Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings XX (2016) XXX–XXX

materialstoday: PROCEEDINGS

www.materialstoday.com/proceedings

PMME 2016

Experimental and numerical analysis of friction stir welded dissimilar copper and bronze plates☆

R Murugan[a]*, N Thirumalaisamy[b]

[a]*Department of Mechanical Engineering, Sriguru Institute of Technology, Coimbatore - 641 110, India*
[b]*Department of Mechanical Engineering, Sriguru Institute of Technology, Coimbatore - 641 110, India*

Abstract

Friction Stir Welding (FSW) is a type of solid-state welding process that involves joining of metals without fusion or filler materials. The frictional heat is produced by a rapid rotating non-consumable high strength tool pin that extends from a cylindrical shoulder. In this paper 6mm, thick copper and bronze plates are friction stir welded at different tool rotational speeds of 800, 1000 and 1200 RPM, with a constant travel speed of 40 mm/min and an axial force of 10 kN. Tests like Optical Microscopy (OM), Scanning Electron Microscopy (SEM) and Microhardness is done to identify the metallography studies. The friction stir welding experiments are carried out with the transverse speed of 40 mm/min of the tool. Vickers hardness test, microstructure analysis is performed on the welded material. The ANSYS model analysis is done in FSW process and the various temperature distributions during different travel time values are evaluated. The findings from these investigations are presented and discussed.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: Friction stir welding; Rotational speed; Numerical analysis; Metallographic structure; Heat distribution

* Corresponding author. Tel.: +91-944-353-3027; fax: +91-422-2229988.
E-mail address: murugan3212000@yahoo.com

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

1. Introduction

In Friction stir welding process the welding occurs at temperatures far below the original melting temperature of the specimen material and thus there is no melting of the parent metals. Frictional heat which is generated between the welding tool (wear-resistant) and the workpiece materials is used to join them. This heat causes the workpieces to soften below the melting point and as the tool traverses along the weld line the weld occurs. Defect free copper welds are achieved by friction stir welding carried out at a constant welding speed of 100 mm/min. [1]. The effect of various input speed on the mechanical properties of friction stir welded Cu–30Zn brass alloy and its microstructure were investigated [2]. Friction stir welding of 5mm thick pure copper plates were done. The characteristics of the microstructure, different heat zones and mechanical properties of welded joints are investigated [3]. The temperature distribution along the weld was studied and also the Brinell's hardness test, microstructure analysis is performed on the welded aluminium alloy material [4]. The mechanical characteristic properties of the aluminium welded joints have been evaluated through micro hardness and tensile test at room temperature [5]. Defect-free pure copper welds were achieved under low heat input conditions of 400–800 RPM for a traverse speed of 50 mm/min. [6]. Friction stir welding procedures were applied to brass plates in different rotation and welding speeds. Welded joints were subjected to mechanical test and microstructure investigations. [7]. Using friction stir process metals like aluminium and copper were easily welded by offsetting the tool to the aluminium side, producing excellent metallurgical bonding having a thin layer on the Al-Cu interface [8]. It is observed that the axial force exhibits more influence on the tensile strength followed by transverse speed and tool rotation speed [9]. During friction stir welding, the effect of speed, friction heat produced etc., on tensile strength, fatigue and crack behaviour of several welded aluminium alloys is described [10]. A three-dimensional model is established to fully couple the energy generation, heat transfer and material flow in Friction stir welding of aluminium alloys [11].

In this paper 6mm, thick copper and bronze plates are friction stir welded at different tool rotational speeds, with a constant travel speed of 40 mm/min and an axial force of 10 kN. The grain recrystallization structure occurring during the welding process is tested using optical microscopy. The distribution of the particles in the weld zone is tested by scanning electron microscopy and the Vickers hardness test was done for the hardness. The ANSYS model analysis is done in FSW process and the various temperature distributions during different travel time values are evaluated.

