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A Study on Friction Stir Welding on various Materials-A Review

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ABSTRACT:
Friction Stir Welding is the process under green technology, which uses no filler material for welding. It was developed by The Welding Institute in 1991. Friction stir welding uses axial load through the tool, with stir a joint is made. Several research scientists tried with friction stir welding by changing various parameters, such as axial pressure, tilting angle of the tool, joining metals or materials, rpm, speed rate (mm/min), pin profile, etc. The effects and defects in FSW by various parameters have been analyzed and discussed in this article

Keywords:Friction Stir Welding, Effects and Defects in FSW

Literature Review:

Many scientists have done their research on friction stir welding. In 1991, The Welding Institute, US, had developed a new concept of green technology in welding process, without adding welding filler material. This technology had developed many research works due to feasibility and due to reason it did not require any filler material or any other material for welding.

1. Many scientists research work is reviewed and their outputs of their experiments have been discussed in this work. Friction Stir Welding (FSW) with preheating treatment at 410^{o}C for 6 hours and FSW established same strength and elongation, but the former one exhibited lower yield strength comparing to later one (J. Yang et al, 2014). When Laser beam welding was done on AA6082-T6 alloy, it exhibited good fatigue strength over the FSW (L. Reis et al, 2014).The hardness measured in heat affected zone [HAZ] in AA6061 Aluminium alloy welded with dissimilar metal AA2024 aluminium alloy exhibitedlower hardness, which caused the root for lesser tensile strength (Sadeesh P et al, 2014). Friction stir welding increased the welding corruption in AA6061-T6 alloy in the welding region by inter-angular attack and pitting corrosion. The increase of intermetallic particles enhanced the corrosion(FarhadGharavi et al, 2015). The stir zone in AA6061 aluminium alloy has fine recrystallized grain and Thermo Mechanically Affected Zone (TMAZ) has coarse grain. The interface between Stir zone (SZ)and TMAZ had the poorest tensile strength location(Jawdat et al, 2015). As the welding speed increased from 3 mm/min the welding strength decreased from 630 MPa to 343 MPa(Manish P. Meshram et al, 2014).

When the good effects of FSW are considered, following are the important results have been concluded by research scientists. The ultrasonic energy has positive influence in FSW in 1060 Aluminium alloy on the parameters such as volume of deformed material, stress-strain rate and material flow velocity(Xiaochao et al, 2015). The porosity disappeared in Ni-Al Bronze (NAB-C95800) in welded zone after Friction Stir Welding(E. Senturk et al, 2014).Addition of Al_2O_3nano-particles improved defect-free surface 7075 Aluminium alloys(Mehdi Saeidi et al, 2015). Many research scientists found that tool and its design played a vital role in friction stir welding. (Sevvel P and Jai Ganesh, 2014).

2. Yadav et al found that the tensile strength of the weld of AA6106 aluminium alloy and copper was low comparing to base metal. Vinayak D. Yadav and Prof. S.G. Bhatwadekar, 2014). The deformation of larger grain in 5754 H11 aluminium alloy was very much influenced by flat shaped shoulder tool comparing to conical shaped shoulder

tool (Giuseppe Casalina et al, 2013). The rotation of higher values was not suitable Friction Stir Welding. When the experiment was conducted from 400 rpm to 1200 rpm, 800 rpm was found to be suitable for Mg-Al-Zn (AZ80) of 6mm thick alloy plates. The grain size of Nugget zone increased as the rotation rate increased. The tensile strength increased when the rotation rate was increased from 400 to 800 rpm. Moreover the efficiency of the joint was increased upto 92%, which was obtained at 800 rpm(J. Yang et al, 2014). Under FSW, preservation of fine grained microstructure in ultra fine grained alloy was studied. FSW improved material softening at stir zone. It was due to recrystallization during FSW when FSW was executed at hot rolled Al-Mg-Sc-Zr alloy, the efficiency of the joint was found to be 85% whereas in the cold rolled condition, the efficiency of the joint by FSW was found to be 57%. That showed that hot rolled sheet improved the joint efficiency(S. Malopheyey et al, 2015).

