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FRICTION STIR WELDING OF ALUMINIUM FOAM SANDWICH PANELS

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Abstract: The friction stir multi-lap welded joint has been created between the sheets of two aluminium Al5052-H32 alloys and the pure copper foil. The values of the shear strengths in the multi-lap weld of dissimilar materials, has been evaluated consisting of a sandwich structure. The sheets used are very thin in terms of thicknesses. The tool material is M2 HSS (High Speed Steel). The design of experiments has been done by following Taguchi method's L9 approach. The ultimate shear strength is determined for all the samples. Microstructure has been evaluated with the scanning electron microscope (SEM) and the optical microscope for the AlA-Cu-AlA sample found to have the highest ultimate shear strength. Also, micro-hardness has been found out for the same. The AlA-Cu-AlA weld having the highest ultimate shear strength was made with the friction stir weld parameters: 800 RPM of tool rotation speed, 5 mm/min of traverse speed & 0.2 mm of the plunge depth. It was also found that the AlA-AlA weld had higher strength than the AlACu-AlA weld for the same set of varying parameters. While dealing with the thin sheets, clamping plays a significant role. The discussed process could be utilised to create the copper cladding over the tubes of aluminium alloys which would make them light weight and excellent heat sinks.

Index Terms: FSW, Al5052-H32, Copper Foil, Taguchi Method's and SEM.

I. INTRODUCTION

Before the advent of friction stir welding, when arc fusion welding was in fashion, the defects to welding ratio was considerably higher. The culprit behind that unfavourable event was the low energy-density fusion welding process which causes the formation of a large pool molten metal and a large heat affected zone. This led to the formation of defects that were developed during the weld pool solidification. In return, these defects led to the distortion of work piece and the welded joint while reducing the strength of the joint as well. Up until 1990s, fusion arc welding and gas welding had been the prevalent players in the welding industry.[1] Not long before the invention of FSW, certain other non-fusion welding processes such as friction welding, had already been developed. However, the former non-fusion welding processes could only find a very limited use in the industrial applications. In the case of friction welding, the two work pieces are made to come in contact with each other and with the help of linear motion or rotations, relative motion is achieved between them. Along with the relative motion, there is also simultaneous application of the compressive force along the two work-pieces. The reason why the geometry of the parts joined by the friction welding is restricted is due to the availability of only two movements: linear and rotational, which can be utilized to create the relative motion between the work-pieces. The principle governing the joining process in friction welding is that due to the relative motion between the two parts that are to be joined, frictional heat is generated. This frictional heat in turn, causes the softening of the metal at ends of parts in contact. At this semi-plastic softened state, when pressure is also applied, the two parts make up a strong joint at the surface of contact. Friction welding is very much similar to the forming process. Even though there had been geometrical restrictions for the use of friction welding and difficulties in clamping varying sections, it proved to be an efficient way for creating a firm joint between metals, plastics and many other polymers as the area of heat affected zone created in friction welding is very minimal just as in most of other solid state welding processes. This new technology involving the frictional heat and the pressure also unleashed the possibilities of dissimilar material joining. Fig.1.1 schematic diagram of friction stir welding process

Another invention that took place during the same period in 1950s when friction welding was prevailing was the laser welding. Since then and until now the laser welding is considered to be a very convenient and efficient mode of creating a joint between the multiples.[2] However, laser beam welding also has a few cost based restrictions and the restrictions cause due the size of parts that are to be joined. In laser beam welding, a high concentration welding source with high degree of penetration heats up the region in the material to be joined very precisely. It is a high density joining process and along with accuracy, offers the minimal affected zone while creating a very thing section of the heat affected zone which is, in some cases, negligible.

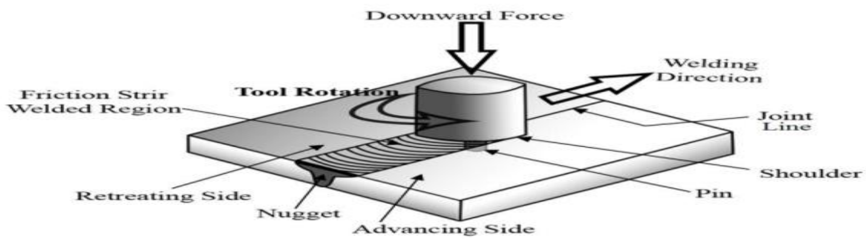


Fig.1.1 Schematic Diagram of Friction Stir Welding Process

1.1MATERIALS AND RESEARCH METHODOLOGY

1.1.1 MATERIAL SPECIFICATIONS

There were a total of three different types of materials involved in the experimentation work. One of the materials made up the tool. Other two materials constituted the sheets to be joined and the foil to be inserted.

