

Influence of Copper and Brass on Tensile Properties of Aluminium Alloy AA6351 Friction Stir Welds

G. Gopala Krishna¹, P. Ram Reddy², M. Manzoor Hussain³

¹Associate Professor, ²Former Registrar, ³Principal

Department of Mechanical Engineering

¹J.B. Institute of Engineering and Technology (Autonomous), Yenkapally, Moinabad, Hyderabad –75,
Telangana, India,

²Jawaharlal Nehru Technological University, Hyderabad, Telangana, India

³JNTUH College of Engineering, Sultanpur, Medak District, Telangana, India.

Corresponding Author's E-mail: ¹krishkans@gmail.com

Abstract

Aluminium alloy applications are increasing day by day because of many attractive features. The combination of reduction of weight and cost is one of the attractive features of these alloys. Aluminium alloys are the best choice for the reduction of weight and as well as the cost and readily replicable steels in many applications. Friction Stir Welding (FSW) process is an efficient and cost-effective process for welding aluminium and aluminium alloys. This process gaining more importance due to a better quality of the joint as it has no effect on the parent metal. This process utilises a non-consumable rotating tool to generate frictional heat between the tool and the abutting surface of the workpiece to accomplish the process. Being a solid state welding process it offers various advantages like low distortion, absent of melt-related defects, high joint strength etc., as compared to conventional fusion welding processes. The present butt jointed FSW experimental work initially compared tensile properties of similar (AA6351 with AA6351) and dissimilar (AA6351 with AA5083). Later the effect of impurities (copper and brass) in thin sheet form (0.1 mm thick), inserted in between two similar aluminium alloy (AA6351 with AA6351) combinations during FSW. Tensile test results of similar aluminium alloy combinations using strip (copper and brass) material and without strip material were also compared.

Keywords: *Friction Stir Welding, Tensile behaviour, Aluminium AA6351 alloy, Copper and Brass.*

INTRODUCTION

Friction Stir Welding (FSW) is a new solid state welding process (that means the metal is not melted during the welding process) which is developed and patented by The Welding Institute (TWI) in 1991. This process found worldwide acceptance throughout the joining and welding community since its inception and emerged as a novel welding technique to be used for high strength alloys that were difficult to join with conventional fusion welding techniques [1]. Though the process was initially developed for aluminium and its alloys [2-10], but now it is found suitable for joining of a variety of other materials including magnesium [11,12], steel [13,14], titanium [15], copper [16,17] composites [18].

Conventional fusion welding of Aluminium alloys produces a weld which suffers from many defects such as porosity developed as a consequence of entrapped gas not being able to escape from the weld pool during the solidification process. In contrast, with FSW, the interaction of non-consumable rotating tool traversing along the joint line creates a welding joint through the plastic deformation and

consequent heat dissipation resulting temperatures below the melting point of the materials being joined. Other interesting benefits of FSW compared to fusion welding processes are low distortion, excellent mechanical properties in the weld zone, execution without a shielding gas and suitability to weld all Aluminium alloys.

The principle used for FSW is very simple and is shown in Fig. 1. A rotating tool with shoulder and pin is inserted in the material to be joined and traversed along the line of the joint. The heating is localised and generated by friction between the rotating tool (harder than the workpiece) and the workpiece, with additional adiabatic heating from deformation of the metal. The design of the shoulder and pin of the tool can be modified in a number of ways to influence the material flow and microstructural evolution.

The important advantages of FSW are low distortion, the absence of melt-related defects, high joint strength and absence of filler-induced problems since the technique requires no filler.

