# STUDY OF HARDNESS IN FRICTION WELDING OF ALUMINIUM ALLOY – A REVIEW PAPER

**[1] R.Hariharan, [2]G.Prabu, [3]R.Praveen Rackson, [4]V.Pravin Kumar, [5]Rubeshwaren**

[1]Assistant Professor, Dept. of Mechanical Engineering, Bharath Institute of Higher Education and Research, Chennai.

[2,3,4,5] UG Student, Dept. of Mechanical Engineering ,Bharath Institute of Higher Education and Research, Chennai.

**ABSTRACT:**

Friction welding method is one of the most simple, economical and highly productive methods in joining of similar and dissimilar metals. Welding is the one of the joining technique to join similar or dissimilar combination of materials with or without application of filler rod. During the friction welding process, heat is generated at the interface of joining the specimen under plastic deformation by converting the rotational energy into heat energy by means of pressure. It is widely used in the automotive, aircraft and aerospace industrial applications. The principal advantage of frictional welding, being a solid-state process, low distortion, absence of melt-related defects and high joint strength, even in those alloys that are that are considered non-weldable by conventional welding techniques.

Keywords: Friction welding, solid-state process,

**INTRODUCTION**:

Friction welding is a type of solid state or simply forge welding, where welding takes place by the application of friction between two mating surfaces of metal along with application of pressure. Required heat can be generated by rubbing two metals on each other and the temperature can be elevated to the level where the parts subjected to the friction may be welded together. Friction Welding is a collection of solid state welding processes, where heat is produced by means of mechanical friction between moving and stationary work pieces with the addition of an upsetting force to displace material plastically. Friction welding was first developed in the Soviet Union, with first experiments taking place in 1956. The American companies Caterpillar, Rockwell International, and American Manufacturing Foundry all developed machines for this process. Patents were also issued throughout Europe and the former Soviet Union. The most extensive historical records are kept with the American Welding Society.

In many areas, the friction welding method more and more often replaces the traditional bonding methods. It is widely applied in industry, first of all thanks to its high performance and possibility of binding similar and dissimilar materials, both steels and non-ferrous metals and their alloys, with no necessity to use additional materials. It is important that, during the process, maximum temperature does not exceed melting points of the bonded materials. In the presented examinations, the method of traditional friction welding was applied. The process consists in bonding two parts, one of them placed in a stationary fixture and the other rotating around their common axis. At least the rotating part should be rotationally symmetrical. The first period of the friction welding process is named the friction period. A clamp brings the parts together until the surfaces get in touch and the friction phenomenon starts. This results in heat generation and as a consequence, in heating the parts to a high temperature close but not exceeding their melting point. So, the process runs in solid state and the weld is created thanks to creep of the softened material and diffusion in the contact area. In the subsequent stage, called the upsetting period, increased pressure is usually applied, called the upsetting pressure . Knowledge of the friction coefficient at a specific temperature for the given friction couple permits more exact calculations with the finite element method of both temperature and deformations in the joint. So far, it was accepted in the research works that the friction coefficient value is constant which can lead to potential calculation errors. However, in a few works carried-out it was proved that the friction coefficient value is variable

## LITERATURE SURVEY:

***An Analytical Study of Dissimilar Materials Joint Using Friction Welding and It's Application:*** Mechanical behavior of the friction welded joint for SS 316 and En-8 is studied by the Taguchi design of experiment and it is observed that the friction processed joint exhibited good strength and joint strength increased with increase in friction pressure and forging pressure at high and moderate levels of rotational speeds and the optimal value of process variables for a higher tensile strength from the Taguchi design is 1580 R.P.M, 28 bar forging pressure and oil quenching. it can be concluded that the joint between the dissimilar materials SS316 and EN-8 can be successfully carried out and the process can be optimized. This enables a pump manufacturing industry to replace 2/3 of expensive material of the shaft with cheaper material EN-8 and thus save huge amounts.

