International Journal of Research
Available at http://internationaljournalofresearch.org/
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 02 Issue 02
February 2015

Some study of friction stir welding-A Review

Saadat Ali Rizvi[a] ,S.P Tewari[b] ,Wajahat Ali[c]

[a]Indian Institute of Technology (BHU), Banaras Hindu University, Varanasi, India

Email:sarizvi1@jmi.ac.in/ saritbhu@gmail.com Mobile No: 00917531026305

[b]Indian Institute of Technology (BHU), Banaras Hindu University, Varanasi, India

[c]Mechanical Engineering Department, SCRIET, (CCS University, Meerut)

Abstract: *This paper reviews the latest developments in friction stir welding. In the present article, the effect of friction stir welding (FSW) parameters on the weldability and the characteristics of aluminum alloys, dissimilar metals, are investigated. The mechanical properties of the welds are studied through microhardness distribution and tensile tests. The microstructures are strongly affected by the heat input, while the grain size within the TMAZ decreases with decreasing heat input per unit length during FSW.*

Keywords: FSW, aluminum alloys, Residual stresses, Tool Geometry, Thermo mechanical model, Microstructures etc.

Introduction: Friction Stir Welding (FSW) is one of the most effective solid states joining process which was invented at The Welding Institute (TWI), UK, in 1991 and has numerous potential applications in many industries to join different metallic alloys that are hard to weld by conventional fusion welding. It is a highly complex process comprising several highly coupled physical phenomena. The experiments are often time consuming and costly. To overcome these problems, numerical analysis has frequently been used since the 2000s. Friction stir welding (FSW) is a significant manufacturing process for producing welded structures in solid state [1]. In FSW process, a rotating tool having a shoulder moves along the welding line. Rotational motion of the shoulder generates frictional heat leading to a softened region around the pin while the shoulder prevents deforming material from being expelled. In fact, a weld joint is produced by the extrusion of material from the leading side to the trailing side of the tool [3].

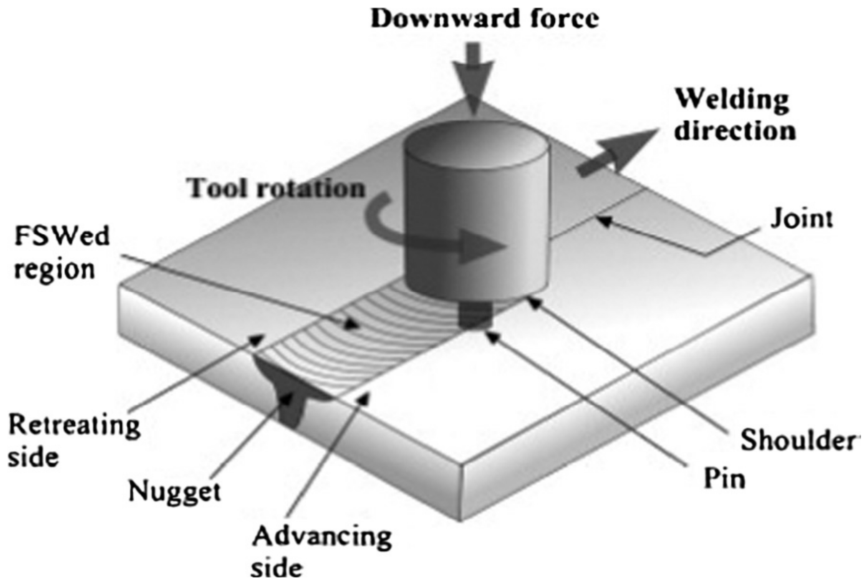


Fig. 1. Schematic drawing of FSW process [1].

Xiaocong He et al [8] studied about the Friction stir welding (FSW) and they told that it is a relatively new solid-state joining technique which is widely adopted in different industry fields to join different metallic alloys that are hard to weld by conventional fusion welding. The complex geometry of some kinds of joints and their three dimensional nature make it difficult to develop an overall system of governing equations for theoretical analyzing the behavior of the friction stir welded joints. This paper reviews the latest developments in the numerical analysis of friction stir welding processes, microstructures of friction stir welded joints and the properties of friction stir welded structures and finally they conclude that a complete characterization of joint behavior is impossible. Accurate and reliable numerical analysis of the FSW is still a very difficult task as the behavior of the FSW joints is influenced by different factors in combination.

Mathematical model:

Mohamed Assidi & Lionel Fourment [2] presented a 3D FSW simulation based on friction models calibration using Eulerian and ALE formulation. Two friction models have been studied to model friction in the tool-plate interface in aluminium alloy 6061-T6 Norton's and Coulomb's. Comparisons with experimental results considering various travel speed has been performed and they told that the study at various travel speeds provides the same quality of results which shows that this friction calibration can be regarded as rather general. However, the temperature in the tool is not perfectly modelled and certainly requires developing accurate model. Fig 2. (a) and (b).

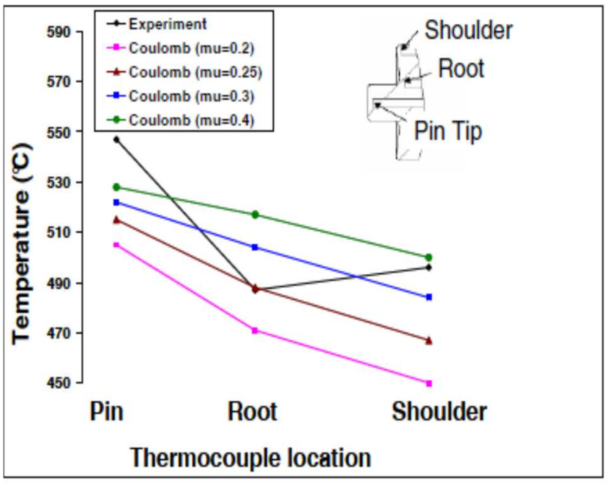
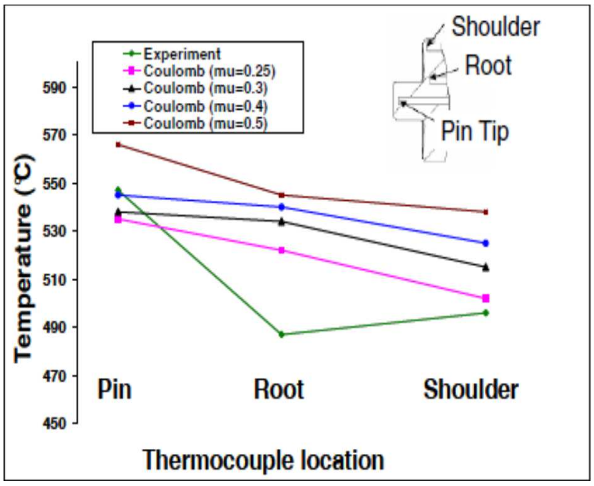


Fig 2(a) Calculated and measured temperatures at pin, root and shoulder locations in the FSW tool with Coulomb friction using an Eulerian formulation[2]



(b) Comparisons of calculated and measured temperature at pin, root, and shoulder locations in the FSW tool with Coulomb friction and the ALE formulation[2]

H. Jamshidi Aval et al [13] investigates relation between the microstructures of thermo mechanically affected zone (TMAZ) and heat input in friction stir welding (FSW) of 5086 aluminum alloy. First, welding heat input has been predicted using a three-dimensional finite element analysis; then, welding experiments have been carried out on annealed and work-hardened conditions to study the developed microstructures and the mechanical properties of the welded metal. In addition, the microstructures are strongly affected by the heat input, while the grain size within the TMAZ decreases with decreasing heat input per unit length during FSW and they told that the frictional power has a major effect in heat generation and temperature distribution within the metal being welded and the temperature in FSW is asymmetrically distributed

Residual stresses:

