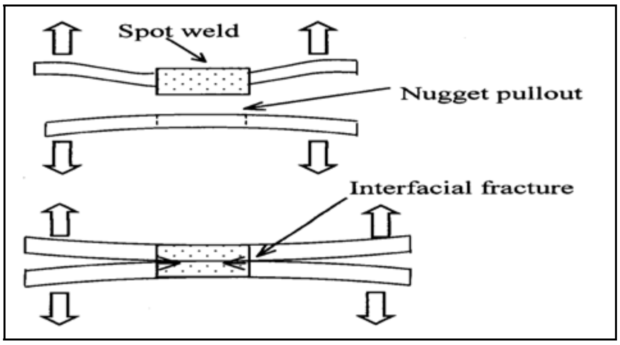


Figure 3: Types of Failure modes in RSW
Source: KAH and MARTIKAINEN (2012)

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

Spot welds for automotive applications should have a sufficiently large diameter, so we require nugget pullout failure mode. Interfacial mode is unacceptable due to its low load carrying and energy absorption capability. Interfacial Failure (or nugget fracture) of the weld nugget through the plane of the weld- the dominant failure mode for small diameter spot welds. When the load is increased, localized necking occurs.

2. LITERATURE STUDY

Car designers today seek materials with the very best stiffness, mass reduction, and safety performance. The competition between different materials for structural applications in cars is intense. Choice centers on mass saving, formability, weldability, corrosion resistance, fatigue resistance, cost, and environmental factors. Safety and crashworthiness, especially, should take priority.

Austenitic stainless steels are preferred materials for structural frameworks and body paneling of buses and coaches. Experience gained in these contexts can be readily transferred to the automotive sector. Stainless steel is an excellent candidate for car body structural applications. Besides offering weight savings, enhanced crashworthiness, and corrosion resistance, it can also be recycled (HAYAT, 2011).

The material blends tough mechanical and fire-resistant properties with excellent manufacturability. Under impact, high-strength stainless steel offers excellent energy absorption in relation to strain rate. It is ideal for the revolutionary “space frame” car body-structure concept. Weldability of a material is one of the key factors governing its application in the auto industry. Resistance spot welding is widely used to join sheet metals in the automotive industry.

The quality and performance of the spot welds significantly affect the durability and safety design of the vehicles. Therefore, the failure characteristics of spot welds are very important parameters for the automotive industry. Failure mode of resistance spot welds (RSWs) is a qualitative measure of mechanical properties. Demands for improved productivity, efficiency, and quality pose challenges to the welding industry.

As materials become ever more sophisticated in their chemical composition to provide ever-better functionally specific properties, a more complete and precise understanding of how such materials can be joined for optimal effectiveness and

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

efficiency will become essential. Traditional options for welding will surely evolve, sometimes to provide unimagined capabilities. In addition, totally new methods will almost certainly emerge as evolution of materials gives way to revolution to meet unimagined new designs and design demands. Kah and Martikainen (2012) discussed some of the role and future direction of welding technology, welding materials, productivity and efficiency, education and safety having an impact on future growth in welding technology.

Analysis of drivers and the key needs of some manufacturing industries have been researched, giving general trends and strong indications as to expected trends in technology that will be seen in the future. It also provides a good foundation for future research and creates awareness of the developmental direction of welding processes and materials in manufacturing industries (SCHUBERTH, et al., 2008).