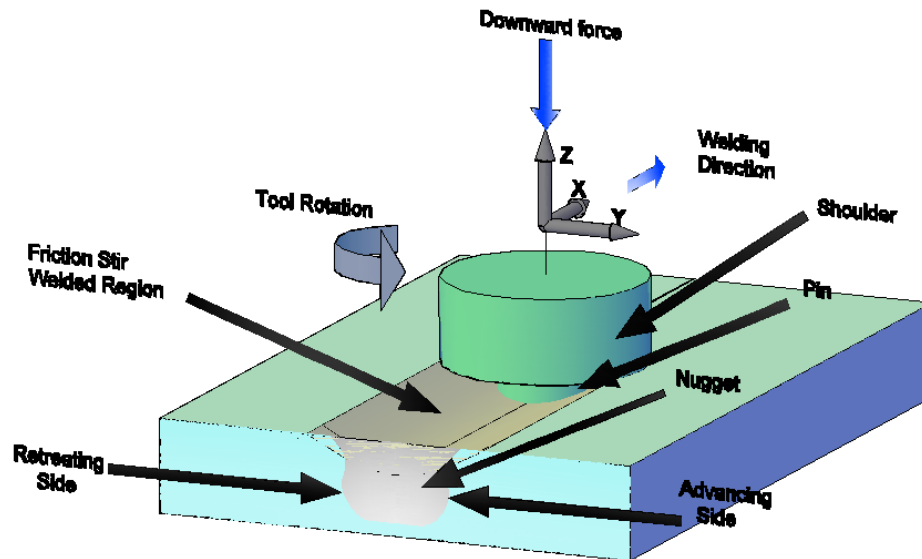


Fig.1: Schematic drawing of Friction Stir welding process

Mechanical properties can improve by various techniques in FSW process such as post weld heat treatment [19, 20], preheating the weld during the process [21], different types of peening processes [22] and overlapping weld passes [23]. Though FSW process requires no additional material during the process but the addition of alloying elements influences microstructure and improves mechanical properties in aluminium alloys [24]. So, an effort has been made to improve the mechanical properties by adding copper and brass (an alloy of copper and zinc) separately to similar aluminium alloy combination, in thin sheet form during FSW.

EXPERIMENTAL PROCEDURE

Aluminium AA6351(standard and experimental chemical composition is

shown in Table 1) and AA5083 (standard and experimental chemical composition shown in Table 2) alloys of 5 mm thickness plates were friction stir (FS) welded in butt joint configuration. Both alloys were FS welded with a different combination. Initially, similar aluminium combination, AA6351 alloy with AA6351 alloy and dissimilar aluminium combination, AA6351 with AA5083 alloy were FS welded as shown in Fig.2. Later similar aluminium alloy combination was FS welded separately with copper (99.95 % of copper) and brass (65 % of copper and 35 % of zinc) sheets of thickness 0.1 mm used as inserts in between two similar aluminium alloy (AA6351 with AA6351) plates separately as shown in Fig.3.

**Table1. Standard chemical composition and chemical composition of base material
(Aluminium alloy AA6351) used for experiments**

Element	Standard	Base material used for experiments
Si	0.8	0.7
Fe	0.5	0.357
Cu	0.1	0.037
Mn	0.4	0.35
Mg	0.4	0.3
Zn	0.2 max	0.004
Ti	0.2 max	0.024
Al	Balance	Balance

**Table2. Standard chemical composition and chemical composition of base material
(Aluminium alloy AA5083) used for experiments**

Element	Standard	Base material used for experiments
Si	0.2	0.134
Fe	0.35	0.284
Cu	0.15	0.028
Mn	0.15	0.58
Mg	5	4.466
Zn	0.25	0.006
Ti	0.1	0.021
Al	Balance	Balance

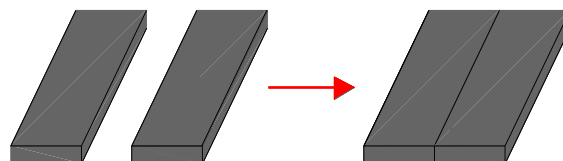


Fig.2: Process FSW of AA6351 with AA6351 and AA6351 with AA5083.