**A research paper on the comparison of weld strength of friction welding of different materials at two different rpm:** According to the two different RPM results were compared according to the data obtained and it clearly shows that the materials which were welded at a higher rpm show higher strength as compared to the materials welded at a lower rpm. Also the result shows that similar materials which were joined together at higher rpm have higher tensile strength as compared to similar material which were joined at a lower rpm. Friction welding was successfully employed to weld similar as well as dissimilar materials. Tensile strength of all the specimens obtained was satisfactory and fusion joint of material were also in good condition.

***Joining the different materials using friction welding:*** Friction Welded Aluminium and Copper Materials: Aluminium alloys are used more due to their superior workability and less expensive cost. For superior strength and good weldability in various structures, it is necessary to join stainless steel and aluminium materials Aluminium and copper are continually replacing steels in electricity supply systems to reduce cost. However, welding of copper and aluminium are usually difficult by conventional fusion welding processes because those have the high thermal diffusivity higher than in many steels alloys. Friction Welded Stainless Steel and Copper Materials: Welding is possible within the limited range of the welding conditions although problems for welding exist because of brittle intermetallic compounds and high thermal conductivity. To minimize the problems, the friction welding parameters must be taken into consideration for strong welds. The maximum strength obtained in the joints is about 75% that of copper parts having the weakest strength. It can be seen that around the interface, the hardness of the copper increases slightly

***Experimental Study of Hardness in Friction Welding of Aluminium Alloy:*** friction welding process is carried out on the aluminum alloy of grade 6061 test specimen and following points are reported. Taguchi Design of Experiment is effectively used in this investigation. Heating Pressure plays major dominating role in the friction welded joint. The optimal process parameters for this experimental investigation is heating pressure of 16 bar, heating time of 3 sec, upset pressure of 24 bar and 5 sec of upset time with constant rotating speed of 1500 rpm. Based on the experimental work, the authors initiated that hardness is considered for the output responses. The authors identified that, during the friction welding process to improve the quality and strength of the welded joint based on the input process parameters. This experimental work is very precious for the researchers to develop the ability of the friction welding on Aluminum Alloy of Grade 6061 specimen is essential for the modern development in the engineering industry.

***Friction Welding to Join Dissimilar Metals:*** austenitic stainless steel **(AISI 304)** and aluminum materials were welded successfully. The welding process was investigated by tensile testing, impact testing, Vickers micro hardness testing, fatigue testing, micro structural observation, and EDS measurements. The results of this study have fundamental importance for the understanding and comprehension of the main characteristics of friction welding process, the bonding mechanisms between dissimilar materials, and the feasibility of applying this process in the production of structural joints that will be used in ship building, light and heavy automotive, electrical, chemical and civil, space and nuclear engineering. these components include concerned the manufacture of hollow aluminum extrusions for deep freezing of fish on fishing boats, explosive cladding of heat exchanger tubes, air bag canisters, axle cases and tubes, drive shafts, drill pipes, tunneling rods, electrical connectors, hydraulic piston rods and cylinders, LNG reactor cooling tanks pump shafts, swivel pins, track rollers, turbo chargers and various agriculture equipments.

***To Review the Friction Welding Joint Brass &Aluminium using Microstructural Behaviour:*** Phases of Friction Welding, The following are the main phases of friction welding. First Friction Phase The purpose of the first friction phase is to burn off any light oils or light oxides at the weld interface. Second Friction Phase. This phase controls the amount of material length loss. Forge Phase: The final phase in friction welding is the forge phase. The spindle is forced to a stop and both components are pressed against each other at extreme pressure and allowed to cool. Friction welding has been successfully employed to weld dissimilar metals. Strength of the joints obtained was good. The confirmation of welded material was observed in the specimen on the side of brass to aluminum due to high friction and high heat at the welding zone. Temperature modelling of friction welded joint has efficiently accomplished.