1.1.2 MATERIAL OF THE TOOL

The material of the friction stir welding tool was M2 (Molybdenum) HSS (High Speed Steel), also known as the tool steel and is a standard to be used for the tools, in industry. The M2 HSS tool used for friction stir welding in this experimentation was used without heat treatment due to the following reasons:

1.) The M2 HSS tool already has a hardness of 60 HRC (Rockwell C Hardness) without the heat treatment which is much higher than the softer material Al5052-H32, with a Brinell hardness of 60, which is to be welded.

2.) After annealing, the shocks would prove more harmful for the tool and it might break under heavy loads as in case of friction stir welding.

3.) Unnecessary hardening the tool would result in superfluous costs and would also cause wastage of time.

The chemical composition of the FSW tool material: M2 HSS is given below:

Table: 1.1 Chemical Composition Of M2 HSS

ELEMENTS	**W**	**Mo**	**Cr**	**V**	**C**	**Si**	**Mn**	**Fe**
MASS(%)	**6.15**	**5.00**	**4.15**	**1.85**	**0.85**	**0.30**	**0.28**	**81.42**

The physical properties of M2 HSS are listed below:

Table: 1.2 Physical Properties Of M2 HSS

Density	8.16 g/cm^3
Melting Point	4680 °C

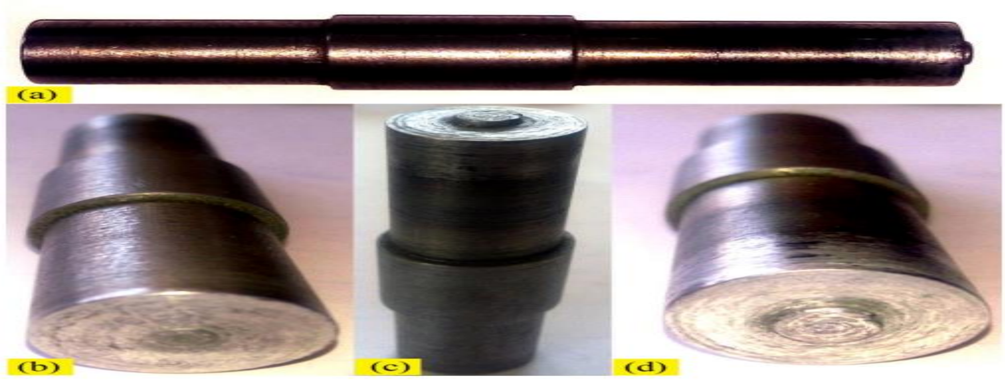


Figure 1.2 M2 HSS Tool Used For Friction Stir Welding

The dimensions of the tool were as follows:

Table: 1.3 Tool Dimensions

Pin Height	Pin Diameter	Shoulder Diameter	Collet Size for Tool	Total Length of Tool
1.5mm	**5.0mm**	**18.0mm**	**18.0mm**	**94.5mm**

1.1.3 MATERIAL OF THE TWO OUTER SHEETS TO BE JOINED

The aluminium alloys are joined in the experimentation of grade Al5052-H32. It is a comparatively softer alloy than stainless steel.

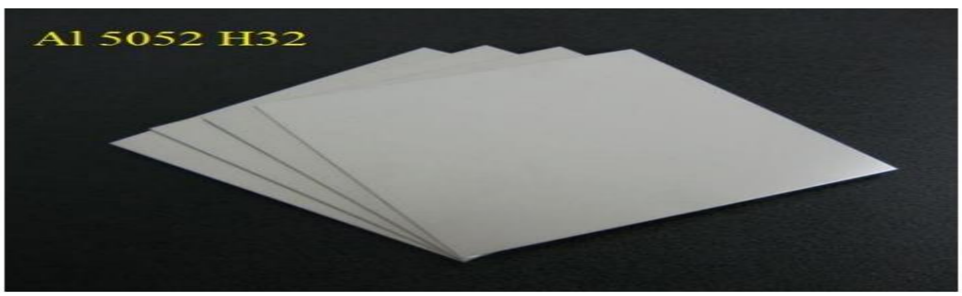


Figure 1.3 Al5052 - H32 Sheets

The chemical composition of Al5052-H32 is given as:

Table: 1.4 Chemical Composition Of Al5052-H32

Element	Mg	Fe	Cr	Si	Mn	Cu	Ti	Al
Mass(%)	2.48	0.30	0.23	0.09	0.03	0.02	0.02	96.83

The physical properties of Al5052-H32 are mentioned below:

Table: 1.5 Physical Properties Of Al5052 - H32

Density	2.68 g/cm^3
Melting Point	607 °C - 649 °C

The aluminium sheets are of the thicknesses 1 mm each and cross-sectional area 150 mm * 150 mm each.

1.1.4 THE SANDWICHED MATERIAL

Pure copper foil is used as the material that is sandwiched in the two sheets of aluminium alloys.