Mohammad Riahi & Hamidreza Nazari [4] study the impact of tool moving Speed in relation with heat distribution as well as residual stress. Simulation was composed of two stages. Firstly, thermal behavior of the piece while undergoing the welding process. In the second stage, attained thermal behavior of the piece from previous stage is considered as inlet heat of an elasto-plastic, thermo mechanical model for the prediction of residual stress and they find that a higher traverse speed induces higher value in longitudinal stress in narrower region that agrees with experimentally reported data. Fig 3

International Journal of Research
Available at http://internationaljournalofresearch.org/
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 02 Issue 02
February 2015

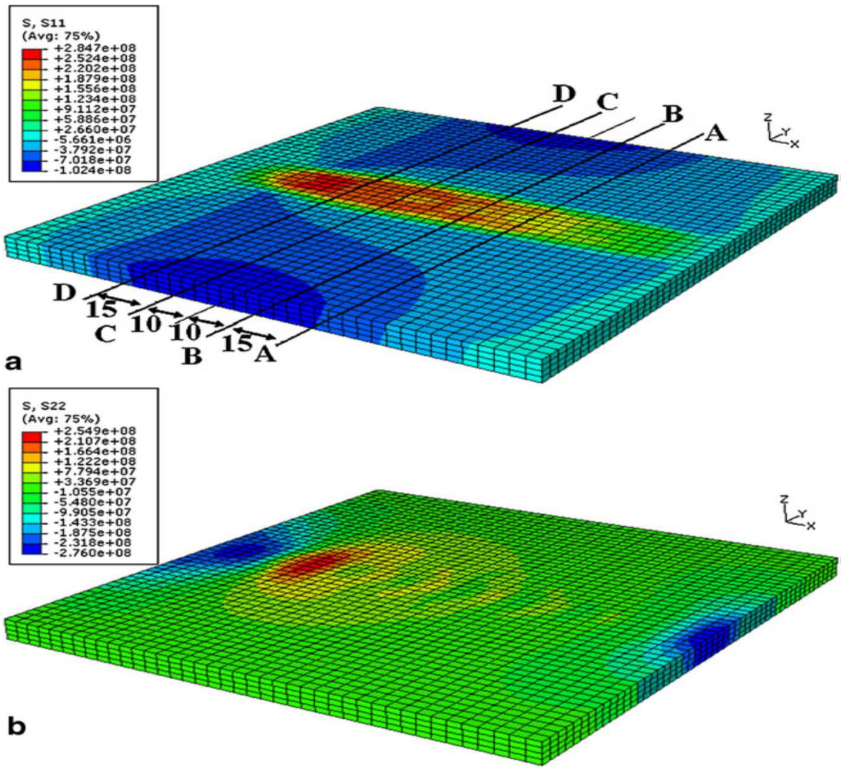


Fig 3.Predicted three-dimensional residual stress distribution in the welded plate. A Longitudinal residual stress and b transverse residual stress (ν = 280 mm/min; ω = 1,250 rpm)

H. Jamshidi Aval et al [9] employ a three-dimensional model and the finite element software **ABAQUS** to evaluate thermo mechanical responses during the dissimilar friction stir welding of aluminum alloys and measured the produced residual stresses in various positions and It is found that tool rotational speed significantly affects the amount of maximum tensile residual stress while traverse speed mainly changes the distribution of transverse residual stresses. Also, welding fixtures significantly affect the residual stress profiles as well as their magnitudes. Fig 4 & 5

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 02 Issue 02
February 2015

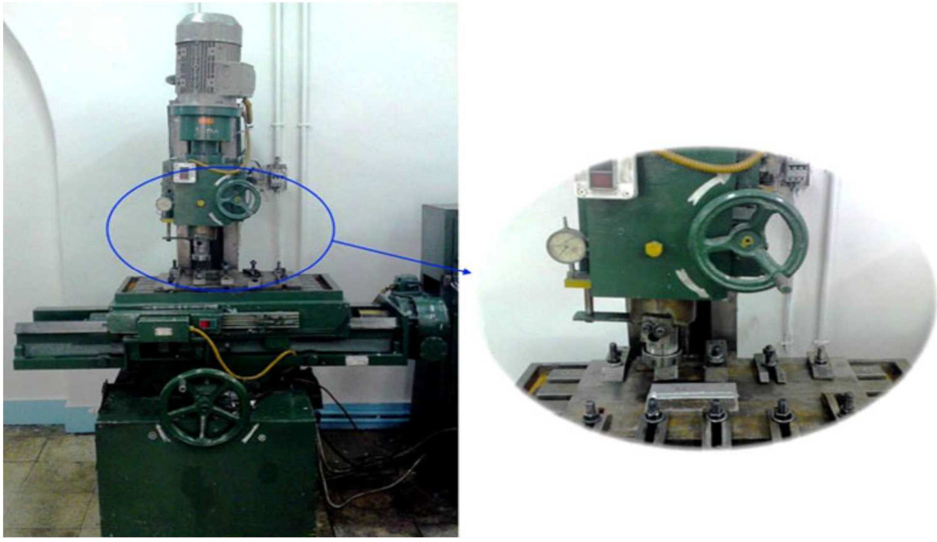


Fig 4.The machine used in the friction stir welding experiments

Longitudinal residual stress **Transverse residual stress**

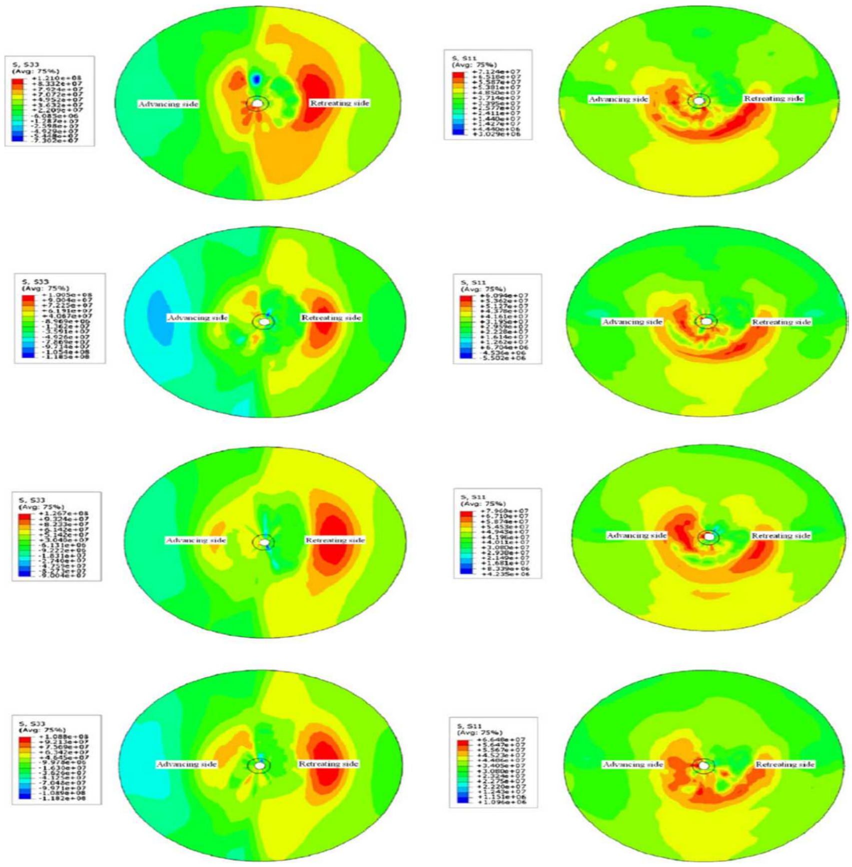
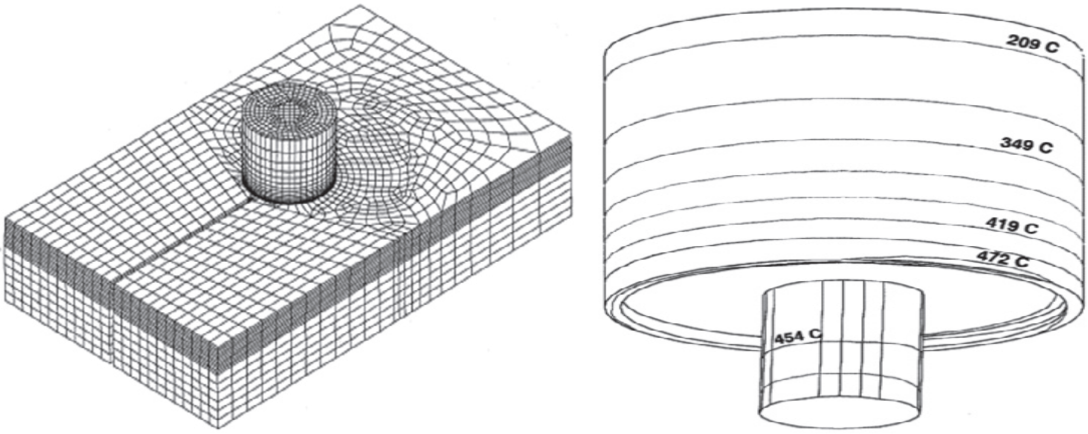