When the rpm speed was about 600-800 rpm and low transverse speed was about 30-60 mm/min, keeping magnesium on advancing side and tool offsetting to Mg 0.3 mm, the defect free Al-Mg dissimilar welding was obtained. The tensile property was improved upto 70%. The input parameter that affected the dissimilar FSW was heat input and the mixing proportion of the materials (Banglong Fu et al, 2015). The different values of surface roughness of 6061 aluminium alloys were taken and their influence on FSW strength was studied. When it was experimented, it was found that the surface with least surface roughness was found to be better than the metal with high surface roughness. Even the tensile strength was affected very much by the surface roughness of the material. The Vicker’s hardness was also improved at heat affected heat affected zone in Al 6061 alloy. The coincidence of the small tool pin and small shoulder diameter was observed with the surface roughness of Al 6061 alloy. The coefficient of friction and the temperature had significant influence in FSW of Al 6061-T6 alloy (TanmoyMedhia et al, 2015). The main force acting on the welding tool was found to be frictional force on the shoulder contact surface. The increase in rotational speed decreased the maximum fatigue stress on the pin in FSW on AA 6061-T6(Z. Zhang et al, 2015). The wide range of speeds ranging from 400 to 1000 rpm in the step of 200 rpm were used along with constant transverse speed of 100 mm/min in 7020-T6 Aluminium alloy of 4mm thickness were experimented. It was found that as the speed decreased from 1000 rpm to 400 rpm, the peak temperature decreased from 311^{o}C to 209^{o}C. This in turn increased the hardness and the tensile strength. The defect free joint were made 600, 800 and 1000 rpm with constant transverse speed of 100 mm/min. The lower rpm formed fine grain size in the FSW(A. SalemiGolezani et al, 2015).

In Aluminium Stainless steel alloy FSW, when oxide film on the stainless steel surface was removed, better FSW was achieved and even by varying the pin profiles, tensile strength upto 250 MPa could be achieved(S. Babu et al, 2015). The tool geometry design played a vital role in FSW of aluminium alloy. The pin length should be in the range of 80-95 % of the plate thickness and pin probe shape to be cylinder flat base. By using the above parameters, it was found that the FSW could be improved A5083 4mm Aluminium alloy plate(M.A.H.M. Jasri et al, 2015). In AA6061-T6 aluminium alloy weld, stationery shoulder friction weld was done. By increasing the welding speed from 100 to 300 mm/min, at constant 150 rpm, the tensile strength of the joint increased upto 77.3% of AA606-T6 aluminium alloy base metal. When the welding speed was about 100-300 mm/min, the hardness was decreased upto 60% of base metal (Dongxiao Li et al, 2014). When two dissimilar metal aluminium alloy of AA7071 and AA6061 was welded by Friction Stir Welding, the tensile strength of the metal weld had reached upto 270 MPa, when the AA6061 alloy was placed on the advancing side and when the rpm was about 1000 rpm. The lower tensile strength of about 160 MPa was achieved when the AA6061 alloy was kept on the retreating side. The above experiment showed that the metal of weaker strength should be placed on the adjoining side for the better tensile strength of the weld (N.A.A. Satharil, 2015).

When the rotational speed was increased along with the increase of axial load, the temperature was increased, but contrary to it, the temperature reduced with enhancement of welding speed(R. Ramesh, 2015). Abnormal grain growth is dependent on macroscopic heterogeneity of the structure inside friction stir welding joint(S. Yu. Mironov, 2015). In 7075 Aluminium alloy with $Zr_{15}Ti_{5}Ni_{10}Cu_{25}Al_{9}$ Bulk Metallic Glass (BMG)