The physical properties of copper are given below:

Table: 1.6 Physical Properties Of Pure Copper

Density	8.96 g/cm^3
Melting Point	1085 °C

The value of Rockwell Hardness (F scale) for copper, is 54.

The thickness of the copper foil is 0.1 mm and the cross sectional area is 150 mm * 40 mm for each foil.

II. RESEARCH METHODOLOGY

2.1 TOPIC SELECTION & MATERIAL SELECTION

The topic was selected seeing the wide use of friction stir welding in the futuristic world. Also, another area that was found interesting was copper cladded aluminium tubes.

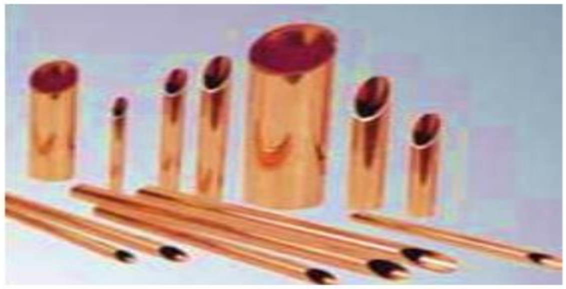


Figure.2.1 Copper Cladded Aluminium Tubes

These kinds of tubes have vast applications in cooling the bigger computer systems and are also used in super cars which heat up quite quickly when run at their limits, because of its excellent heat sinking capability. Besides, the inner material is aluminium alloy (Al5052 H32) which is light weight as well as cheap and only a thin layer of copper enhances its thermal properties. The copper cladded aluminium tubes could be used as a radio frequency cable or as the refrigeration tubes. In this thesis work also the fundamentals of joining two aluminium sheets with a copper foil in middle could be used to clad copper to aluminium alloy.

Among the different types of aluminium alloys, Al5052 was found to have good machinability, good weldability, flexibility and also good corrosion resistance. On the other hand, copper was the best choice available to construct a heat sink. Thus, both of them made a very good combination.

2.1.1 SELECTION OF EQUIPMENT

The Vertical Milling Centre (VMC) which a type of vertical milling machine having a CNC (computer numeric control) interface was readily available rather than a dedicated FSW Setup which has not penetrated into the market at a large scale. Moreover, the clamping modifications and tool mounting was very easy on a VMC. So it was the best choice to conduct experiments.

2.1.2 SELECTION OF TOOL PROFILE AND MATERIAL

Upon going through various research papers, it was clear that the cylindrical pin profile was giving out best results in terms of ultimate shear strengths in case of tensile strength for FSW joints. Also, since the thickness of sheets forming the lap joint was very thin with the total thickness accounting to 2.1 mm, it was quite difficult to form threading on the tool. However, only a single tool was used throughout which was straight cylindrical (not tapered). The tool material was M2 HSS which is a tool standard and a trusted name in industry having Rockwell hardness of 60 HRC without heat-treatment and 65 HRC after the heat treatment. For obvious reasons as discussed in section 2.1.1, tool was used without any heat treatment.

2.2 PARAMETERS IN WORK

It is very essential to set restrictions in the boundary of research so as to be able to follow more vertical approach. For the same, the tool material, tool profile and direction of rotation were kept constant while the tool rotational speed, plunge depth and traverse speed were varied.

2.3 DESIGN OF EXPERIMENTS – TAGUCHI

A series of experiments were conducted, some of which failed with the tunneling defects in the friction stir weld zone. With this the, favorable limits for the sampling method: Taguchi were set to obtain samples defect free. Only the shear strengths of defect-free samples were considered.

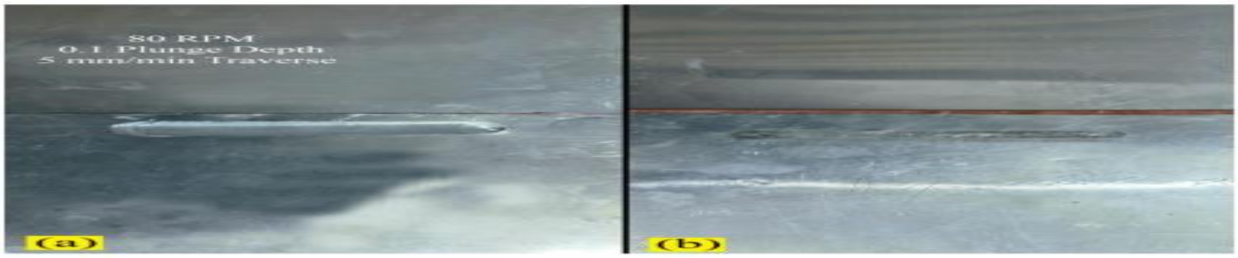


Figure.2.2: FSW at 800 RPM; 0.1 mm Plunge Depth; 5 mm/min Traverse Speed (a) Front Side of Weld (b) Back Side of Weld

