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# Investigation and Optimization of Aluminium Alloy with Copper by FSW using Filler Material – A Review

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***Abstract*: Welding is one of the most utilized process in fabrication for joining process. With the increase of industrialization, there has been a great demand for the effective joining techniques for metal, nonmetals, polymers as well as composites. Friction Stir Welding stir the material for both the joining work pieces in the plasticized state to form the strong joint. In present work scenario, the main objective lies to investigate and optimize the various affecting parameters during the joining of Aluminum alloy with copper. The first phase consists of joining dis-similar metal (Aluminum alloy & Copper) without utilizing filler material by two different tool profile. Whereas in the second phase, the joint of the plates are formed by the addition of filler materials. The development in the microstructural properties of both the phases are observed. The tastings are conducted to analyze and determine the most effective parametric conditions to form strong joint for Al alloys and copper by the Friction Stir Welding (FSW).**

***Keywords*: FSW, Filler Material, Aluminum alloy, Copper, Parametric Optimization**

## 1. Introduction

Friction Stir Welding is the solid-state joining process which utilizes a non-consumable tool to join the work pieces without melting the w/p material. The heat is generated between the tool & the w/p material, which tends to soften dur to friction region near the FSW tool. The tool is travelled along the join linings of the work pieces & mechanically intermixes the two pieces of metal. It also forges the hot & softened metal with the help of mechanical pressure which is applied by the tool. Thus, the two metal intermixes and gets joined in the solid state without being converted into the liquid state. A rotating cylindrical tool with a profiled probe is fed or inserted into a joint between two clamped work pieces with the fixtures, until the shoulder, which has a larger diameter than the pin which then touches the surface of the work pieces. The probe or pin is slightly shorter than the weld depth required, with the tool shoulder riding at the top of the work surface. After a short dwell time and insertion in between the plates to be joint, the tool is moved forward along the joint line at the pre-set welding speed to stir the material. The heat is generated due to friction between the wear-resistant tool and the work pieces. This heat which is generated by the mechanical forces forms the mixing process and the heat within the material and it causes the stirred materials to soften without their melting. As the tool is moved forward, a special profile on the probe forces the plasticised material from the leading face to the rear, where the high forces assist in a forged consolidation of the weld to form joint. This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid-state deformation by the mixing of both the metals and involving dynamic recrystallization of the base material. The frictional heat is generated in between the materials which converts in into the plasticized state. Thus, the materials get mixed with each other and forms the strong joint. The material of the tool should have enough strength to withstand the heat and the various affecting forces takes place during the Friction Stir Welding.

## 2. Review of literature

R. Nandan, T. Debroy et al [1] performed the research on being conducted in depth on of the main materials and alloys. They provided the various results and researched being carried out on Friction stir Welding. They also laid their focus on the various tool geometries and their effects being done by the various researchers. They also researched on the HAZ, TMAZ & Nuggets and the various parameters that affects on the welding process. They also discussed the various results emerged from various papers. However, they does not able to explain the effective process that can be used by optimizing the parameters in friction stir welding. Effective methodology can be used to optimize and generate the results. The results and conclusion are based upon the theoretical and the experiments are not conducted by themselves to generate of finalize the results. Wayne M. Thomas et al [2] performed research about the development of tool in the friction stir welding process. Firstly they performed the Friction stir Welding on the 6mm 5083-O aluminum alloy wrought sheet. Their scope of development lies in both the butt as well as the lap joint. They illustrated that the good welding can only be done by the use of

the proper toll for the particular application. They developed the Flared Triflate, probe skew stir & Re-stir. They concluded that the Re-stir can be helpful for tailor welded blanks, compound lap and spot welding. However, the research is based only on the Re-stir technique and does not includes the other method of development. The studied is carried out only on single tool geometry and no other geometries. Does not optimized the best suitable parameters for speed and power in Friction stir welding. Ankur Vasava et al [3] provided the overview on the actual process being done in the Friction stir welding. They provided the description on the material selections, tool selection and the tool geometry. The tool can be formed of Tool steel, Nickel and Cobalt base alloys, Carbides and Metal Metrix composites and Cubic Boron Nitride. The basic materials can be selected are copper & its alloys, Magnesium alloys, Zinc, Plastics, Mild steel, stainless steel and Nickel alloys. They also explained about the Heat Affected Zone (HAZ) and its process. However, they only provided the overview and does not leads to any specific results. They studied on various theocratical and does not performed any practical data.