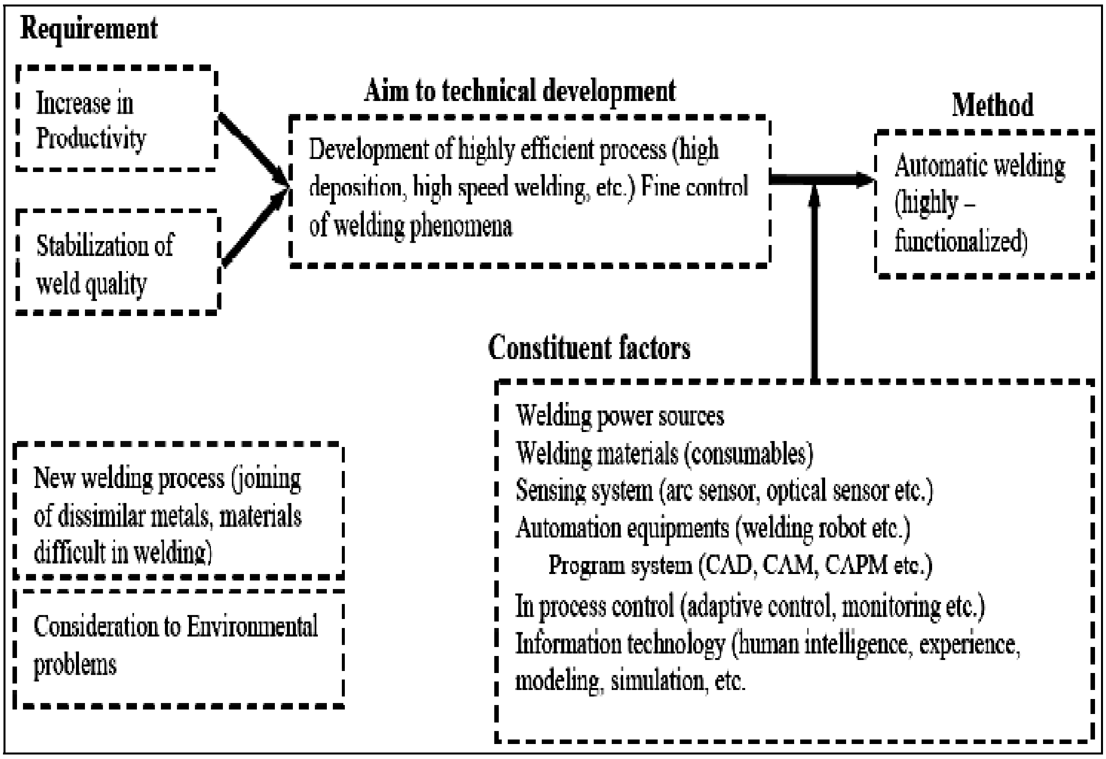


Figure 4: Requirements for welding production technology permitting its integration to automatization

Source: Schuberth, et al. (2008)

Failure mode of AISI304 resistance spot welds is studied by Majid Pouranvari etal under quasi-static tensile-shear test. Their results showed that the conventional weld size recommendation of 4t0.5 is not sufficient to guarantee pullout failure mode for AISI304 steel RSWs during tensile-shear test. Shamsul and Hisyam (2007) studied on austenitic stainless steel types 304 were welded by resistance spot welding.

The relationship of nugget diameter and welding current was investigated. Hardness distribution along welding zone was also investigated. The results indicated that increasing welding current gave large nugget diameter. The welding current did not much affect the hardness distribution. Hayat (2011) studied on resistance spot weldability of 180 grade bake hardening steel (BH180), 7123 grade interstitial free steel (IF7123) and 304 grade austenitic stainless steel (AISI304L) with each other was investigated. it was determined that with increasing weld time, tensile shear load bearing capacity (TLBC) increased with weld time up to 25 cycle and two types of tearing occurred.

It was also determined that while the failure occurred from IF side at the BH180+IF7123 joint, it occurred from the BH180 side at the BH180+AISI304L joint. R.K Rajkumar, Fatin Hamimi etal discussed in their paper about spot welding of dissimilar materials. A good weld from spot welding mechanism is what most of the manufacturers preferred and desired for mechanical assemblies in their systems.

The robustness is mainly relies on the joining mechanism of mechanical parts; especially when combining two different materials and therefore this paper analyzes the spot weld growth on 302 austenitic stainless steel and low carbon steel of 1mm of thickness. Ladislav Kolarik etal presented an analysis of the properties of resistance spot welds between low carbon steel and austenitic CrNi stainless steel. The thickness of the welded dissimilar materials was 2 mm (HAYAT, 2011).

A DeltaSpot welding gun with a process tape was used for welding the dissimilar steels. Resistance spot welds were produced with various welding parameters (welding currents ranging from 7 to 8 kA). Light microscopy, micro hardness measurements across the welded joints, and EDX analysis were used to evaluate the quality of the resistance spot welds. The results confirm the applicability of DeltaSpot welding for this combination of materials.

3. EXPERIMENTAL SET UP

An austenitic stainless steel (AISI304) and Al 6063 sheet of 1.2 mm thick was used as the materials (samples size as per **ANSI/AWS/SAE/D8.9-97** standards are shown in Figure 8). Resistance spot welding was performed using a pedestal type

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

resistance spot welding machine. Welding was conducted using a 45-deg truncated cone electrode with 10-mm face diameter.

Welding current was varied from 5 kA to 10 kA and welding time, electrode pressure and holding time were fixed at 10 cycles, 2 bar and 30 cycles, respectively. The tensile-shear tests were performed at a cross head of 2 mm/min with a tensometer. The Failure mode was determined from the failed samples.

Figure 5: Resistance Spot Welding Equipment (pedestal type) & Specimens during resistance spot welding for lap and T-joints

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

Figure 6: Digital Tensometer attached with capacitive type displacement transducer (Mikrotech, Bangalore, model: METM2000ER1)

Figure 7: failure mode of lap shear test specimen & failure mode of T-peel test specimen

Table 1: Typical chemical composition and physical properties for aluminium alloy 6063

Element	% Present
Si	0.2 to 0.6
Fe	0.0 to 0.35
Cu	0.0 to 0.1
Mn	0.0 to 0.1
Mg	0.45 to 0.9
Zn	0.0 to 0.1
Ti	0.0 to 0.1
Cr	0.1 max
Al	Balance

Property	Value
Density	2700 kg/m^3
Melting Point	600°C
Modulus of Elasticity	69.5 GPa
Electrical Resistivity	$0.035x10^{-6}$ Ù.m
Thermal Conductivity	200 W/m.K
Thermal Expansion	23.5 x 10^{-6} /K

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

Table 2: Typical chemical composition and physical properties for Austenitic Stainless Steel (AISI304)

Component	Wt. %
C	Max 0.08
Cr	18 - 20
Fe	66.345 - 74
Mn	Max 2
Ni	8 - 10.5
P	Max 0.045
S	Max 0.03
Si	Max 1