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decreased first and increases as the distance increased away from the joint (Hao Zhang, 2015). When induction was used to heat High Density Polyethylene (HDPE) plate, a thermoplastic material under FSW, it enabled softening of the material which made easy for friction stir welding. The ductile property of the material played a vital role, when tool pin temperature was high. When cold tool pin was used, material turbulence played a vital role in the strength of the weld (BandariVijendra et al, 2015).The different types of tool pin had been used, tools with arched pin type and half pin type exerted high pressure than the half pin. Comparing to above pin, the offset pin type exerted less force than tool with pins of concentric type(SaeidAmini et al, 2014). In Al-Li Alloy AA2198, as the rotation speed increased, the grain size of the stirred zone increased along with decrease of density of the strengthening particles. In the thickness direction of all welds, symmetrical hardness distribution was attained. As the rotational speed increased, the tensile strength of the joint increased first and then decreased with the maximum strength efficiency of 80% (F.F. Wang, 2015). In AA8011 aluminium alloy FSW, the rotational speed of 680 rpm, the feed rate of 24 mm/min, and the tilt angle of tool of about 85 degrees gave the good weld quality(K. Palani et al, 2015). When the fatigue test was conducted between FSW of two dissimilar metals AA5754 and AA6082 and FSW of AA6082 similar metal, the fatigue strength in the former is lesser than later. That was due to hook effect in dissimilar metals under FSW(V. Infanate et al, 2015). In 6061 Aluminium alloy weld, if the tool pin profiles are changed into tapered cylindrical, triangular and square type, the triangular type pin profile produced good weld strength comparing to other welded joints produced by other pin profiles (H.I. Dawood et al, 2015). In Al6061-T6 alloy and copper Electrolytic Tough Pitch (ETP)-C11000 weld, the axial force of about 1500 N, rotational speed of about 675 rpm, welding speed of about 40 mm/min established the higher tensile strength of about 224.62 N/mm^2, whereas the rotational speed of about 510 rpm, welding speed of about 30 mm/min and the axial strength of about 1000 N established lower tensile strength of about 107.25 N/mm^2. The Friction stir welding lap weld had the maximum ultimate strength of 72.25% of the base metal of the ultimate tensile strength (G.I.Shaikh et al, 2015). When two dissimilar alloy sheet AA6082-T6 and AA2014-T6, the welding was experimented at 1000 rpm, welding speed of 40 mm/min and axial force of 11,000 N, the tensile strength was found to be good(R. Ramesh et al 2014).

After FSW, post weld heat treatment (PWHT) was conducted for AA6061 aluminiumalloy; it was found that tensile strength was increased by 4.7% after heat treatment of about 16 hours, along with the increase of hardness. The highest tensile strength was found to be 204.08 MPa comparing to simple FSW weld, tensile strength value of 166.08 MPa (R. Ahmad et al, 2015). In aluminium alloy 6061-O joint, the tool speed of about 1250 rpm, transverse speed of about 0.88 mm/sec and the axial load of 9000 kg, established a defect free joint(A. Varun Kumar et al, 2015).In thin plates of polypropylene and polyethylene, the defect was increased in retreating side of the welds, comparing to FSW in metallic materials. The material degradatation incurred due to generation of excessive heat, when the traversing speed of about 20 mm/min (ShayanEslami et al, 2015). The highest fatigue strength was about the twice of the value of AA6082 aluminium alloy (K. Krasnowski, 2015) In 6 mm thick AA6061-T6 alloy, Al_2O_3nano particles were added at adjoining joints. Here 1600 rpm and 45 mm/min speed produced good yield strength. Addition of Al_2O_3 increased tremendous wear resistance (Mohsen FarahmandNikoo et al, 2015).

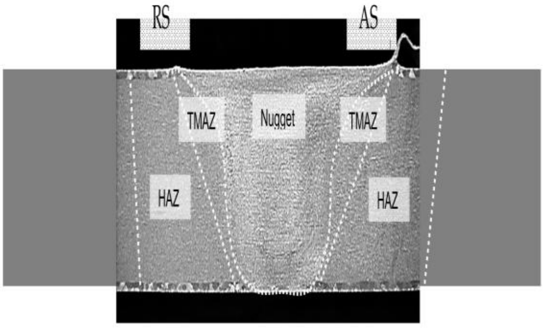

Fig.1. Zones of Friction Stir Welding (S.Kahl, 2010)

Before going to other defects in FSW, the various types of zones have to be learnt as shown in fig.1(S.Kahl, 2010).The different types of zones are Heat Affected Zone (HAZ). HAZ is the zone where there is no plastic deformation, but affected by heat, which creates the change at micro structural level.

