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A Review on Friction Stir Welded T-Joint

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Abstract

This survey presents a literature review on friction stir welding (FSW) with a special focus on the dissimilar metal T-Joint. Friction stir welding is widely applied for similar and dissimilar metal welding. In current scenario, FSW is widely applied for several industries such as aerospace, automobile, reactors etc. FSW has an ability to weld dissimilar metals having different melting points. The main advantages of FSW process are very eco-friendly and produces less waste. Friction stir welded region have high strength, low distortion, no melt related defects. The absence of filler materials and air eliminates filler induced defect, and porosity. FSW technique is uses to produce T, lap and butt shaped welding and also used in hollow pipes, pressure vessels etc. This review shows the types, application and testing of T-joint welded by FSW process.

Keywords: Friction Stir Welding, Dissimilar Metals, T- Joint, Mechanical Testing

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I. INTRODUCTION

Friction Stir Welding (FSW) was developed and patented by The Welding Institute, Cambridge, UK in 1991 [1, 2]. FSW is a solid-state welding process, performed below the melting temperature of the material. This minimises some typical defects encountered in fusion welding such as cracking and porosity [3, 4]. FSW produces less waste, long life, high weld quality and performance. FSW process does not emit any fumes and very less impact on environment. Therefore, FSW is a green manufacturing technique due to its environmental friendly and energy efficient working process. FSW has been successfully uses to weld similar and dissimilar metals like aluminium, copper, steels, titanium, magnesium and their alloys. It can also be successfully brought to metal matrix composites (MMC) [5-7]. This technique can be used for producing T-joint, butt joint, lap joint, corner joint, spot joint and fillet joints. FSW can also use to weld hollow objects, such as tanks and pipes [8-10].

The basic principle behind FSW is a non-consumable rotating tool with a specially designed pin and a shoulder [11-13]. This pin penetrated into the metal parts needs to join. The shoulder applies a downward pressure to the work piece surface and constrains the plasticised material around the tool. Shoulder also generates heat through the friction process and causes plastic deformation in a relatively thin layer under the bottom surface of the shoulder [14, 15]. The rotating tool pin mainly drags along the welded region. The tool plasticises and mixes the adjacent material in the stir zone and creating a joint without fusion, by moving the tool along the line of joint. The main factors affecting the friction stir welding process are given below.

- Spindle speed (rpm)
- Welding speed (mm/s)
- Axial force (N)

A. Spindle Speed

Spindle speed is one of the major parameter in Friction stir welding process. Optimum spindle speed is required for obtaining good welded joints [16]. The tool rotation generates frictional heat as well as stirring and mixing the material around the tool pin. Optimum stirring and sufficient heat generation is required to produce sound joints with fine recrystallized grains. This exhibits higher wear resistance. Increase in frictional heat generation is observed with increase in tool rotational speed. Lower heat input condition prevails at lower tool rotational speeds and lack of stirring. The net result is poor consolidation of material and leads to poor wear resistance at lower tool rotational speeds. Higher tool rotational speeds lead to higher heat generation than required and release excessive stirred materials. Excessive stirring causes irregular flow of plasticized material. Micro level voids appear at higher tool rotational speeds. The generated frictional heat during welding affects the grain size. Roughening of grains takes place at higher tool rotational speeds which leads to poor wear resistance. Further the temperature distribution is influenced by tool rotational speed which may contribute to this trend.

B. Welding Speed

Welding speed is another major parameter that affects the properties of welding region. The fatigue property of the welded region is increases up to 16 mm/min and then decreases the fatigue property of the joints for further increases in welding speed. [17, 18]. The microstructure and grain size generated while welding is varies according to the increase and decrease of welding speed. The better grain size were obtained at a welding speed of 16-18 mm/min and the grain size increases on further increase of welding speed [19]. The welding speed prompts the translation of tool which in turn pushes the stirred material from front and back of the tool pin and completes the welding. The rubbing of tool shoulder and pin with the work piece generates frictional heat [18-29]. The welding speed determines the exposure time of frictional heat per unit length of weld, and subsequently affects the grain growth. Optimum exposure time and translation of stirred material will lead to good consolidation of material with fine grains. Joints experience such condition during welding will exhibit higher wear resistance.