Mechanical Properties	
Hardness, Brinell	123
Hardness, Rockwell B	70
Hardness, Vickers	129
Tensile Strength, Ultimate	505 MPa
Tensile Strength, Yield	215 MPa
Elongation at Break	70 %
Modulus of Elasticity	193 - 200 GPa
Poisson's Ratio	0.29
Charpy Impact	325 J
Shear Modulus	86 GPa

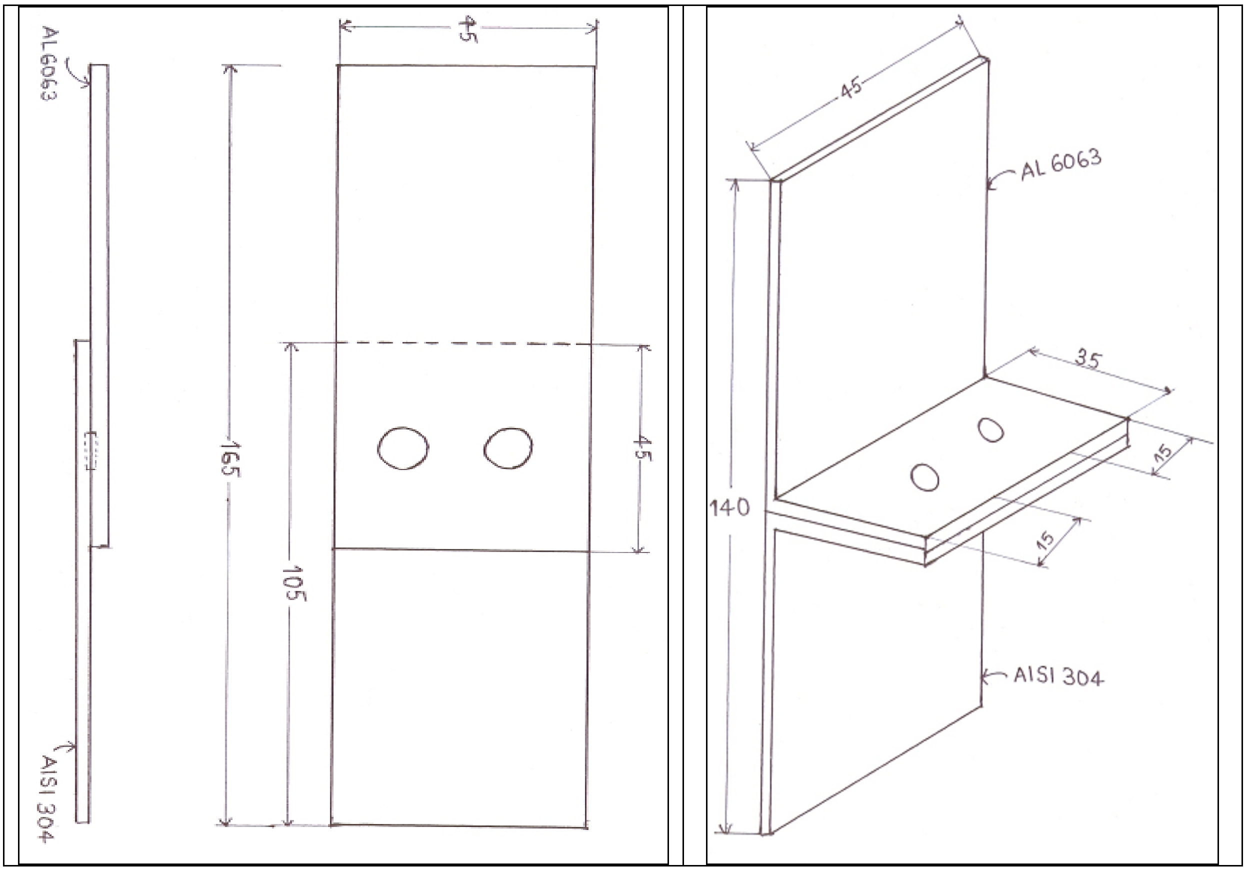


Figure 8: Samples geometry and dimensions: (a) Lap shear, (b) T-peel

3.1. Lap shear Test

In the **lap-shear** geometry, a shear load is applied. The weld nugget rotates to align with the loading line. When the load is increased, localized necking occurs (see Figure 9 below). Fracture initiates at one of the localized necking points, when the

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

ductility of the sheet metal is reached (see Figure 18, below). Although a shear load is applied, the failure mechanism is tensile.