The next zone is Thermo Mechanically Affected Zone (TMAZ) where the both plastic deformation and influence by heat takes place. The other zone is nugget, where recrystallization takes by heat affected zone. Sometimes nugget is considered as Stir zone (SZ). The Advancing Side (AS) is the side which moves along with the travel of the tool pin or along the direction of tool movement. The side which moves against the travel of the tool is called Retreating Size (RS)(S.Kahl, 2010).

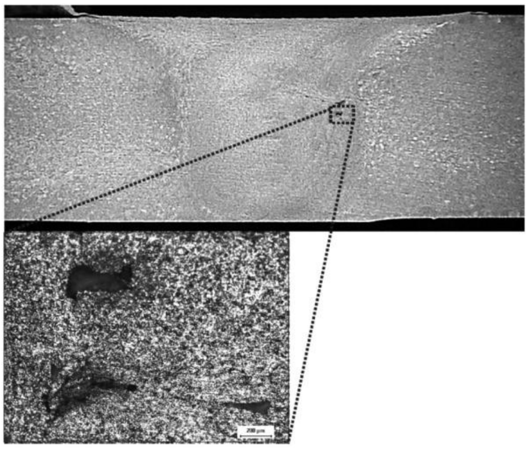

Fig.2 Friction Stir Welding with Running Void in AA6061-T6(S.Kahl, 2010)

When AA6061-T6 aluminium alloy was weld under FSW, when the tool pressure was low, the tool spinning speed rpm was very low or when there was more gap in between the welding plate, friction stir welding created a void in welding region which is shown in fig.2 and fig.3(S.Kahl, 2010).

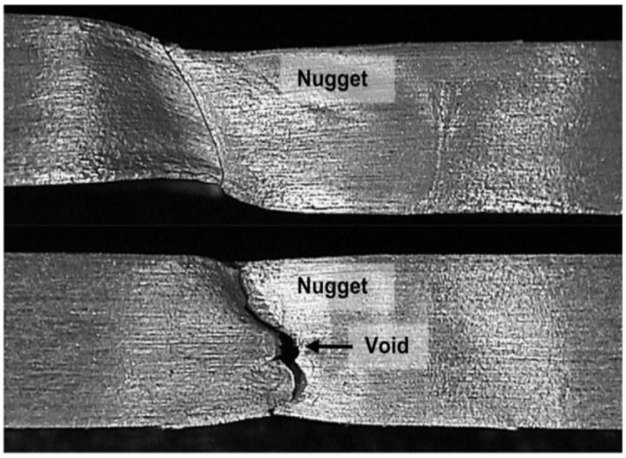

Fig.3. Friction Stir Welding with Running void in AA6061-T6 – Tensile Test(S.Kahl, 2010)

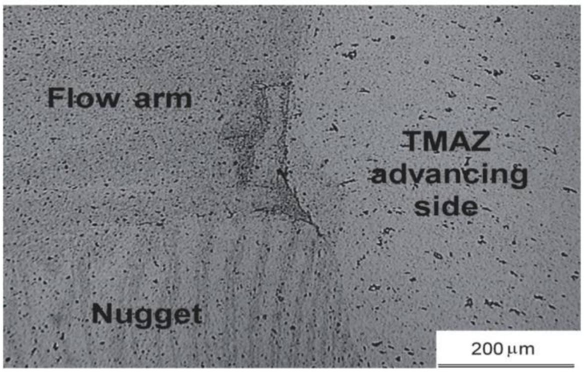

Fig.4. Initial Stage of Tunnel Defect in FSW 03 (J.Adamoswki et al, 2007)

Similarly, when the pressure on the tool was less or when the tool rpm or speed of rotation was low, then there was a chance of tunnel defect in the welded region under FSW. This is shown in fig.4 in sample 3 of aluminium alloy of AW6082-T6 (J.Adamoswki et al, 2007).