Fig 5.Longitudinal and transverse residual stress profiles for: a sample A, b sample B, c sample C, and d sample D

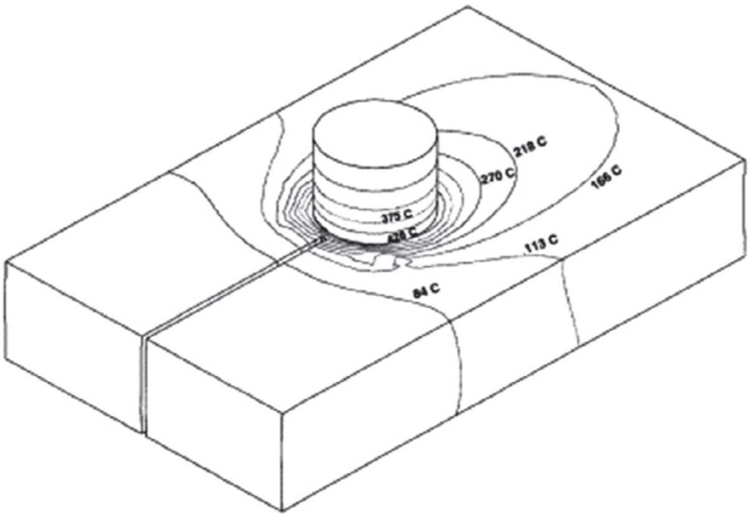
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 02 Issue 02
February 2015

Ulysse presented an attempt [15] to describe the FSW process using 3D viscoplastic FE modeling. Parametric studies were conducted to determine the effect of various tool speeds on plate temperatures and to validate the model predictions using available measurements. The model can be useful in designing welding tools which will yield the desired thermal gradients. The FE mesh And the temperature distribution are showed in Fig. 6.



(a) FE mesh of the FSW model

(b) Predicted isotherms (in °C) on an enlarged view of the stir-welding tool.



(c) Temperature contours (in °C) on the tool and workpiece surfaces.

Fig. 6. FE mesh and the temperature distribution in the FSW process [15]

A 3D FE model with general validity for different joint configurations was used by Buffa et al. [16] to simulate the FSW process of butt joints through a single block approach. The model is able to predict the residual stresses by considering thermal actions only. A good agreement between calculated and experimentally measured data was found. The effectiveness of the presented numerical procedure was evaluated by comparing the calculation times of the proposed method with the ones of already known FE approaches. Figs. 7 show the configurations and the residual stress distribution simulation of the FSW joint separately.

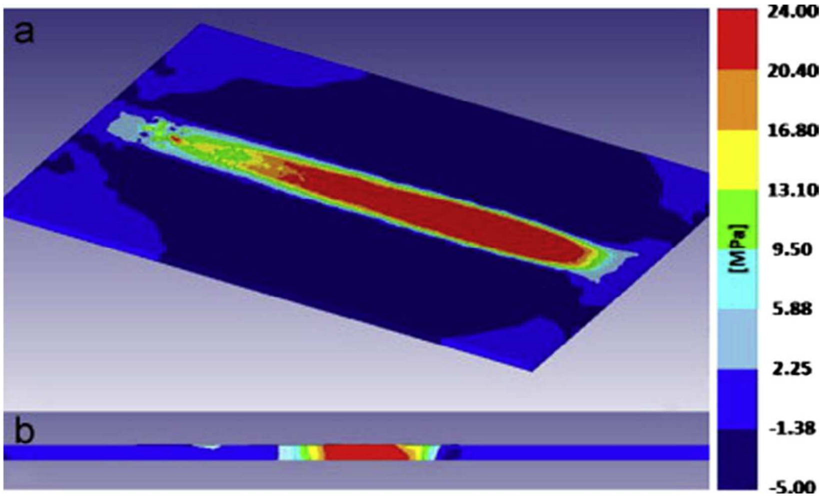


Fig. 7. Longitudinal residual stress distribution (a) on the top surface and (b) in a transverse section of the joint—500 rpm and 225 mm/min case study [16].

Welding of dissimilar metal:

Pouya Bahemmat et al [5] evaluate the weldability of two dissimilar Aluminum alloys I,e AA2024-T4 and AA7075-O by using the macrostructural analysis to observe whether making a notch in a threaded cylindrical tool will lead to a better blend rather than the threaded taper tool or it will have no effects. The mechanical properties of the welds are studied through micro hardness distribution and tensile tests. Furthermore, the microstructure analysis is performed to study the influence of the pin profile and the rotational speed on the grain size. And they find out that heat generation and the heat dissipation patterns which are mainly controllable by adjusting the welding and rotational speeds, were two significant parameters in determining a sound weld and they told that on increasing the rotational speed and reducing the welding speed culminated in a decrease in the overall hardness value in the SZ. Fig. 8 to 11.

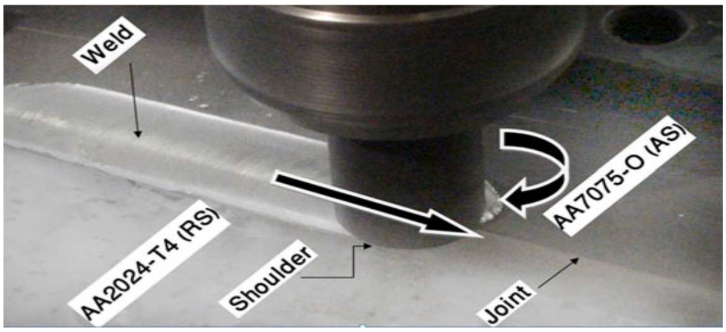


Fig. 8 Schematic representation of FSW principle [5]

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 02 Issue 02
February 2015

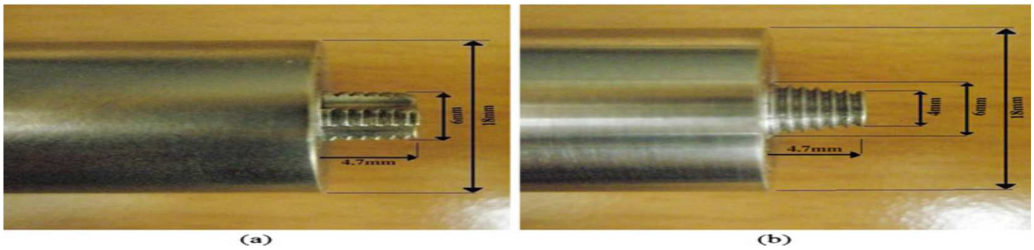


Fig. 9 the geometries of tools (a) threaded 4-flute tool (b) threaded taper tool [5]