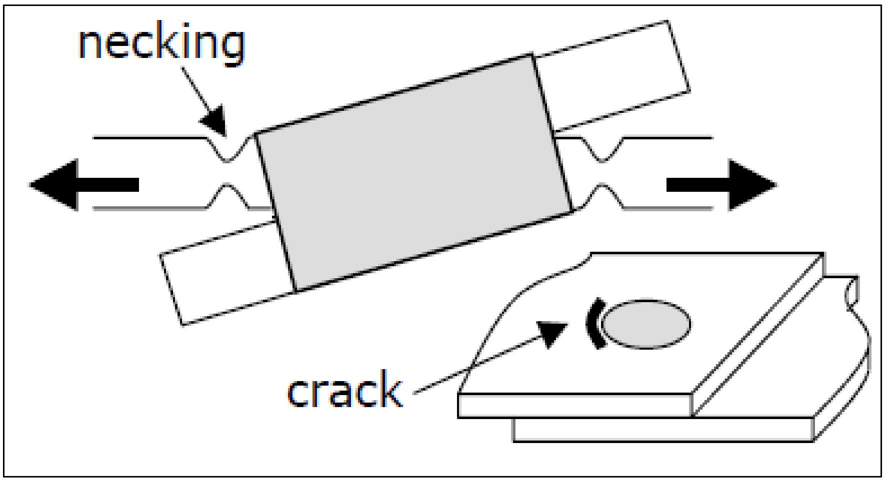


Figure 9: Failure mechanism for lap-shear sample

Observation during tensile test of lap shear samples reveals the failure process as schematically demonstrated in Figure 7. As the sample is pulled initially, the weld nugget experiences a rotation, which essentially aligns the nugget with the loading line.

In first stage the material surrounding the nugget is subjected to a predominantly tensile load and the deformation near the nugget is similar to a rigid button embedded in a ductile sheet. As the load increases, localized necking of the sheet metal occurs at the two apices, at locations near the juncture of the nugget and the base metal.

Note that these two points are on the two different pieces of the coupons. Fracture then initiates at one of these two points, when the ductility of the sheet material is reached. Eventually pullout failure of the weld occurs as the initial crack grows around the circumference of the weld nugget.

3.2. T- Peel Test

The peel test is a simple test for measuring the nugget size. When welding samples, the second weld nugget (B) should be marked as shown in Figure 10. In the peel test, the sheets are first separated on one end of a lap joint, and the roller rolls up one sheet while the other is gripped. As the roller rolls over the weld, half of the workpiece is torn off at the weld and a weld (A) button is left.

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

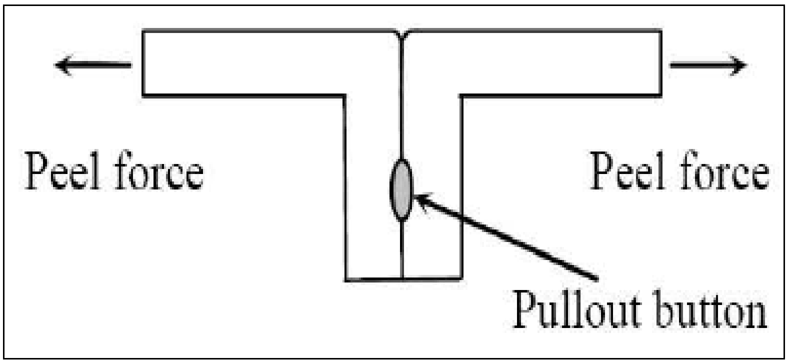


Figure.10 Peel test for measuring nugget diameter

With continued peeling, the whole workpiece is torn off and another weld (B) button is left. The nugget size can be estimated and recorded as a parameter for welding quality by measuring the diameter of pullout button (B). If the button shape is irregular, the button diameter is determined by taking an average of the maximum and minimum dimensions. Manually measured the nugget diameter for each of the pullout buttons (B) for each welding sample, and an enlarged view shown in Figure 11 is taken for each to be able to measure the diameter for each nugget.

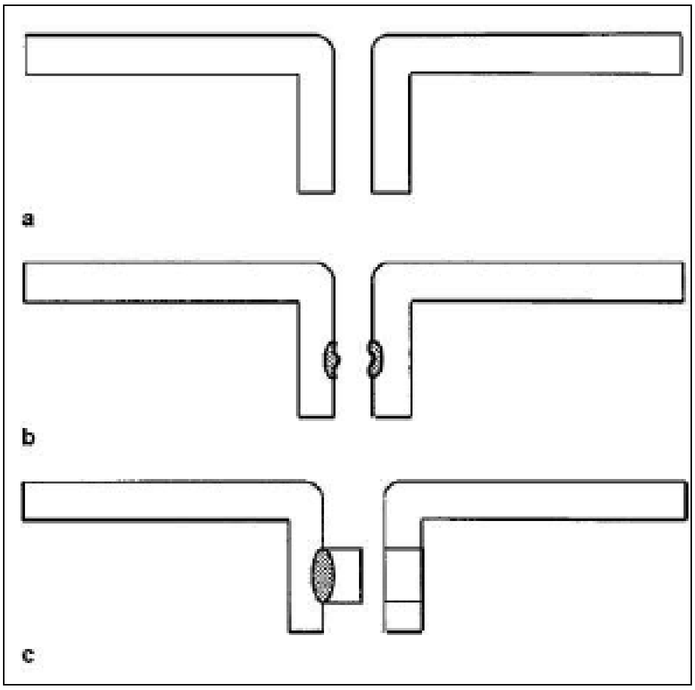


Figure.11 Schematic showing joint failure modes during peel test

Interface failure is due to lack of bonding or only weak bonding between sheets. Once a weld nugget formed, joints generally failed through the nugget when the nugget diameter is small or by a button pullout when it is above a certain size, which is called weld failure or button pullout. The failure modes usually serve as a rough indicator of whether a specimen size is adequate or not.