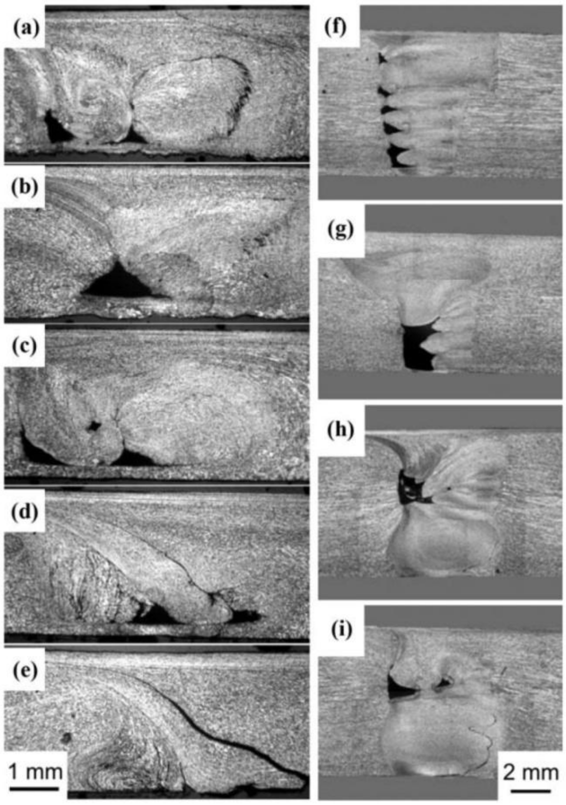

Fig.5 Tunnel Profiles- Samples (a) to (i) (Sebastian Balos et al, 2014)

The various types of tunnel defects are shown in fig.5, which depicts the tunnel profiles formed in aluminium- Magnesium alloy EN-AW 5052-H32 of size 3 mm and 8 mm thickness were taken with samples from (a) to (e) under 3 mm thickness and (f) to (i) under 8 mm thickness. Two types of tunnel defects were found such as closed tunnel defect and opened tunnel defect (Sebastian Balos et al, 2014).

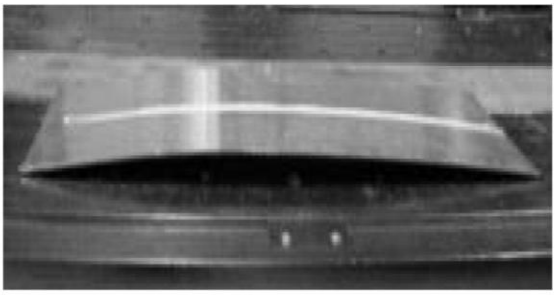

Fig.6. Distortion – FSW(Yan Dong-yang et al, 2010)

When the aluminium alloy of 6056 type was welded under FSW, the distortion of upper portion and lower portion was about 8.5 mm depicting like a saddle pattern. When the aluminium alloy of 6056 type was welded under TIG (Tungsten Inert Gas) welding, the welding was quite unlike saddle pattern under FSW(Yan Dong-yang et al, 2010).

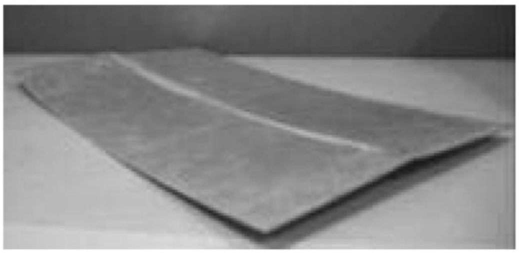

Fig.7. Distortion – TIG (Yan Dong-yang et al, 2010)

Conclusion:

The effect and defects of friction stir welding (FSW) were studied. The parameters for FSW are found to be traverse speed, pin profile, axial load, angle tilt of tool, material under weld. Based on the above parameters various methods of production were involved for study of characteristics of the materials after FSW and there is a wide scope further for investigation of FSW by changing the methodology, materials, etc. In this study we observed from various papers that,

Spindle speed is a predominant factor and proper selection of speed could give defect free high tensile strength welded joint. Higher spindle speed and lower transverse feed produces defect free weld joint.

