A Review on Friction Stir Welding of Dissimilar Aluminum alloys

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Abstract- *Friction stir Welding is an upgraded version of the conventional welding process. It is considered one of the most important innovations during the last two decades. Friction stir welding (FSW) is a revolutionary green manufacturing technique due to its energy efficiency and environmental friendliness. Friction Stir Welding is more of a forging process than an actual welding process, and simply uses a spinning pin tool and axial forge force to create a bond between two pieces. Effect of FSW parameters such as tool design, tool pin offset, rotational speed, welding speed, tool tilt angle and position of workpiece material in the fixture for the dissimilar Aluminium alloys are summarized in the present review paper. Additionally, welding defects, microstructure and intermetallic compound generation is also discussed.*

Keywords- Friction Stir welding (FSW), FSW of Dissimilar Al alloys, Microstructure and Mechanical Properties.

I. INTRODUCTION

Welding has always been given prime importance in industries among the manufacturing technologies due to its ability to manufacture complex parts which cannot be cast or manufactured directly. But general welding has some limitations. These limitations have been tried to be eliminated by using Friction Stir Welding (FSW) [1].

Friction Stir Welding is one of the new off-center welding techniques which has made extraordinary progress in Welding technology. Friction Stir Welding was invented at The Welding Institute (TWI), UK in 1991 as a solid-state welding technique and was primarily industrialized for Al alloys. Due to prevalence of non-heat treatable and powder metallurgy Al alloys to which conventional fusion welding cannot be applied, the spotlight has been turned to Friction Stir Welding as the joining technology that does not have troubles normally associated with fusion welding process [2-6]. FSW offers a lot of advantage over conventional fusion welding process because of its low heat input and absenteeism of solidification process. As FSW is a solid state welding process it has good dimensional stability, no loss of alloying element, excellent mechanical properties in the welded area, fine recrystallized microstructure, no solidification cracks.

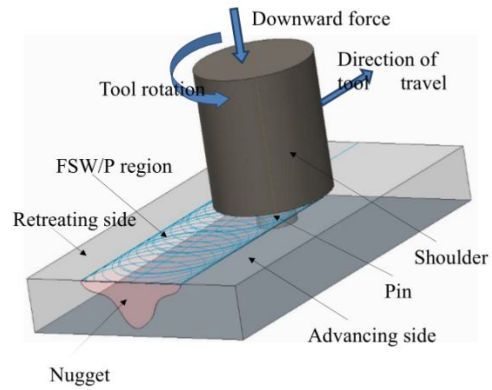

Fig. 1. Principle of Friction stir welding/processing.

Joining of dissimilar materials by any welding process is always difficult because of the enormous differences in mechanical and metallurgical properties [7-9]. The joints of dissimilar materials are increasingly employed in different sectors of industries due to its technical and economic advantages. FSW has environmental welfares as no shielding gas is required, no filler material needed, no detrimental emissions, abolishes grinding waste, etc.

II. LITERATURE REVIEW

FRICTION STIR WELDING PROCESS:

It consists of a rotation tool which is pressed against the surface of two abutting or overlapping plates, between two severely clamped substrates on a backing plate support. Friction stir welding can be divided into three stages: Plunge, Dwell and Traverse. A cylindrical tool rotating at high speed is slowly plunged into the plate material until the shoulder of the tool touches the upper surface of the material. After piercing the tool at the required depth is held in that position for 5-20 seconds [10]. A downward force is applied to maintain the contact. Frictional heat, generated between the tool and the material, causes the plasticized material to get heated and softened, without reaching the melting point. The tool is then traversed along the joint line until it reaches the end of the weld. As the tool is moved in the direction of welding, the leading edge of the tool forces the plasticized material, on either side of the butt line, to the back of the tool. In effect, the transferred material is forged by the intimate contact of the shoulder and the pin profile as shown in Fig. 1. It should be noted that, in order to achieve complete through-thickness welding, the length of the pin should be slightly less than the plate thickness, since theonly limited amount of deformation occurs below the pin. The tool is generally tilted by 2-4°, to facilitate thebetter consolidation of the material in the weld. Upon reaching the end of the weld, the tool is withdrawn, while it is still being rotated. As the pin is withdrawn, it leaves a keyhole at the end of the weld. This is the main disadvantage of FSW and few variants are being used to overcome this aspect [11-12].