The design of tool influences heat generation, power required for plastic flow and the uniformity of the welded joint. The shoulder generates most of the heat and prevents the plasticised material from escaping from the work piece while both the shoulder and the tool pin affects the material flow. The design of the tool is a critical factor and a good tool design can improve both the quality of the weld and as well as the maximum possible welding speed.

It is desirable that the material of the tool is sufficiently strong, hard and tough wearing at the welding temperature. The tool material used in this work was high-speed steel (HSS) with conical shape probe without threads. Then the tool was

subjected to heat treatment to improve hardness, the hardness tool after the heat treatment process is 54 HRC.

A vertical Computer Numerically Controlled (CNC) milling machine was used to carry out welding process. The two plates are partitioned in the fixture which is prepared for fabricating FSW joint by using mechanical clamps so that the plates will not separate during the welding process. Two aluminium alloys were perfectly clamped in CNC milling machine bed on a back plate. The tool is plunged into the joint in the downward direction. Higher tool rotation generates temperature because of higher frictional heating and resulted in the more intense stirring of mixing material.

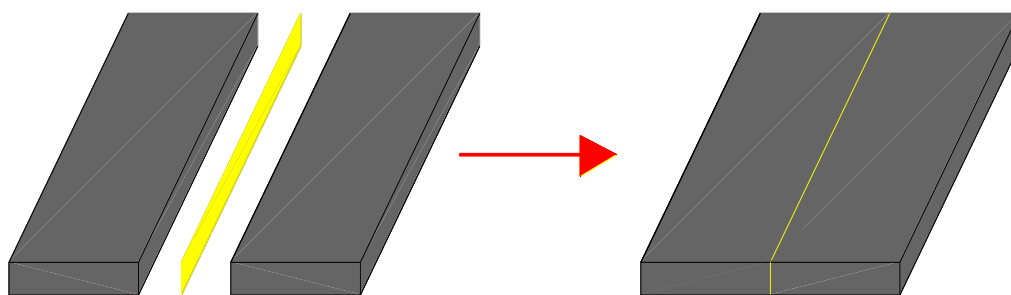


Fig.3: Process FSW of AA6351 with AA5083 with copper/brass thin sheet.

RESULTS AND DISCUSSIONS

In this study, all three combinations of Aluminium alloy AA 6351 joints were welded successfully by friction stir welding process by using six different rotational speeds of the tool. All these six rotational speeds of the tool performed for similar alloy (AA6351 with AA6351) and dissimilar alloy combinations (AA6351 with AA5083) and also for similar alloy combination alloys with copper and brass as insert materials.

Tensile tests were performed to determine the tensile properties (yield strength, tensile strength and percentage elongation) for all FS welded all combination samples. Some interesting developments of tensile properties were observed in the weldments. Tensile properties were lower at lower rotational speeds of the tool and increases with increase in rotational speeds and after reaching optimum value reverse trend has been observed i.e., tensile properties decrease with increase in rotational speed of the tool. This type of trend observed for all the combinations of alloys i.e., similar alloy, dissimilar alloy and similar alloy using strip material combinations.

Figures 4,5 and 6 shows the effect of rotational speed of the tool on yield strength, tensile strength and percentage

elongation of similar aluminium alloy combination, AA6351 alloy with AA6351 alloy and dissimilar aluminium alloy combination, AA6351 alloy with AA5083 alloy respectively. It is clear from these figures that at lower rotational speed (1000 rpm), tensile properties of both similar and dissimilar alloy combination were lower and reaches a maximum at 1300 rpm. After reaching an optimum value at 1300 rpm rotational speed, a tensile property decreases with increase in rotational speed of the tool. This type of trend coincided with authors [25 & 26].

