Friction Stir Welding methodology for ferrous and non- ferrous alloy to analyze the mechanical performance and characterization: A review

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Abstract: Friction stir welding currently a new emerging assembling process, which comes under solid state joining process. This research paper provides information related to the basic principles of the friction stir welding technique, procedure parameters for it and the research and advancements in this field. The basic principles include schematic and terminology used for FSW. FSW's numerous advantages when compared with the other conventional welding processes are also represented in this article. Different welding process parameters including joint configuration, tool profile designing, and temperature control are discussed by some researchers for producing sound weld. The most recent applications are additionally examined, the greater part of which are ongoing advances in aeronautic trade, car industry, and ship building and so on.

Keywords: Friction stir welding, FSW, process parameter, rotational speed, tilt angle, FSP, welding

Introduction: Friction stir welding (FSW) is an innovative technique to join metals in the plasticity field, thus before reaching ot its melting temperature. Accordingly, the joining procedure creates fantastic joint properties, is vitality effective, condition well-disposed and adaptable [1-2]. It was created by Wayne Thomas at The Welding Institute, U.K. and the first and foremost patent were lodged in U.K. in December, 1991[3]. Since then it has found wide variety of applications especially in aerospace, shipbuilding and automobile area.

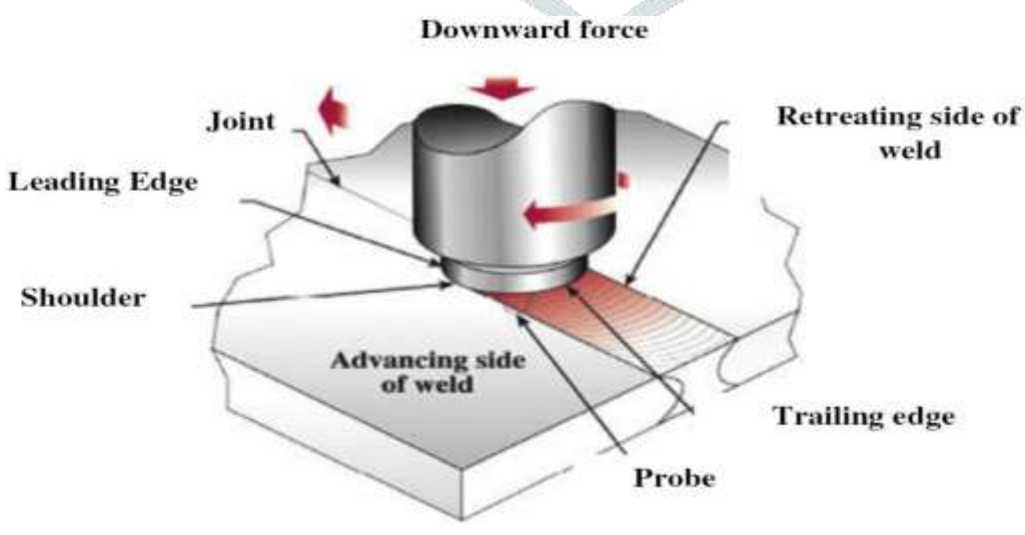

Figure 1 Representation of Friction Stir Welding Method [3]

Jiang *et al.* 2004 [4] investigated the mechanical performance at the weld nugget for the fsw of dissimilar material AL 6061 –T6 and AISI 1018 steel grade as well as defect free weld has been produced, during their study they found that inter-metallic compounds of Al-Fe has been formed at the nugget zone due to this hardness was varied and formation of secondary phase at the interface and the high tensile strength was observed at the boundary between the nugget zone and thermo-mechanically affected zone. Amirizad *et al.* 2006 [5] studied Fswed of aluminium matrix composite of A356 & 15% SiC_p, distribution of SiC_p particle is homogenous in eutectic phase as well as improvement of mechanical properties i.e. young's modulus, yield strength, UTS strength, percentage elongation in order of 57%, 26%, 34% and 154% as compare to base material. Because of band like settlement of SiC_p and silicon needles which indicates to enhance the hardness at the stir zone. Cavaliere *et al.* 2006 [6] studied about the behavior of mechanical properties i.e. tensile strength, endurance limit stress and micro-hardness of the FSW welded specimen as well as microstructural evolution has been done on 'as welded' specimen and 'after rupture tested' specimen.