Figure.2.3: 500 RPM; 0.4 mm Plunge Depth; 20 mm/min Traverse Speed (a) Front Side of Weld (b) Back Side Of Weld

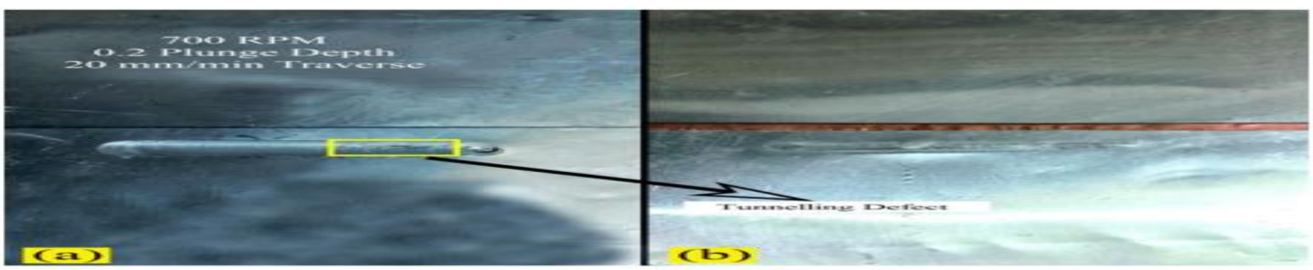


Figure.2.4: 700 RPM; 0.2 mm Plunge Depth; 20 mm/min Traverse Speed (a) Front Side of Weld (b) Back Side Of Weld

The design of experimentation has been done in accordance with the Taguchi method, with the help of "Minitab" software, and is listed below:

Table 2.1 Design and Actual Welding Parameters By Taguchi Method

S.No	Rotational Speed(RPM)	Traverse(mm/min)	Plunge Depth (mm)
1	700	5	0.1
2	700	10	0.2
3	700	15	0.3
4	800	5	0.2
5	800	10	0.3
6	800	15	0.1
7	900	5	0.3
8	900	10	0.1
9	900	15	0.2

III. RESULTS AND DISCUSSIONS

There were a total of nine friction stir welded specimens tested for the shear strengths as per the L9 orthogonal array of Taguchi sampling method, having a sandwich structure with the two Al5052-H32 aluminium alloy sheets having thickness of 1 mm each on the outer sides and the copper foil of thickness 0.1 mm, place in the middle. Then, as per two parameters where the shear strengths came out to be the highest in case of AlA-Cu-AlA multi-lap friction stir welded joints, two samples of AlA-AlA were friction stir lap welded and their shear strengths were also determined.

The highest ultimate shear strength came out to be 4.413 MPa in the case of AlA-Cu-AlA joint with the parameters: 800 rpm, 5 mm/min traverse and 0.2 mm plunge depth. For the same parameters, the ultimate shear strength came out to be even higher as in the case of AlA-AlA joint having the ultimate shear strength as 5.955 MPa. Moreover, the second highest value of the ultimate shear strength came out to be 3.921 MPa, in case of AlA-CuAlA joints at the parameters: 800 rpm, 15 mm/min traverse and 0.1 mm plunge depth. For the same parameters, the ultimate shear strength for the AlA-AlA joint came out to be 4.922 MPa.

The need of proper clamping was felt during experimenting, especially in case of the thin sheets which bend quite easily when the sliding load is applied. Moreover, setting the clamps very tightly over the work-piece material deformed the surface of sheets as Al5052-H32, the work-piece material used, is a soft metal. So, the resolution of the problem could be incorporation of more clamps in the middle or bring some modification in the design of additional clamps such as the use of roller type clamp which is movable as well.

3.1 EXPERIMENTAL WORK

3.1.1 DESIGN OF EXPERIMENTS (D.O.E.)

Table 3.1 Actual Design of Experiments by Taguchi Method

S. No	Level 1: Rotational Speed (RSM)	Level 2: Traverse (mm/min)	Level 3: Plunge Depth (mm)
1	700(S)	5(S)	0.1(S)
2	700(S)	10(U)	0.2(U)
3	700(S)	15(W)	0.3(W)
4	800(U)	5(S)	0.1(S)
5	800(U)	10(U)	0.2(U)
6	800(U)	15(W)	0.3(W)
7	900(W)	5(S)	0.1(S)
8	900(W)	10(U)	0.2(U)
9	900(W)	15(W)	0.3(W)