***Optimization on Friction Welding of Aluminium Alloy 6082 T6 and Austenitic Stainless steel 304:*** Dissimilar welding of Austenitic Stainless steel and Aluminium alloy was studied in this project. Experiments were conducted for various combinations of friction pressure, forging pressure, friction time and forging time. The strength of the joint was analyzed by tensile test. following observations are made from the studies: Response surface method (RSM) can be effectively used to find optimum condition for friction welding of aluminium alloy 6082 T6 and Austenitic Stainless steel 304. The tensile strength for welded joints increased as friction time and forging pressures increased and on further increase, the strength decreased. The tensile strength for welded joints decreased as friction pressure and forging time decreased and on further increase, the strength increased. The Microstructure analysis showed the difference in grain structure which resulted in higher and lower tensile strengths for welded joints.

***Welding of AA1050 aluminum with AISI 304 stainless steel by rotary friction welding process:*** The friction welding process was very efficient in the welding of dissimilar materials such as AA1050 aluminum and AISI 304 stainless steel. It is showed by the results of tension mechanical tests that presented mechanical properties which are not possible to achieve by means of fusion welding processes, values measured in the side of AA1050 aluminum and in the side of AISI 304 stainless steel, near the bonding interface, central region, were higher than in the metal bases. As the measurement points move away from the interface, they decrease until they reach the reference values of micro hardness for each material. The results of this study have fundamental importance for the understanding and comprehension of the main characteristics of friction welding process, the bonding mechanisms between dissimilar materials, and the feasibility of applying this process in the production of structural joints that will be used in aeronautic and aerospace industry.

***Evaluation of Mechanical and Metallurgical properties of dissimilar materials by friction welding:*** This study investigates some factors affecting the joint performance of friction-welded joint of austenitic stainless steel to copper and the various tests were carried out to evaluate the joint performance. Based on the results produced through mechanical and micro-structural analysis, the following conclusions were obtained. Friction welding has been used to successfully join with austenitic stainless steel and copper. The tensile strength values obtained on joints were varied with three different rotational speeds of 500 rpm, 1000 rpm and 2000 rpm. The bond strengths were comparable to parent material of copper. Strength of the joints obtained was good and ductility was reasonable in copper. The welded joint made with the austenitic stainless steel and copper was achieved in nearly all the conditions. The quality and the strength of the bond produced are varied. The use of higher friction pressure with low upset pressure increases the tensile strength of friction-welded joint whereas with lower friction pressure and high upset pressure results decrease in joint of dissimilar material.

***Friction welding of steel to ceramic:*** this literature study show that there are two major points that are important when it comes to welding steel to a ceramic material. The use of an interlayer is necessary to reduce the amount of residual stresses that are induced because of the different thermo mechanical properties of the work piece. Aluminium sheet is a commonly used interlayer. Attention is needed to control the creation of a brittle intermetallic compound layer that grows in the aluminium-steel weld interface in proportion to the friction time.

**Study on Effect of Interlayer in Friction Welding for Dissimilar Steels: SS 304 and AISI 1040:** The research work in this thesis examined the influence of a nickel interlayer on the microstructure and mechanical properties of dissimilar friction welds between **AISI 1040** and SS304 stainless steel materials. The Ultimate tensile strength of welds without using interlayer was directly depend on the forging pressure, that is the maximum strength **636 Mpa** was achieved at highest forging pressure of 1.884 ton. But when nickel interlayer was introduced highest strength of **661 MPa** was achieved at highest burn off length of 8 mm. Micro hardness results showed a decrease in peak hardness at the interface (391 Hv) which was 454 Hv when welded without using interlayer which is due to the reduction in the precipitation of chromium carbide at the interface due to presence of nickel. the microstructure of the weld and EDS spectrum indicated the composition of the weld part at the scan area.