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

4. EXPERIMENTAL OBSERVATIONS

4.1. Tensile- Shear Test:

Table 3: Observations measured under lap tensile shear test on Tensometer up to failure

Sample 1		**Sample 2**		**Sample 3**	
welding time=30s		**welding time=35s**		**welding time=40s**	
Load(Kg)	Elongation(mm)	Load(Kg)	Elongation(mm)	Load(Kg	Elongation(mm)
0	0	0	0	0	0
32	0.1	20	0.1	20	0.1
46	0.2	32	0.2	32	0.2
67	0.3	41	0.3	45	0.3
82	0.4	64	0.4	-----	-----
98	0.5	75	0.5	-----	-----
-----	----	78	0.6	-----	-----

4.2. T-Peel Test:

Table 4: Observations measured under T-peel test on Tensometer up to failure

Sample 1		**Sample 2**		**Sample 3**	
welding time=30s		**welding time=35s**		**welding time=40s**	
Load(Kg)	Elongation(mm)	Load(Kg)	Elongation(mm)	Load(Kg)	Elongation(mm)
0	0	0	0	0	0
1	0.1	2	0.1	3	0.1
3	0.2	4	0.3	4	0. 4
4	0.4	5	0.6	5	0.7
5	0.7	6	0.8	6	0.9
6	1.3	7	1.2	7	1.5
7	1.8	8	1.6	8	1.8
8	2.2	9	1.9	9	2.2
9	3.2	10	2.4	10	2.8
10	3.8	11	2.7	11	3.6
11	4.5	12	3.2	12	4.9
12	5.6	13	4.5	13	5.6
-----	6.2	14	5.6	14	6.6
-----	-----	15	6.8	14	7.5
-----	-----	------	7.9	14	10
-----	-----	------	------	15	10.6
------	-----	------	------	16	11.9
------	-----	------	------	17	12.8
------	------	------	------	18	13.9
-----	------	------	-------	19	14.8
-----	------	-------	-------	19	17.2
-----	------	------	-------	---------	18.5

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

4.3. Nugget diameter

Table 5: Nugget diameters (average) measured manually on failed samples under lap tensile shear test on Tensometer

Tensile- Shear Test						
sample	Al 6063			AISI304		
	d_1(mm)	d_2(mm)	$d_{average}$(mm)	d_1(mm)	d_2(mm)	$d_{average}$(mm)
1	4	4	4	4	4	4
2	11	14	12.5	7	7	7
3	8	13	10.5	8	7	7.5
T-Peel Test						
1	7	5	6	5	5	5
2	7	4	5.5	5	5	5
3	4	4	4	4	4	4

5. RESULTS AND DISCUSSION

The results as shown in Table 5 indicate that the nugget diameter varies between 4.0 to 12.5 mm and from table 3, tensile shear force varies between 480 to 980 N by taking welding time 40s, 35s and 30s. It was found that tensile shear force decreased with increase in welding time. The curves are depicted in Figure 12 and in table 4 under T-peel test, tensile shear force varies between 120 to 190 N by taking welding time 30s, 35s and 40s.

It was found that tensile shear force increased with increase in welding time. The curves are depicted Figure 13 clearly shows an increasing trend within the investigation range of both nugget diameter and tensile shear force for an increase in welding time. The nugget diameter is a critical response in determining the quality of the spot weld. Also it was observed that the elongation of Al6063 material is more than AISI304 it is generally due to softness of material in both tests.

The load verses elongations during both tests are depicted in Figure 14 & Figure 15 using tensometer. When there is an increase in nugget diameter, of course increase in cross sectional area, the load carrying capacity also increases leading to increase in tensile shear force.

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

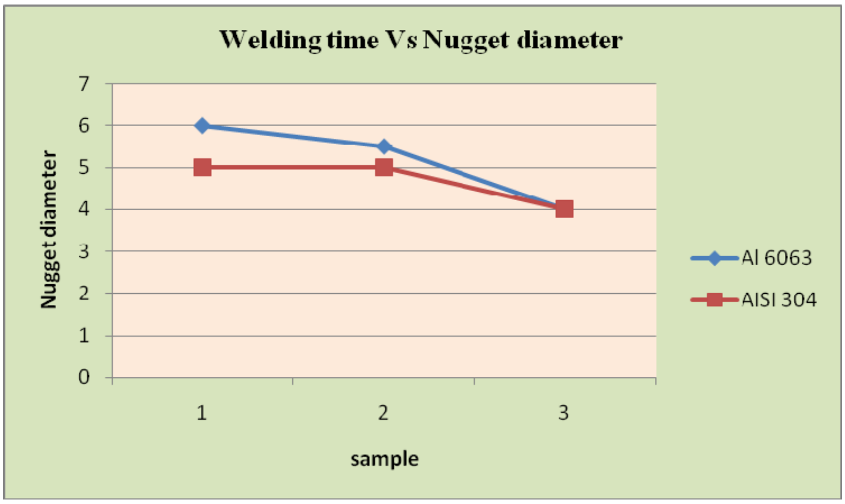


Figure 12: Relation between welding time and nugget diameter in Lap tensile shear test (sample 1-welding time=30s, sample2-welding time=35s, sample3- welding time=40s)