Lower spindle speed and transverse feed could give better weld joints for the ferrous materials. Grain size refinement at the stir zone increases the hardness and gives strength to the joints. Formation of intermettallic compound influences the welding strength and effectiveness of the joint.

Proper Selection of tools and tool pin profile of the tool improves the quality of the weld joint. Especially square pin profile gives more strength and defect free weld joint.

In this study we conclude that the optimized process parameters and selection lead to sound weld joints for various combinations of metals and non metals

Reference:

- A.SalemiGolezani and R. VatankhahBarenji, A. Heidarzadeh and H. Pouraliakbar, "Elucidating of tool rotational speed in friction stir welding of 7020-T6 aluminum alloy", International Journal of Advanced Manufacturing Technology, May 2015.
- Varun Kumar and M. Balasrinivasan, "Influence of Process Parameters on Aluminium Alloy 6061-O Joints by Friction Stir Welding Process", Bonfring International Journal of Industrial Engineering and Management Science, 2015, Vol. 5, No. 3.
- BandariVijendra and Abhay Sharma, "Induction Heated Tool Assisted Friction Stir welding (i-FSW): A Novel Hybrid Process for Joining of Thermoplastics", Journal of Manufacturing Porcesses, July 2015.
- Banglong Fu, Guoliang Qin, Fei Li, XiangmengMeng, Jianzhong Zhang and Chuansong Wu, "Friction stir welding process of dissimilar metals of 6061-T6 aluminum alloy to AZ31B magnesium alloy", Journal of Materials Processing Technology, 2015, Vol.218, pp.38–47.
- Dongxiao Li, Xinqi Yang, Lei Cui, Fangzhou He and HaoShen, "Effect of welding parameters on microstructure and mechanical properties of AA6061-T6 butt welded joints by stationary shoulder friction stir welding", Materials and Design, 2014, Vol.64 pp.251–260.