**Friction welding of AA6061 to AISI 4340 using silver interlayer**: A friction welding technique has been developed for joining aluminium**(AA6061)** to low alloy steel (AISI 4340) using an interlayer of silver. Silver as an interlayer partially reduces the formation of Fee Al based intermetallic and replaces it with Ale Ag based intermetallic, such as $Ag_3Fe_2$, $Ag_2Al$ and $Ag_3Al$, resulting in better tensile strength and ductility of welds. Presence of silver as an interlayer reduces Mg concentration at the weld interface by intermittently replacing it with Si on AA6061 side, which restricts the interaction of Fe with aluminium. The higher strength and ductility of aluminium to low alloy steel dissimilar metal welds with silver as an interlayer was attributed to the formation of ductile phases like **$Ag_3Fe_2$, $Ag_2Al$** and **$Ag_3Al$**.

***A Research Paper on Temperature Modelling of Friction Welding of Aluminium and Stainless Steel-304:*** Friction welding has been successfully employed to weld dissimilar metals. Strength of the joints obtained was good. Highest micro hardness values were observed in the specimen on the side of SS due to high friction and high heat at the welding zone. The reason for higher micro hardness was observed to be re-crystallization. At interface and AL maximum area fraction of un-dissolved regions was formed through the SEM examination. These un-dissolved regions results in higher micro hardness values. Temperature modelling of friction welded joint has efficiently accomplished.

***Effect of friction welding parameters on joint strength of dissimilar metals:*** that friction welding is appropriate technology for joining of aluminium, copper, their alloys and other hard materials such as stainless steel efficiently. It was observed that the friction time has maximum influences on weld strength. Moreover, hardness of the weld is particularly affected by friction pressure. With increase in pressure, hardness in the vicinity of the weld area increases. Microstructure at the weld zone can be controlled with key parameters such as friction time, friction pressure and rotational speed of the metal piece.

## METHODOLOGY:

**Study on effect of interlayer in friction welding for dissimilar steels:** ss 304 an AISI 1040: The materials used in the experiments were cylindrical rods of length 75mm and diameter 10mm for AISI 1040 and SS304 rods of length 55 mm, diameter 10 mm with the holding side of diameter 20 mm. The materials were so machined to match the machine requirements. The chemical composition of the AISI 1040 and SS304 and stainless steel are given in Table1.The cylindrical specimens were faced to prepare the weld surfaces, further sought grinding was done with emery paper. Nickel which was selected as the interlayer material was deposited by electroplating on SS304 substrates with a range of 50±3μm on specified number of specimens for friction welding and other specimens were welded without the nickel interlayer. The friction welding machine used was a 3 ton horizontal friction welding machine manufactured by ETA technology Private Limited Bangalore capable of operating with high precision and excellent repeatability of all weld parameters. The spindle motor is of 20 HP, 3 phase AC and operating speed can be varied from 1 to 2700 RPM. The friction pressure was kept constant at .28 Ton. Nine different combinations were welded for both specimens with interlayer and without interlayer. The parameter combinations were selected by Taguchi orthogonal array method (L9 orthogonal array for 3 parameters and 3 level using Minitab) which was optimized for maximum tensile strength. The quality and integrity of the optimized welds were examined by carrying out tensile tests and hardness tests. FESEM analysis was done to observe changes in microstructure in the interfaces region.

**Chemical composition of base material**

***Table 1***

| MATERIALS | C% | Si% | Mn% | Ni% | Cr% | Cu% | Fe% |
|---|---|---|---|---|---|---|---|
| Medium Carbon Steel | .18 | .11 | .39 | .016 | .02 | .02 | 99.10 |
| Austenitic Stainless Steel | .09 | .29 | 1.42 | 8.413 | 14.08 | 1.24 | 74.53 |

FIGURE 1**- ETA friction welding machine and Friction Welded Specimen**

**ETA friction welding machine**

**Friction Welded Specimen**

*Table 2*- **Friction Welding Parameters**

| Runs | Speed (rpm) | Forging Pressure (Ton) | Burn of Length |
|---|---|---|---|
| S1/NS1 | 2500 | 1.884 | 8 |
| S2/NS2 | 2500 | 1.57 | 6 |
| S3/NS2 | 2500 | 1.256 | 4 |
| S4/NS3 | 2300 | 1.884 | 6 |
| S5/NS4 | 2300 | 1.57 | 4 |
| S6/NS5 | 2300 | 1.256 | 8 |
| S7/NS6 | 2100 | 1.884 | 4 |
| S8/NS7 | 2100 | 1.57 | 8 |
| S9/NS8 | 2100 | 1.256 | 6 |