Lower rotational speeds of the tool lowers the heat input during FSW which results in lower tensile properties because of wavy zigzag pattern formation on weldment cross section [27] and crack or pinhole defect [25]. Higher rotational speed of the tool results higher temperature at weld joint [28] which results in large size defect like tunnel [25]

Similar aluminium alloy combination AA6351 with AA6351 shows higher tensile properties compared to dissimilar alloy combination AA6351 with AA5083 because weaker alloy (AA5083) dictates the performance of the weld joint [29]

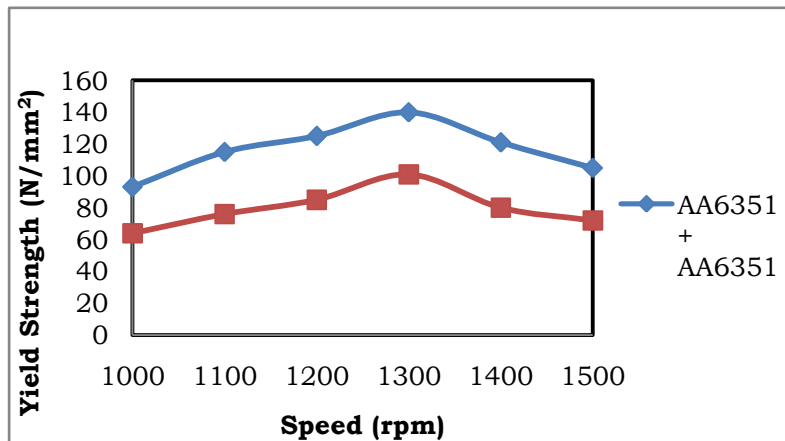


Fig.4. Effect of the rotational speed of tool on yield strength for both similar and dissimilar aluminium alloy combination.

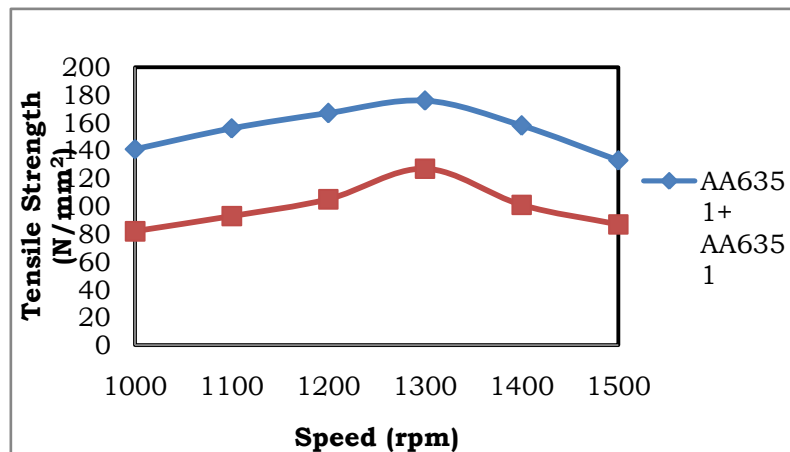


Fig.5. Effect of the rotational speed of tool on tensile strength for both similar and dissimilar aluminium alloy combination.

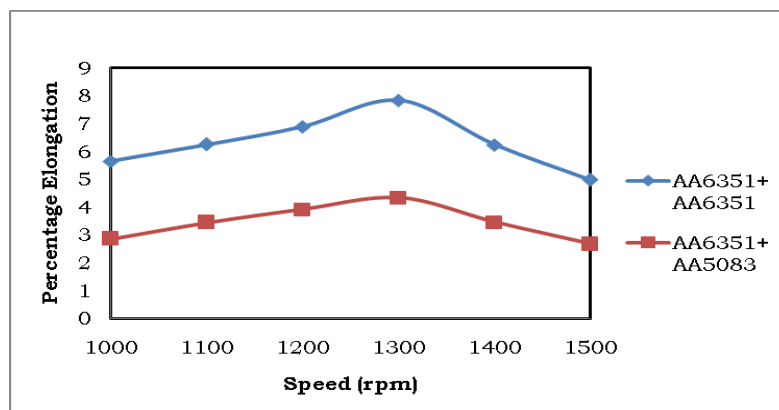


Fig.6. Effect of the rotational speed of tool on percentage elongation for both similar and dissimilar aluminium alloy combination.