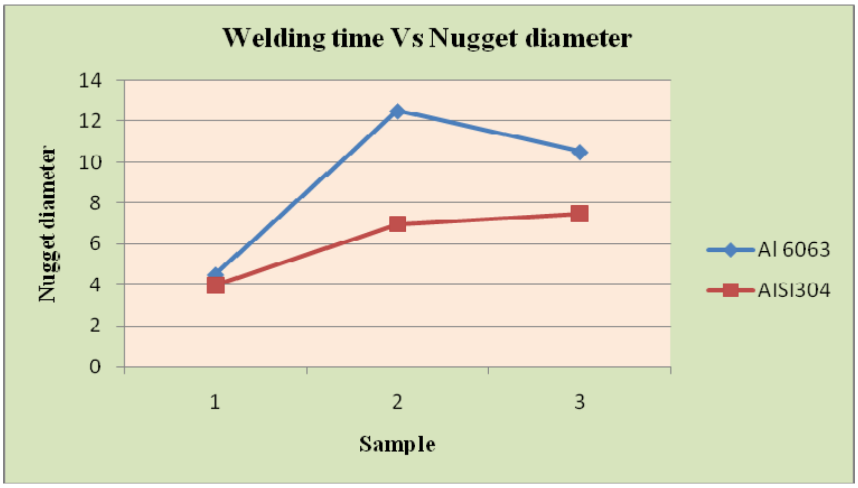
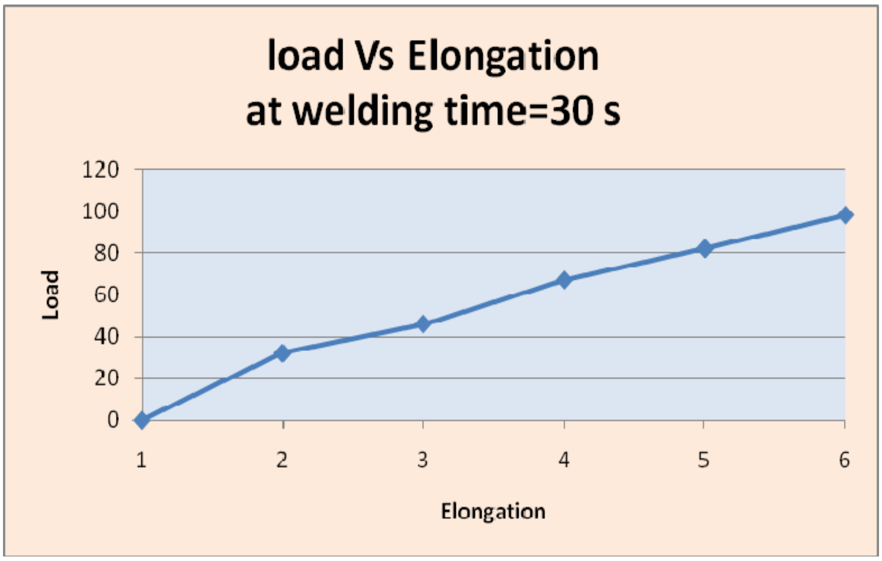


Figure13: Relation between welding time and nugget diameter in T-peel test (sample 1-welding time=30s, sample2-welding time=35s, sample3- welding time=40s)



ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

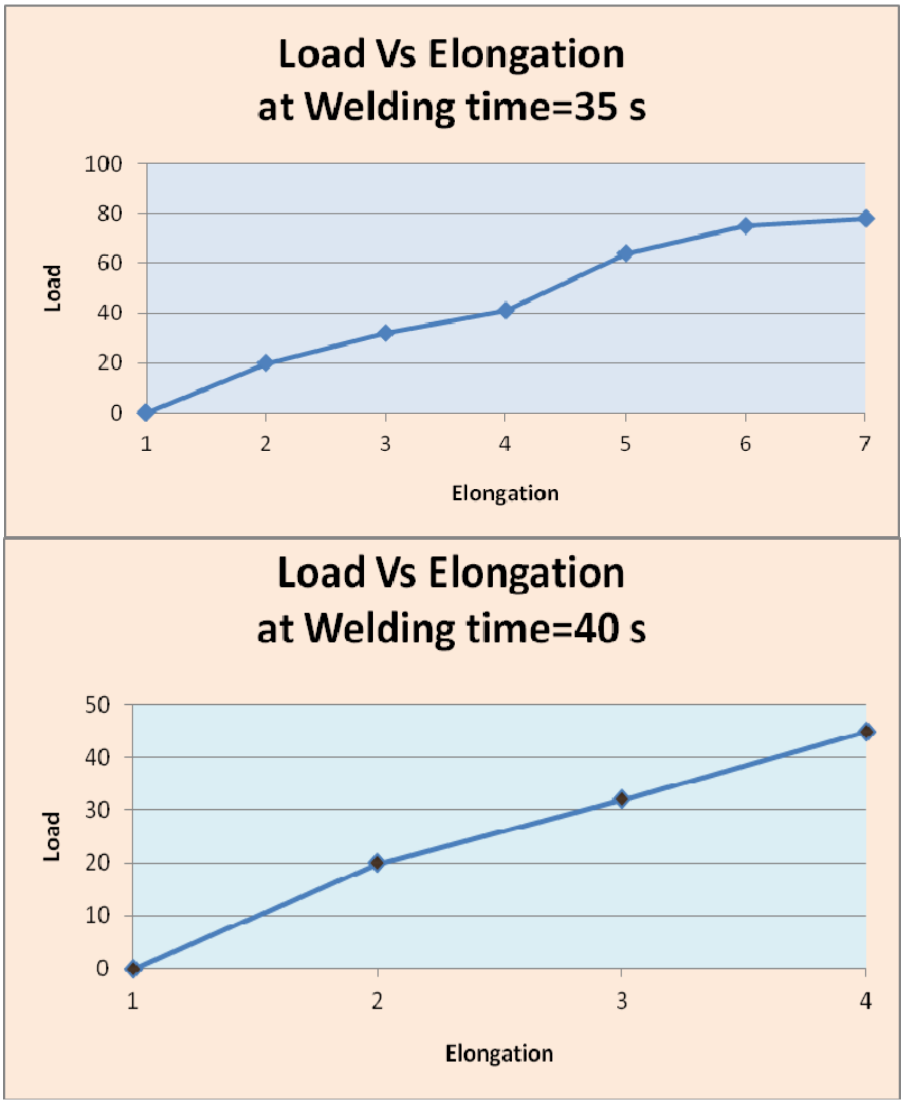
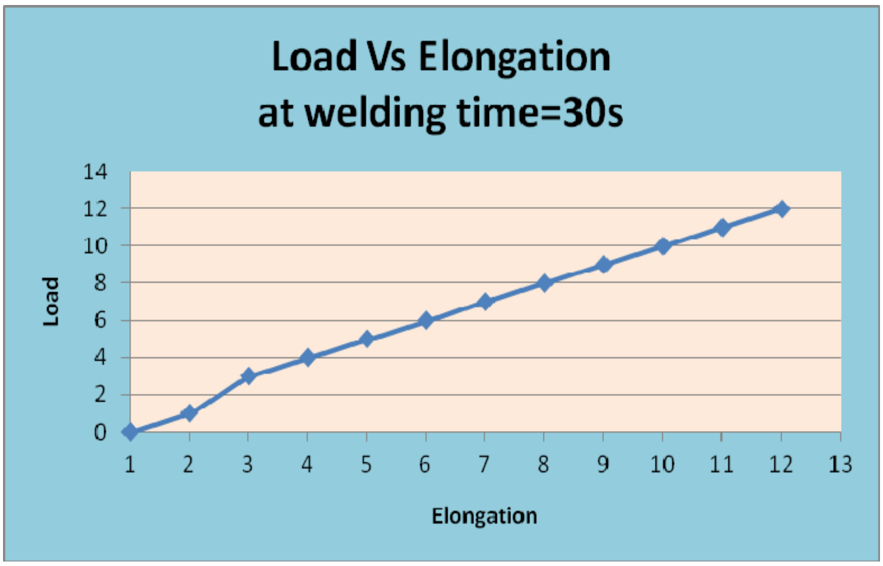