**Welding of AA1050 aluminum with AISI 304 stainless steel by rotary friction welding process:** The materials used in this study were AA1050 aluminum (commercially pure aluminum, 99.5% Al) and **AISI 304** austenitic stainless steel. Both materials were machined with a diameter of **14.8 mm** and lengths **of 100** and **110 mm**, respectively. After machining, they were subjected to a cleaning with acetone to remove organic contaminants such as oils, greases etc. Tables 1 and 2 present chemical compositions and mechanical properties of materials, A rotary friction welding machine of brand GATWIK was used with fixed speed **of 3,200 RPM, P1 = 2.1 MPa, t1 = 32 seconds, P2 = 1.4 MPa and t2 = 2 seconds.**

*Table 3:* **Nominal chemical compositions of materials.**

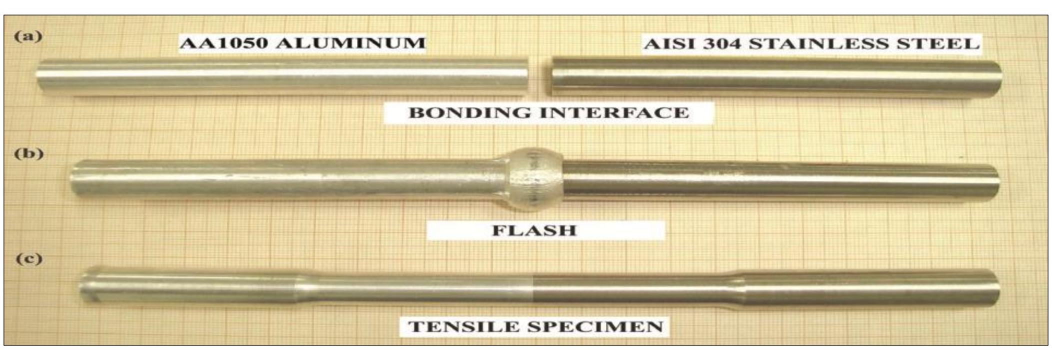
| | | | **Elements (wt %)** | | | | |
|---|---|---|---|---|---|---|---|
| **AA1050 aluminum** | **Si Fe** | **Cu** | **Mn** | **Mg** | **Cr** | **Zn** | **Ti** |
| | 0.07 0.26 | <0.001 | - | <0.001 | - | <0.002 | <0.007 |
| **AISI 304 stainless steel** | **Si S** | **P** | **Mn** | **C** | **Cr** | **Ni** | **-** |
| | 0.38 0.024 | 0.036 | 1.67 | 0.054 | 18.2 | 8 | - |

*Table 4:* **Mechanical properties of material used in present study**

| **Material** | **Mechanical properties** | **Elongation ε (%)** | **Modulus of** | **Fracture** | **elasticity E (Gpa)** |
|---|---|---|---|---|---|
| | **Strenghtσ (MPa)** | | | | |
| | **Yield** | **Maximum** | **Maximum** | | |
| **AA1050 aluminum** | 44.7 | 78.48 | 21 | 43 | 59.12 |
| **AISI 304 stainless steel** | 354.69 | 643.79 | 48 | 63 | 177.1 |

**Tensile test**: After welding was performed, tensile tests were carried out to evaluate the mechanical properties of joints, besides parameter settings, optimization and qualification of welding procedures and processes. The welded specimens were machined according to ASTM E 8M (2004), and subjected to tensile tests on a machine brand ZWICK 1474 with a load cell of 100 kN at room temperature of 25°C, and a test speed of 3 mm/minute. Vickers micro hardness tests: A sample with the same parameters of the junction which showed 100% of efficiency was analyzed by Vickers micro hardness using a digital micro hardness tester (Future-Tech Corporation, Japan) with a 300 gF load (stainless steel) and 100 gF (aluminum) for 10 seconds. Micro hardness was conducted at the interface of the weld and in the regions near both the aluminum and the AISI 304 stainless steel sides Metallographic analysis: The joints were cut in the transverse weld, embedded in an array of bakelite, polished and examined in the region of the interface on the aluminum and AISI 304 stainless steel sides, according to ASTM E3 (2007).