3.2 CALCULATION OF ULTIMATE SHEAR STRENGTH

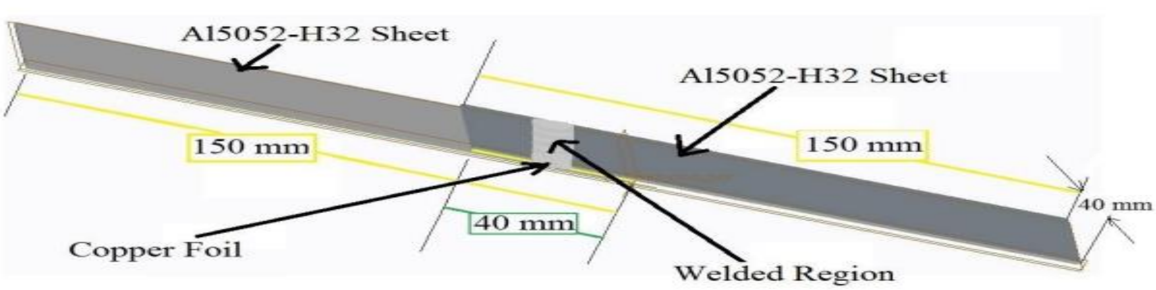


Figure: 4.1 Sample Preparations for Shear Testing

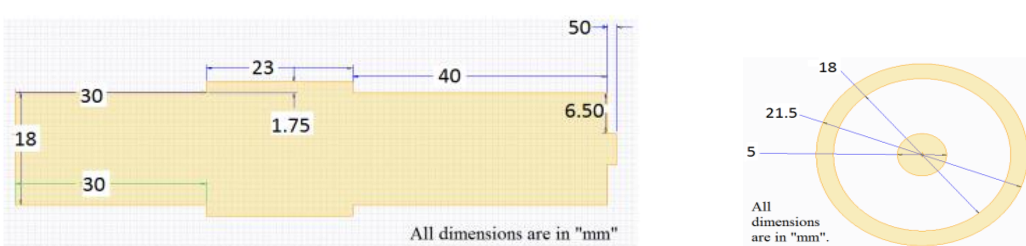


Figure.3.1: Front View of the Tool &Top View of the Tool

Thus, Area = Diameter of tool shoulder * Width of sample = 0.018 m * 0.04 m = $7.2 * 10^{-4}$

Also, ultimate shear strength (MPa) = maximum load of fracture (N) / contact area (m^2) Hence, the values for the ultimate shear strength are given as:

Table: 3.2 Ultimate Shear Strength Values

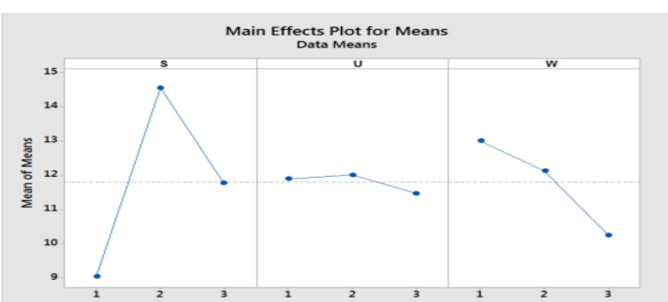
S.No.	Parameters for AlA-Cu-AlA Joint (Tool Rotation Speed in RPM; Traverse Speed in mm/min; Plunge Depth in mm)	Maximum Shear Load (N)	Ultimate Shear Strength (MPa)
1	800;5;0.2	3177.459	4.413
2	800;15;0.1	2823.318	3.921
3	900;10;0.1	2819.394	3.915
4	800;10;0.3	2727.180	3.787
5	900;15;0.2	2442.690	3.392
6	700;5;0.1	2159.181	2.998
7	900;5;0.3	1799.154	2.498
8	700;10;0.2	1654.947	2.298
9	700;15;0.3	1617.669	2.246

Table: 3.3 Response Table for Means

Level	S	U	W
1	9.053	11.893	13.003
2	14.548	12.004	12.125
3	11.769	11.472	10.241
Delta	5.495	0.532	2.7622.762
Rank	1	3	2

Table: 3.4 Response Table for Signal to Noise Ratios (Larger is better)

Level	S	U	W
1	19.06	21.26	22.21
2	23.24	21.34	21.37
3	21.27	20.96	19.98
Delta	4.18	0.38	2.24
Rank	1	3	2



