Journal of Manufacturing Engineering, December 2015, Vol. 10, Issue. 4, pp 171-178

EFFECT OF HARDFACED TOOLS ON THE PERFORMANCE OF FRICTION STIR WELDED COPPER ALLOYS JOINTS

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ABSTRACT

In the present work, an attempt was made to develop high temperature wear resistant hardfaced tools for friction stir welding (FSW) of commercial grade copper alloys. Hardfacing was applied on mild steel rod using Tungsten carbide forming powder by plasma transferred arc (PTA) hardfacing process and Tungsten carbide forming consumables by Shielded metal arc hardfacing (SMA) process. Commercially available tool material high speed steel (HSS) was also used to friction stir weld copper alloy for comparison purpose. From this investigation, it is found that the PTA hardfaced tool yielded defect free joints without tool wear compared to other tools. The optimum level of heat generation, formation of finer grains and higher hardness of stir zone are main reasons for the superior tensile properties of the joints fabricated by PTA hardfaced tungsten carbide tools.

Keywords: *Plasma transferred arc welding, Shielded metal arc welding, Friction Stir Welding, Mild steel, Tensile properties and Microstructure.*

1. Introduction

Copper is one of the important engineering materials widely used in the manufacturing industries. Since it has excellent electrical and thermal conductivity, it is used in the manufacturing of electrical Components. Apart from these, during the joining of copper by traditional method of welding process, the weld joint is seriously affected by the impurities and influence of oxygen [1].Due to high thermal conductivity, the base metal properties changed results in poor strength at the weld joints. The efficiency of the conventional welding process is also low. Various researches were carried out to improve the mechanical and metallurgical properties of the welded joints of copper. But it is very difficult to reduce the problems of conventional fusion welding process such as splatter, shrinkage, distortion and porosity [2].After the invention of FSW a new focus on material flow mechanism and micro structural changes during welding was studied vigorously. Moreover FSW greatly reduced the problems of conventional fusion welding process and almost 70 to 80% of the base material properties were retained [3].

Friction stir welding (FSW) is a kind of solid-state joining technique, which was invented at The Welding Institute (TWI) of UK in 1991 and was originally applied to Al alloys. With the rapid development of this technique and the application of high strength and durable rotation tools, the use of FSW has been expanded to many other materials including Mg, Cu, Ti, steels and Ni alloys etc [4].The welded joint is fundamentally defect-free and displays excellent mechanical properties when compared to conventional fusion welds [5]. Such joining process is demonstrated to avoid severe distortions and the generated residual stresses are proved particularly low, compared to the traditional welding processes [6].

The main obstacle to use FSW with these higher melting point materials is the development of tool materials capable of surviving the high temperatures and forces generated by the process Considerable advances have been made, mainly through improved materials selection and tool design [7]. Even though FSW produced better joints of copper, the mechanical and metallurgical properties of joints and tool life not attained applicable range. One of the major challenges in expanding the application of FSW processes to new materials is the lack of suitable tools for welding materials with high melting temperatures. To be effective, tool materials must resist physical and chemical wear, possess sufficient mechanical strength at elevated temperatures, and effectively dissipate the heat carried to the tool during the welding process [8]

Weld hard facing techniques are employed mainly to extend or improve the service life of engineering components either by rebuilding or by fabricating in such a way as to produce a composite wall section to combat wear, erosion, corrosion. Surface properties and quality depend upon the selected alloys and deposition processes [9]. Nowadays chemical and

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fertilizer plants, nuclear, steam power plants space, aircraft components, and in numerous industries employ weld hardfacing processes [10]. SMAW is used very heavily in construction because of its quality, portability, and versatility. SMAW can weld most of the metals such as stainless steels and carbon steels, and with special electrodes, can weld high-carbon steels, copper, brass, and even aluminium [11]. In recent years, one of the coating methods used for those purposes is plasma transferred arc coating process. This method stands out for its high quality, metallurgical bonded with substrate and low diluted coatings. These coatings also exhibit high homogeneity, low oxide content, and low concentrations of other unwanted inclusions [12]. Hence, in this investigation an attempt has been made to understand the influence of tool material on Heat input, material flow behavior, microstructure formation and tensile strength properties of friction stir welded copper alloy joint and comparing conventional tools with hardfacing tools.