MICRO-STRUCTURE:

The joint material can be separated into four visually distinct micro-structural zones according to how they are affected:

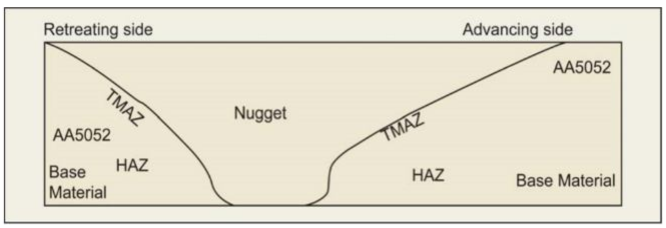

Fig. 2. Schematic of the cross-section of the friction stir weld showing the various characteristic regions

These zones can be famed as follows:

1. SZ: Stirred Zone or weld nugget, which is the central area where the pin traverse between both sheets. This region is characterized by a fine-grained dynamically recrystallized structure.

2. TMAZ: Thermally Mechanically Affected Zone, on each side of SZ (these zones seem to be more narrow in the unconventional - bobbin tool - conditions).

3. HAZ: Heat-Affected Zone, situated between the minimum of hardness and the base material as shown in Fig. 2.

TOOL DESIGN:

Tool technology is the heart of Friction Stir Welding process. It is considered as one of the important factors in Friction Stir Welding. The FSW tool has two basic parts: (I) Pin and (II) shoulder as shown in Fig. 3. Important elements of these parts are shoulder diameter, shoulder surface angle, pin geometry, including its shape and size, and the nature of tool surfaces [13].

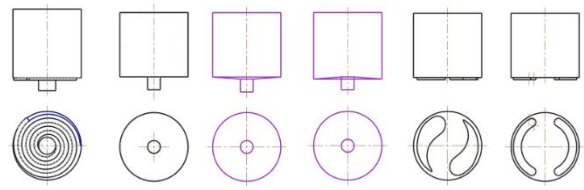

Figure 3 Shoulder Geometries which can be used in Friction Stir Welding [14]

In FSW, the shoulder diameter is maximum responsible for heat generation. It has been found that the shoulder generates around 87% heat by rubbing action between the shoulder surface and the work piece [15]. Tool Shoulder is the region of the tool in contact with work piece surface. To enhance the material flow, the tool shoulder can have negative or positive scrolls. Negative Scrolls is a depression in shoulder surface and work piece material fills this. A positive scroll is a protrusion of shoulder surface. Moreover, the layer of IMCs is found thicker when the larger shoulder diameter (i.e. 25 mm) was applied. So, the micro-hardness varies as the shoulder diameter changes. Three shoulder geometries such as concave, convex, flat with special profile feature like scrolled, ridges, grooves, concentrating can be provided to increase material deformation and uniform mixing in FSW [16]. Selection of proper shoulder geometry/ feature depends on the workpiece and tool materials as well as work piece thickness.

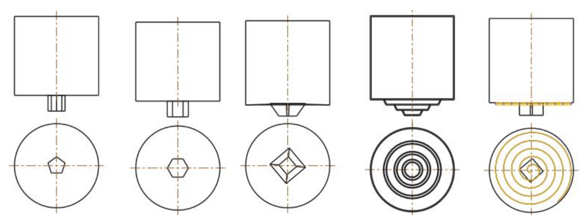

Figure 4 Pin profiles which can be used in Friction Stir Welding

Tool pin also called as theprobe is inserted in the workpiece and influences horizontal material flow from front to back as well as vertical material flow from top to bottom. Advancing side tool pin surface rotation direction and traverse direction has same vectorial sense. Because of the tools forward movement, the material wants to flow back, but the pins surface rotation opposes the flow on this side of the tool. Retreating side: the tool pin surface rotational direction and tool traverse direction have opposite vectorial sense. The material flow is easier on this side of the tool pin as the pin surface helps the tool material flow backward. Friction Stir Welding of aluminum alloys Machine characteristic, workpiece thickness and control mechanism will also affect the quality of the weld. From the experimental analysis, it has been found that Square pin profile givers better quality of the weld. This is due to the pulsating action of the square tool profile [17].