2. Material and Parameter Selection

2.1 Material Selection

Friction stir welding can also make hybrid components by joining dissimilar copper alloys. Copper has high electrical conductivity and thus also high thermal conductivity. Bronze plate is usually produced by mixing copper alloyed with zinc, is easily shaped. It has a fair electrical conductivity, excellent forming, drawing properties and good strength. So, it is difficult to do fusion welding of copper and bronze. In fusion welding, the evaporation of zinc becomes the major problem during the welding process of copper and bronze. At the end of welding, the welded metal becomes porous. Moreover, the amount of the zinc in the alloy is reduced due to evaporation. In this process, the bronze material loses its physical and chemical properties which it normally possesses. Hence the copper and bronze materials are selected for the friction stir welding. Both the copper and bronze plates were taken and cut into the required size (100mm×49.8mm×6mm) by power hacksaw cutting and grinding. The specimen plates and their dimensions are illustrated in Fig. 1,2, 3 and 4.

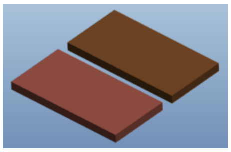

Fig.1. Specimen material

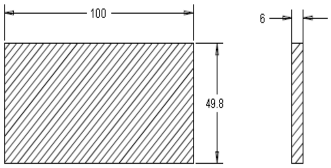

Fig. 2. Dimensions of plate material

Fig. 3. Bronze Plate

Fig. 4. Copper plate

2.2 Material Composition

The composition of H13 tool steel, bronze and copper are given in the below tables 1, 2 & 3.

Table 1. Composition of H13 tool steel

Elements	Composition (%)
Carbon	0.32 – 0.45
Chromium	4.75 – 5.50
Manganese	0.20 – 0.50
Molybdenum	1.10 – 1.75
Phosphorus	0.03 max.
Silicon	0.80 – 1.20
Sulphur	0.03 max.
Vanadium	0.80 – 1.20

Table 2. Composition of bronze

Elements	Composition (%)
Copper	97.5
Tin	1.0
Phosphorus	0.2
Zinc	0.3
Iron	0.1
Lead	0.05

Table 3. Composition of copper

Elements	Composition (%)
Copper	100

2.3 Process Parameters

The microstructure of a friction stir weld depends on the applied pressure, tool design, the rotation and traverse speeds and also the characteristics of the material being joined. Weld quality depends on

- Tool rotation (spindle speed)
- Traverse speed or welding speed (feed rate)
- Axial load
- Tool tilt angle

2.4 Tool Design

The design of the tool greatly influences the uniformity of the welded joint, heat generated during the welding process and the power required. In this design a large amount of heat is generated on the shoulder, preventing the plasticized material from escaping the workpiece. While the material flow affects both the shoulder and the tool–pin. The tool has hardened to 58HRC. Hence double tempered H13 tool steel with given dimension is taken for this welding process as shown in Fig.5 and 6.

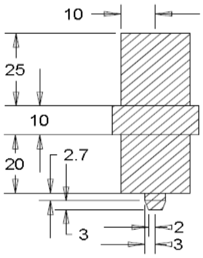

Fig. 5. Dimensions of H13 tool steel

Fig. 6. Double tempered H13 tool steel

3. Experimental procedure

Fig. 7 shows the friction stir welding machine in which the experimental work was carried out. The plates to be welded are prepared for the removal of foreign materials like oil and dust. Next both the plates are placed on the fixture and clamped in place. The tool is fixed with a slight tilt of 2.5 degree to the vertical axis. The spindle speeds for our experiment is selected as 800, 1000 and 1200 RPM. The tool is brought in contact with the specimen with an axial force of 10 kN to produce frictional heat. Transverse movement of 40 mm/min is given to the work table after a few seconds, which moves the tool along the weld axis. Table 4 gives the various specifications of the machining parameters.