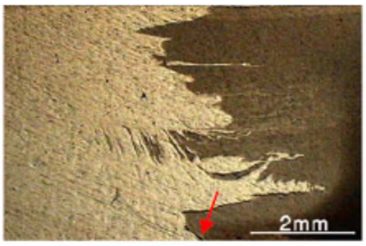
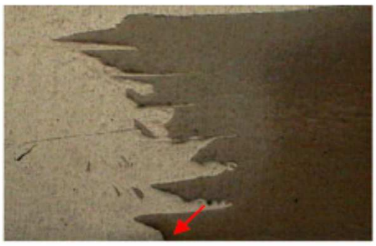
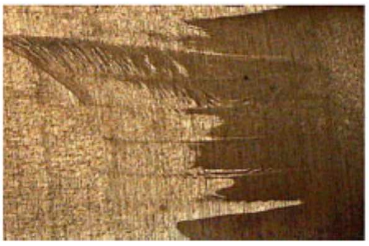
Welding speed / Rot. Speed	50 (mm/min) AS AA7075-O — RS AA2024-T4	80 (mm/min) AS AA7075-O — RS AA2024-T4
500 rpm	a) 	d) 
800 rpm	b) 	e) 
1100 rpm	c) 	f) 

Fig. 10 Macrostructure figures of weld cross-section for different welding and rotational speeds (threaded taper tool) [5]

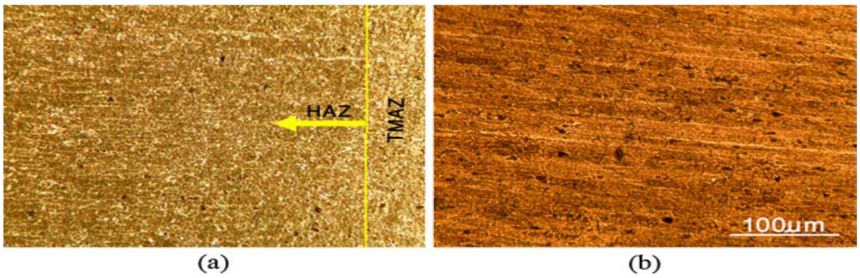


Fig. 11 a the microstructure of TMAZ and HAZ on AA7075 side and b the microstructure of HAZ on AA2024 side [5]

Sadeesh P et al [6] used the five different tool for joining of dissimilar AA2024 and AA6061 aluminium plates of 5mm thickness and optimize the process parameters using statistical approach. Effect of welding speed on microstructures, hardness distribution and tensile properties of the welded joints were investigated by varying the process parameters, defect free and high efficiency welded joints were produced. The ratio between tool shoulder diameter and pin diameter is the most dominant factor. From microstructural analysis it is evident that the material placed on the advancing side dominates the nugget region. The hardness in the HAZ of 6061 was found to be minimum, where the welded joints failed during the tensile studies. Fig.12 & 13

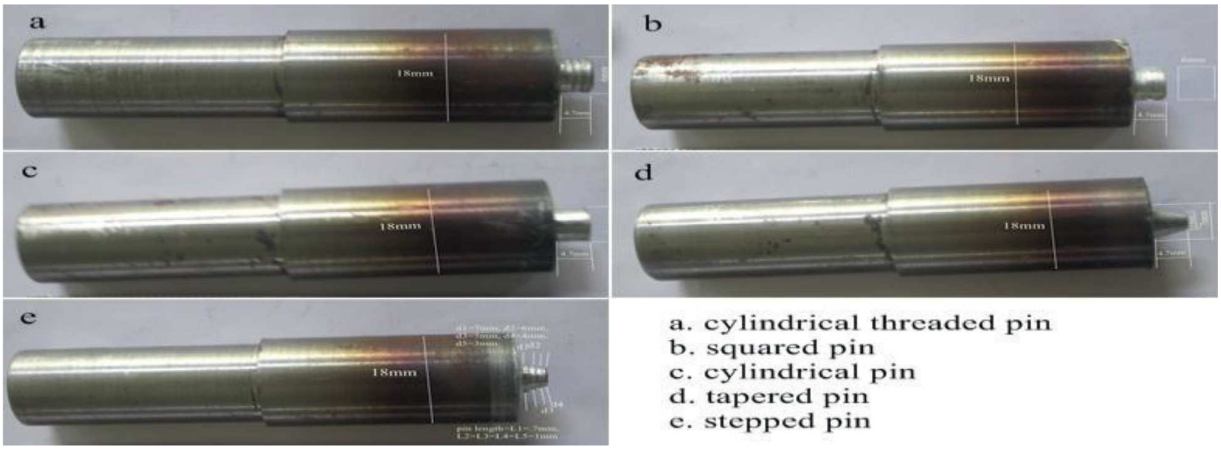


Fig.12 shows the tool diagram used for this experimental work [6]

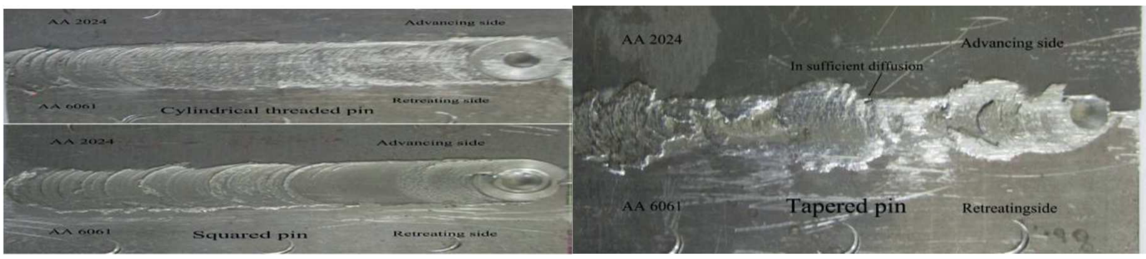


Fig.13, Surface morphologies of weld, a- without defects, b- with defects. [6]

International Journal of Research
Available at http://internationaljournalofresearch.org/
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 02 Issue 02
February 2015

Finally they optimized the process parameters with respect to mechanical and metallurgical properties of the Weldments. It is inferred that the rotational speed of 710 rpm, traverse speed of 28mm/min and D/d ratio of 3, for cylindrical pin, is considered to be the most efficient. Furthermore, better mechanical properties were observed with 6 mm squared pin, rotational speed of 1000 rpm and traverse speed of 40mm/min. in addition, the cylindrical threaded and squared pin tool profile are found to be the best among other tool profiles that were considered.