The relation between pin and shoulder dimension is defined as a shoulder to pin diameter ratio (SPR). SPR of dissimilar Cu-Al FSW system depends on the type and thickness of alloys being joined. However, the general range of 2:1 to 5:1 is noted by researchers. This mentioned range of SPR is relatively higher than the similar material FSW system. In a dissimilar system of Cu and Al materials (which is having different thermal conductivities and specific heats), the SPR should be such that the thermal input and the distribution of it can be maintained. So, by keeping relatively higher SPR, the thermal input can be raised in an appropriate way, and at the same time, the distribution of it can be managed by the other process parameters such as tool pin offset, the position of the workpiece material, rotational speed and welding speed.

TOOL MATERIAL:

During FSW/P, high temperature and workload experienced by the tool material results in the high amount of material wear and considerable damage to the material. Failure of the tool, as well as tool wear, are the most common issues observed in the fabrication of surface composites due to hard reinforcement particles during Additive Friction stir Processing (AFSP). Tungsten-rhenium (W-Re), Iridium Rhenium, cobalt alloys, tungsten carbide and Polycrystalline Boron Nitride (PCBN) are employed successfully for hard alloys such as brass, Titanium based alloys and steels due to its high thermos-mechanical performance[18]. However, low wear and good weld quality along with some other factors such as strength, hardness, reactivity with work material and ductility that may influence tool material selection.

ADVANTAGES AND DISADVANTAGES OF FRICTION STIR WELDING:

ADVANTAGES:

Friction Stir Welding can solve some problems which are associated with conventional welding process. This category is called as non-weldable alloys. They are easily welded by FSW. Practically, we get defect free weld which is not possible by conventional technique. Conventional welding is associated with various types of welds. Due to fusion of the metal a weld pool is formed which results in solidification cracks, shrinkage, formation of air bubbles, etc. but as we do not melt the metal in FSW these defects are eliminated resulting in almost defect free weld. It has been found out experimentally that a continuous weld as long as 1 km can be obtained by FSW. The strength of the weld is found out to be comparable to the parent metal in similar as well as dissimilar metal. There is no loss of energy as heat is strictly generated in the required space which is to be welded. Due to this reason and as no filler material and shielding gas is needed we can a novel environmental friendly technique. There is also no emission of harmful gases i.e. smoke, fumes and other gases which is found in arc welding.

Dis-advantages:

FSW process is comparatively less flexibile compared to that of TIG, MIG, electrical arc welding, etc. A fixture is required to firmly hold the sheets which is not required as in case of conventional welding. Acute tolerances are required to be maintained during FSW process. After the plates are welded, an exit hole is formed while removing the tool. FSW can be easily applied to material having low strength and high elasticity. Materials having high strength and elasticity require special tools which are much costlier than the regular tools.

DEFECTS:

The process of friction stir welding is reasonably free from defects which are inexorable to occur in fusion welding processes [19-20]. Even though defects in friction stir welded samples are experienced which are the outcome of improper selection of a combination of different process parameters, the defects found in friction stir welded samples are mostly subsurface [21]. This brings the limitation to visual inspection methods for identification of defects in the welded samples. Available non-destructive methods are applicable in the detection of internal defects but these methods need high investment and precise experience for the analysis of the collected information. Most of the researchers contributed towards finding the optimum range of different process parameters to avoid defects. Contributions toward detection of defects in friction stir welding though non-destructive manner is less. Vertical force, traverse force, tool rotational speed and main spindle motor current signatures are the four process signals acquired and analyzed for the same. Signal information extracted though fractal theory will provide an indicator based on which conclusions can be drawn from samples to be defective or defect-free.

Insufficient weld temperature, resulting from lower rotational speed and high transverse speed causes the long tunnel defect, which may be produced on the surface or subsurface. A lower temperature may also reduce the forging action of the tool and reduce the continuity of the bond from each side of the weld [22-23]. Light contact between the materials has given rise to the name kissing bond for such cases. This type of defect is extremely difficult to detect by non-destructive testing.