Fig. 7. Friction stir welding machine

Table 4. Specification of parameters

Parameters	Sample 1	Sample 2	Sample 3
Rotational Speed	800 rpm	1000 rpm	1200 rpm
Welding Speed	40 mm/min	40 mm/min	40 mm/min
Axial Force	10 kN	10 kN	10 kN
Tool Tilt Angle	2.5^0	2.5^0	2.5^0

In this experiment, the grain structure and hardness of the welded zone are measured by using optical microscopy, and scanning electron microscopy. Whereas the hardness was tested using the Vickers hardness testing machine. The welded zone of the sample specimens is shown in Fig. 8.

Fig. 8.(a)Welded sample 1 (b) Welded sample 2 (c)Welded sample 3

4. Results and Discussion

4.1 Scanning Electron Microscopy Test

The SEM micrographs presented on the Fig. 9 shows the variation of microstructures as a function of volume in the welded plates at higher magnification. With the increase in rotation speed the particle size and the interspacing between the particles decreases in the weld zone. The uniform distribution of copper and bronze particles can be attributed to the adequate generation of frictional heat due to stirring and plasticized material flow across the friction stir welding zone.

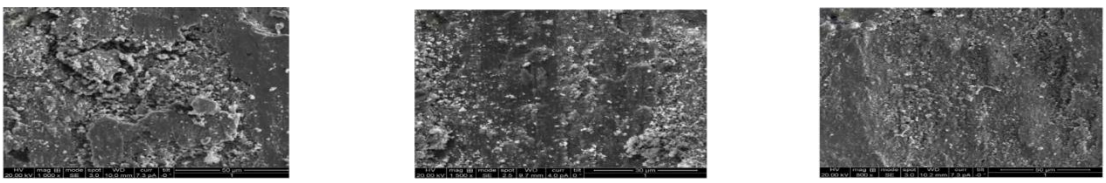

Fig. 9. SEM Micrograph of (a) specimen 1, (b) specimen 2, (c) specimen 3

4.2 Optical Microscopy Test

The optical micrographs of friction stir welded plates are shown in Fig.10 which displays dynamically recrystallized grain structures. These optical micrographs show the uniform distribution of copper and bronze particles in the welded zone and also the grain structure of the parent material. The each region of the stir zone received different thermo-mechanical effect. The exact central region of weld zone shows the very fine and equalized grain structure due to the recrystallization caused by the plastic shear deformation and frictional heat.

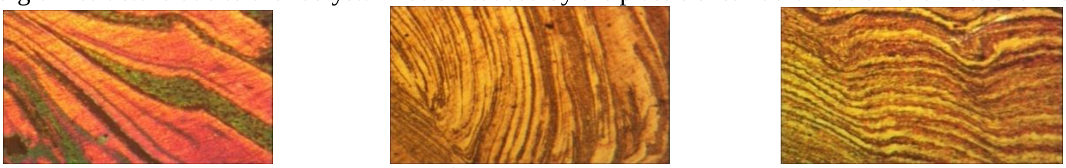

Fig.10 Optical micrograph of (a) specimen 1, (b) specimen 2, (c) specimen 3

4.3 Microhardness Test

The microhardness test is measured by using a Vickers hardness machine at 500g load applied for 5s in various locations in each welded specimen. The specifications of the Vickers hardness machine are given in Table 5.

Table 5. Specification of the Vickers hardness machine.

Item	Specification
Lens a	X50
Lens b	X10
Indenter	Vickers
Load	Hv0.05
Upper	0
Lower	0
Timer	5
Number	256
Table	Hard
Scale	Hv

The hardness of welded specimens is shown in the Fig.11, 12 and 13. The hardness in the welded zone is found to be higher when compared to other zones and it varies according to the process parameter selected, particularly the tool rotation speed. By increasing the tool rotation speed, the grain size becomes reduced in microstructural level. Thus the increase in speed increases the microhardness of the welded zone.

