Joining of AA 6063 to Pure Copper using Green Welding Technique

C.Devanathan[1 *], R.Giri [2], A.Sivanand[1] P.Naresh[3], R.Mohan[3]

Abstract— Advanced lightweight materials are considered as a backbone for any transportation industries to improve the fuel economy, performance and safety. The multi material concept including light hybrid materials is now the buzz word in automotive industry. The areas like body structure of the automobile and power train demands the joining of dissimilar materials. In the present work, an attempt was made to join 6mm thick aluminium 6063 to pure copper using an autogenous friction stir welding process. Four experiments were conducted by varying welding speed at two different values using two non-consumable rotating tools having square and cone shaped pin profiles. The specimens were tested for its quality using visual and radiographic non-destructive testing method. The welded specimens were also tested for its impact strength and hardness. The joints prepared by cone shaped pin at 20 mm/min had a continuous tunnel like defect and lead to poor weld. On the other hand the square pin tool had produced defect free good quality weld. Impact test results showed that impact strength of the welded specimen had directly proportional relationship with welding speed for both tools. Square pin tool had produced better impact strength than cone pin tool by means of effective stirring of the workpiece materials.

Index Terms— Dissimilar welding, Green welding technique, Impact strength, Tapered tool, square tool, Radiographic test

1 INTRODUCTION

Welding is considered as an important manufacturing technique which is used to produce compact, complex and efficient products that are used in aerospace, ship building, automobile and other industrial areas. Most of the welding processes are exceptionally complex in nature and multi dimensional in terms of materials used and workman skill which make the fabrication of good quality joints very difficult.In order to make a single structure consists of various components, often joining of different materials together are in demand. Joining of dissimilar materials repeatedly poses severe challenges due to difference in mechanical, physical, and metallurgical properties of the material to be welded. The welded joint may fail due to difference in melting point, thermal conductivity, and coefficient of thermal expansion. [1].

Dissimilar material joining can be classified in to three groups based on material combination used during welding. Different alloys from same class of metallic materials like AA 6XXX to AA 7XXX, different class of materials but melting temperature are not much different from each other like aluminum to magnesium, different class of materials but also have different melting point like Aluminum to steel.

Recently Honda Motor Corporation has executed FSW to join dissimilar aluminum alloys and steel in their production of Honda Accord vehicle and state that total body weight was reduced by 25% compared to the conventional steel sub frame. Mazda Motor Corporation has developed direct friction stir spot welding technique to weld aluminum alloys to steel and claimed that this technique had the potential to connect dissimilar metals along with reducing the cost of production. Seimens medical solutions were also used FSW process to fabricate components and join aluminum sheets with stainless steel sheets. Friction Stir Welded joints were largely replaced the usage of riveted joints in aerospace with low cost [2].

Generally joining copper to aluminum by fusion welding has the tendency to form large intermetallic compounds which are normally brittle in nature and leads lot of defects.

Solid state welding technique is the group of joining methods where amalgamation takes place at room temperature without melting the materials being joint. Heat input is very much lower than fusion welding and bonding happens through plastic deformation. Because of low heat input and absence of complete melting, FSW offers several advantages over the conventional fusion welding process. The process is also called as green welding technique due to absence of filler materials, fumes, grinding wastes, etc., Friction stir Welding was invented and patented by Wanye Thomson at The Welding Institute (TWI) in Cambridge, UK. [3-4]

Friction stir welding uses non consumable rotating tool which has two major functions such as heating and soften the base material, extruding the base material from front to back, top to bottom and finally form the joint in the solid state.

Zhao et.al had welded aluminum to copper using three different tool pin profiles such as cylinder with thread, taper cylinder and straight cylinder. The experimental results revealed that taper pin had produced maximum strength among the other joints [5].

Ahmet et al studied the effect of welding speed on temperature of the workpiece. Temperature variation of the plates from stir zone to the base metal at equal distance was detected using thermocouples. The maximum temperature values were obtained very close to the joint line and highest temperature values were obtained for 1500 rpm and 32mm/min [6].