CORROSION SUSCEPTIBILITY:

Corrosion may be a serious issue during FSW, particularly during unprotected dissimilar alloy combinations. This is because metallurgical and microstructural zonal heterogeneities developed during the welding process. The development of marked regional heterogeneities (or distinctly different metallurgical and microstructural zones) will, most likely, lead to the formation of micro-galvanic corrosion cells in the weld. Pronounced zonal heterogeneities are unavoidable in welds involving dissimilar materials. The galvanic-coupling effect between the zones can be catastrophic if the materials are both conductive and have widely separated corrosion potentials. Therefore, it is very important to establish the extent of zonal heterogeneities in the microstructures of welds/dissimilar welds relative to the welding parameters, the processing history and the compositions of the alloys involved in order to increase in service performance where no additional corrosion protection is present [21].

APPLICATIONS:

Weldability is one of the most important factors determining the application of novel materials. High strength alloys like 2XXX and 7XXX series alloys are classified as non-wieldable by fusion welding technique. So when FSW was invented, it opened new opportunities to weld high strength aluminum alloys. [24] FSP has replaced riveting technology. Friction Stir Spot welding is used in Automobile technology. Friction Stir Welding has grown into an important industrial process that has led to many worldwide applications, predominantly in the fabrication of aluminum components and panels. FSW is being used in all transport industries including shipbuilding, automotive, rail,and aerospace industries [24]. In shipbuilding industry, the FSW process is used for the production of large aluminum panels, which are made from aluminum extrusions. Large tanks for satellite launch vehicles are fabricated by FSW from high-strength aluminum alloys for the aerospace industry. Several companies [25] (The Boeing Company, Eclipse Aviation Corporation, Airbus etc.) manufacture lightweight aluminum airframe structures, fuselage and wing applications using FSW for commercial and military aircrafts. The railway industry uses FSW for the production of large prefabricated aluminum panels, which are made from aluminum extrusions. The automotive industry uses FSW in the production of components like light alloy wheels and fuel tanks.

Very suitable for robotics and automation applications.

TRENDS IN FRICTION STIR WELDING:

The desire for a better standard of living resulted in the continuous development of the existing manufacturing technologies [26]. Particularly friction stir welding was developed for welding non-weldable metals and alloys, which cannot be welded by a conventional technique. Apart from that friction stir welding had an enormous growth as we can weld similar as well as non-similar metals, polymers, 3D printed objects, etc.

Owing to the fact that, it is a mechanical solid-state welding technique, it can also be applied underwater. The welding speed is dependent on the thickness of the plate to be welded. For thicker plates,double-sided friction stir welding can be applied as shown in Fig. 5 [22].

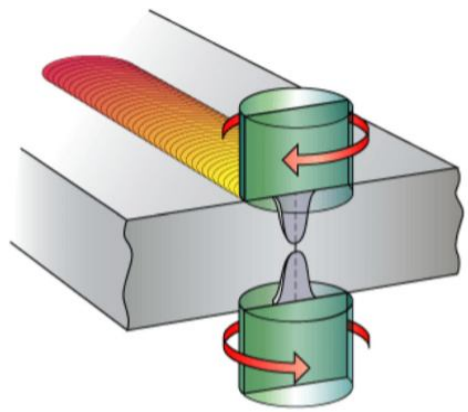

Figure 5 Double Sided Friction Stir Welding[13]

FRICTION STIR WELDING OF DISSIMILAR ALUMINUM ALLOYS:

FSW of dissimilar alloys/metals has attracted extensive research interest due to potential engineering importance and problems associated with conventional welding. Several different dissimilar aluminum alloy combinations have been successfully friction stir welded with excellent joint efficiencies [27-28].Work hardening and precipitation hardenable Aluminum alloys cannot be welded by a conventional welding technique. Friction Stir Welding has made it possible to weld these Al alloys. FSW was primarily developed for welding Al alloys. It was found that when 2014 and 7075 were welded, they showed net increase in strength in the longitudinal direction with respect to transverse direction. Even fatigue life was increased by Friction Stir Welding [30-31]. It has been found by Joaquín M. Piccinia et al. [29] fracture load increases with tool penetration depth. But even that has a limit up to increasing fracture load, for which the fracture mechanism changes from interfacial to circumferential.