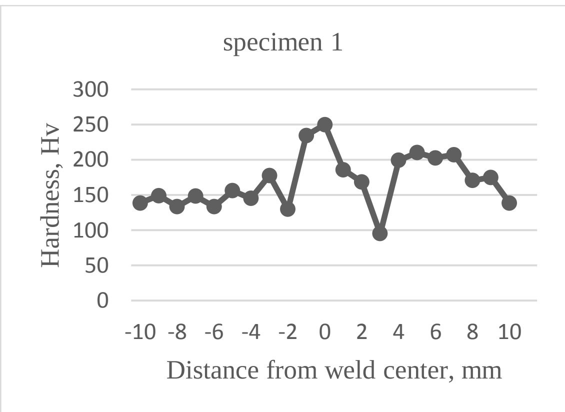

Fig. 11. Microhardness for specimen 1

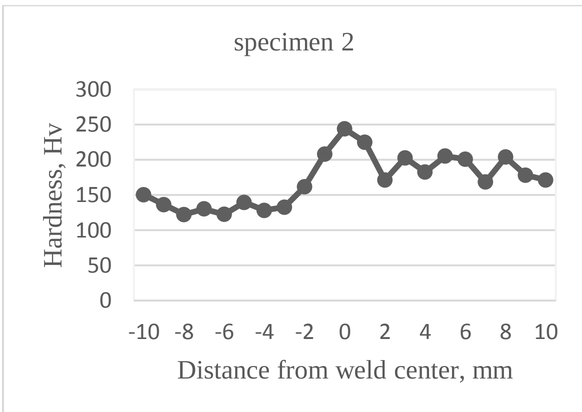

Fig. 12. Microhardness for specimen 2

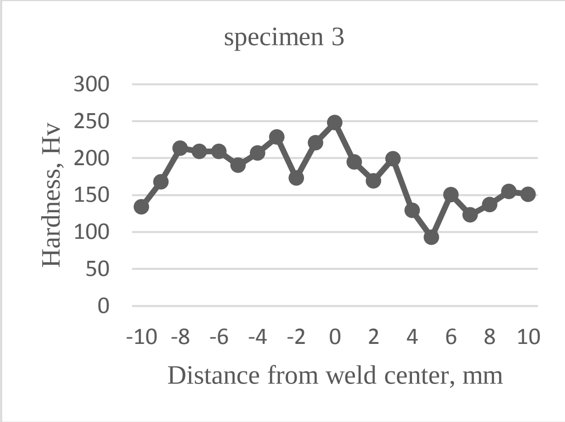

Fig. 13. Microhardness for specimen 3

5. Numerical Analysis

5.1. Temperature Distribution

The temperature distributions on the welded samples are studied using the ANSYS software which is illustrated in Fig. 14. The temperature value becomes high and it achieves the recrystallization temperature when the plates are in contact with the rotating tool. Behind the tool, the process transports hot material away, while in front new cold material enters the tool.

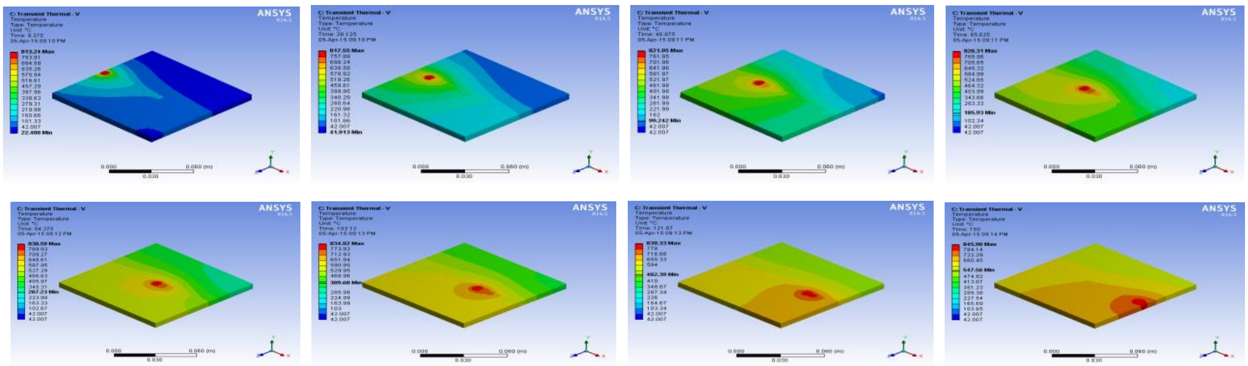

Fig. 14. Temperature distribution during FSW using ANSYS model

From the ANSYS analysis, it can be seen that the maximum temperature achieved for welding is well below the melting point of the copper and bronze plates. The temperature values increase with respect to increasing in time duration, along the weld axis. From the experiment results, the temperature values decrease with respect to increasing in distance and increases with respect to time duration along with the perpendicular to the weld axis.