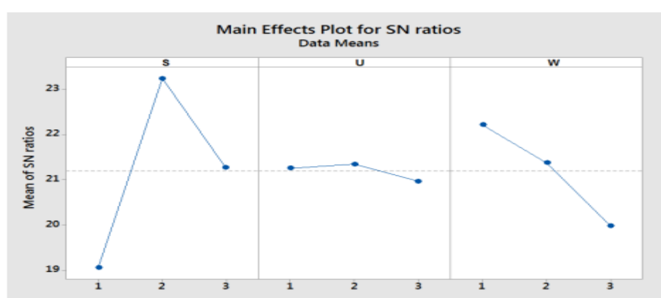


Figure: 3.2 Main Effects Plot For Means & Main Effects Plot For SN Ratio

3.3 MACROSTRUCTURE AND MICROSTRUCTURE AFTER F.S.W.

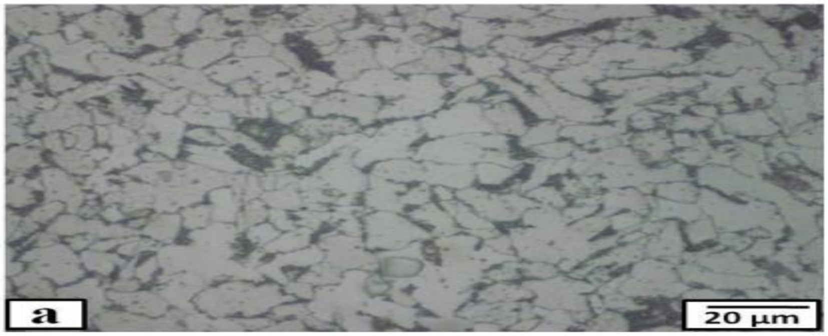


Figure: 3.3 Microstructure of Welded Sample Having Highest Ultimate Shear Strength