C. Axial Force

The quality of friction stir processed (FSP) zone is controlled by the welding parameters of rotational speed, welding speed, and axial force. The optimization of all these parameters is very essential to obtain defect free joints. The formation of defect free FSP zone is influenced by both welding speed and pin profile [20]. The formation of defects and discontinuities are controlled by the parameters such as spindle speed, welding speed and axial force. These defects and discontinuities obviously influence the tensile properties of the FSW joints. The wear rate decreases as axial force increases. Further increase in axial force leads to increased wear rate. The wear resistance follows an inverse trend of wear rate as estimated. Bonding occurs in FSW when a pair of surfaces is brought in the area of inter atomic forces. Adequate axial force exceeding the flow stress of material is required to make defect free joints. Axial force propels the plasticized material in the weld zone to complete the extrusion process. Axial force is also responsible for the plunge depth of the pin.

II. DISSIMILAR METAL WELDING

The main reason for joining dissimilar metals is to reduce weight. By reducing the weight the energy efficiency in automobiles, aerospace vehicles and cryogenic engines were enhanced [5, 6]. Several welding methods are used for joining dissimilar metals but it may not be applicable for metals having wide difference in thermal properties, and those metals which have a tendency to form brittle inter-metallic compounds. Welding methods such as laser welding and arc welding have been used for joining dissimilar metals and their alloys, the poor seam surface of the weld, porosity in the welded region and the high welding cost hinder the application of these technique in practical [7]. Friction stir welding has been help to produce a sound weld without forming inter-metallic phases. Friction welding can also been produce such product but it can only perform operations in cylindrical parts. Nowadays friction stir welding has been widely applied in the industries for joining dissimilar metals and alloys having higher thermal expansions, like welding aluminium with steel. The main issue behind the dissimilar metal joining are the high difference in melting points, material flow behaviour and the microstructure evolution, FSW method has been helped to produce good welded region compared to conventional methods [30, 31]. The tool wear encountered in high melting point materials and the condition monitoring of the tool are main problem that arises in the FSW process. Aluminium and Aluminium alloys are widely applied in industries such as automobile [32], aerospace, marine etc. The joining of similar and dissimilar aluminium alloys is very much needy for these industries. These metal and alloys are welded by using conventional methods such as TIG and etc. The FSW process will provide welding region having high strength compared to conventional method [33- 35]. The welded metal has only 20% lower tensile strength and 10% higher hardness than the parent metals [36].

III. T-JOINT

Friction stir welding has been used for aerospace and aircraft industries for welding complex profiles and joining so called ‘skin and stinger’ are very often utilized for flying structural bodies. Also, FSW has been used in the fabrication industries such as ships, off-shore structures and pressure vessels. The results of wide range of experiments on T-joint parts, FSW process engineering has been developed with the aim of determining the specific process parameters that make up the soundness of the obtained T-part [37].

- T-butt joint
- T-fillet joint
- T-lap joint

A. T-Butt Joint

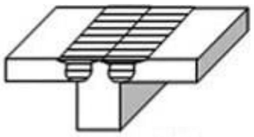

Fig. 1: T-butt joint

In T-butt joint the tool has been penetrated in to the material from the top [38- 41]. In this process a twin welding or joining process was done. The tool pin moves through the skin metal and edges of stinger as shown in figure: 1. This type of welding provide very high strength and has been applicable for skin metal having medium or small thickness. This method has been used by aerospace applications.

B. T-Fillet Joint

The T-fillet joint has been done just like the conventional method. Tool is set to 45° angle for this operations, the shoulder profile is entirely different from normal tool shoulder. This type of welding is applicable for metal plates having large thickness. The T fillet joint configuration is shown in figure: 2. Applications which need high strength will prefer this type of welding process.

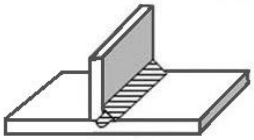

Fig. 2: T-fillet joint

C. T-Lap Joint

T-lap joint is the simplest and fastest T-joint production technique. In this method the tool penetrates to the skin metal and the contact face of the stinger is shown in figure :3 [39- 41]. The tool never moves along the stinger corners. This method is only applicable for metals having thickness range from 2 mm-7 mm. The surface finish and heat affected zone for this type of welding is low comparatively.