6. Conclusion

The microstructural and mechanical properties of a friction stir welded copper and bronze plates were investigated. Based on the results, the main conclusions are as follows:

- No welding defect was detected in the joints welded at lower welding speed.
- The grain structure was found to be dynamically recrystallized in the welded zone than that of the parent metal.
- Increasing rotational speed was observed to be a more effective method for reducing the welding torque.
- Results from SEM and OM convey the presence of reinforcement and uniform distribution of material throughout the weld zone.

- The microhardness of the weld zone was found to be higher than that of the other zones and it varies according to the tool rotation speed.
- With the increase in welding speed, the average hardness of nugget zone first decreased and then increased, but the welding speed had very small effect on the hardness of the other regions.
- The generation and distribution of the heat energy are analysed in friction stir welding of copper and bronze by using ANSYS software. It can be seen that the welding of the plates takes place well below the melting point of the parent materials.

Acknowledgements

The authors would like to thank for the support given by the Coimbatore Institute of Technology (CIT), Coimbatore to do this experimental work at their research centre.

References

[1] H.J. Liu, J.J. Shen, Y.X. Huang, L.Y. Kuang, C. Liu and C. Li. Effect of tool rotation rate on microstructure and mechanical properties of friction stirs welded copper, Science and Technology of welding and joining 14 (2009) 577-583.
[2] M. SarvghadMoghaddam, R. Parvizi, M. Haddad-Sabzevar, A. Davoodi. Microstructural and mechanical properties of friction stir welded Cu–30Zn brass alloy at various feed speeds: Influence of stir bands, Materials and Design 32 (2011) 2749–2755.
[3] P. Xue, G. M. Xie, B.L.Xiao Z. Y. Ma;and L. Geng. Effect of Heat input conditions on microstructure and mechanical properties of Friction stirs welded Pure copper, Scripta Materialia 41A (2010) .
[4] Selvamani S.T, Umanath K and Palanikumar K. Heat Transfer Analysis during Friction Stir Welding of Al6061-T6 Alloy, 1(4), 1453-1460.
[5] Jawdat A. Al-Jarrah, SallamehSwalha, Talal Abu Mansour, Masould Ibrahim, Maen Al-Rashdan, Deya A. Al-Qashsi. Welding equality and mechanical properties of aluminium alloys joints prepared by friction stir welding, Materials and Design 56 (2014) 929-936.
[6] G. M. Xie, Z. Y. Ma;and L. Geng. Development of a fine-grained microstructure and the properties of a nugget zone in Friction stir welded pure copper, Scripta Materialia 57 (2007) 73-76.
[7] Cemal Meran, The joint properties of brass plates by friction stir welding, Materials and Design 27 (2006) 719-726.
[8] P. Xue, B.L.Xiao, D.R.Ni, Z.Y. Ma* Enhanced mechanical properties of friction stir welded dissimilar Al-Cu joint by intermetallic compounds Material Science and Engineering A 527(2010) 5723-5727.
[9] C.Devanathan, A.SureshBabu. Friction stir welding of metal matrix composite using coated tool, procedia materials science 6 (2014) 1470-1475.
[10] Pasquale Cavaliere* Friction stir welding of Al alloys: analysis of processing parameters affecting mechanical behaviour, Procedia CIRP 11 (2013) 139-144.
[11] H. Su, C.S. Wu, A.Pittner, M.Rethmeier. Thermal energy generation and distribution in friction stir welding of aluminium alloys, Energy 77 (2014) 720-731.