Cavaliere *et al.* 2009 [7] examined the mechanical properties and microstructure which is influenced by various process parameter for dissimilar fsw butt weld of AA6082 – AA2024 as well as by changing the material in advancing side. It was observed that superior tensile strength and fatigue strength was observed in AA6082 in proceeding side with progressing speed of 115 mm/min. Chen *et al.* 2009 [8] investigated the influence of tool shape on mechanical properties and microstructure of FSW of lap joint of AZ31 Mg Alloy and Steel. For fleecy steel the failure load is increased at the joint section with increasing probe length. For zinc covered steel, short probe length leads to high strength joint without any defects. Jana *et al.* 2010 [9] studied the feasibility of joining magnesium alloy to steel lap joint, average peak load was observed for AZ31 with 0.8mm electro galvanized mild steel was 5.1± 1.5 KN and the average peak load was observed for AZ31 with 1.5 mm hot dipped galvanized steel was 6.3 ± 1.0 KN. As well as study of intermetallic compounds or formation of Zn – Mg layer investigated. Aval *et al.* 2011 [10] investigated the thermo-mechanical performance and microstructural development of Fsw of like and unlike metal of AA5086 and AA6061 using 3D finite element software and compared with the experimental result at different process parameter. It is found that by using diverse strengthening mode in AA5056 and AA6061, hardness variation is observed at welded section and the fine grain size distribution is there in AA6061 side. Improvement in mechanical properties of natural ageing of AA6061 after weld for similar weld joint is more as well as peak temperature and rate of cooling for similar weld of AA6061 is superior as compared to dissimilar weld. Aonuma *et al.* 2012 [11] investigated the FSW butt welding of dissimilar metal Zk60 (Mg–Zn–Zr) alloy and titanium, the tensile strength at the stir zone is higher than the pure magnesium and titanium. The fracture at joint has been occurred mainly at stir zone of Mg-Zn-Zr and partially at joint line during tensile examination since, thin reaction layer has been established at the joint line which expands the mechanical strength of magnesium alloy and titanium.

Beygi *et al.* 2012 [12] examined the microstructure and hardness profile at the stir zone of Al-Cu bilayer sheet using butt FSW. Metal flow was investigated and the banded microstructure at the advancing side with the existing particle of Al but there is no Al particle observed in retreating side, which leads to increase the hardness at advancing side as compare to retreating side. Coelho *et al.* 2012 [13] investigated joint efficiency of FSW of different grade of HSS with AA6181-T4.It was found that similar microstructure was produce but only the differences are size and amount of steel particle in aluminium alloy. As well as the welding strength was also similar. Dehghani *et al.* 2013 [14] investigated the influence of various process parameters and tool geometry on the properties of Fsw of 3003 H18 Al Alloy and mild steel, it was reported that at constant welding speed and increasing rotational speed there is formation of cavity and more heat generation indicates that decrease in UTS of joint from 112 N/mm^2 to 28 N/mm^2. As well as at constant RPM and increasing feed rate leads to surge the UTS from 28 N/mm^2 to 100 N/mm^2 as well as if annealing was done at the joint which reduces the mechanical strength. It was also observed that at faying surface conical tool is not suitable for welding Al alloy with steel due to no interaction was produced. Choi *et al.* 2013 [15] examined the mechanical properties and characterization behavior of fsw of AZ31 with CaO Mg Alloy (% Wt), it was observed that due to presence of intermetallic compounds of Al2Ca of small particle at the stir zone, which leads to increase the hardness at stir zone because of fine grain were present as compare to base metal. Bisadi *et al.* 2013 [16] investigated the effect of various process parameters of Fsw over mechanical properties and microstructure evolution of FSW of Lap joint, as well as various defects are also analyze. It was witnessed that at different traverse and rotational speed, some defects are also occurred due to inappropriate heat generation at stir zone and the highest tensile strength has been observed at 825 rpm at 32mm/min. welding speed. And maximum hardness was observed at copper side due to fine grain size. Cole *et al.* 2014 [17] studied the effect of alloy placement and offset tool from the joint line towards retreating side with AA7075 leads to increase the tensile strength at lower average weld temperature with greater amount of AA7075-t6. The assurance of serious permanent deformation and peak temperature generation in the stirred region during FSW/FSP carries out about re-crystallization and up-gradation of surface at the innermost compound zone and accelerates disintegration and coarsening internally and besides the diversified zone. In light of miniaturized scale basic interpretation of grains and inspires, three different precise zones, blended (SZ) zone, thermo-precisely influenced zone (TMAZ), and warmth influenced zone, have been distinguished. The mechanical characterization deviates in different zones have the critical consequences for post weld mechanical properties. In this way, the microstructural development during welding process has been considered by various agents [18].