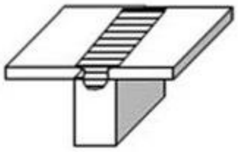

Fig. 3: T-lap joint

IV. TESTING OF WELDMENTS

There are several testing and testing procedures for welded joints. In case of T-joint, it is unusual. The available testing for T-joint are

A. Conventional testing

- Tensile test
- Bend test
- Impact test
- Hardness test

B. Non-Destructive Testing

- Ultrasonic test
- Radiographic test
- Microscopic test

V. TENSILE TESTING ARRANGEMENT

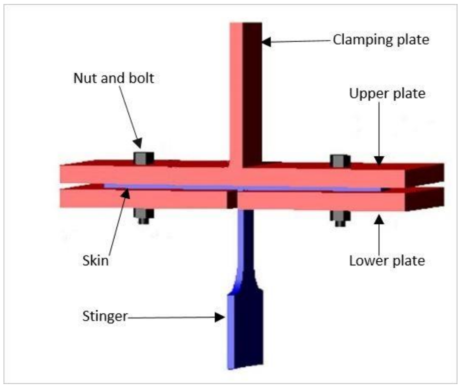

Fig. 4: Tensile testing arrangement

The prime most testing to confirm the strength of welded joint is by using tensile test. Conducting tensile test for a T-joint needs a self-made clamping device. In this method the skin is fixed in between the clamping module by using nut-bolt [42]. The clamping arrangement should have higher strength comparatively. The testing arrangement is shown in figure: 4. The dog bone shape specimen has been prepared as per ASTM standards. This is shown in Figure: 5.

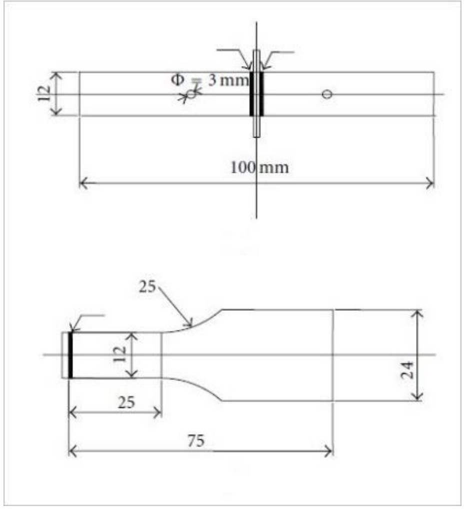

Fig. 5: Specimen preparation

VI. BEND TEST

A bend test has been carried out for the T-joint in order to calculate the punch stroke that generates the transition from elastic to plastic behaviour [43]. The experiments were carried on aluminium alloys and observed that there is strong improvement in the performance of FSW joints for the various values of the nuting angle.

VII. NON-DESTRUCTIVE TESTING

Non- destructive testing are widely applied in the field of welding. The NDT methods will help to find out the main defect in the welded region such as root flaws, lack of penetration, tunnels, and hardness of the welded region. The radiographic testing will help to find out the blowholes and flaws inside the welded region.

VIII. MICROSTRUCTURE ANALYSIS

The investigation of fatigue and fracture behaviour in the low and high cycle regime represents an important task to validate the process [44]. The fractography studies executed by employing high resolution instruments such as scanning electron microscope equipped with field emission gun has been extremely useful to detect the rupture mechanism and deduce the typology and distributions of the significant defects involved into failure.

In order to evaluate the macroscopic fracture modality, additional low magnification observations have been performed, the regions of microscopic crack initiation and stable crack growth have been identified as well as the regions which presumably have been subjected to the final failure process or overloading effects [45].

The fine-scale topography and the microscopic mechanisms governing fracture needed to be characterized [46,47]; for this purpose higher magnification observations have been performed in the zones of early microscopic crack growth to identify the size, location and number of the microscopic cracks and their progression in the material microstructure [38-52].

IX. CONCLUDING REMARKS

The review on the friction stir welded dissimilar alloys, including many recent papers provides a complete picture of both the joining methods and tensile testing procedure for T-joints [5- 7]. Although friction stir welded dissimilar metal T-joint has found many commercial applications [8, 36, and 47] such as aerospace and automobile. Expansion of the scope of its application to harder alloys will require the development of economic, wear resistant tools with necessary tool life [21-29]. In summary, significant progress has been made in FSW used dissimilar metal T-joint formation, FSW has been a cost effective and reliable welding method for aluminium and other light weight alloys [39- 41]. The abrasive metal removal happen to the tool is very high. Still now there is no attempt to produce a sustainable tool for FSW. Welding with harder alloys such as steels, titanium etc., will require considerable further development.

REFERENCES

[1] W. M. Thomas, E. D. Nicholas, J. C. Needham, M. G. Murch, P. Temple-Smith and C. J. Dawes: GB Patent no. 9125978.8, 1991.