R. K. Kesharwani et al [7] presents multi objective optimization of parameters affecting weld quality in tailored friction stir butt welding of 2.0 mm thin dissimilar sheets of AA5052-H32 and AA5754-H22 using Taguchi grey based approach. AA5052-H32 and AA5754-H22 sheets have been used for fabrication of dissimilar metal tailored friction stir butt welded blanks, because of their wide applications in automotive car body panel and marine industries etc. Sheets of dimensions 200mmx100mmwere cut from bulk sheet with the rolling direction, and the cut edges were filed to make them smooth. And finally they conclude that 1800 rpm of tool rotational speed, 50 mm/min worktable translational speed, 20 mm of tool shoulder diameter and square pin geometry are the optimum parameters for fabrication of AA5052-H32 and AA5754-H22 dissimilar 2.0 mm thin tailored friction stir butt welded blanks. Fig. 14 & 15

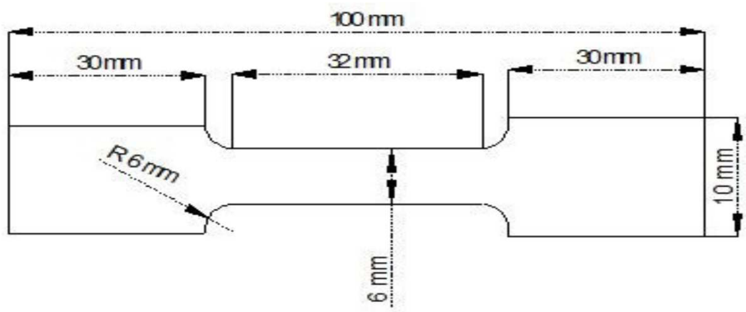


Fig. 14 ASTM E-08 sub size tensile test specimen. ASTM E-08 sub size tensile test specimen.[7]

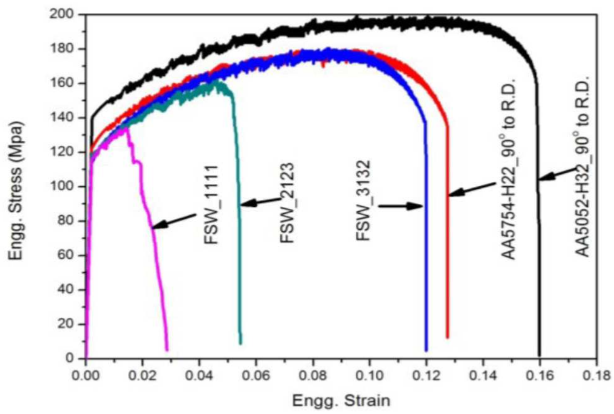


Figure .15. Typical engineering stress strain curves for both BM and TFSWBs [7]

Huseyin Uzun et al [10] welded dissimilar metal I,e Al 6013-T4 alloy and X5CrNi18-10 stainless steel by friction stir welding. Microstructure, hardness and fatigue properties of fiction stir welded 6013 aluminium alloy to stainless steel have been investigated. Results show that FSR can be used the joining of dissimilar Al 6013 alloy and X5CrNi18-10 stainless steel. A good correlation between the hardness distribution and the welding zones are observed in this studied. Fig. 16

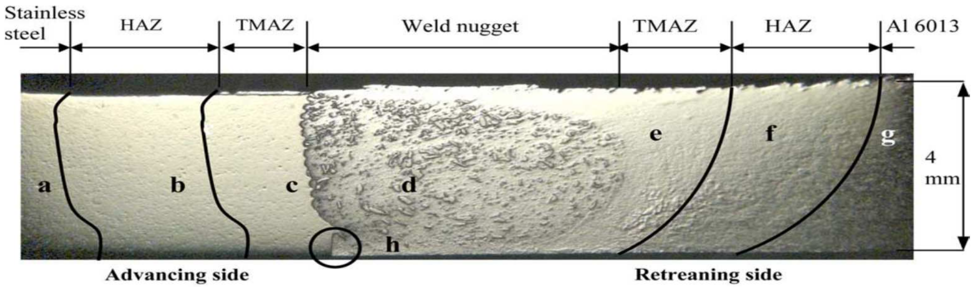


Fig. 16 Macroscopic overview of the cross-section of the friction stir welded Al 6013-T4 alloy to X5CrNi18-10 stainless steel [10]

and they told that hardness value slightly decreases in the TMAZ at the advancing side (Al 6013-T4 alloy side).The minimum hardness indicated to the HAZ in the Al 6013-T4 alloy is located around 6 to 11 mm from the weld Centre at the retreating side and Fatigue properties of Al 6013-T4/stainless steel joints were found to be approximately 30% lower than that of the Al 6013-T6 alloy base metal.

Banglong Fu, et al [11] joined the two different material 6061-T6 aluminum alloy to AZ31B magnesium alloy at 600–800 rpm. When Mg was on advancing side, tool offset to Mg 0.3 mm, and the tensile strength of the joints could reach up to 70% of that of Mg base metal. Heat input in Al–Mg dissimilar metal FSW could be calculated accurately based on measuring x-axis torque and spindle torque and they told that Sound defect-free FSW joints could be obtained with the combination of intermediate rotation rate (ω = 600–800 rpm) and low traverse speed (v = 30–60 mm/min) by placing Mg on advancing side, tool offsetting to Mg 0.3 mm. The tensile strength obtained could reach up to 70% of that of the Mg base metal heat input increased, and it decreased with the increase of rotation rate and traverse speed.

J.F. Guo et al [12] Dissimilar AA6061 and AA7075 alloy have been welded with a variety of different process Parameters and they investigated the microstructure, micro hardness distribution and tensile property of the joints. It was revealed that the material mixing is much more effective when AA6061 alloy was located on the advancing side and multiple vortexes centers formed vertically in the nugget. It was found that the tensile strength of the dissimilar joints increases with decreasing heat input. Fig. 17 & 18

International Journal of Research
Available at http://internationaljournalofresearch.org/
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 02 Issue 02
February 2015

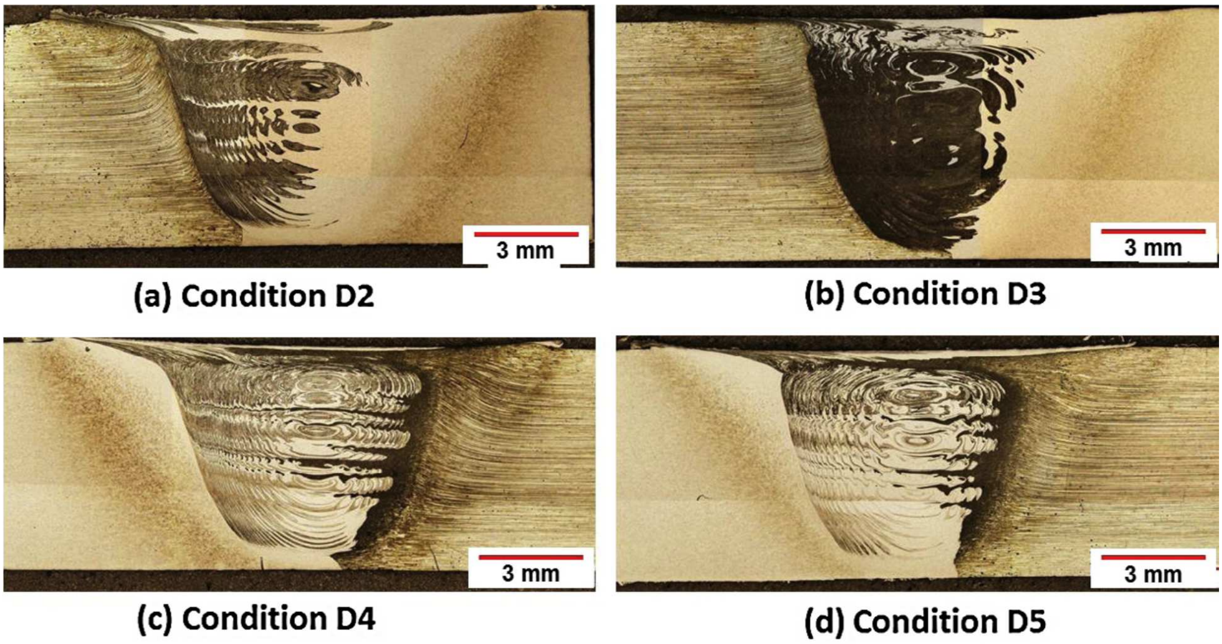


Fig. 17 Macro-views of the cross sections of joints produced under different conditions [12]