Kush et al studied the formation of defects under different process parameters while joining copper and aluminum alloys. The effect of tool pin design, tool offset, welding speed and tilt angle on formation weld defects were studied. Defects were identified by visual inspection and microstructure examination. The examination results revealed that taper tool had produced longer voids at root side of the weld. Tunnel defects were observed for larger tool pin offset. Pores were present on the welded joint for their lower tilt angle [7]. Many researchers had tried different dissimilar materials by friction stir welding and found that the technique is more advantageous than other methods while joining different materials [8 –10] and few researchers presented a detailed review study on friction stir

- *1 C.Devanathan, Assistant Professor, Department of Mechanical Engineering, Rajalakshmi Engineering College, Chennai, 602 105.*
- *2 R.Giri, Professor, Department of Mechatronics Engineering, Rajalakshmi Engineering College, Chennai, 602 105.*
- *3, A.Sivanand, Assistant Professor, Department of Mechanical Engineering, Rajalakshmi Engineering College, Chennai, 602 105.*
- *4, P.Naresh, UG Student, Department of Mechanical Engineering, Rajalakshmi Engineering College, Chennai, 602 105.*
- *5, R.Mohan, UG Student, Department of Mechanical Engineering, Rajalakshmi Engineering College, Chennai, 602 105.*

welding of dissimilar materials and the challenges need to be faced on joining different materials [11 – 14].
In the present experimental work, AA 6063 was joined with pure copper by changing the welding speed and tool pin profile at two different levels. Totally four samples were welded by varying welding speed and tool pin profile in two different levels. Other process parameters like spindle speed, axial force, tool offset were maintained constant. The welded samples were tested visually for their surface defects and tested by Radiography technique for internal defects. The impact strength and hardness of the welded specimen was measured and results were discussed.

2 EXPERIMENTAL PROCEDURE

2.1 Selection of Workpiece and tool material

Copper and aluminum materials are widely used in different industries due to their better conductivity and corrosion resistance property. In most of the cases it is essential to join aluminum and copper to get the best out of both the materials. These materials have very good thermal and electrical conductivity due to which it is used in applications like electrical connectors, bus bars, refrigerator tubes, heat exchanger tubes and many more.
In this experimental work, AA 6063 and pure copper were selected as workpiece material to prepare the butt joint configuration. The base material is 6 mm thick and cut to 100 mm X 50mm size. The chemical properties of the base materials are given in the table 1. The sample aluminum and copper workpieces are shown in the figure 1.

Table 1 : Chemical Compositions of Base materials

AA 6063	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
Wt %	0.45	0.26	0.05	0.06	0.8	0.06	0.1	0.07	Ba
Pure Cu	Zn	Pb	Sn	P	Fe	Ni	Co	Al	Cu
Wt %	0.01	0.02	0.005	0.002	0.02	0.02	0.03	0.002	Bal


Fig 1. Sample Workpieces


Fig 2. Cone and square pin FSW tool

In FSW process, tool is considered as an important element which is actually responsible for heat generation through friction and plastic deformation of the stirred material. The tool primarily has two parts such as shoulder and pin. The profile of the pin can be designed in different shapes based on which performance of the welding process changes.
In the present experimental work, FSW tool was designed with two different pin profiles namely cone and square. The diameter of the shoulder was 24 mm and height of the pin was 5.5 mm which is 0.5 mm less than thickness of the workpiece. The tool is made of H13 High speed steel and after machining heat treated to improve hardness.