Nidhi Sharma, Zahid A. Khan et al [4] provided the overview of the various researches being performed on the Al alloy & Copper. They also mentioned the various laggings of the researches being conducted on it. They described the various influencing parameters, pin design and rotation speed of the tool. Research of Aluminium alloy on copper of Al-AA5083, AA5052, AA5A06, AA1100, etc of other's work are described. However, here they just provided the overview of the papers and not any proof of real experimental work. Furthermore, they also does not leads to the most effective methods that can be adopted from the various study of the research papers. In the overall experiments, they also lags in concept of welding improvements of the addition of filler materials. Nitin Panaskar, Ravi Terkar [5] performed the research on the reviews on some of the advance developments that used to solve the problems in the friction Stir Welding. It consists of the three different reviews being conducted on external cooling medium, combining FSW with the cold process & addition of the filler materials. However, they doesn't consider the affects of the various other parameters like filling of the materials in FSW and other variables on the real practical basis. I. Galvaoa, D. Verderab, D. Gestob et al [6] emphasize the work done on the developments of the FSW on the heat treatable Aluminium alloy (AA 6082) & Non-heat treatable (AA 5083) with copper. They founded that properties of the AA 5083 & AA 6082 Aluminium alloys, at high temperature and strain rates, have an important effects to the metallurgical and material flow properties. However, they evaluated the properties based on the microstructural evaluation and not on real test basis. Further, they also not considered the effect of filler materials that can be take place on the micro structural properties improvements and other effects. M.V.R.Durga Prasad, Kiran Kumar Namala [7] performed the research & the optimized variables are 800rpm, welding speed of 20 mm/min and tool tilt angle of 2 degrees. Welding speed contributes around 67.52% and the tool rotation speed has the least effect with 4.39%. Tool tilt angle has the effect of hardness at HAZ with 65.30% while welding speed has the least effect with 6.23%.The optimum parameters to obtain better hardness at HAZ are tool rotation speed of 1200rpm, welding speed of 20 mm/min and tool tilt angle of 0 degree. However, they does not provide the testing of the specimen like fatigue life and creep. The various Parameters are optimized experimentally and does not compared on the theoretical basis. M. Guerra, C . Schmidt et al [8] conducted the research on the flow pattern of the materials during the friction stir welding. Materials on the retreating side of the nib is entrained but never rotates around the nib and fills in the materials on the retreating side of the nib wake. There is the very large movement of material within the rotational zone caused by the wash and backwash of the threads. Material near the top of the weld moves under the influence of the shoulder rather than threads of the nib. However, the study on the flow patterns is studied. However, the effect of the flow pattern properties is not carried out. The procedure for the best flow pattern is not provided.

Arun Kumar Kadian, Pankaj Biswas [9] performed the research and they considered the thermal effect for the joining of the Aluminium Alloy (AA-6061) and the Coper Alloy (Cu-B370) by the Friction Stir Welding. Experimentally by the Thermocouple they concluded that the heat travelled at the Copper side is more than that of the Aluminium Alloy, so the isotherms obtained at the Copper Side were much larger than the Al side. Also, VOF model applied to get the information for dissimilar material flow was validated using thermal profiles and their properties. However, Here, they evaluated the properties based on the microstructural evaluation and not on real test basis. Further, they also not considered the effect of filler materials that can be take place on the micro structural properties improvements and other effects. The research is limited to VOF (Volume of Fluid) approach. Vukcevic Milan, Plancak Mirorslav et al [10] presents the research conducted on the Aluminum Alloy 6082-T6 (AlMgSi1Mn) The shoulder of dia 26.46 mm and pin dia of 5.92 mm with the tilt angle of pin $\alpha$=3.87 degrees with t he rotation speed of 630 rpm & welding speed of 125 mm/min. They successfully welded and measure the force along the three axes. The forces were measured by the digital measuring equipment connected to the information measuring system was performed. They concluded that the dimesion of the tool has the larger effect on the quality of the including the speed. However, the research is only conducted on the aluminum alloy. Process are not optimized by the various optimizing factors. Finite Element Analysis is note carried out. Tensile testing is only conducted i.e. lack of other testing's required for the welding. Qixian Zheng, Xiaomei Feng et al [11] performed the experimental analysis by the addition of filler material in the Aluminum (6061) and the Steel (SS 316). They formed the sandwich structure i.e. placed the Zin in between the Aluminum and steel to form the joint. After, they

performed the Vickers's hardness test to determine the strength of the joint. However, they only performed their analysis based on the sandwich structure and not on the other positions of weld. Also, no any information about the effects of the Aluminum alloy to steel by using other metals apart from Zinc is obtained. Research covers the specific of Aluminum & Steel an don't any other elements. Milenko Perovic, Darkoveljic, Markorakin et al [12] explains the friction stir welding performed on the AW 7049A in a T652. They made the 3D model to form Finite Element Analysis which is developed in ABAQUS or Explicit using the Langrangia-Eulerian formulation and Johnson Cook Material Law & Coloumb's Law of friction. They performed Keller's Test & Hardness test. The Ultimate tensile strength was found to be 80% to 90% than that of the welding material. The temperature is increased with the increase of speed. However, they conducted research only on the 7049A in a T652 and not such class or sub class materials. Does not provide the effective result the effects due to Heat Affected Zone. More testing required to be performed in order to calculate the actual properties of the welded parts.