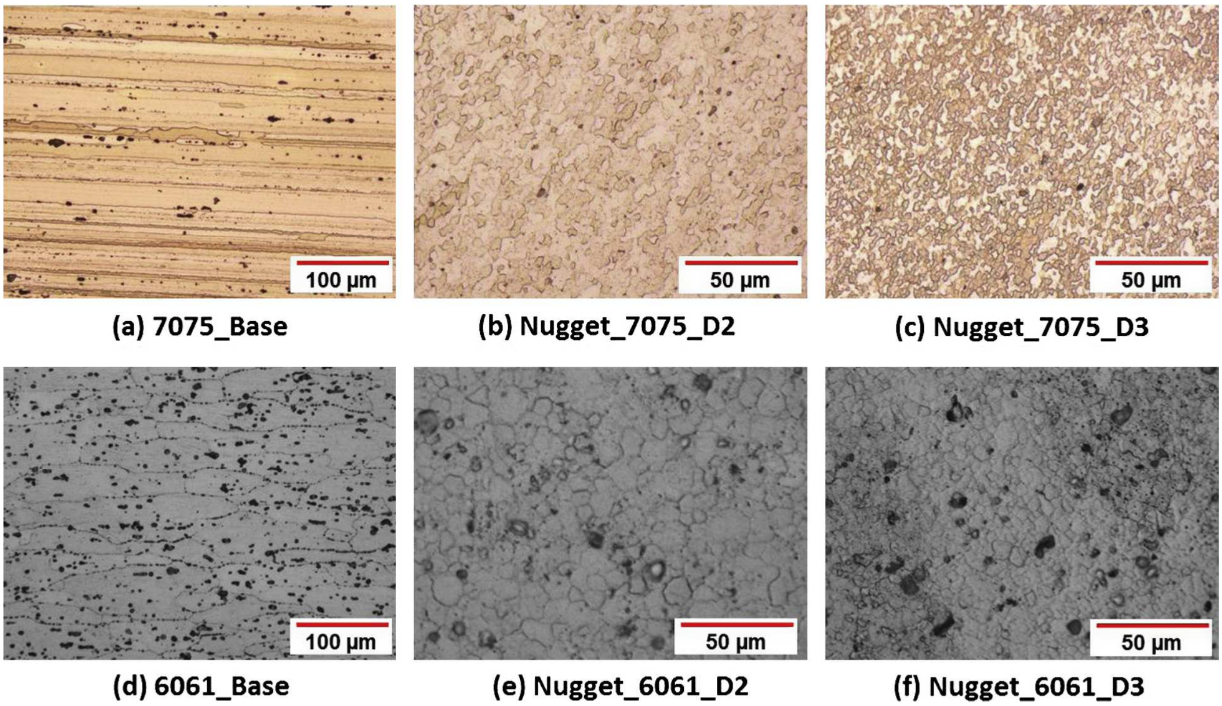


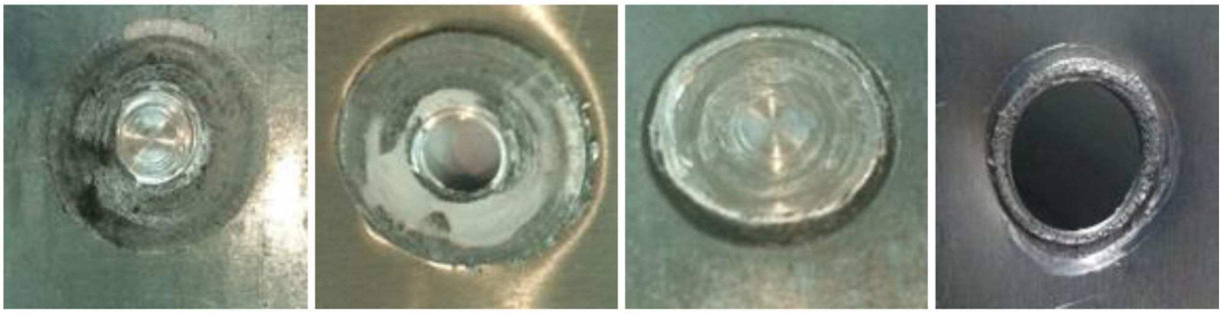
Fig.18 Optical micrographs showing the grain structures of different alloy sub-layers in the nugget zones of the dissimilar welds and the two base metals[12]

And they find out that the material mixing is much more effective when AA6061alloy was located on the advancing side and multiple vortexes centers formed vertically in the nugget center. Both AA6061 and AA7075 alloys have experienced dynamic recrystallization and the grain size in both alloys decreases significantly with the

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 02 Issue 02
February 2015

increase of welding speed and minimum hardness values are observed in the HAZ on the AA6061 side regardless of the relative materials position or the applied process parameters.

Sladjan Lazarevic et al [14] studied about the welding of two dissimilar material, the significant process parameters were identified and their optimized settings for the current experimental conditions defined using a design of experiments methodology. A scanning electron microscope was used to characterize the bonding and joint structure for single and multi-pin configurations. Two failure modes, aluminum sheet peeling and bonding delamination, i.e. braze fracture, were identified and they found that the presence of zinc coating on the steel and overall joint geometry greatly affected the joint strength. The aluminum–zinc braze joint appears to be the largest contributor to joint strength for the single-pin joint configuration. Fig. 19



(a) Steel workpiece (b) Al workpiece (c) Steel workpiece (d) Al workpiece

Fig. 19 Failures modes: (a) and (b) bonding delamination mode with the torn aluminum inside of the ring of delamination. (c) and (d) aluminum sheet peeling mode showing a ring of aluminum bonded to the steel [14]

Welding speed:

D. Trimble et al [17] take an attempt to characterize the effects of tool shape and rotational speed on increasing the welding speed during the FSW of 4.8 mm thick AA2024-T3 plates. This was assessed through a combination of post weld assessment and monitoring of the tool forces generated and they conclude that it is possible to achieve good weld quality at speeds up to 355 mm/min by welding with a scroll shoulder and tri flute pin at a rotational speed of 450 rpm. Welds produced at this speed achieved a tensile strength of 93.9% of that of the parent material with relatively good ductility (8.5% tensile elongation) and the presence of no internal or surface defects Fig. 20 & 21

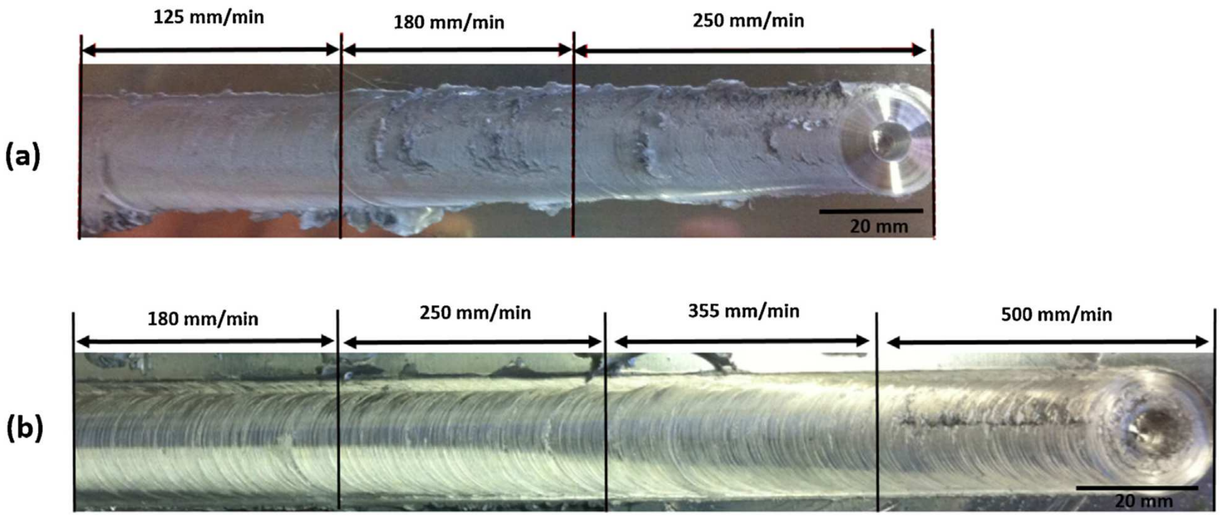


Fig. 20 Comparison of (a) concave and (b) scroll shoulders at increasing welding speed [20]