2.2. Selection of process parameters

When compared to conventional fusion welding, Friction stir welding has limited process parameters which can be easily controlled in order to join the workpiece materials. Generally these parameters are grouped as machine related parameters and tool related parameters. Tool rotational speed, welding speed, axial plunge force, tool tilt angle are the parameters controlled in machine. Whereas diameter of the shoulder, size of the pin, tool material is considered as parameters related to tool used in the process. In this work, profile of the tool pin and tool traverse speed were considered as process parameters and varied in two different levels. The other parameters were not included in the study. The details of the process parameters were given in the table 2

Table 2 : Process Parameters

Si no	Process Parameter	Unit	Level 1	Level 2
1	Welding speed	Mm/min	20	25
2	Tool pin profile	-	Cone	Square

2.3 Conducting the Experiments

In friction stir welding of dissimilar material the position of the workpiece places a crucial role in quality of the weld formation. In the process, the side of the joint in which direction of tool rotation and feed are in same direction is known as advancing side and the other side is known as retreating side where the direction of tool traverse and tool rotation are opposite nature. In this experimental work, the aluminum and copper is placed on advancing side and retreating side respectively. The workpieces were firmly held in table surface of the Computer controlled vertical milling machine to prepare the butt joint configuration. The machine used is shown in the fig 3.

Fig 3: vertical milling machine

The sample workpieces were prepared based on the process parameters considered. Totally four samples were prepared which are show in the fig4. The sample [A] and [B] were prepared by square tool for welding speed of 20mm/min and 25mm/min respectively. The samples prepared by cone pin tool were given in [C] and [D].

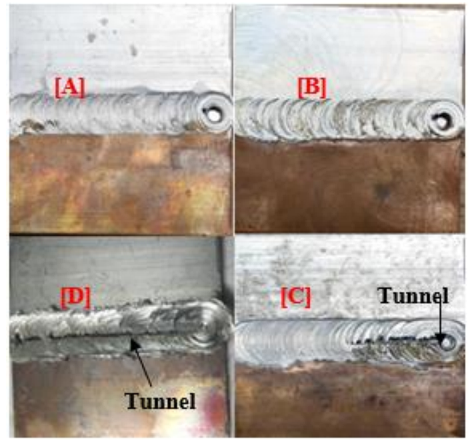

Fig 4. Welded Specimen

3 RESULTS AND DISCUSSION

The specimens prepared were subject to various stages of inspection to check the presences of defects and to find the mechanical properties of the welded joints. The inspection methods include nondestructive testing such as visual inspection and radiographic inspection methods. The welded specimens were also tested for its impact strength by izod method and hardness at different locations of the welded specimen.

3.1 Visual Inspection

The welded specimens were tested for its surface defects on the weld region. From the fig 4, it was observed that the specimens [C] and [D] were having volume defects like tunnel because of the improper mixing of the base materials.

3.2 Non Destructive testing

After Visual inspection was completed on the welded specimens, the first three specimens [A – C] were tested for its internal defects by radiography non destructive testing method to check for any internal defects which are normally difficult to identify by visual method. The radiography film of three specimens was shown in the fig 5. The radiography test results of three specimens revealed that there were no internal defects present in the welded specimen. The specimen D was not tested for their internal defects due to the presence of continues tunnel defect

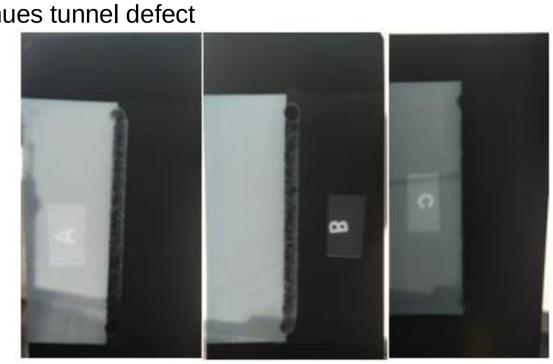

Fig 5: Radiography film of welded specimen

3.2 Destructive testing

Impact strength of the material is the ability of the material to withstand the sudden or shock load. Most of the machines and mechanism have welded joints which are subjected to sudden loads. So it is important to study about the impact strength of the welded joints to avoid the failure due to sudden loads. In this experimental work, effect of welding speed and tool pin profile on impact strength was studied. The impact test was conducted by izod method and samples were prepared as per ASTM standard D 256 – 10. From each welded specimen three samples were prepared and shown in the fig 6.