[2] C. Dawes and W. Thomas: 'Friction stir joining of aluminium alloys', TWI Bull., 1995, 6, 124–127.

[3] A.P. Gerlicha, and T. Shibayanagi "Grain boundary sliding during friction stir spot welding of an aluminum alloy" ScriptaMaterialia 60 (2009) 236–239

[4] Ying Li, L.E. Murr and J.C. McClure "Solid-state flow visualization in the frictionstir welding of 2024 Al to 6061 Al" ScriptaMaterialia, Vol. 40, No. 9, pp. 1041–1046, 1999

[5] T. DebRoy and H. K. D. H. Bhadeshia, "Friction stir welding of dissimilar alloys – a perspective" Science and Technology of Welding and Joining 2010 VOL 15 NO 4 266, DOI 10.1179/174329310X12726496072400

[6] K. Kimapong and T. Watanabe, "Friction Stir Welding of Aluminum Alloy to Steel", welding journal 277 –s

[7] C.M. Chen, R. Kovacevic. "Joining of Al 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding" International Journal of Machine Tools & Manufacture 44 (2004) 1205–1214

[8] L Fratini, G Buffa, L Filice, and F Gagliardi, "Friction stir welding of AA6082-T6 T-joints: process engineering and performance measurement", Proc. IMechE Vol. 220 Part B: J. Engineering Manufacture, DOI: 10.1243/09544054JEM327

[9] R.A.S. Castro, V. Richter-Trummer, S.M.O. Tavares, P.M.G.P Moreira, P. Vilaça, P.M.S.T. de Castro., "Friction stir welding on t-joints: residual stress evaluation" Mecânica Experimental, 2011, Vol 19, Pgs 55-65

[10] Paul A. Fleming, Christopher E. Hendricks, D. M. Wilkes, George E. Cook, Alvin M. Strauss., "Automatic seam-tracking of friction stir welded T-joints", International Journal of Advanced Manufacturing Technology (Impact Factor: 1.21). 04/2012; 45(5):490-495. DOI:10.1007/s00170-009-1990-2

[11] K. Lakshminarayanan, V. Balasubramanian&K. Elangovan., "Effect of welding processes on tensile properties of AA6061 aluminium alloy joints" Int J AdvManufTechnol (2009) 40:286–296 DOI 10.1007/s00170-007-1325-0

[12] M. Jayaraman, R. Sivasubramanian, V. Balasubramanian, S. Babu, "Influences of Process Parameters on Tensile Strength of Friction Stir Welded" Cast A319 Aluminium Alloy Joints" Met. Mater. Int., Vol. 15, No. 2 (2009), pp. 313~320 DOI: 10.1007/s12540-009-0313-3 Published 27 April 2009

[13] P. JanakiRamulu, R. Ganesh Narayanan, Satish V. Kailas, Jayachandra Reddy., "Internal defect and process parameter analysis during friction stir welding of Al 6061 sheets" Int J AdvManufTechnol DOI 10.1007/s00170-012-4276-z

[14] M. De Giorgi, A. Scialpi, F.W. Panella1 and L.A.C. De Filippis. "Effect of shoulder geometry on residual stress and fatigue properties of AA6082 fsw joints" Journal of Mechanical Science and Technology 23 (2009) 26~35

[15] Z.Zhang, Y.L.Liu&J.T.Chen. "Effect of shoulder size on the temperature rise and the material deformation in friction stir welding" Int J AdvManufTechnol (2009) 45:889–895 DOI 10.1007/s00170-009-2034-7

[16] JinwenQian, Jinglong Li, Fu Sun, JiangtaoXiong, Fusheng Zhang and Xin Lin "An analytical model to optimize rotation speed and travel speed of friction stir welding for defect-free joints" ScriptaMaterialia 68 (2013) 175–178

[17] Kanwer S. Arora, Sunil Pandey, Michael Schaper, Rajneesh Kumar. "Effect of process parameters on friction stir welding of aluminum alloy 2219-T87" Int J AdvManufTechnol (2010) 50:941–952 DOI 10.1007/s00170-010-2560-3

[18] M. Ericsson, R. Sandstrom "Influence of welding speed on the fatigue of friction stir welds, and comparison with MIG and TIG" International Journal of Fatigue 25 (2003) 1379–1387

[19] T. Sakthivel, G. S. Sengar, J. Mukhopadhyay. "Effect of welding speed on microstructure and mechanical properties of friction-stir-welded aluminium" Int J AdvManufTechnol (2009) 43:468–473 DOI 10.1007/s00170-008-1727-7

