Mechanical Behaviour of Friction Stir Welding Joints of Aluminium alloy of AA6351 with AA6351 and AA6351 with AA5083

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***Abstract*— Modern structural application demands reduction in both the weight and as well as cost of the fabrication and production of materials. Aluminium alloys are the best choice for the reduction of weight, cost and replacing steels in many applications and Friction Stir Welding (FSW) process efficient and cost effective process. FSW is solid state welding process in which material is not melted during welding process so it overcomes many welding defects compared to conventional fusion welding process which is initially used for low melting materials. This process is initially developed for low melting materials like Aluminium, Magnesium, Zinc but now process is useful for high melting materials like steel and also for composites materials. The present study describes the effect of FSW process involving butt joining of similar Aluminium alloy combinations of AA6351 with AA6351 and dissimilar Aluminium ally combinations of AA6351 with AA5083 on the tensile, hardness and impact behaviour.**

***Keywords*— Friction Stir Welding, Tensile behaviour, Hardness behaviour, Impact strength, Aluminium alloys AA6351 and AA5083.**

I. INTRODUCTION

Friction Stir Welding (FSW) is a solid state welding process developed and patented by The Welding Institute (TWI) in 1991. It is emerged as a novel welding technique to be used in high strength alloys that were difficult to join with conventional welding techniques [1]. The process were initially developed for aluminium alloys [2-10], but since then FSW was found suitable for joining other materials like magnesium [11,12], steel [13,14], titanium [15], copper [16,17] and also composites [18].

The basic principle of FSW process is remarkably simple. Instead of a conventional welding torch, friction stir welding uses a non consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edged of the two parts to be welded and traversed along the line of the joint as shown in Fig.1. The heating is localised and generated by friction between the rotating tool and work piece, with additional adiabatic heating from metal deformation. The pin and shoulder of tool can be modified in number of ways to influence material flow and microstructural formation.

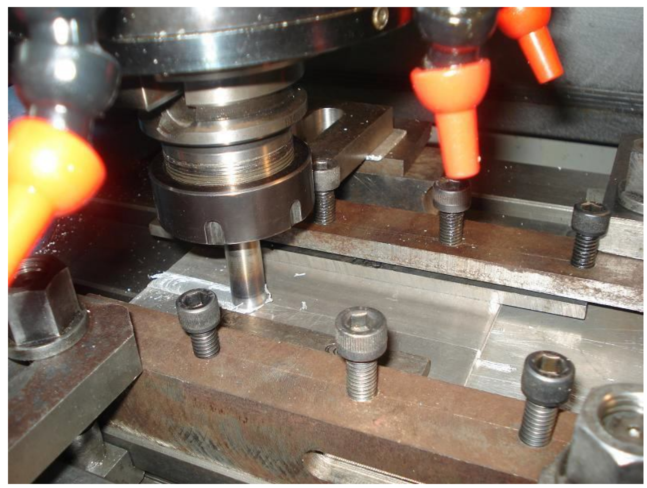

Fig.1. Friction Stir Welding Experimental Setup

II. EXPERIMENTAL PROCEDURE

A. Material

The materials used for this investigation are aluminium alloys AA6351 and AA5083 of size 150 X 60 X 5 mm. The standard chemical composition and base materials used for this experiment chemical composition are listed in table no.1 and 2 respectively. A vertical CNC (Computer Numerically Controlled) milling machine is converted in to friction stir welding machine for welding process. Mechanical properties of aluminium alloy AA6351 and AA5083 are represented in table 3.

TABLE 1
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

TABLE 2
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

TABLE 3
MECHANICAL PROPERTIES OF ALUMINIUM ALLOY AA6351 AND AA5083

Aluminium alloy	AA6351	AA5083
Hardness Brinell	95	87
Hardness Rockwell A	40	37.2
Hardness Rockwell B	60	54
Yield Strength (MPa)	283	250
Tensile Strength (MPa)	310	320
Elongation at break	14	10

B. *Welding Procedure*

Aluminium alloys of AA6351 and AA5083 were chosen for in this experimental work. Similar aluminium alloy combinations of AA6351 with AA6351 and dissimilar combinations of AA6351 with AA5083 friction stir welded in this experiment. Specially designed tool was used in this friction stir welding process. The tool material used in this work was high speed steel (HSS) with conical shaped probe without threads. The FSW tool was subjected to heat treatment process to improve hardness, the hardness of tool after heat treatment process is 54 HRC. A vertical CNC (Computer Numerically Controlled) milling machine is converted in to friction stir welding machine 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 welding process. Two aluminium alloy plates of size 150X60X5 mm were perfectly clamped in CNC milling machine bed on a back up plate. The FSW tool is inserted into the tool holder. Tool is plunged into the joint in the downward direction with a feed rate of 20 mm/min in clockwise direction. Higher tool rotation generates temperature because of higher frictional heating and results more intense stirring of mixing material.