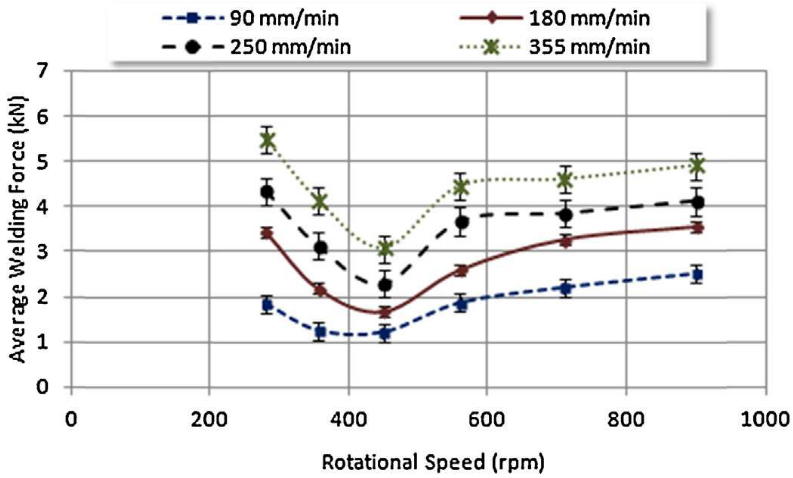


Fig. 21 Welding force with increasing rotational speed [20]

Fei Zhang et al [18] made Samples of a super high strength aluminum alloy with high Zn content were friction stir welded with rotation rates of 350–950 rpm and welding speeds of 50–150 mm/min. The effect of welding parameters on the microstructure and mechanical properties was investigated. It was observed that the grain size of the nugget zones decreased with the increasing welding speed or the decreasing tool rotation rate. The greatest ultimate tensile strength of 484 MPa and largest elongation of 9.4 were obtained at 350 rpm-100 mm/min and 350 rpm-50 mm/min, respectively. The ultimate tensile strength and elongation deteriorated drastically when rotation rate increased from 350 to 950 rpm at a constant welding speed of 100 mm/min Fig. 22

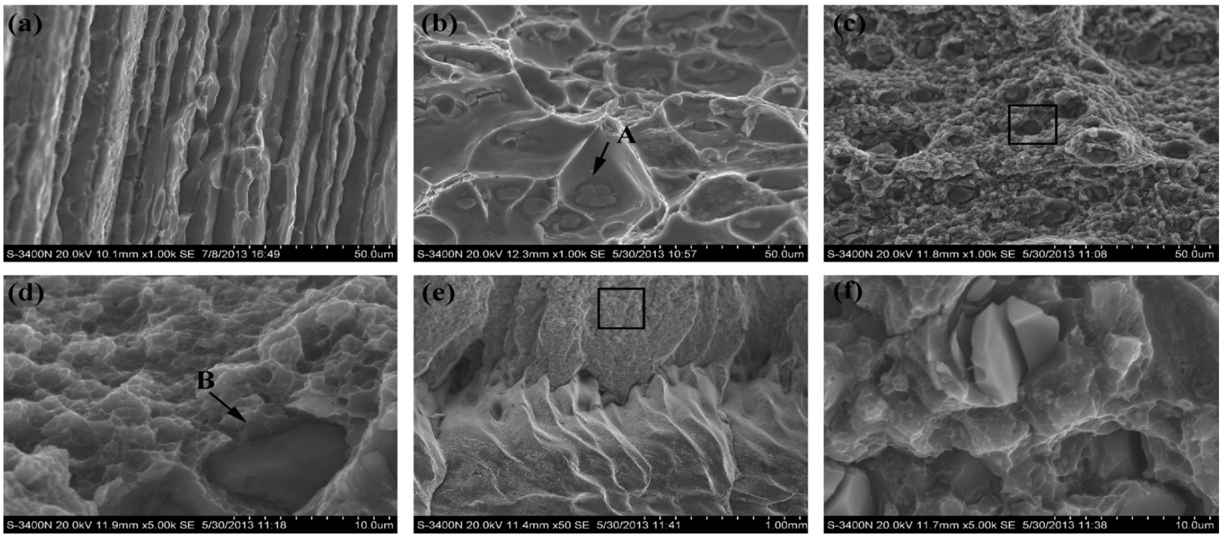


Fig. 22 SEM fractographs of (a) BM, (b) 350 rpm-50 mm/min, (c) 350 rpm-100 mm/min, (d) higher magnification of (c), (e) 650 rpm-100 mm/min, and (f) higher magnification of (e).

N. Mendes et al [19] examine the effect of main friction stir welding (FSW) parameters on the quality of acrylonitrile butadiene styrene (ABS) plate welds. welding parameters studied were the tool rotational speed which varied between 1000 and 1500 (rpm); the traverse speed which varied between 50 and 200 (mm/min), and the axial force ranging from 0.75 to 4 (kN) and they conclude that Good quality welds are achieved without using external heating, when the tool rotational speed and axial force are above a certain threshold. Fig. 23

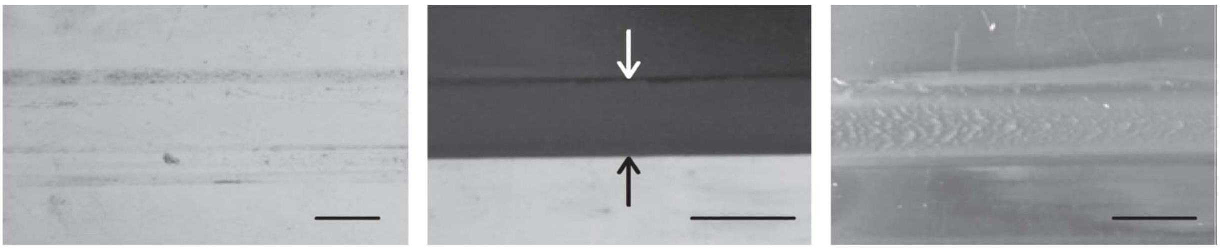


Fig. 23 Effect of traverse speed on the morphology of the weld crown: (a) R1250T50F3.75, (b) R1250T100F2 and (c) R1250T200F3.25 [19]

S.Ugender et al [20] welded the Mg AZ31B alloy by Friction stir welded with different rotational speeds of 900 rpm, 1120 rpm, 1400 rpm and 1800 rpm and with change of tool materials such as High speed steel (HSS) and Stainless steel (SS) at a constant welding speed of 40 mm/min, tilt angle of 2.5^0 and axial force of 5 KN and finally they investigated that the effect of tool material and rotational speed on microstructure and mechanical properties of that the joint fabricated using SS tool material at a rotational speed of 1120 rpm obtained higher mechanical properties as compared to those of 900 rpm, 1400 rpm and 1800 rpm and also to those of HSS material. Fig.24