- E. Senturk, T. Kucukomeroglu, G. Cam and G. Purcek, "Effect of Stir Intensity on Microstructure during Friction Stir Welding of Nickel-Aluminum Bronze", Conference in NANOSPD6, Metz, France, June 30 - July 4, 2014, Nanomaterials by Severe Plastic Deformation.
- FarhadGharavi, Khamirul Amin Matori,RobiahYunus, NorinsanKamil Othman and FirouzFadaeifard, "Corrosion behavior of Al6061 alloy weldment produced by friction stir welding process" Journal of Materials Research and Technology, March 2015.
- F.F. Wang , W.Y. Li, J. Shen, S.Y. Hu and J.F.dos Santos, "Effect of tool rotational speed on the microstructure and mechanical properties of bobbin tool friction stir welding of Al–Li alloy", Materials and Design, 2015, Vol.86, pp.933–940.
- Giuseppe Casalino, Sabina Campanelli and Michelangelo Mortello, "Influence of Shoulder Geometry and Coating of the Tool on the Friction Stir Welding of Aluminium Alloy Plates", 24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013, Procedia Engineering, 2014, Vol.69, pp.1541 – 1548.
- G. I. Shaikh1 and U. A. Dabade, "Experimental Investigation on Friction Stir Welding of Dissimilar Metals", 5th National Conference on "Recent Advances in Manufacturing (RAM-2015)", 15-17 May, 2015.
- Hao Zhang, Yunzhuo Lu, Yongjiang Huang, Aihan Feng, Zuoxiang Qin and Xing Lu, "Joining of Zr51Ti5Ni10Cu25Al9 BMG to aluminum alloy by friction stir welding", 2015, Vacuum, Vol.120, pp.47-49.
- H. I. DAWOOD, Kahtan S. MOHAMM ED, Azmi RAHMAT and M. B. UDAY, "Effect of small tool pin prof iles on microstructures andmechanical properties of 6061 aluminum alloy by friction stir welding", Transactions of Nonferrous Metals Society of China 2015, Vol.25, pp.2856 2865.
- J. Adamowski, M. Szkodo, "Friction Stir Welds (FSW) of aluminium alloy AW6082-T6", Journal of Achievements in Materials and Manufacturing Engineering, January-February 2007, Volume 20 Issues 1-2.
- Jawdat A. Al-Jarrah , Masoud Ibrahim SallamehSwalha and NabeelGhraibeh, "Effect of Applied Pressure on Mechanical Properties of 6061 Aluminum Alloy welded joints Prepared by Friction Stir Welding", Sylvan, April 2015.
- J. Yang, D.R. Ni, D.Wang, B.L. Xia and Z.Y. Ma, "Friction stir welding of as-extruded Mg–Al–Zn alloy with higher Al content. Part I: Formation of banded and line structures", Materials Characterization 2014, Vol.96, pp.142–150.
- J. Yang, D.R. Ni, D.Wang, B.L. Xiao and Z.Y. Ma, "Friction stir welding of as-extruded Mg–Al–Zn alloy with higher Al content. Part II: Influence of precipitates", Materials Characterization, 2014, Vol.96, pp.135–141.
- K. Krasnowski, "Technology of friction stir welding of aluminium alloy 6082 T-joints and their behaviour under static and dynamic loads", Material.-wissenchaftundWerkstofftechnik, 2015, pp.1–13.
- K.Palani and C.Elanchezhian, "MultiplePerformance Characteristics Optimization for AA8011 on Friction Stir Welding by RSM Based DEA", Applied Mechanics and Materials, 2015, Vols. 813-814, pp.451-455.
- L. Reis, V. Infante, M. de Freitas, F.F. Duarte, P.M.G. Moreira and P.M.S.T. de Castro, "Fatigue Behaviour of Aluminium Lap Joints Produced by Laser Beam and Friction Stir Welding", XVII International Colloquium on Mechanical Fatigue of Metals (ICMFM17), Procedia Engineering, 2014, Vol.74, pp.293 – 296.
- M.A.H.M. Jasri, M. Afendi, A. Ismail, and M. Ishak, "The Hardness Effect of Friction Stir Welding by MILKO 37 Milling Machine", AIP Conference Proceedings, 2015.
- Manish P. Meshram, Basanth Kumar Kodli and Suhash R. Dey, "Friction Stir Welding of Austenitic Stainless Steel by PCBN Tool and Its Joint Analyses", 3rd International Conference on Materials Processing and Characterisation (ICMPC 2014), Procedia Materials Science, 2014, Vol.6, pp.135 – 139.
- Mehdi Saeidi, Reza Abdi Behnagh, BabakManafi, Mohsen FarahmandNikoo and Mohammad KazemBesharatiGivi, "Study on ultrafine-grained aluminum matrix nanocomposite joint fabricated by friction stir welding", Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, January 2015.
- Mohsen FarahmandNikoo, Nader Parvin and Mohsen Bahrami, "Al_2O_3-fortifed AA6061-T6 joint produced via friction stir welding: The effects of traveling speed on microstructure, mechanical, and wear properties", Journal of Materials: Design and Applications, 2015
- N.A.A. Sathari1, A.R. Razali, M. Ishak and L.H. Shah, "Mechanical strength of dissimilar AA7075 and AA6061 aluminum alloys using friction stir welding", International Journal of Automotive and Mechanical Engineering (IJAME) 2015, Vol.11, pp.2713-2721.
- R. Ahmad and M.B.A. Asmael, "Effect of Aging time on microstructure and mechanical properties of AA6061 Friction Stir Welding Joints", International

Journal of Automotive and Mechanical Engineering (IJAME), 2015, Vol. 11, pp. 2364-2372.