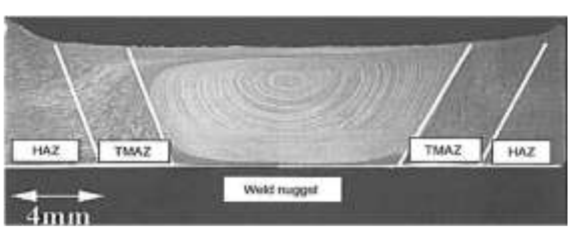

Figure 2 Temperature variation zones [1]

Yadvinder Singh *et al*., [19] used high carbon steel in their research work, due to its low wear rate. The consequence of shoulder with pin shapes on the strength of (AA6061) in solo and dual sided friction stir welds. In this work the speed of tool rotational speed were taken as 3080 rpm, transverse speed as 30mm/min. also, tool tilt edge was taken as 2°. In both single and twofold pass, the most elevated rigidity of the joints was acquired by utilizing the square stick profile instrument.L. Karthikeyan, *et al.*, [20] investigated by using Cylindrical threaded tool on Workpiece of Al 6063- T6 The effects of process variables such as axial force, tool feed and rotational speed(rpm) There is increase in Yield strength, Ultimate tensile strength, Ductility, and Micro hardness. B.T. Gibson *et. al.*, [21] has studied that by using Steel H13 as tool material having cylindrical threaded probe and workpiece of AA 6061- T6 & 7075-T6 Alloys and analyze Friction stir welding Process, automation, and control and techniques for evaluating weld excellence are measured as well. H. Bisadi, *et. al.*, [22] discussed about the effects of process parameters on micro-structures and strength of FS Welded of Al5083 and pure copper pieces of lap joints by using Steel H13 as tool Material and having a tilt of 3° and the maximum hardness, ultimate tensile stresses analyze. M.MEHTA *et. al.*, [23] investigated the impact of shoulder diameter on thermal rotations, crowning heats, control necessities, and twisting. An ideal tool shoulder distance across is distinguished utilizing a 3D, heat move and materials stream theory and analyze allowable strength in yielding and ductility, having work-piece of AA 7075 - T6 Alloys and EN24 Steel as a tool material cylindrically tapered pin by the tool tilt angle of 2°. R. Rai *et. al.*, [24] in their research work they select the appropriate tools as per geometry and shoulder diameter of Tungsten Alloy having cylindrical threaded on AA 6111 T-4.and investigate tool physical properties that could affect the weld quality, tool wear and performance. P. Prasanna, *et al.*, [25] in their research work they utilized four diverse tool pin profiles to distinguish the mechanical properties of AA 6061 aluminum composite by keeping stable procedure variable of tool speed 1200RPM, travel speed 14 mm/min and axial thrust of 7kN. Dissimilar warmth techniques like tempering, normalizing and quenching have been used on the joints and assessment of the strengthen properties like rigidity, level of prolongation, micro-hardness and grains orientation and structure in the FSW development zone and the maximum tensile strength and % of elongation was observed on Hexagonal pin profile tool with annealing process.