Kush P. Mehta, Vises J. Badheka [13] conducted the research on various tool profile of varying their pin diameter by keeping the machine parameters constant on the Aluminium (AA6061-T651) and the Copper Materials. They concluded that the high pitch copper and Aluminium of 6.3mm thickness were successfully Friction Stir Welded at process parameters such as tool with cylindrical pin profile of 8 mm pin diameter and 26.64 mm shoulder at the rotational speed of 1500 r/min, welding speed 50 mm/min tilt angle $2^{o}$ at the tool pin offset of 2 mm with base. However, they conducted the research by varying the tool pin diameters and not the other machine parameters. They also doesn't considered the effects of the various adding of filler materials or the effects of changing the various tool materials. Kulwant Singh, Gurbhinder Singh et al [14] presented the research on the parameters width of the friction stir zone was about 6 mm which is equal to pin dia. The grains were found comparatively finer in the retreating side than the grains in the advancing side of thermo-mechanically affected zone. The FSW joint shows yield strength 175 MPa, tensile strength 220 MPa, elongation about 7.2% and efficiency of joint about 82%. The formation of finer grains in the stir zone results in provement in hardness of the joint. The microhardness of base metal is higher than that of thermo-mechanically affected zone but lower than that of stir zone. However, the study based only on the Microstructure Evaluation and not other practical basis. Welding strength of FSW with the other such alloys are not been performed and effects of such combination are not studied. Seung Hwan C. Park, Yutaka s. sate et al [15] conducted the research & they examined the micro structure of the Magnesium alloys and the relationship with the mechanical properties with the microstructure. There concluded that dislocations are occurred at the very high rate which just leads to outside the stir zone. Microstructural observations showed that he FS weld had roughly uniform distributions of grain size and dislocation density. Besides grain size and dislocation density crystallographic orientation on distribution strongly affected tensile properties of the homogeneously hard FS weld of Mg alloy AZ61. However, Microstructure and the fracture dislocations ere only examined during the tensile tests. However, the dislocations and micro structure can also be studied during the various other tests to reach to some appropriate results. No effective way or the methodology is provided to improve such affect ting factors. L. Commin, M. Dumont, J. E. Masse et al [16] presented the research work on the analysis of the friction stir welding. They did the friction stir welding and performed the various testing's in order to analyze its properties. As per their analysis and results, sound weld is obtained when V>200 mm/min W2sV>4000 rpm2 min/mm. The nugget temperature can be calculated from the shoulder's edge. Higher stress levels are obtained at the retreating sides. The friction stir welding produced lower tensile mechanical properties for this hot rolled base metal alloy. However, they performed the friction stir welding on the Magnesium alloy rolled sheets, their result is based on the experimental calculation and does employs the theoretical procedure for calculation like various methods, FEM, etc. Woong Jo Choi, Justin D. Morrow et al [17] present research work on the minimum power and energy consumption of 6061-T6 aluminum butt welds created by FSW were experimentally investigated. The power is mini mized with a combination of lowest possible spindle speed and weld speed and the energy consumption is minimized by operating at the highest possible weld speed. The result proves that the dominant factor in determining the energy consumption is the weld speed, while the power increases with both increasing spindle speed and welding speed. However, the minimum power is optimized by the by the speed. There are also other factors which are responsible like material strength which are not considered.

### 3. Analysis based on literature study and research gap

Based on the Literature survey from the various above papers, idea about the recent advance developments that have been performed in the Friction Stir Welding (FSW) is performed. We found that, various researches are being conducted over the Aluminium alloy, very few researches are being carried out on the Aluminium and the Copper. As the joining of these two metals are very beneficial due to their good properties, the effective methods to be utilized which provides the best condition for the joining of these two metals. As from the above Literature Study, very few researches are being conducted on the joining of Aluminium with Copper. Aluminium & copper are widely utilized in various electrical, heating & others as they have high thermal & electrical conductivity, high strength & high corrosion resistance. As a result, most effective & economical methods to be provided for the joining of these two alloys and metals. In the various researches as above, the study are being conducted only on the Aluminium alloy with copper or with copper alloy without the

utilization of the filler Materials. Qixian Zheng, Xiaomei Feng et al conducted only the addition of Zn filler materials in Aluminium alloy (6061) with Stainless steel and not on the Aluminium to Copper [11]. Kuang et al performed FSW on 2 mm thick Aluminium alloy 1A99 with the 2 mm thick industrial copper. The pin less tool of 16 mm dia was used & a thin foil was used in between the intermediate layer i.e. the sandwich form and the thickness of foil used was 0.2 mm thickness. They doesn't concluded about the Lap joint position. Hence, from the above Literature Study, the gap occurs for the best Parametric condition in order to form the strength joint of Aluminum alloy with Copper by the addition of Filler Materials.