Figures 7, 8 and 9 shows the effect of rotational speed of the tool on yield strength, tensile strength and percentage elongation of similar aluminium alloy combination (AA6351 with AA6351), similar aluminium alloy (AA6351 with AA5083) with copper and brass strip material respectively. It is clear from these figures that at lower rotational speed (1000 rpm), tensile properties of all the combination were lower and reaches a maximum at 1300 rpm. After reaching an optimum value at 1300 rpm rotational speed, tensile properties decrease with increase in rotational speed of the tool.

Tensile values of similar alloy combination with copper addition values are lower than the pure similar combination. Tensile values of similar alloy combination with brass addition value lower than that of both pure similar aluminium alloy combination and also of copper addition combination. The main reason for lower values for copper and brass addition are complete melting and mixing of copper and brass material was not taking place at bottom sides of the welded plates though the thickness of copper and brass sheet is too small (0.1mm).

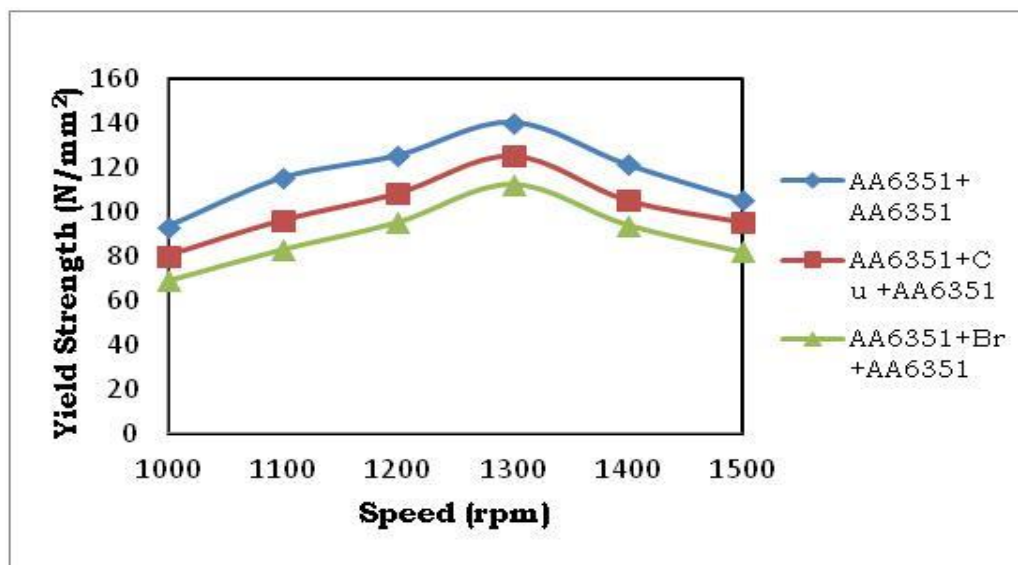


Fig.7 Effect of the rotational speed of tool on yield strength for pure dissimilar aluminium alloy, and the effect of copper and brass addition on dissimilar aluminium alloy combinations.