C. *Tensile Testing*

The tensile tests were conducted to determine the tensile properties of similar aluminium alloys of AA6351 with AA6351 and dissimilar aluminium alloy of AA6351 with AA5083 friction stir weldments at different rotational speed of the tool (1000 rpm to 1500 rpm) in a Universal Testing Machine (UTM) as per ASTM standards.

D. *Hardness Testing*

Brinell and Rockwell hardness tests were performed to determine hardness of FS weldments of similar alloy combinations and dissimilar alloy combinations at different rotational speed of the tool i.e., from 1000 rpm to 1500 rpm.

E. *Impact Testing*

The Charpy impact test was performed to determine the impact energy of similar aluminium alloys combinations of AA6351 with AA6351 and dissimilar aluminium alloy combinations of AA6351 with AA5083 friction stir weldments at different rotational speed of the tool (1000 rpm to 1500 rpm) as per ASTM standards.

III. RESULTS AND DISCUSSIONS

A. *Tensile Test*

Tensile tests were performed to determine the tensile properties (yield strength, tensile strength and percentage elongation) of the aluminium alloy similar alloy combination of AA6351 with AA6351 and aluminium alloy dissimilar combination of AA6351 with AA5083. Fig.2, Fig.3 and Fig.4 shows the effect of rotational speed of the tool on tensile properties (yield strength, tensile strength and percentage elongation) of friction stir welded aluminium alloy AA6351 with AA6351 and aluminium alloy AA6351 with AA5083. It seen from these figures that at lower rotational speed of the tool (1000 rpm), lower tensile properties of the FSW welded joint were observed. When rotational speed increased from 1000 rpm onwards tensile properties were also increased and reaches maximum at 1300 rpm. If the rotational speed is increased more than 1300 rpm, a reverse trend has been observed i.e. the tensile properties of the welded joint has decreased. The optimum values observed at rotational speed of 1300 rpm were observed for both the cases.

The tensile properties and fracture locations of the welded joints are dependent on rotational speed of the tool and other process parameters like rotational speed, welding speed and axial force of the tool, tool tilt angle etc. The lower rotational speed results lower heat input and defects like crack and pinholes in friction stir processed zone and resulted lower tensile values. On the other hand when the rotational speed increases (1400 rpm and 1500 rpm), the heat input also increases which results poor tensile properties due to rise in temperature, which increases grain growth, higher rotational speed also effects in the metallurgical change like re-precipitation, solubilisation and coarsening of strengthening precipitates at the weld zone area and lowering of dislocation density [19].

Similar aluminium alloy of AA6351 with AA6351 combinations yielded superior tensile properties as compared to dissimilar aluminium alloy of AA6351 with AA5083 combinations because proper mixing of material at weld location is not taking place of different melting points of AA6351 (melting point at solidus state is 554 °C and at liquidus state is 649 °C) and AA5083 (melting point at solidus state is 591°C and at liquidus state is 638°C).

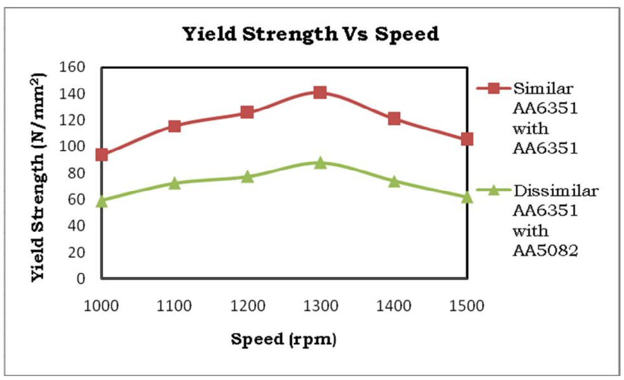

Fig.2. Effect rotational speed of the tool on yield strength.