### 4. Problem formulation and research methodology

With the advancement of Industrialization and Globalization, the demand for the quality, zero defect & time specified welding is increased. There are various research gap like some tries to optimize based on practical and lags in theoretical while some optimize the theoretical parameters and not the practical parameters, some researches does not verify the complete testing of the specimens, etc. There are very few researches conducted on effect of the properties of on the welded joints by the addition of the filler materials. Here, our main aim lies in joining of the Aluminium alloy with copper by the FSW as they have varied large applications as specified as Tube of Heat Exchangers, Transformer's Foil Conductor, Electrical Connectors, Busbars, Condenser & Capacitor foil windings, Refrigeration tube and Tube sheets. The effect of fillers materials on the dis-similar metals of Aluminium alloy and copper is not being conducted. Hence, research is performed on the dis-similar metal by filler materials having two different tool profile on the various affecting parameters on the Friction Stir Welding (FSW). They have the tendency to react at the temperatures greater than 120º C, which results in formation of intermetallic compounds. Thus, Low strength joint is formed with low electrical and Low thermal conductivity. [5] Various advanced machinery like Laser Welding, Explosion welding, etc are used but not economical. As a result, the effective techniques to be deployed for the joining of both these two metals with economical and Effective techniques. Therefore, in the current research work, we try to optimize the best welding that can be obtained by the addition of the filler materials by keeping the various parameters. Thus, the main aim lies in determining the best process parametric conditions to obtain the strong joint by the addition of filler materials.

### 5. Research methodology

As mentioned above, it begins with the dept study of the various research methodology & the study of the thesis. From the research paper, after the reviewal of the number of papers, the research gap is created. From the research gap, the important area in which the research to be performed is decided. Now, the materials are specified as per the literature survey and on that basis the tool design is performed. Simultaneously, the design parameters on which the research to be performed is decided. Now, the real experiment study is carried out to analyses the parameters based on the above. The testings of the joints are performed as per the standard specifications in order to evaluate the best condition for the desired parameters as per the Taguchi's method.

### 6. Selection and tool design

In order to get withstand at high temperature, the material of the tool should have more strength to resist deformation during the FSW. Therefore, we select the heat-treated SS 316 for the formation of FSW tool [3]. As mentioned in Fig. 1, the following design is made of the tool is to be used for FSW made from SS 316. Where, 1= Shank, 2=Collar, 3=Shoulder, 4=pin

The designed tool is used for the FSW of the Aluminum Alloy (AA 6082) to Copper for the plate thickness of 5 mm. The tapered tool is designed for 5 mm thick plate as per the below [1]: (1) Height of Pin = (t-0.3) mm; Where, t=thickness of the plate. (2) Dia of Collar = 3 X Height of the pin. (3) Dia of Shoulder > 2 times the dia of Shoulder. The dia of the shank is selected as per the machine specifications to be fitted in the Arbor of Vertical Milling Machine.

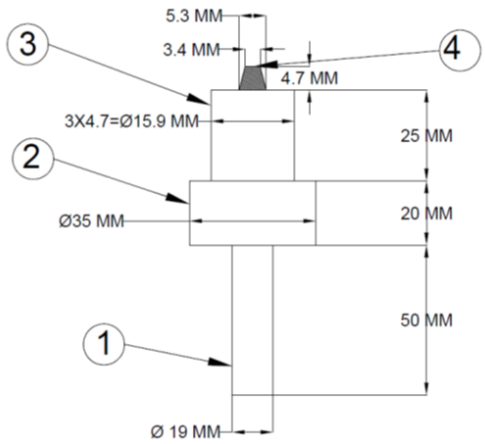


Fig. 1. Tool design

### 7. Selection of filler material

The main objective of this research lies in determining the strength of the Friction Stir welded joints of Aluminum alloy (AA 6082) with Copper by the addition of filler material. Very few researches are conducted for the addition of filler material specified as per Literature survey below: Elrefaey et al. Performed FSW using 2 mm thick pure aluminum A1100H24 to 1.0 mm in thick pitch copper. They used the zinc foil of 50 um thickness was used as an intermediate filler material. However, the structure is of Sandwich type and it doesn't explain about the lap joint or other positions. Qixian Zheng, Xiaomei Feng et al performed the experiment on the Aluminum alloy (6061) to SS 316 by the addition of Zn as the filler. Therefore, in order to use the filler material for FSW, they should have the good alloying properties with Aluminum as

well Copper. In the present Experiment we will use the Zn strip of 0.5mm ~ 1.5mm thick in the butt joining of both the plates.

## 8. Conclusion

This paper presented an overview on investigation and optimization of aluminium alloy with copper by FSW using filler material.

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