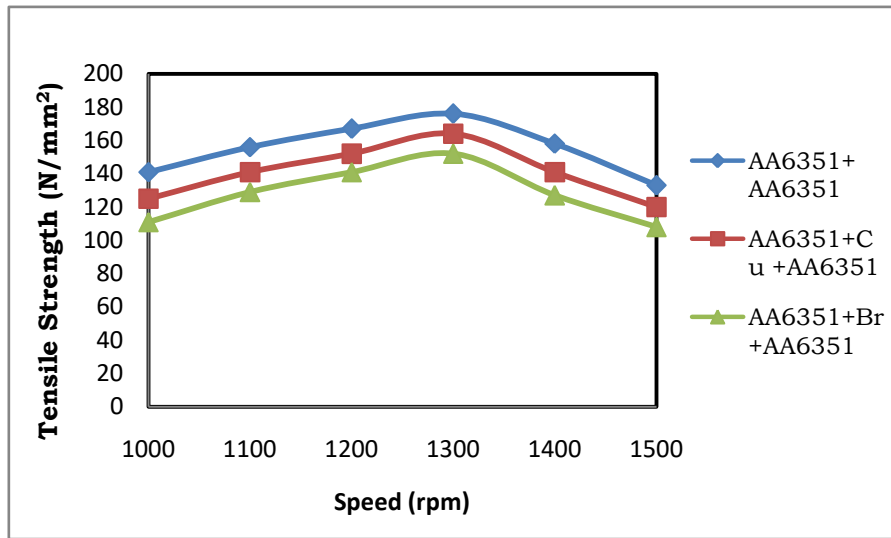


Fig.8 Effect of the rotational speed of tool on tensile strength for pure dissimilar aluminium alloy, and the effect of copper and brass addition on dissimilar aluminium alloy combinations.

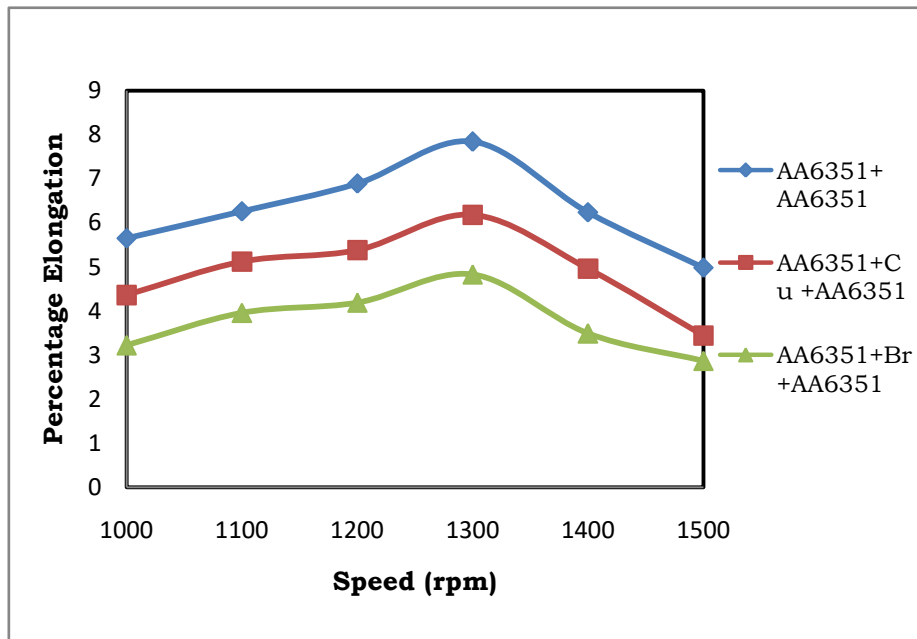


Fig.9 Effect of the rotational speed of tool on percentage elongation for pure dissimilar aluminium alloy, and the effect of copper and brass addition on dissimilar aluminium alloy combinations.

CONCLUSIONS

1. Tensile properties (yield strength, tensile strength and percentage of elongation) are increases with increase in rotational speed of the tool and after reaching an optimum value at 1300 rpm, a reverse trend has been observed, that is with an increase in rotational speed of the tool, all the tensile properties are decreasing. This type of trend is common for all types of combinations.
2. Tensile values of similar aluminium alloy combination of AA6351 with AA6351 are greater than the dissimilar aluminium alloy combination of AA6351 with AA5083.
3. Copper addition as strip material in similar aluminium alloy combination tensile properties shows less value compared to pure similar aluminium alloy combination but better than the brass addition on similar aluminium alloy tensile values.
4. Brass addition as strip material in similar aluminium alloy combination tensile properties show least values compared to both pure similar aluminium alloy combination and also

a copper addition in similar aluminium alloy combination.