*Figure 3*- **Interfaces of pins that were joined (A); flash generated by the process (B); specimen for tensile test (C); samples on graph paper**



Mechanical strength of the joint welded by friction: The results of tensile tests for different welding parameters used (t1, t2 and P2) are shown in Table 3. The junction with the best mechanical strength (σt max.) refers to the specimen number 8, with higher mechanical strength to the material with lower mechanical strength – aluminum AA1050.Time t1 and friction welding pressure P2 were the parameters that most influenced in joint strength. In the welding of dissimilar materials such as AA1050 aluminum and AISI 304 stainless steel, the friction time t1 = 32 seconds allowed the increase of temperature, at the bonding interface, to values sufficient for a perfect union between the materials.

## DISCUSSION

- **AA6061 to AISI4340 using silver interlayer:** from the micrograph the aluminium Alloy **(AA6061)** is deformed extensively while no deformation on the low silver interlayer, a week bonding can be observed. Arrows slow the Steel surface is exposed indirection either no bonding on the bond is so weak left no mark of aluminium on steel surface.
- **Welding of AA1050 aluminium with AISI1304 stainless steel by rotatory fiction welding process:** In microstructure level it was observed the formation of flashes with circular symmetry different format and also significant reductions in the length of aluminium. In 32 seconds dissimilar materials like aluminium and Steel are welded together .
- **Experimental study of hardness in friction welding of aluminium Alloy:** Input process parameter-heating pressure heating time upset pressure upset time and spindle speed of **1000 RPM.** This experimental investigation based on Taguchi lg orthogonal array by using Mini lab software version 16 and various level of correction between input parameter and output response of hardness.
- **Study on effect of interlayer in friction welding for dissimilar SteelSS304 and AISI1040:** The thermal conductivity of AISI 1040 is more than that of SS 304 this is because of lower conductivity. The friction welding not only produces inter metallic layer but also creates referred zone regions. In the current study the Nickel introduced as interlayer is expected to reduce the intermetallic formation at the bond line at Higher for giving pressure to reduce the width of softened zone which could result in better Mechanical properties achieved.

## FUTURESCOPE:

- It will play major role in future industries.
- It will be an available larger application compare to present
- In pump manufacturing industry to replace 2/3 of expensive material of the shaft with cheaper material EN-8 and thus save huge amounts.
- The Microstructure analysis showed the difference in grain structure which resulted in higher and lower tensile strengths for welded joints.

**CONCLUSION:**

Friction welding technique has been developed for joining aluminum **(AA6061)** to low alloy steel **(AISI 4340)** using an interlayer of silver. The higher strength and ductility of aluminum to low alloy steel dissimilar metal welds with silver as an interlayer was attributed to the formation of ductile phases like **Ag3Fe2, Ag2Al and Ag3Al.**A research paper on the comparison of weld strength of friction welding of different material at two different RPM Study on Effect of Interlayer in Friction Welding for Dissimilar Steels: **SS 304** and **AISI 1040**, the maximum strength **636 MPa** was achieved at highest forging pressure of 1.884 ton. But when nickel interlayer was introduced highest strength of **661 MPa** was achieved at highest burn off length of 8 mm. Micro hardness results showed a decrease in peak hardness at the interface (391 Hv) which was 454 Hv when welded without using interlayer FESEM images showed the microstructure of the weld and EDS spectrum indicated the composition of the weld part at the scan area.