- R. Ramesh, S. Suresh Kumar, V. Sivaraman, and R. Mohan, "Finite Element Analysis and simulation of Al 7075 alloy joints produced by Friction Stir Welding", Applied Mechanics and Materials, 2015, Vols 766-767, pp.1116-1120.
- R. Ramesh, S.M.Sivagami, A.A.MuhammadIrfan and N.Murugan, " Evaluation of Metallurgical and mechanical properties of dissimilar Aluminium alloy 2014-T6 and 6082-T6 joints produced by Friction Stir welding", Technology Letters, 2014, Vol.1, No.12 ,pp.5-9.
- SaeidAmini and M. R. Amiri, "Pin axis effects on forces in friction stir welding process", The International Journal of Advanced Manufacturing Technology, 2014, Vol.75, No.9-12.
- Sadeesh P, VenkateshKannan M, RajkumarV,Avinash P, Arivazhagan N, DevendranathRamkumar K and Narayanan S, "Studies on friction stir welding of AA 2024 and AA 6061 dissimilar metals", Procedia Engineering, 2014, Vol.5 pp.145 – 149, 7th International conference on materials for advanced technology.
- Sebastian Balos and LeposavaSidjanin, "Effect of Tunneling Defects on the joint strength efficiency obtained with FSW", Materials and technology, 2014, Vol.48, No.4, pp.491–496.
- Sevvel P and Jai Ganesh V, "A detailed investigation on the role of different ToolGeometry in Friction Stir Welding of various Metals & their Alloys", International Colloquium on Materials, Manufacturing and Metrology, ICMMM 2014, August 8-9, 2014, IIT Madras, Chennai, India.
- S. Babu, S.K. Panigrahi and G.D. Janaki Ram, P.V. Venkitakrishnan, R. Suresh Kumar, "Friction stir welding of Austenitic stainless steel to an aluminium-copper alloy", Friction Stir Welding and Processing VIII, TMS (The Minerals, Metals & Materials Society), 2015.
- ShayanEslami, Tiago Ramos, Paulo J. Tavares and P. M. G. P. Moreira, "Procedia Engineering, 2015, Vol.114, pp.199 – 207.
- S. Kahl, "The influence of small voids on the fatigue strength of friction stir welds in the aluminium alloy AA6061-T6, HERON Vol. 55 (2010) No. 3 / 4 pp.223-234.
- S. Malopheyev, S. Mironov, V. Kulitskiy and R. Kaibyshev, "Friction-stir welding of ultra-fine grained sheets of Al–Mg–Sc–Zr alloy", Materials Science & Engineering-A, 2015, Vol.624, pp.132–139.
- S. Yu. Mironov, "About Abnormal Grain Growth in Joints Obtained By Friction StirWelding", Metal Science and Heat Treatment, 2015, Vol. 57, Nos. 1 – 2.
- TanmoyMedhia, BarnikSaha Roy, SubodhDebbarma and S.C.Saha, "Thermal modelling and effect of process parameters in friction stir Welding", 4th International Conference on Materials Processing and Characterization, Materials Today: Proceedings 2, 2015, pp.3178 – 3187.
- V. Infante, D.F.O. Braga, F. Duarte, P.M.G. Moreira, M. de Freitas and P.M.S.T. de Castro, "Study of the fatigue behaviour of dissimilar aluminium joints produced by friction stir welding", International Journal of Fatigue, 2015.
- Vinayak D. Yadav and Prof. S. G. Bhatwadekar, "International Journal of Engineering Sciences & Research Technology",Vol. 3(12): December, 2014, pp.505-508.
- Xiaochao Liu, Chuansong Wu and Girish Kumar Padhy, "Characterization of plastic deformation and material flow in ultrasonic vibration enhanced friction stir welding", ScriptaMaterialia, 2015, Vol.102, pp.95–98.
- YANDong-yang, WU Ai-ping, SILVANUS Juergen, ZHANG Zeng-lei and SHING Qing-yu, "Characteristics and mechanism on the distortion of friction stir welded aluminum alloy sheet", Transactions of Joining and Welding Research Institute, 2010, Vol.39, No. 2.
- Z. Zhang and Q. Wu, "Analytical and numerical studies of fatigue stresses in friction stir welding", The International Journal of Advanced Manufacturing Technology, 2015, Vol.78:1371–1380.