[20] H. Abd El-Hafez "Mechanical Properties and Welding Power of Friction Stirred AA2024-T35 Joints" JMEPEG (2011) 20:839–845 DOI: 10.1007/s11665-010-9709-y

[21] Sandra Zimmer, Laurent Langlois, Julien Laye, Régis Bigot. "Experimental investigation of the influence of the FSW plunge processing parameters on the maximum generated force and torque" Int J AdvManufTechnol (2010) 47:201–215 DOI 10.1007/s00170-009-2188-3

[22] Arora "Load bearing capacity of tool pin during friction stir welding" Int J AdvManufTechnol (2012) 61:911–920 DOI 10.1007/s00170-011-3759-7

[23] M.K. Sued, Dirk Pons, Jason Lavroff, Ee-Hua Wong. "Design features for bobbin friction stir welding tools: Development of a conceptual model linking the underlying physics to the production process" Materials and Design 54 (2014) 632–643

[24] S.K. Chionopoulos1, CH.I. Sarafoglou1, D.I. Pantelis1, V.J. Papazoglou. "Effect of tool pin and welding parameters on friction Stir welded (fsw) marine aluminium alloys", Proceedings of the 3rd International Conference on Manufacturing Engineering (ICMEN), 1-3 October 2008, Chalkidiki, Greece

[25] H. K. Mohanty, M. M. Mahapatra, P. Kumar, P. Biswas and N. R. Mandal "Effect of Tool Shoulder and Pin Probe Profiles on Friction Stirred Aluminum Welds – a Comparative Study", J. Marine Sci. Appl. (2012) 11: 200-207, DOI: 10.1007/s11804-012-1123-4

[26] Mustafa Kemal Kulekci& Aydin Şik&ErdinçKaluç., "Effects of tool rotation and pin diameter on fatigue properties of friction stir welded lap joints" Int J AdvManufTechnol (2008) 36:877–882 DOI 10.1007/s00170-006-0901-z

[27] O. Lorrain, V. Favier, H. Zahrouni, D. Lawrjaniec "Friction stir welding using unthreaded tools: analysis of the flow" Int J Mater Form (2010) Vol. 3 Suppl 1:1043 – 1046 DOI 10.1007/s12289-010-0949-z

[28] K. Elangovan& V. Balasubramanian& M. Valliappan. "Influences of tool pin profile and axial force on the formation of friction stir processing zone in AA6061 aluminium alloy" Int J AdvManufTechnol (2008) 38:285–295 DOI 10.1007/s00170-007-1100-2

[29] C. Blignault, D.G. Hattingh, and M.N. James. "Optimizing Friction Stir Welding via Statistical Design of Tool Geometry and Process Parameters" JMEPEG (2012) 21:927–935 DOI: 10.1007/s11665-011-9984-2

[30] Esther T. Akinlabi Member, IAENG and Stephen A. Akinlabi, Member, IAENG. "Friction Stir Welding of Dissimilar Materials – Statistical Analysis of the Weld Data", IMECS 2012, March 14-16, Hong Kong

[31] Scialpi, M. De Giorgi, L.A.C. De Filippis , R. Nobile , F.W. Panella . "Mechanical analysis of ultra-thin friction stir welding joined sheets with dissimilar and similar materials" Materials and Design 29 (2008) 928–936

[32] W.S. Miller, L. Zhuang , J. Bottema , A.J. Wittebrood , P. De Smet ,A. Haszler , A. Vieregge. "Recent development in aluminium alloys for the automotive industry", Materials Science and Engineering A280 (2000) 37–49

[33] H.J. Liu, H. Fujii, M. Maedaa, K. Nogi. "Tensile properties and fracture locations of friction-stir-welded joints of 2017-T351 aluminum alloy", Journal of Materials Processing Technology 142 (2003) 692–696

[34] M. Ghosh , K. Kumar , S.V. Kailas , A.K. Ray., "Optimization of friction stir welding parameters for dissimilar aluminum alloys", Materials and Design 31 (2010) 3033–3037

[35] Gopi. S, Manonmani. K., "Predicting tensile strength of double side friction stir welded 6082-T6 aluminium alloy", Science and Technology of Welding and Joining 2012 Vol 17 No: 7 pp.601-607

[36] Wang Deqing, Liu Shuhua., "Study of friction stir welding of aluminium" Journal of Materials Science 39 (2004) 1689 – 1693