Figure 14 graphs show load vs elongation in lap tensile-shear test



ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

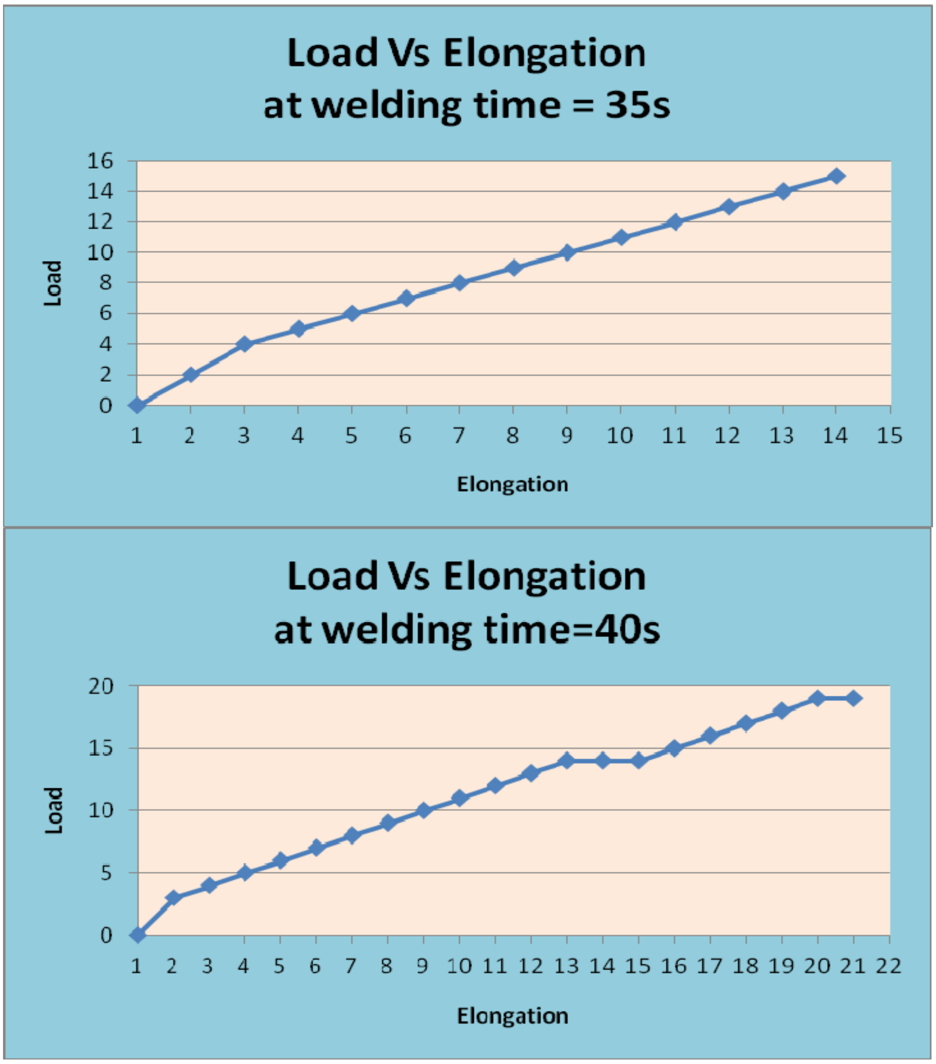


Figure .15 graphs shows load vs elongation in T-Peel test

6. CONCLUSIONS

- With constant welding current and welding time, nugget size and mechanical strength are improved. However, increasing the welding time and the joint strength should be controlled to avoid expulsion in the welding zone especially on Al6063 alloy.
- The highest internal tensile residual stress occurs in the center of the nugget zone and decreases slightly towards the nugget edge. The behavior of the surface residual stress is different, and decreases from center of the weld zone towards the edge of the nugget. However, after this area, the value of the residual stress falls down.
- With increasing the welding time, the residual stress is decreased in the weld zone. However increasing the welding time and the welding current boil down

http://www.ijmp.jor.br v. 5, n. 4, October - December 2014
ISSN: 2236-269X
DOI: 10.14807/ijmp.v5i4.231

to increase input heat to the weld zone, the maximum temperature doesn't change by much, while the size of the weld nugget increases; and thus, the rate of temperature reduction (despite a fixed amount of holding time) decreases and as a result, the maximum residual stress diminishes.

REFERENCES:

ETAL, L. K. (2012), Resistance Spot Welding of dissimilar Steels, **Acta Polytechnica**, v. 52, n. 3, p. 43-47

GOODARZI, M.; MARASHI, S. P. H.; POURANVARI, M. (2009). Dependence of overload performance on weld attributes for resistance spot welded galvanized low carbon steel. **Journal of Materials Processing Technology**, v. 209, n. 9, p. 4379–4384.

HAYAT, F. (2011) Resistance Spot Weldability of Dissimilar Materials: BH180-AISI304L Steels and BH180-IF7123 Steels, **Journal of Material Science Technology**, v. 27, n. 11, p. 1047-1058.

KAH, P.; MARTIKAINEN, J. (2012) Current trends in welding processes and materials: improve in effectiveness, **Rev.Adv.Mater. Sci.**, n. 30, p. 189-200.

KHAN, M. I.; KUNTZ, M. L.; ZHOU, Y (2008) Effects of weld microstructure on static and impact performance of resistance spot welded joints in advanced high strength steels. **Science and Technology of Welding and Joining**, v. 13, n. 1, p. 49–59.

POURANVARI, M. (2011) Prediction of Failure Mode in AISI 304 Resistance spot welds, Association of Metallurgical Engineers of Serbia**, Metalurgija-MJoM**, v. 17, n. 1, p. 23-29.

POURANVARI, M.; ABEDI, A.; MARASHI, P.; GOODARZI, M. (2008) Effect of expulsion on peak load and energy absorption of low carbon resistance spot welds. **Science and Technology of Welding and Joining**, v. 13, n. 1, p. 39–43.

POURANVARI, M.; MARASHI, S. P. H. (2012), Failure Mode Transition in AISI 304 Resistance Spot Welds, **Welding Journal**, v. 91, p. 303-309.

RAJKUMAR, R. K.; HAMIMI, F.; CHARDE, N. (2012) Investigating the Dissimilar Weld Joints of AISI 302 Austenitic Stainless Steel and Low Carbon Steel, **International Journal of Scientific and Research Publications**, v. 2, n. 11.

SHAMSUL, J. B.; HISYAM, M. M. (2007) Study Of Spot Welding Of Austenitic Stainless Steel Type 304, **Journal of Applied Sciences Research**, v. 3, n. 11, p. 1494-1499.

SCHUBERTH, S.; SCHEDIN, E.; FROHLICH TH.; RATTE, E (2008) Next generation vehicle engineering guidelines for stainless steel in automotive applications, **Proceedings** of the 6th STAINLESS STEEL SCIENCE AND MARKET CONFERENCE. Helsinki, Finland. June 10–13.