P. Cavaliere et al. found that the joint of Al 2024 and 7075 shown very good mechanical properties as compared to that of its parent metals. The joint showed very good properties of yielding. The mechanical results were good considering the drastic condition the material was subjected during the friction stir welding process.

III. CONCLUSION

The salient features of Friction Stir Welding have been summarized. The effect of different process parameters on the properties of dissimilar materials are also discussed in detail. It has been found that tool geometry and plays an important role in FSW. It can be noted that dissimilar joining of Al alloys by FSW is still not widely employed because of low mechanical properties and formation of IMCs in large amount. Imperfections such as fragmental defects, voids, pores, and cracks are commonly found in dissimilar Al FSW system which are formed due to improper process parameters that consequently forms different IMCs and lead to the low mechanical properties. These IMCs also increases the hardness of joint area and that also makes the joint area brittle which is driving parameter for brittle fracture and low elongation [30-31].

It can also be summarized that maximum force occurs during plunge stage and reduce significantly (35%) during the translation stage. During the initial plunge stage, the process to damage the tool is most likely to occur whereas during translation stage damage to tool shoulder is most likely to occur [32].

REFERENCES

[1] Joining of Dissimilar Materials K. Martinsen , S. J. Hu, and B. E. Carlson, ELSEVIER 0007-8506.

[2] Friction Stir Welding of various Aluminum Alloys ISSN: 2278-1684, p-ISSN : 2320–334X

[3] W.M. Thomas, E.D. Nicholas, J.C. Needham, M.G. Church, P. 33. A.W. Bowen: Mater. Sci. Technol., 1990, vol. 6, pp. 1058-71.

[4] Temple smith, and C.J. Dawes: International Patent, Application No. 34. J. Hirsch and K. Lu¨cke: Acta Metall., 1988, vol. 36, pp. 2863-82.

[5] PCT/GB92, Patent Application No. 9,125,978.8, 1991. 35. K. Lu¨cke and O. Engler: Proc. 3rd Int. Conf. on Aluminum Alloys,

[6] E.D. Nicholas and W.M. Thomas: Int. J. Mater. Product Technol., Trondheim, Norway, 1992, pp. 439-52.1998, vol. 13, pp. 45-54. 36.

[7] S. Gourdet, E.V. Konopleva, H.J. McQueen, and F. Montheillet E. Schofer: Mat.-wiss. Werkstofftech., 1999, vol. 30, pp. 693-96. 37.

[8] M.W. Mahoney, C.G. Rhodes, J.G. Flintoff, R.A. Spurling, and W.H. Sci. Forum, 1996, vols. 217–222, pp. 441-46.

[9] Altenkirch, A. Steuwer, M. Peel, D.G. Richards, P.J. Withers, The effect of tensioning and sectioning on residual stresses in aluminium AA7749 friction stir welds. Mater. Sci. Eng. 488,16–24 (2008)

[10] J.Altenkirch, A. Steuwer, P.J. Withers, S.W. Williams, M. Poad, S.W. Wen, Residual stress engineering in friction stir welds by roller tensioning. Sci. Technol. Weld. Join. 14, 185–192 (2009)

[11] J.Altenkirch, A. Steuwer, M.J. Peel, P.J. Withers, The extent of relaxation of weld residualstresses on cutting out cross-weld test-pieces. Powder Diffr. 24, S31–S36 (2009b)

[12] Gurel Cam and Selcuk Mistikoglu, Recent Developments in Friction Stir Welding of Al-alloys ASM International 1059-9495, 2014

[13] C.D. Sorensen, Friction stir welding tool designs, in ASM Handbook, Volume 6A: Welding Fundamentals and Processes, ed. by T. Lienert, T. Siewert, S. Babu, V. Acoff (ASM International, Materials Park, 2011)

[14] N.T. Kumbhar and G.K. Dey, Friction Stir Welding of Aluminum Alloys Materials Science Division and K. Bhanumurthy Scientific Information Resource Division

[15] Yan-huaZhao, San-baoLin, LinWuFu, xing Qu, The influence of pin Geometry on Bonding and Mechanical properties in Friction Stir Weld 2014 Al Alloy, Material Letters, Volume 59, Issue 23, October 2005, Pages 2948-2952

[16] A. Chandrashekar, B. S. Ajay Kumar and H. N. Reddappa, Friction Stir Welding: Tool Material and Geometry Department of Mechanical Engineering, Bangalore Institute of Technology, Bangalore, India.