[37] Yuh J. Chao, Shu Liu and Chi-HuiChien. "Friction stir welding of al 6061-t6 thick plates: part i – experimental analyses of thermal and mechanical phenomena", Journal of the Chinese Institute of Engineers, Vol. 31, No. 5, pp. 757-767 (2008)

[38] CiroBitondo, Umberto Prisco, AntoninoSquilace, Pasquale Buonadonna, GennaroDionoro. "Friction-stir welding of AA 2198 butt joints: mechanical characterization of the process and of the welds through DOE analysis" Int J AdvManufTechnol (2011) 53:505–516 DOI 10.1007/s00170-010-2879-9

[39] Sarang Shah, SabriTosunoglu. "Friction Stir Welding: Current State of the Art and Future Prospects" The 16th World Multi-Conference on Systemics, Cybernetics and Informatics | WMSCI 2012 | Orlando | Florida | July 17-20, 2012

[40] R.S. Mishraa, Z.Y. Ma., “Friction stir welding and processing” Materials Science and Engineering R 50 (2005) 1–78
[41] L. Donati1, L. Tomesani1, A. Morri. “Structural T-joint produced by means of Friction Stir Welding (FSW) with filling material” Int J Mater Form (2009) Vol. 2 Suppl 1:295–298 DOI 10.1007/s12289-009-0439-3
[42] Min Li, Zhuguo Li, Yong Zhao, Hao Li, Yuhua Wang, and Jian Huang., “Influence of Welding Parameters on Weld Formation and Microstructure of Dual-Laser Beams Welded T-Joint of Aluminum Alloy” Advances in Materials Science and Engineering, Volume 2011 (2011), Article ID 767260, 6 pages.
[43] L Fratini1, G Buffa, L Filice, and F Gagliardi., “Friction stir welding of AA6082-T6 T-joints: process engineering and performance measurement” Proc. IMechE Vol. 220 Part B: J. Engineering Manufacture IMechE 2006 DOI: 10.1243/09544054JEM327
[44] P. Cavalierea, R. Nobilea, F.W. Panellaa, A. Squillace., “Mechanical and microstructural behaviour of 2024–7075 aluminium alloy sheets joined by friction stir welding” International Journal of Machine Tools & Manufacture 46 (2006) 588–594
[45] Squillace, A. De Fenzo, G. Giorleo, F. Bellucci., “A comparison between FSW and TIG welding techniques: modifications of microstructure and pitting corrosion resistance in AA 2024-T3 butt joints”, Journal of Materials Processing Technology 152 (2004) 97–105
[46] Gurmeet Singh , Kulwant Singh , Jagtar Singh., “Effect of Process Parameters on Microstructure and Mechanical Properties in Friction Stir Welding of Aluminum Alloy” Trans Indian Inst Met (August–October 2011) 64(4–5):325–330 DOI 10.1007/s12666-011-0101-x
[47] T. Sakthivel, G. S. Sengar, J. Mukhopadhyay., “Effect of welding speed on microstructure and mechanical properties of friction-stir-welded aluminium” Int J AdvManufTechnol (2009) 43:468–473 DOI 10.1007/s00170-008-1727-7
[48] M.J. Jones , P. Heurtier, C. Desrayaud, F. Montheillet, D. Allehaux , J.H. Driver., “Correlation between microstructure and microhardness in a friction stir welded 2024 aluminium alloy”, ScriptaMaterialia 52 (2005) 693–697
[49] Amir Abbas Zadpoora, Jos Sinkeb, RinzeBenedictusb, RaphPietersb. “Mechanical properties and microstructure of friction stir welded tailor-made blanks” Materials Science and Engineering A 494 (2008) 281–290
[50] Christian B. Fuller , Murray W. Mahoneya, Mike Calabresea, Leanna Miconab, “Evolution of microstructure and mechanical properties in naturally aged 7050 and 7075 Al friction stir welds” Materials Science and Engineering A 527 (2010) 2233–2240
[51] Jian-Qing Sua, Tracy W. Nelson a, Colin J. Sterling. “Microstructure evolution during FSW/FSP of high strength aluminum alloys” Materials Science and Engineering A 405 (2005) 277–286
[52] S. Rajakumar, C. Muralidharan, V. Balasubramanian. “Statistical analysis to predict grain size and hardness of the weld nugget of friction-stir-welded AA6061-T6 aluminium alloy joints” Int J AdvManufTechnol (2011) 57:151–165 DOI 10.1007/s00170-011-3279-5