In giving legitimate contact and in this way guaranteeing a great join, the utmost significant control include is thrust force. This ensures great caliber even where tolerance inaccuracies in the materials to be combined might emerge. It additionally empowers powerful governor during higher travel speeds, as the thrust force will assure the stage of rubbing warmth to mollify the material. When utilizing FSW, the accompanying variables essential to be measured: axial force, welding speed, rotational speed of the welding tool and tilting edge. Just four primary parameters should be aced, making FSW perfect for motorized welding. R. Palanivel, *et. al.*, [26] in their exploration work the dissimilar aluminum compounds AA5083-H111 and AA6351-T6 were made utilizing three diverse tool rotating rates of 600, 950 and 1300 rpm respectively and five distinctive tool pin profile. The tool revolving speed and pin contour significantly impacted the microstructure and rigidity of the joints. The welded joint which utilizing tool revolve speed of 950 rev/min. and straight profile of tool pin gives the most elevated elasticity of 273 MPa. The two procedure parameters influenced the joint quality because of varieties in material stream conduct; damage of cold work in the heat affected zone of AA5083 direction, disintegration and over maturing of accelerates of AA6351 side and arrangement of perceptible imperfections in the weld zone. Ihsan Küçükrendeci, *et. al.,* [27] has found Effect of Welding Parameters on Al Alloy EN AW6060 workpiece and tool of Steel 4140 Mixer having screw profile, the Welding Microstructure utilizing three unique rates and three diverse feed rate joined with uneven at Micro-hardness the occasion of contact with the material locale the most elevated hardness was acquired. K.D.Bhatt, *et al.,* [28] explored in their examination work, to showcase high heating zone and rate of change of fow at and in front-facing of the tool during the FSW by changing tool dimensions and utilizing computational setup HyperWorks9.0 for AA6061-T6 aluminum compound which is generally utilized in applications in high specific strength to-weight proportion as in aviation to validate the result. A. Pastor *et al.,* [29] in their research work they used Aluminum AA7075-T651 alloy with tool having cylindrical pin with tilt angle of 2°examined the mechanical properties with the normal maturing time develops Heat Affected Zone (HAZ) exponentially with respect to time, accomplishing at 1300 hr. approximately after the welding roughly 66% of micro-hardness and at 1440 hr. 73% of the elasticity of the base material. A.K. Shettigar, *et al.,* [30] used dissimilar Alloys in their research work having AA6061 with 4.5 % weight of copper compound and 5 % weight of silicon carbide composite material has been prepared to examine the mechanical properties and Micro-structural characterization of the weld zone to dissect the imperfections, for example, pin hole, tunnel, worm gap, kissing bond, crisscross and funneling because of the inappropriate progression of the metal and inadequate solidification of the metal in the mix zone that is completed by material characterization. Assessment of micro-hardness was moreover supported through the welded region. Masoud Jabbari, *et al*., [31] built-up an explanatory model to simulate the contact temperature and the impact of the preheating temperature of Al Alloy 6061-T6 on the procedure period was researched, The outcomes expressed that the expansion of the prior heating temperature builds up the superior weld quality, however, it additionally diminishes procedure time. A M Khourshid *et al,* [32] in their examination work aluminum pipe (Al 6061) could be joined with a most extreme joining proficiency (78.7%) as far as extreme strength in tension , utilizing 1400 RPM revolving speed, 4 mm/min travel speed.

Materials and Method: The workpiece materials used for FSW is suitable for joining of Al and alloys, Mg and alloys, Cu and alloys, Ti and alloys, steel and joining of dissimilar metals and alloys as well as Al matrix based composites. And the tool material to be selected as per the working temperature condition and workpeice material i.e. H13 steel, tungsten based tool, PCBN etc. The process for FSW requires the non-consumable tool for joining two plates with the help of heat generation due to friction and the some important parameters i.e. welding process parameter and tool parameters along with other influencing parameter must be analyzed to produce sound weld. The welding variables includes tool revolving speed, travel speed, penetration of tool inside the job, tool tapered angle and axial force and the tool related parameters includes tool pin profile, shoulder diameter, probe length, probe diameter. In this article every researcher has optimized the process parameter and tool parameter very effectively for producing defect free weld joint. By choosing the optimized various parameters welding joint has been analyzed by using experimental and computational analysis method like impact toughness test, Micro-hardness test, tensile testing, micro-structural characterization using optical microscopy and SEM, CFD analysis, temperature region (thermal cycle) analysis during welding.

Conclusion: In this review paper, the effect of various welding parameters has been observed by the researchers to produce defect free welded joint for similar and dissimilar material. Micro-structure and strengthens properties, material based difficulty. Applications of FSW have been studied in this article. tool geometry is a significant factor for creating sound welds. Fusing parameters, comprising travel speed, penetration of tool inside the job, tool tapered angle and axial force and the tool related parameters includes tool pin profile, shoulder diameter, probe length, probe diameter to create a sound and defect free weld. It is generally acknowledged that material stream inside the join during FSW is exceptionally mind-boggling and still ineffectively comprehended. Certain scientists recommended that Friction Stir Welding and Friction Stir Processing can be commonly depicted as an in-situ expulsion method and the mixing and blending of material occurred distinctly at the outward layer of the welded joint adjoining the turning shoulder. Three distinctive grains characterizations have been illustrates in FSW, i.e., nugget locale encountering extraordinary plastic distortion and high-temperature introduction and described by fine and equi-axed recrystallized grains, TMAZ encountering medium temperature and disfigurement and portrayed by twisted only, and HAZ encountering just temperature and portrayed by precipitation coarsening. Prior heating is advantageous for refining the weld quality just as increment in the welding rate. So, diverse experimental approaches give the sound welded joint along with improved mechanical properties at the joint region.