REFERENCES

- I. W. Thomas, E. Nicholas, J. Needham, M. Murch, P. Templesmith, C. Dawes, 1995, Patent-Friction stir butt welding, I.P.N.PCT/GB92/02203, Editor, GB Patent No. 9125978.8, US Patent No.5.460.317. (1991).
- II. Yeong-Maw Hwang , Zong-Wei Kang , Yuang – Cherng Chiou , Hung – Hsiou Hsu, Experimental study on temperature distributions within the workpiece during friction stir welding of aluminium alloys, International journal of machine tools & manufacture, 48 (2008), pp.778-787.
- III. Hua-Bin Chen, Keng Yan, Tao Lin, Shan-Ben Chen, Cheng-Yu Jiang, Yong Zhao, The investigation of typical welding defects for 5456 aluminium alloy friction stir welds, Material science and engineering A, 433 (2006), pp. 64-69.
- IV. K. Elangovan, V. Balasubramanian, Influences of post weld heat treatment on tensile properties of friction-stir-welded AA6061 aluminium alloy joints, Material

- characterization 59 (2008), pp.1168-1177.
- V. P.M.G.P. Moreira, T. Santos, S.M.O. Tavares, V. Richter-Trummer, P. Vilaca, P.M.S.T.de Castro, Mechanical and metallurgical characterization of friction stir welding joints of AA6061-T6 with AA6082-T6, Materials and design, 30 (2009), pp. 180-187.
- VI. C. Leitaó, R.M.Leal, D.M. Rodrigues, A. Loureiro, P. Vilaca, Mechanical behaviour of similar and dissimilar AA5182-H111 and AA6016-T4 thin friction stir welds, Materials and design, 30 (2009), pp. 101-108.
- VII. W. Gan, K. Okamoto, S. Hirano, K. Chung, C. Kim, R.H. Wagoner, Properties of friction-stir welded aluminium alloys 6111 and 5083, Journal of engineering materials and technology, 130 (2008), pp. 031007-1 – 031007-15.
- VIII. W.B. Lee, Y.M. Yeon, S.B. Jung, The improvement of mechanical properties of friction-stir-welded A356 Al alloy, Material science and engineering A, 355 (2003), pp.154-159
- IX. Yutuka S. Sato, Hideki Takauchi, Seung Hwan C. Park, Hiroyuka Kokawa, Characteristics of the kissing-bond in friction stir welded Al alloy 1050, Material science and engineering A, 405 (2005), pp. 333-338.
- X. William D. Lockwood, Borislav d, A.P. Reynolds, the Mechanical response of friction stir welded AA2024: experiment and modelling, Material science and engineering A, 323 (2002), pp. 348-353.
- XI. Dr Richard Johnson, Dr Philip Threaddill, Friction stir welding of magnesium alloys, Magnesium technology 2003, Edited by Howard I. Kaplan TMS (The minerals, metals & material society), (2003), pp.147-152.
- XII. Naiyi, Li, Tsung-Yu Pan, Ronald P.Cooper, Dan Q. Houston, Zhili Feng and L. Santella, Friction stir welding of magnesium AM60 alloy, Magnesium technology 2004, Edited by Alan A. Luo TMS (The minerals, metals & material society), (2004), pp.19-23
- XIII. T.J. Lienert, W.L. Stellwag, JR., B.B. Grimmett, and R.W. Warke, Friction stir welding studies on mild steel, Welding research, Supplement to the welding journal (January 2003), pp.1s-9s.