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 02 Issue 02
February 2015

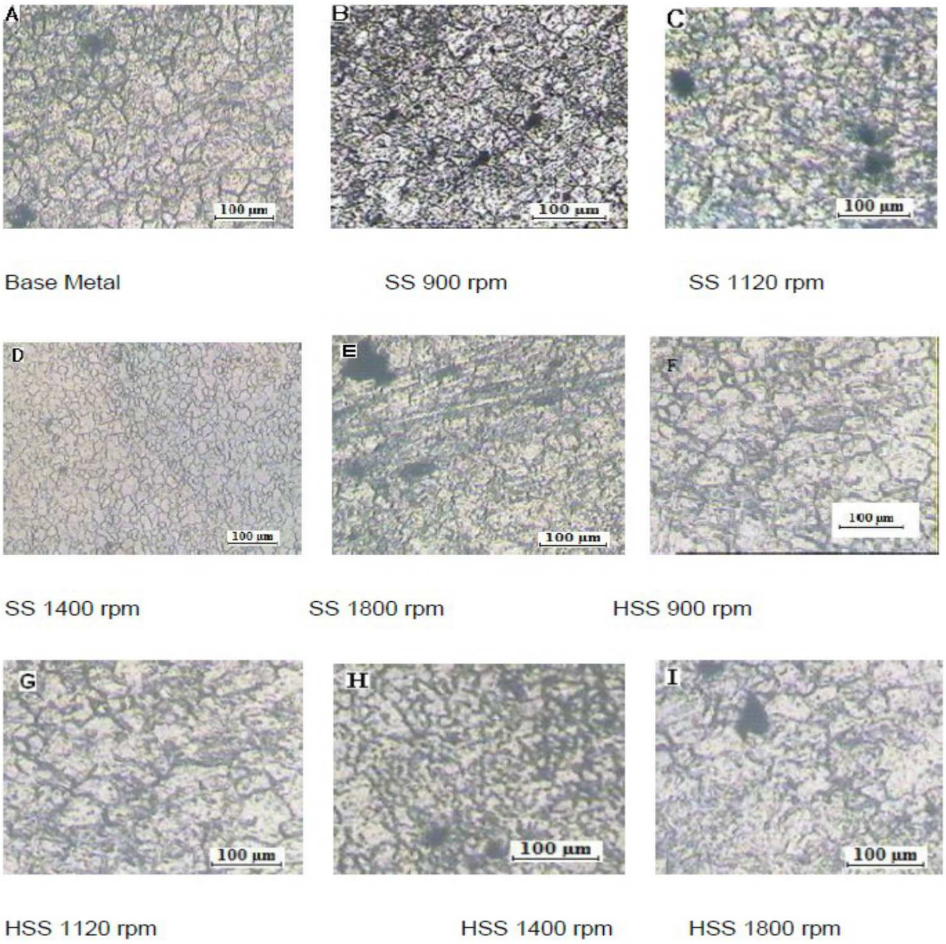


Fig.24 (A-I): Effect of tool material on stir zone Microstructure with SS tool and HSS tool [20]

Conclusion:

In this review paper, the research activities and progress to date in the development of numerical analysis of FSW are reviewed and their applicability to the manufacturing of components is emphasized. Firstly, different types of numerical methods and modeling techniques are considered; then the variables involved in numerical modeling of the FSW process are discussed. The microstructure behavior modeling of the FSW is described. The references presented in this paper are by no means complete but they comprehensively represent the application of different numerical methods on the subject area. The main goal of the paper is to review recent progress in FSW and to provide a basis for further research. Considerable residual stress and distortion can be produced by the FSW process, impeding industrial implementation. The ability to accurately predict residual stresses and the resultant distortions is a key product from simulations of assembly processes. Tool target depth is also important for producing sound welds. Shallow target depth results in generation of welds with inner channels or surface grooves. Deep target depths result in excessive flash.

REFERENCES

[1] The Welding Institute TWI. <www.twi.co.uk>.

[1] Gemme F, Verreman Y, Dubourg L, Jahazi M. Numerical analysis of the dwell phase in friction stir welding and comparison with experimental data. Mater Sci Eng A 2010; 527:4152–60.

[2] Mohamed Assidi& Lionel Fourment ” ACCURATE 3D FRICTION STIR WELDING SIMULATION TOOL BASED ON FRICTION MODEL CALIBRATION” International Journal Mater Form (2009) Vol. 2 Suppl 1:327–330

[4] Mohammad Riahi & Hamidreza Nazari “Analysis of transient temperature and residual thermal stresses in friction stir welding of aluminum alloy 6061-T6 via numerical simulation” International Journal of Advanced Manufacturing Technology (2011) 55:143–152

[5] Pouya Bahemmat & Mohammad Haghpanahi & Mohammad Kazem Besharati Givi & Kambiz Reshad Seighalani “Study on dissimilar friction stir butt welding of AA7075-OAnd AA2024-T4 considering the manufacturing limitation” International Journal of Advanced Manufacturing Technology 2011.

[6] Sadeesh P, Venkatesh Kannan M, Rajkumar V, Avinash P, Arivazhagan N, Devendranath Ram kumar K & Narayanan S “Studies on friction stir welding of AA 2024 and AA 6061 dissimilar Metals” ICMAT Symposia Proceedings 75 (2014) 145 – 149

[7] R. K. Kesharwani, S. K. Panda, S. K. Pal “Multi Objective Optimization of Friction Stir Welding Parameters for Joining of Two Dissimilar Thin Aluminum Sheets” 3rd International Conference on Materials Processing and Characterization (ICMPC 2014) 6 (2014) 178 – 187

[8] Xiaocong He, Fengshou Gu & Andrew Ball” A review of numerical analysis of friction stir welding” Progress in Materials Science 65 (2014) 1–66

[9] H. Jamshidi Aval & S. Serajzadeh & A. H. Kokabi “Experimental and theoretical evaluations of thermal histories and residual stresses in dissimilar friction stir welding of AA5086-AA6061” International Journal of Advanced Manufacturing Technology October 2011

[10] Huseyin Uzun, Claudio Dalle Donne, Alberto Argagnotto, Tommaso Ghidini & Carla Gambaro “Friction stir welding of dissimilar Al 6013-T4 To X5CrNi18-10 stainless steel” Materials and Design 26 (2005) 41–46

[11] Banglong Fu, Guoliang Qin, Fei Li, Xiangmeng Meng, Jianzhong Zhang, Chuansong Wu” Friction stir welding process of dissimilar metals of 6061-T6aluminum alloy to AZ31B magnesium alloy” Journal of Materials Processing Technology 218 (2015) 38–47

[12] J.F. Guo , H.C. Chen, C.N. Sun, G. Bi, Z. Sun, J. Wei “Friction stir welding of dissimilar materials between AA6061 and AA7075 Al alloys effects of process parameters” Materials and Design 56 (2014) 185–192

[13] H. Jamshidi Aval & S. Serajzadeh & A. H. Kokabi “Theoretical and experimental investigation into friction stir welding of AA 5086” Int J Adv Manuf Technol (2011) 52:531–544

[14] Sladjan Lazarevic, Scott F. Miller, Jingjing Li, Blair E. Carlson “Experimental

analysis of friction stir forming for dissimilar material joining application" Journal of Manufacturing Processes 15 (2013) 616–624

[15] Ulysse P. Three-dimensional modeling of the friction stir-welding process. International Journal of Mach Tools Manuf 2002; 42:1549–57.

[16] Buffa G, Ducato A, Fratini L. Numerical procedure for residual stresses prediction in friction stir welding. Finite Elem Anal Des 2011; 47:470–6

[17] D. Trimble∗, G.E. O'Donnell, J. Monaghan "Characterization of tool shape and rotational speed for increased speed during friction stir welding of AA2024-T3" Journal of Manufacturing Processes xxx (2014) xxx–xxx

(2014) 1600 – 1609

[18] Fei Zhang, Xuekuan Su, Ziyong Chen and Zuoren Nie" Effect of welding parameters on microstructure and mechanical properties of friction stir welded joints of a super high strength

Al–Zn–Mg–Cu aluminum alloy" Materials and Design xxx (2014) xxx–xxx

[19] N. Mendes , A. Loureiro , C. Martins , P. Neto and , J.N. Pires" Effect of friction stir welding parameters on morphology and strength of acrylonitrile butadiene styrene plate welds" Materials and Design 58 (2014) 457–464

[20] S.Ugender, A.Kumar , A. Somi Reddy "Microstructure and Mechanical Properties of AZ31B Magnesium alloy by Friction stir Welding" Procedia Materials Science 6