References

[1] Axel Fehrenbacher, Neil A. Duffie, Nicola J. Ferrier, Frank E. Pfefferkorn, Michael R. Zinn, "Effects of tool-workpiece interface temperature on weld quality and quality improvements through temperature control in friction stir welding", Int J Adv Manuf Technol, pp165-79, 2014.

[2] Xiaomin Deng, Shaowen Xu, "Two-Dimensional finite element simulation of material flow in the Friction Stir Welding process", J Manuf Process, pp 125-33, 2004.

[3] Thomas WM, Nicholas ED, Needham JC, Murch MG, Temple-Smith P, Dawes CJ "Friction stir butt welding" International Patent Application No. PCT/GB92/02203, GB Patent No. 9125978.8, 1991; U.S. Patent No. 5460317: 1995.

[4] W H Jiang and R. Kovacevic, "Feasibility study of friction stirs welding of 6061 –T6 aluminium alloy with AISI 1080 steel", Proceedings of the Institution of mechanical engineers, vol 218, pp 1323-1331, 2004.

[5] M. Amirizad, A.H. Kokabi, M. Abbasi Gharacheh R. Sarrafi, B. Shalchi, M. Azizieh, "Evaluation of microstructure and mechanical properties in friction stir welded A356+15%SiCp cast composites", Materials Letters 60, pp 565–568, 2006.

[6] P. Cavaliere, R. Nobile, F.W. Panella, A. Squillace, "Mechanical and microstructural behaviour of 2024–7075 aluminium alloy sheets joined by friction stir welding", International Journal of Machine Tools & Manufacture 46, pp 588–594, 2006.

[7] P. Cavaliere, A. De Santis , F. Panella, A. Squillace, "Effect of welding parameters on mechanical and microstructural properties of dissimilar AA6082–AA2024 joints produced by friction stir welding", Materials and Design 30, pp 609–616, 2009.

[8] Y.C. Chen, K. Nakata, "Effect of tool geometry on microstructure and mechanical properties of friction stir lap welded magnesium alloy and steel", Materials and Design 30, 2009: pp 3913–3919, 2009.

[9] S. Jana, Y. Hovanski, and G.J. Grant, "Friction Stir Lap Welding of Magnesium Alloy to Steel A Preliminary Investigation", Metallurgical and Materials Transactions vol 41A, pp 3173-3182, 2010.

[10] H. Jamshidi Aval, S. Serajzadeh, A.H. Kokabi, "Evolution of microstructural and mechanical properties in similar and dissimilar friction stirs welding of welding of AA5086 and AA6061", Materials Science and Engineering A528, pp 8071–8083, 2011.

[11] Masayuki Aonuma ,Kazuhiro Nakata, "Dissimilar metal joining of ZK60 magnesium alloy and titanium by friction stir welding", Materials Science and Engineering B 177, pp 543– 548, 2012.

[12] R. Beygi, M. Kazeminezhad, A. H. Kokabi, "Butt joining of Al-Cu bilayer sheet through friction stir welding", Trans. Non-ferrous Met. Soc. China 22, pp 2925-2929, 2012.

[13] R.S. Coelho, A. Kostka, J.F. dos Santos, A. Kaysser-Pyzalla ,"Friction-stir dissimilar welding of aluminium alloy to high strength steels: Mechanical properties and their relation to microstructure", Materials Science & Engg. A 55, pp 175–183, 2012.

[14] M. Dehghani, S. A. A. Akbari Mousavi, A. Amadeh, "Effects of welding parameters and tool geometry on properties of 3003-H18 aluminum alloy to mild steel friction stir weld", Trans. Non-ferrous Met. Soc. China 23, pp 1957-1965, 2013.

[15] Don-Hyun Choi, Shae-Kwang Kim, Seung-Boo Jung "The microstructures and mechanical properties of friction stir welded AZ31 with CaO Mg alloys", Journal of Alloys and Compounds 554, pp 162–168, 2013.

[16] H. Bisadi, A. Tavakoli, M. Tour Sangsaraki, K. Tour Sangsaraki, "The influences of rotational and welding speeds on microstructures and mechanical properties of friction stir welded Al5083 and commercially pure copper sheets lap joints", Materials and Design 43, pp 80–88, 2013.