**REFERENCES**:

(1) SirajuddinElyasKhany, S.N.Mehdi and G.M.Sayeed Ahmed, An Analytical Study of Dissimilar Materials Joint Using Friction Welding and It's Application, International Journal of Scientific and Research Publications, Volume 5, Issue 2, February 2015

(2) GauravVerma, Sandeep Kumar and Bharat Raj Bundel,A RESEARCH PAPER ON THE COMPARISON OF WELD STRENGTH OF FRICTION WELDING OF DIFFERENT MATERIALS AT TWO DIFFERENT RPM, International Journal of Mechanical Engineering and Technology (IJMET) , Volume 7, Issue 6, November–December 2016

(3) S R Divagar, and M MuthuKumaran,JOINING THE DIFFERENT MATERIALS USING FRICTION WELDING, International Journal of mechanical engineering and Robotics Research, Vol. 4, No. 1, January 2015

(4) M. Ganesan, N. Baskar, S. Karthikeyan, M. R. AnanthaPadmanaban , S. Abdul Rahim , M. Gopinath , S. HariPrasanth, N. Kumarasamy, Experimental Study of Hardness in Friction Welding of Aluminium Alloy, SSRG International Journal of Mechanical Engineering (SSRG-IJME) - Special Issue ICRTECITA April2018

(5) Shubhavardhan RN, SurendranS,Friction Welding to Join Dissimilar Metals, International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 7, July 2012

(6) Rishant and LalitKumar,To Review the Friction Welding Joint Brass &Aluminium using Microstructural Behaviour, International Journal of Electrical, Electronics and Mechanical Fundamentals, Vol. 23, Issue 01, June 2016

(7) Deepak Kumar M, Venkatakrishnan,Optimization on Friction Welding of Aluminium Alloy 6082 T6 and Austenitic Stainless steel 304, International Journal of Engineering Development and Research, 2014 ,Volume 2, Issue 1

(8) Eder PaduanAlves, Francisco PiorinoNeto, Chen Ying An, J. Aerosp.Technol. Manag., São José dos Campos, Welding of AA1050 aluminum with AISI 304 stainless steel by rotary friction welding process, Vol.2, No.3, pp. 301-306, Sep-Dec., 2010

(9) Shanjeevi.C, SatishKumar.S , Sathiya.P, Evaluation of Mechanical and Metallurgical properties of dissimilar materials by friction welding, Elsevier Ltd, Procedia Engineering 2013

(10) Rombaut, W. De Waele, and K. Faes, FRICTION WELDING OF STEEL TO CERAMIC,Sustainable Construction and Design 2011 by Laboratory Soete

(11) JeswinAlphy James, Sudhish. R,Study on Effect of Interlayer in Friction Welding for Dissimilar Steels: SS 304 and AISI 1040, 2212-0173 ,2016 The Authors. Published by Elsevier Ltd

(12) SURESH D. MESHRAM,G.MADHUSUDHAN REDDY, Friction welding of AA6061 to AISI 4340 using silver interlayer , defence technology 11, Elsevier B.V ,2015

(13) Mr. Sachin Kumar, Mr. Deepak Bhardwaj, Mr. JagdeepSangwan, International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463 Vol. 3 Issue 6, June-2014, pp: (319-327)

(14) AndrzejAmbroziak,MarcinKorzeniowski,PaweBKustroN,MarcinWinnicki, PaweBSokoBowski,andEwaHarapiNska, Hindawi Publishing Corporation Advances in Materials Science and Engineering Volume 2014, Article ID 981653, 15 pages

(15) KamaldeepChugh, AmitHanda and Kamaljit Singh, EZUCURSION-16, NATIONAL CONFERENCE ON INNOVATIONS IN CIVIL AND MECHANICAL ENGINEERING, 2016

(16) Muralimohan, s haribabu, hariprasadhareddy, v. muthupandi, k. sivaprasd,Muralimohanevalution of micro stuctures and mechanical properties of dissimilar metals by friction welding, international conference on manufacturing and material engineering 2014.