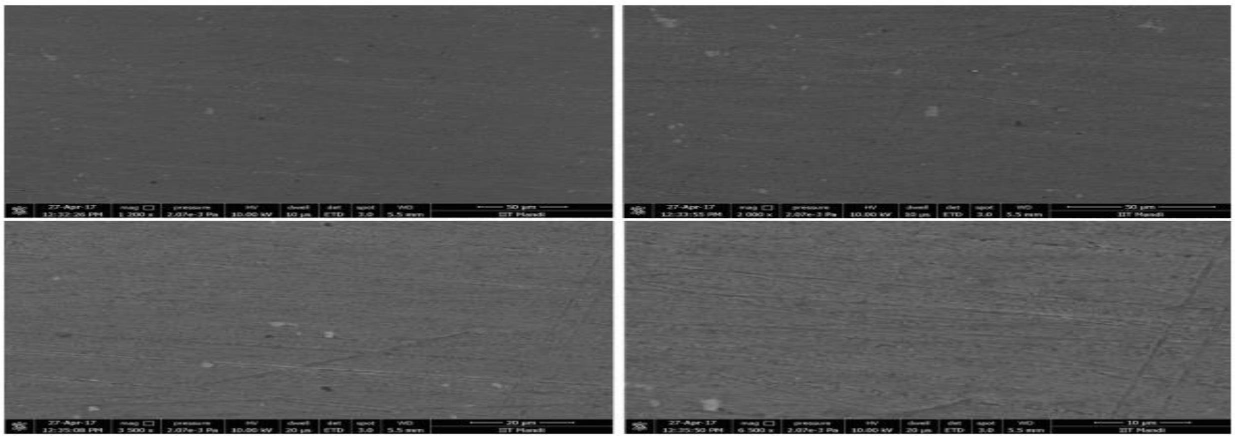


Figure: 3.4 SEM images of the weld surface at 1200X, 2000X, 3500X & 6500X Zoom

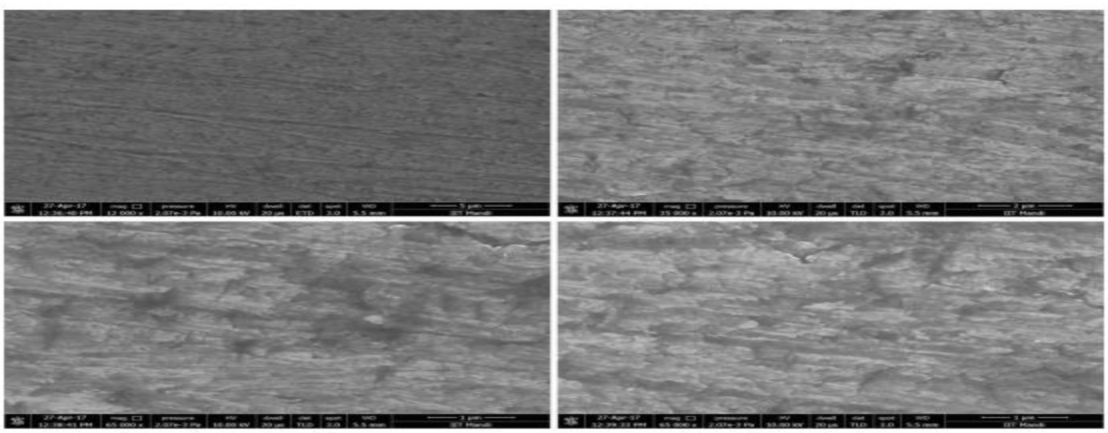


Figure: 3.5 SEM images of the weld surface at 12000X, 35000X & 65000X

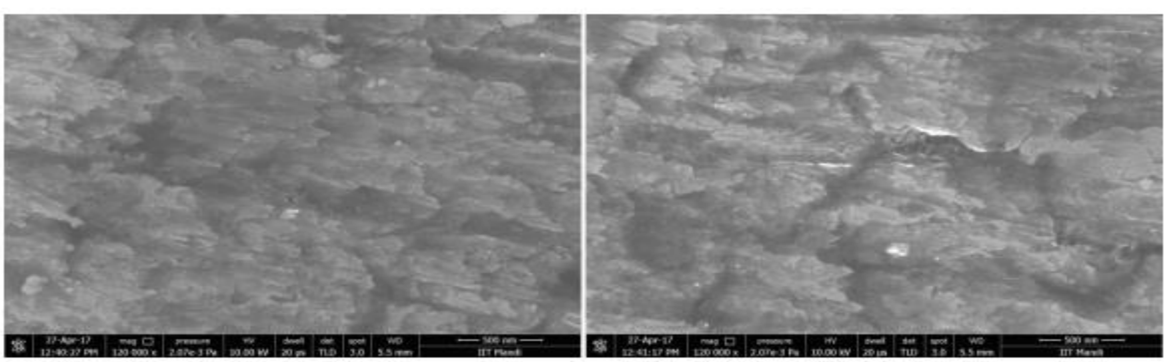


Figure: 3.6 SEM images of the weld surface at 120000X Zoom

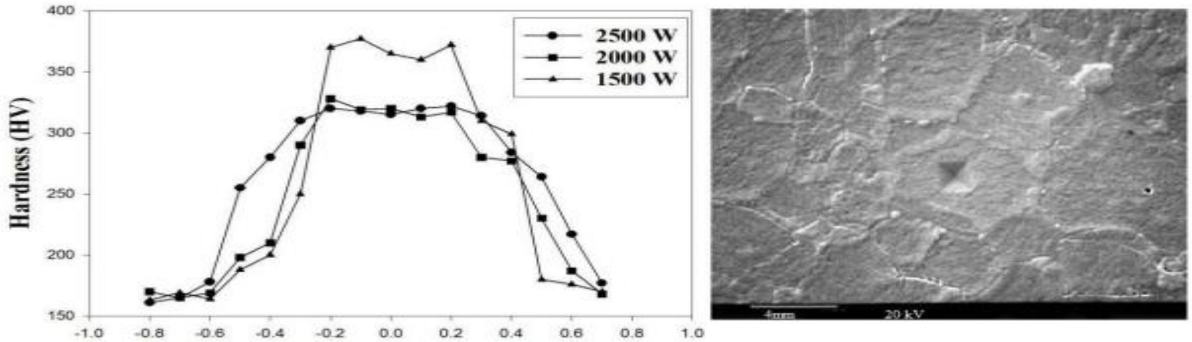


Figure: 3.7 Vicker's Micro-hardness for the Sample with Optimum Parameters

3.4 CONCLUSION

After carrying out a series of experiments on the friction stir welded specimens, we come to the following conclusions:

1.) The friction stir lap welded bond of AlA-AlA always has ultimate shear strength higher than the AlA-Cu-AlA FSW lap joint for the same parameters.

2.) For the thin sheets, clamping is vital because otherwise the sheets may bend under the heavy loads.

3.) All the factors: plunge depth, tool rotational speed and the traverse speed play a very significant role in the surface as well as the strength of the joint.

4.) In case of thin sheets of AL5052, lower values of tool rotational speed cause the material not to plasticize properly and thus making a weak and irregular joint while the higher values of tool rotational speeds burn the work-piece material and cause tunneling defects.

Friction stir welding, the process discussed in this thesis report has potential to be used in the aerospace industry (since it doesn't add any extra material to the existing mass), in heat exchangers as well as in the radio communication industry. Also, as friction stir welding has the ability to make a leak-proof joint between the dissimilar Al5052-H32 and pure Cu, the process could be utilized for the AlA-Cu structures based near water bodies, even though it is not recommended due to electrolytic reaction and thus corrosion, yet is a better option than other kind of welding processes.

REFERENCES

[1] Çam G. Friction stir welded structural materials: beyond Al-alloys. International Materials Reviews. 2011;56:1-48.

[2] Farrokhi H, Heidarzadeh A, Saeid T. Frictions stir welding of copper under different welding parameters and media. Science and Technology of Welding and Joining. 2013;18:697-702.

[3] Motalleb-nejad P, Saeid T, Heidarzadeh A, Darzi K, Ashjari M. Effect of tool pin profile on microstructure and mechanical properties of friction stir welded AZ31B magnesium alloy. Materials & Design. 2014;59:221-6.

[4] Mishra RS, Ma ZY. Friction stir welding and processing. Materials Science and Engineering: R: Reports. 2005;50:1-78.