[17] E. G. Cole & A. Fehrenbacher , N. A. Duffie, M. R. Zinn, F. E. Pfefferkorn, N. J. Ferrier, "Weld temperature effects during friction stir welding of dissimilar aluminum alloys 6061-t6 and 7075-t6",Int J Adv Manufacturing Technology, pp 643–652, 2014.

[18] Blignault C."Design, development and analysis of the friction stir welding process", M.Tech dissertation. Faculty of Engineering, Port Elizabeth Technikon, South Africa, 2002.

[19] Yadvinder Singh, I.C. Ramola, "Study of Mechanical properties for aluminum alloy (6061) by using different tool shapes in friction stir welding", International Journal of Research in Engineering & Applied Sciences, volume 3, issue 10, 2013.

[20] L.Karthikeyan, V.S. Senthil Kumar "Relationship between process parameters and mechanical properties of friction stir processed AA6063-T6 aluminum alloy", Materials and Design 32, pp 3085–3091, 2011.

[21] B.T. Gibson, D.H. Lammlein, T.J. Prater, W.R. Longhurst, C.D. Cox, M.C. Ballun, K.J. Dharmaraj, G.E. Cook, A.M. Strauss, "Friction stir welding: Process, automation, and control" , Journal of Manufacturing Processes, Arpil 2013.

[22] H. Bisadi, A. Tavakoli, M. Tour Sangsaraki, K. Tour Sangsaraki, "The influences of rotational and welding speeds on microstructures and mechanical properties of friction stir welded Al5083 and commercially pure copper sheets lap joints", Materials and Design 43, pp 80–88, 2013

[23] M. Mehta, A. Arora A. DE, and T. Debroy, "Tool Geometry for Friction Stir Welding—Optimum Shoulder Diameter",The Minerals, Metals & Materials Society and ASM International 2011.

[24] R. Rai, A. De, H. K. D. H. Bhadeshia and T. DebRoy, "Review: friction stir welding tools", Institute of Materials, Minerals and Mining; Science and Technology of Welding and Joining, vol 16 no -4, pp 325, 2011

[25]]P.Prasanna, Dr.Ch.Penchalayya, Dr.D.Ananda mohana Rao, "Effect of tool pin profiles and heat treatment process in the friction stir welding of AA 6061 Aluminum alloy", American Journal of Engineering Research e-ISSN: 2320-0847 p-ISSN : 2320-0936 Volume-02, pp 07-15, 2013.

[26] R. Palanivel, P. Koshy Mathews, N. Murugan, I. Dinaharan, "Effect of tool rotational speed and pin profile on microstructure and tensile strength of dissimilar friction stir welded AA5083-H111 and AA6351-T6 aluminum alloys", Materials and Design 40, pp 7–16, 2012.

[27] Ihsan Küçükrendeci "Effect of Welding Parameters on Welding Microstructurein EN AW-6060 Aluminum Alloy Combined with Friction Stir Welding Process" (2013); World Applied Sciences Journal 22 (3): pp 300-306, 2013.

[28] K.D.Bhatt Bindu Pillai A.M. Trivedi "Effect of Size of Tool on Peak Temperature & Viscosity during Friction Stir Welding of AA6061-T6 Aluminum Alloy Using HyperWorks", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, 2013.

[29] A. Pastor, H. G. Svoboda, "Time-evolution of Heat Affected Zone (HAZ) of Friction Stir Welds of AA7075-T651", Journal of Materials Physics and Chemistry, 2013, Vol. 1, No. 4, pp 58-64, 2013.

[30] A.K. Shettigar, Giridhar Salian, Mervin Herbert, and Shrikantha Rao, "Microstructural Characterization and Hardness Evaluation of Friction Stir Welded Composite AA6061-4.5Cu-5SiC (Wt.%)", Defence Science Journal, Vol. 63, No. 4, July 2013, pp. 429-434, 2013

[31] Masoud Jabbari "Effect of the Preheating Temperature on Process Time in Friction Stir Welding of Al 6061-T6"(2013)"; Hindawi Publishing Corporation Journal of Engineering Volume 2013, Article ID 580805, 5 pages

[32] A M Khourshid,"Analysis and design of friction stir welding", International Journal of Mechanical Engineering and robotics research ISSN 2278 – 0149 Vol. 2, No. 3, July 2013.