-
- XIV. Ling Cui, Hidetoshi Fujii, Nobuhiro Tsuji and Kiyoshi, Nogi, Friction stir welding of a high carbon steel, Scripta Materialia, 56 (2007), pp. 637,640.
- XV. Yu Zhang, Yutaka S. Sato, Hiroyuki Kokawa , Seung Hwan C. Park ,Satoshi Hirano , Microstructural characteristics and mechanical properties of Ti-6Al-4V friction stir welds, Material science and engineering A, 485 (2008), pp. 448-455.
- XVI. Z. Barlas, H.Uzum, Microstructure and mechanical properties of friction stir butt welded dissimilar Cu/CuZn30 sheets, Journal of achievements in materials and manufacturing engineering, 30(2) (2008), pp.182-186.
- XVII. Ratnesh K.Shukla, Dr. Pravin K. Shah, Experimental investigations of copper joining by friction stir welding, proceedings of the international conference on emerging research and advances in mechanical engineering (ERA 2009), Velammal engineering college, Chennai-600 066, Taminadu, India. Pp.657-660
- XVIII. L. Ceschini, I. Boromei, G. Minak, A. Morri, F. Tarterini, Effect of friction stir welding on microstructure, tensile and fatigue properties of the AA7005/10 vol.%Al₂O₃p composite, Composites science and technology, 67 (2007), pp. 605-615.
- XIX. K.Elongovan, V.Balasubramanian, Influences of post weld heat treatment on tensile properties of friction stir welded AA6061 aluminium alloy joints, Materials Characterization (2008), vol. 59, pp. 1168-1177.
- XX. G.Madhusudhan Reddy, P.Mastanaiah, C.V.S.Murthy, T.Mohandas and N.Viswanathan, Microstructure, residual stress, distribution and mechanical properties of friction stir AA60611 aluminium alloy weldments, Proc. National Seminar on Non-Destructive Evaluation (Dec. 7-9, 2006) Hyderabad.
- XXI. Omid Ali Zargar, The preheating influence on welded joint mechanical properties prepared by friction stir welding aluminium alloy H20-H20, Middle East Journal o Scientific Research (2013), Vol. 15, pp. 1415-1419.
- XXII. Omar Hatamleh, Effect of peening on mechanical properties in friction stir welded 2195 aluminum alloy joints, Materials Science and
-

- Engineering A (2008), vol. 492, pp. 168-176.
- XXIII. R.M.Leal and A.Loureiroir, Effect of overlapping friction stir welding passes in the quality of welds of aluminium alloys, *Materials and Design* (2008), vol. 29, pp. 982-991.
- XXIV. R.S.Rana, Rajesh Purohith and S.Das, Reviews on the influences of alloying elements on the microstructure and mechanical properties of aluminium alloys and aluminium alloy composites, *International Journal of Scientific and Research Publications* (2012), vol. 2, pp. 1-7.
- XXV. K.Elagovan, V.Balasubramanian, S.Balu, Predicting tensile strength of friction stir welded AA6061 aluminium alloy joints by a mathematical model, *Materials and Design* (2009), vol. 30, pp. 188-193.
- XXVI. R.Palanivel, P.Koshy Mathews and N.Murugan, Development of a mathematical model to predict the mechanical properties of friction stir welded AA6351 aluminium alloy, *Journal of Engineering Science and Technology Review* (2011), vol. 4, pp. 25-31.
- XXVII. Yutako S.Sato, Hideaki Takauchi, Seung Hwan C.Park, Hiroyuki Kokawa, Characteristics of the kissing bond in friction stir welded Al alloy 1050, *Materials Science and Engineering A* (2005), vol. 405, pp. 333-338.
- XXVIII. Weifeng Xu, Jinhe Liu, Guohong Luan, Chunlin Dong, temperature evolution, microstructure and mechanical properties of friction stir welded thick 2219-O aluminium alloy joints, *Materials and Design* (2009), vol. 30, pp. 1886-1893.
- XXIX. S.T. Amancio-Filho, S.Sheikhi, J.F.dos Santos, C.Bolfarini, Preliminary study on the microstructure and mechanical properties of dissimilar friction stir welds in aircraft aluminium alloys 2024-T351 and 6056-T4, *Journal of Materials Processing Technology* (2008), vol. 206, pp. 132-142.