[17] C.B. Fuller, Friction stir tooling: tool materials and design, Ch. 2, in Friction Stir Welding andProcessing, ed. by R.S. Mishra, M.W. Mahoney (ASM International, Materials Park, OH,(2007), pp. 7–35

[18] B. Dasa, S. Pala, S. Baga, Defect detection in friction stir welding process using signal information and fractal theory, Procedia Engineering, Volume 144, 2016, Pages 172-178.

[19] AllisonA,ScudamoreR(2014)StrategicResearchAgenda:Joining:JoiningSubplatform.AvailablefromJoining%20Sub-Platform%20SRA%2X%202014.pdfi[cited201421.12.2014].

[20] Corrosion susceptibility of dissimilar friction stir welds of AA5083 and AA6082 alloys U. Donatusa*, G. E. Thompsona, X. Zhoua, J. Wanga, A. Cassella, K.

Beamishb a School of Materials, The University of Manchester, Manchester M13 9PL, UK. bTWI Ltd, Granta Park, Great Abington, Cambridge, CB21 6AL, UK.

[21] H.J.K. Lemmen, R.C. Alderliesten, R.R.G.M. Pieters, R. Benedictus, J.A. Pineault, Yield strength and residual stress measurements on friction-stir-welded aluminum alloys. J. Aircr. 47, 1570–1583 (2010)

[22] H. Lombard, D.G. Hattingh, A. Steuwer, M.N. James, Effect of process parameters on the residual stresses in AA5083-H321 friction stir welds. Mater. Sci. Eng. 501, 119–124 (2009)

[23] Trimble, J. Monaghan, G. E O'Donnell, Fore generation during friction stir welding of AA2024-T3 D. Department of mechanical and manufacturing engineering, Trinity College, Dublin, Ireland

[24] Sreesabari,. Malarvizhi,. Balasubramanian., Influences of tool traverse speed on tensile properties of air cooled and water cooled friction stir welded aa2519-T87 Aluminum alloy joints, Journal of Materials Processing Technology, Volume 237, November 2016, Pages 286-300.

[25] T. Watanabe, H. Takayama, A. Yanagisawa, Joining of aluminum alloy to steel by friction stir welding. J. Mater. Process. Technol. 178, 342–349 (2006)

[26] P. CAVALIERE, , E. CERRI, Mechanical response of 2024-7075 aluminium alloys joined by Friction Stir Welding, J O U R N A L O F M A T E R I A L S S C I E N C E, 4 0 (2 0 0 5) pp.3669 – 3676

[27] Joaquín M. Piccinia,, Hernán G. Svobodab, Effect of the tool penetration depth in Friction Stir Spot Welding (FSSW) of dissimilar aluminum alloys, International Congress of Science and Technology of Metallurgy and Materials, SAM - CONAMET 2013

[28] P. Mehtaa & Vishvesh J. Badhekaa, Dissimilar Friction Stir Welding of Copper to Aluminum: Process, Properties and Variants, Volume 31, 2016 - Issue 3, 2015.

[29] R.S. Mishra, Z.Y. Ma, Friction stir welding and processing. Mater. Sci. Eng. R 50, 1–78 (2005) C.D. Sorensen, Friction stir welding tool designs, in Welding Fundamentals and Processes, ed. (ASM Handbook, Novelty, OH, 2011)

[30] P. Cavaliere, G. Campanile, F. Panellaand A. Squillace, Effect of welding parameters on mechanical and microstructural properties of AA6056 joints produced by Friction StirWelding, Journal of Materials Processing Technology, 180(2006) 263-270.

[31] M.M. Shtrikman, Trends in the development of the friction stir welding process National Institute for Aviation Technologies, Russia.