Fig 6. Izod Impact test sample specimen

The experimental results revealed that for both the tool pin profile increasing the welding speed increases the impact strength. Among the two tool pin profiles, square pin tool had given the better impact strength than cone shaped tool. The sample which had the tunnel defect produced least impact strength of 3.6 joules. This is because of poor stirring action of the cone profiled tool and defect formation in the welded workpiece. The effect of welding speed on impact strength for both the tools is present in the fig 7.

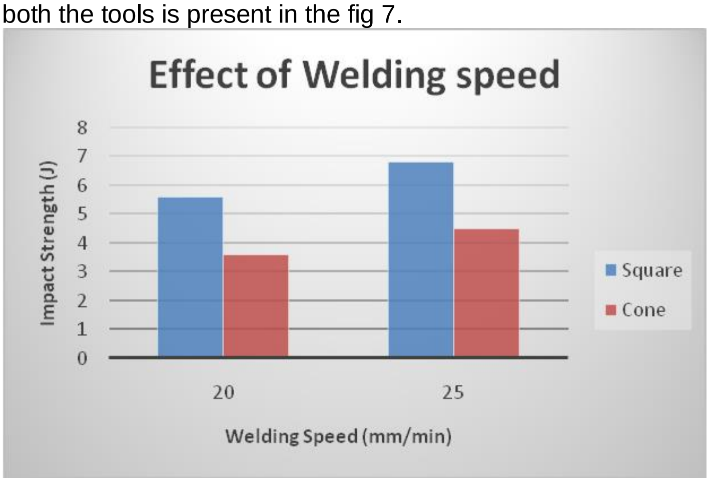

Fig 7. Effect of welding speed and pin profile on Impact strength

The welded specimens were also tested for its hardness at different location of the workpiece. The hardness values were measured at five different locations namely two measurements at base materials region and three measurements at welded region. The sample locations were the hardness values measured are shown in the fig 8.

Fig 8. Location of hardness Measurement

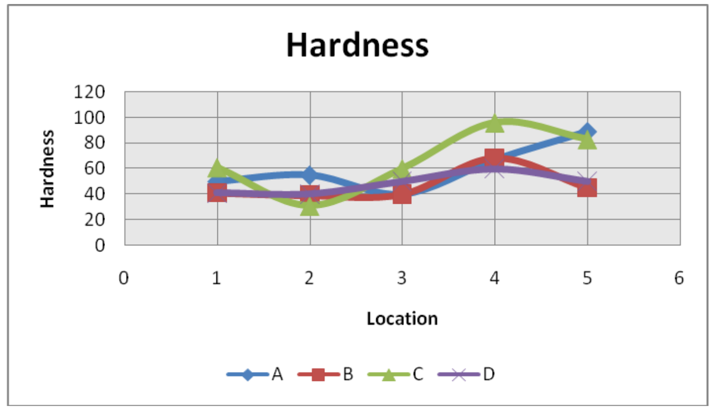

Fig 9. Hardness values in welded specimen

The measured readings were drawn as a graph which is shown in the fig 9. From the results it was observed that hardness values at the stir zone is less than other portions of the workpiece. The values on the aluminum side of the workpiece are higher than the pure copper side. From the results it was understood that there was no standard predictable trend for harness of the welded specimens. Few researchers found that the hardness was improved in the stir zone than the base material due to stirring action of the plasticized workpiece by non-consumable rotating tools. Whereas in this work results were contrary due to the presences of defects.

4 CONCLUSION

In this experimental work, an attempt was made to join aluminum 6063 to pure copper using friction stir welding. The experiments were conducted by varying the welding speed in two different levels by two different tool pin profiles namely square pin profile and cylindrical cone pin. The welded specimens were subjected to visual and radiographic inspection followed by impact test and hardness test. The results revealed that, radiographic test was effective way to identify the internal and sub surface defects. The tunnel defect was occurred when using cone tool at 20mm/min. The impact test results showed that increasing the welding speed increases the impact strength of the welded specimen and among the two different tools pin profiles square tool had produced better results due to proper stirring of the base material. Hardness measurement at different locations of the welded specimen showed that hardness at stir zone is less than the other portions of the workpiece.

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