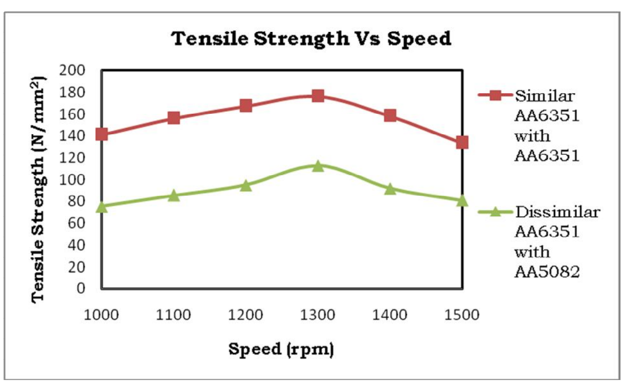

Fig.3. Effect rotational speed of the tool on tensile strength.

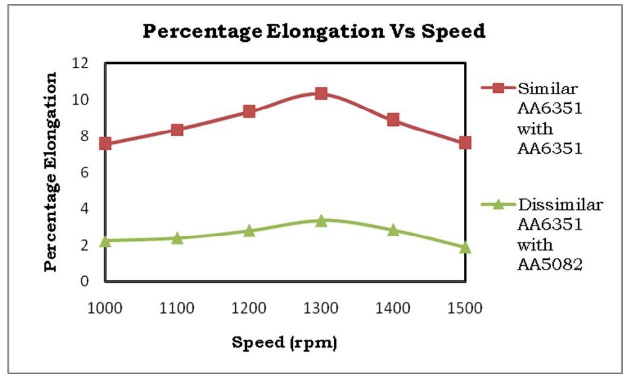

Fig.4. Effect rotational speed of the tool on percentage elongation.

B. *Hardness Test*

Hardness tests were performed to determine the Brinell hardness number and Rockwell hardness number values of the aluminium similar alloy combination AA6351 with AA6351 and aluminium dissimilar alloy combination AA6351 with AA5083 with various rotational speed of the tool. Fig.5 and 6 shows the effect of rotational speed of the tool on Brinell and Rockwell hardness numbers, it is clear from the figures that as rotational speed increases from 1000 rpm to 1300 rpm both the hardness values of the FSW joints increases, reaches maximum at 1300 rpm and decreases with further increase in rotational speed of the tool from 1300 to 1500 rpm. Out of six rotational speed of the tool used to fabricate FSW joints, the joints fabricated at a rotational speed of 1300 rpm yielded superior hardness properties for both similar and dissimilar alloy combinations.

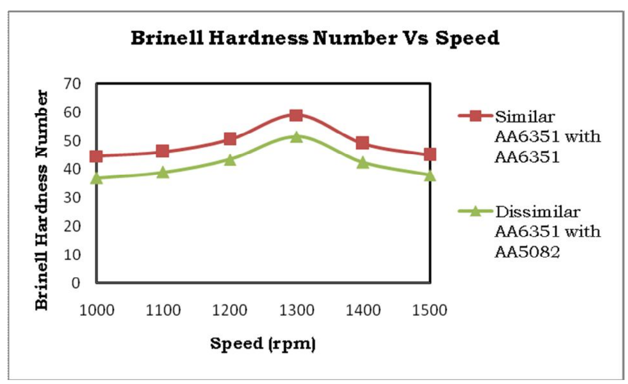

Fig.5. Effect rotational speed of the tool on Brnell Hardness Number.

Similar aluminium alloy of AA6351 with AA6351 combinations yielded superior hardness properties as compared to dissimilar aluminium alloy of AA6351 with AA5083 combinations because aluminium alloy AA5083 standard hardness values are lower than aluminium alloy AA6351 so the combination of AA6351 with AA5083 results lower hardness values.

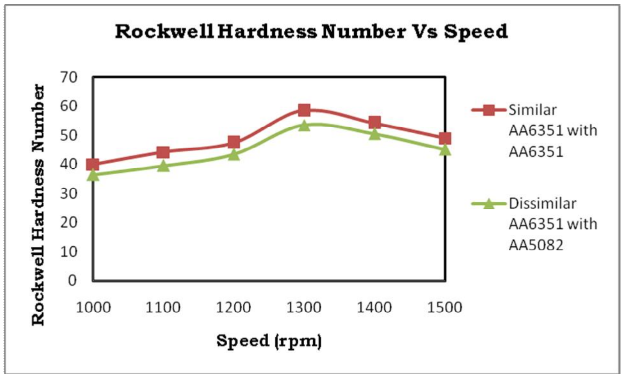

Fig.6. Effect rotational speed of the tool on Rockwell Hardness Number.