[5] Amber Shrivastava, Michael Zinn, Neil A. Duffie, Nicola J. Ferrier, Christopher B. Smith, Frank E. Pfefferkorn. Force measurement-based discontinuity detection during friction stir welding. Journal of Manufacturing Processes 26 (2017) 113–121

[6] Pankaj Sahlot, Kaushal Jha, G.K. Dey, Amit Arora. Quantitative wear analysis of H13 steel tool during friction stir welding of Cu-0.8%Cr-0.1%Zr alloy. Wear378- 379(2017)82–89.

[7] Bipul Das, Sukhomay Pal, Swarup Bag. Torque based defect detection and weld quality modelling in friction stir welding process. Journal of Manufacturing Processes 27 (2017) 8–17. [8] Goebel, Jannik, Reimann, Martin, Norman, Andrew, dos Santos, Jorge F., Semistationary shoulder bobbin tool friction stir welding of AA2198-T851.Journal of Materials Processing Technology http://dx.doi.org/10.1016/j.jmatprotec.2017.02.011

[9] Kush P. MEHTA, Vishvesh J. BADHEKA. Influence of tool pin design on properties of dissimilar copper to aluminum friction stir welding. Trans. Nonferrous Met. Soc. China 27(2017) 36−54.

[10] G.M. Karthik, G.D. Janaki Ram, Ravi Sankar Kottada. Friction stir selective alloying. Materials Science & Engineering A 684 (2017) 186–190.

[11] N.Z. Khan, A.N. Siddiquee, Z.A. Khan, A.K. Mukhopadhyay, Mechanical and microstructural behavior of friction stir welded similar and dissimilar sheets of AA2219 and AA7475 aluminium alloys, Journal of Alloys and Compounds (2016), doi: 10.1016/j.jallcom.2016.11.389.
[12] Wei Zhang, Yifu Shen, Yinfei Yan and Rui Guo, Dissimilar friction stir welding of 6061 Al to T2 pure Cu adopting tooth-shaped joint configuration: microstructure and mechanical properties, Materials Science & Engineering A, http://dx.doi.org/10.1016/j.msea.2017.02.091
[13] Shude Ji, Zhengwei Li, Liguo Zhang, Yue Wang. Eliminating the tearing defect in Ti-6Al-4V alloy joint by back heating assisted friction stir welding. Materials Letters.
[14] Nan Xu, Qining Song, Yefeng Bao, Yongfeng Jiang and Jun Shen, Achieving good strength-ductility synergy of friction stir welded Cu joint by using large load with extremely low welding speed and rotation rate, Materials Science & Engineering A, http://dx.doi.org/10.1016/j.msea.2017.01.052
[15] Hui Shi, Ke Chen, Zhiyuan Liang, Fengbo Dong, Taiwu Yu, Xianping Dong, Lanting Zhang, Aidang Shan. Intermetallic Compounds in the Banded Structure and Their Effect on Mechanical Properties of Al/Mg Dissimilar Friction StirWelding Joints. Journal of Materials Science & Technology (2016).
[16] Ahmed, M.M.Z., Ataya, Sabbah, El-Sayed Seleman, M.M., Ammar, H.R., Ahmed, Essam, Friction stir welding of similar and dissimilar AA7075 and AA5083.Journal of Materials Processing Technology http://dx.doi.org/10.1016/j.jmatprotec.2016.11.024
[17] H. Dawson, M. Serrano, S. Cater, N. Iqbal, L. Almásy, Q. Tian, E. Jimenez- Melero, Impact of friction stir welding on the microstructure of ODS steel, Journal of Nuclear Materials (2017), doi: 10.1016/j.jnucmat.2016.12.033.
[18] Kim, K.H., Bang, H.S., Bang, H.S., Kaplan, A.F.H., Joint properties of ultra thin 430M2 ferritic stainless steel sheets by friction stir welding using pinless tool.Journal of Materials Processing Technology http://dx.doi.org/10.1016/j.jmatprotec.2016.12.018
[19] V.C. Sinha, S. Kundu, S. Chatterjee. Microstructure and mechanical propertiesof similar and dissimilar joints of aluminiumalloy and pure copper by friction stir welding. Perspectives in Science (2016) 8, 543—546 51
[20] Q. Zheng, X. Feng, Y. Shen, G. Huang, P. Zhao, Dissimilar friction stir welding of 6061 Al to 316 stainless steel using Zn as a filler metal, Journal of Alloys and Compounds (2016), doi: 10.1016/j.jallcom.2016.06.092.
[21] A. Yazdipour, A. Heidarzadeh, Effect of friction stir welding on microstructure and mechanical properties of dissimilar Al 5083-H321 and 316L stainless steel alloy joints, Journal of Alloys and Compounds (2016), doi: 10.1016/j.jallcom.2016.03.307.