C. *Impact Test*

Charpy impact test was done to determine the impact energy of FS weld at a sudden load by using pendulum on V notch specimen. Fig.7 shows the effect of rotational speed of the tool on impact energy of friction stir welded aluminium alloy AA6351 with AA6351 and aluminium alloy AA6351 with AA5083. The impact energy of FS weld is lower when the rotational speed of the tool is lower (1000 rpm). When the rotational speed of the tool increases from 1000 rpm the impact enrgy decrease and reaches minimum at 1300 rpm. If the rotational speed of the tool is increased further beyond 1300 rpm then impact energy of the joint increased.

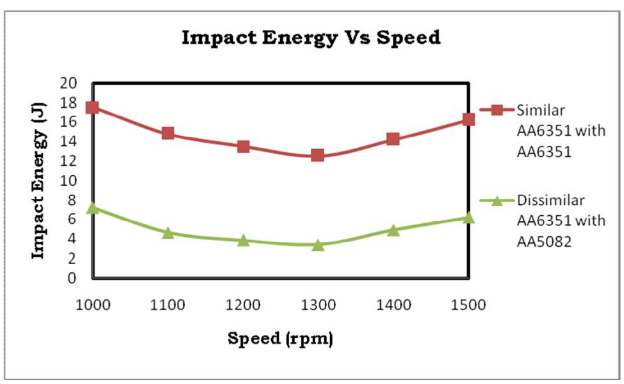

Fig.7. Effect rotational speed of the tool on Impact energy.

IV. CONCLUSIONS

The following conclusions arrived from the above experimental investigation.

- The results indicated strong relation between the rotational speed of tool and tensile properties of the welded joint. Yield strength, tensile strength and percentage of elongation of the joint decrease with the increase in speed of the tool and after reaching optimum values at 1300 rpm speed the values decreases with increase in speed of the tool.
- The results related hardness (both Brinell and Rockwell hardness) reveal that increase in hardness of welded joint with increase in speed of the tool and the value comes down with still increase in speed of the tool after reaching maximum value at 1300 rpm.
- The Charpy impact strength results shows that decrease in impact strength of welded joint with increase in speed of the tool and reaches minimum at 1300 rpm and value increase with further increase in speed of the tool.
- Tensile, hardness and impact properties of Aluminium alloy of similar alloy combinations exhibits better values compare to dissimilar alloy combinations.

REFERENCES

[1] 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).

[2] 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, vol. 48, pp.778-787, 2008.

[3] 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, vol. 433, pp. 64-69, 2006.

[4] K. Elangovan, V. Balasubramanian, "Influences of post weld heat treatment on tensile properties of friction stir-welded AA6061 aluminium alloy joints", Material characterization vol. 59, pp.1168-1177, 2008.

[5] 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, vol. 30, pp. 180-187, 2009.

[6] C. Leitao, 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", vol. 30, pp. 101-108, 2009.

[7] 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, vol. 130, pp. 031007-1 – 031007-15, 2008.

[8] 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, vol. 355, pp.154-159, 2003.

[9] 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, vol. 405, pp. 333-338, 2005.

[10] William D. Lockwood, Borislav d, A.P. Reynolds, "Mechanical response of friction stir welded AA2024: experiment and modeling", Material science and engineering A, vol. 323, pp. 348-353, 2002.

[11] 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), pp.147-152, 2003.

[12] 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), pp.19-23, 2004.

[13] 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, pp.1s-9s, January 2003.

[14] Ling Cui, Hidetoshi Fujii, Nobuhiro Tsuji and Kiyoshi, Nogi, "Friction stir welding of a high carbon steel", Scripta Materialia, vol. 56, pp. 637-640, 2007.

[15] 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, vo. 485, pp. 448-455, 2008.

[16] 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, vol. 30, issue 2, pp.182-186, 2008.

[17] 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, 2009.

[18] 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.%Al_2O_{3p} composite", Composites science and technology, vol. 67, pp. 605-615, 2007.

[19] S. Lomolino, R. Tovo and J. Dos Santos, "On the fatigue behaviour and design curves of friction stir butt welded Al alloys", International journal of fatigue, vol. 27, pp.305-316, 2005.