2. Experimental Procedure

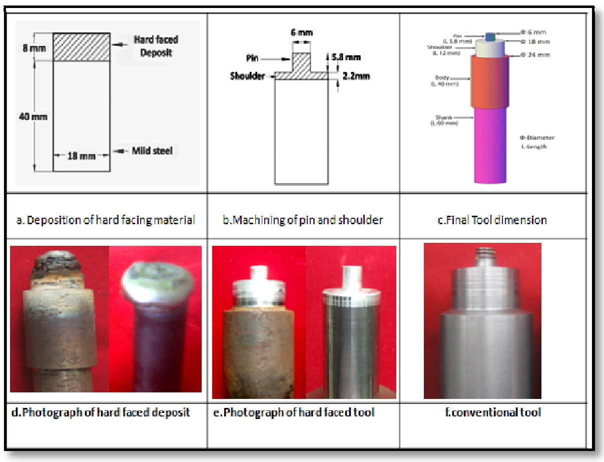
The commercially available mild steel rod was used as substrate for the deposition of the hardfacings material. The chemical composition of hardfacing powder and conventional tool material are presented in Table 1.

Table 1Chemical composition of tool material

Tool Used	C	Cr	Fe	Mn	Mo	Si	V	W	Co
HSS	0.75	4.2	-	-	5.0	-	2.0	6.0	-
MWC	1.2	-	1.0	-	0.6	0.3	-	Bal.	0.3
PWC	1.4	10.0	8.0	1.0	5.0	2.5	0.5	Bal.	13.0

The tool fabrication by hardfacing method was shown in Fig1and the tool dimension was shown in Fig 1c.Here Tungsten carbide forming consumables were used to deposit hardfaced layer onto the mild steel rod by Shielded metal arc welding (SMAW) technique.

The Plasma transferred arc process was used to form deposition from Tungsten carbide Powder (WC) was shown in Fig 1d and a self fluxing powder NiCrBSi was added for further increase of the coating adhesion and avoids the temperature mismatch between the particle and substrate.



a. Deposition of hard facing material

b.Machining of pin and shoulder

c.Final Tool dimension

d.Photograph of hard faced deposit

e.Photograph of hard faced tool

f.conventional tool

Fig.1 Schematic representation of hardfaced tool fabrication

Hardfacing were produced using optimized process parameters with powder composition consisting of 60 mass percent (%) WC and 40 mass percent (%) NiCrBSi. Argon gas was used as plasma gas, shielding gas as well as powder transporting gas. PTA Hardfacing and SMAW hardfacing Process parameters are shown in Table 2. After deposition, it was machined by help of diamond wheel followed by hard turning to obtain the pin and top surface of the shoulder shown in Fig 1e.

Pure copper plates of 6 mm thickness is machined into proper welding dimension of 175 mm × 150 mm (Length × Width) shown in Fig 2(a). The chemical composition and mechanical properties of the base metals in weight percent is given in Table 3 and 4.Specimens were extracted from various locations of the joint was shown in Fig 2(b) and for preparing tensile and metallographic analysis

Table 2. Parameters used for hardfacing

Parameter	PWC	MWC
Transferred arc current (Amps)	160	140
Voltage	22	18
Travel speed (mm/min)	170	-
Powder feed rate (gms/min)	30	-
Torch oscillation frequency(cyl/min)	42	-
Standoff distance (mm)	10	-
Electrode diameter(mm)	-	4

Table 3. Chemical Composition (wt%) of base metal

Fe	S	Bi	Ag	Pb	Sb	Cu
0.005	0.005	0.001	0.005	0.005	0.002	Bal.

The specimen free of volumetric defect and lack of penetration was considered as the optimized welding condition. Also care was taken to avoid the tool pin failure and control the heat input by controlling the combination of tool rotational speed and welding speed. The welding conditions and optimized process parameters presented in Table 5 were used to fabricate the joints for further investigation. An indigenously designed and developed CNC controlled friction stir welding machine was used in position control mode to fabricate the FSW joint. The base metals are butt welded along its length by using Friction Stir welding machine. The standard dimensions of the tool with a pin (Ø6 × 5.8 mm) and a shoulder (Ø18 mm) is used for all the tool material. Samples are welded at a constant rotation rate of 1200 rpm and welding speed of 25 mm/min.

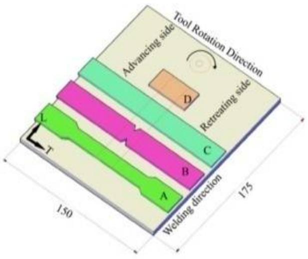
Two different tensile specimens were prepared as shown in Fig 2(c) and 2(f), to evaluate the transverse tensile properties. Unnotched smooth tensile specimens were prepared to evaluate the transverse tensile properties of the joints such as yield strength, tensile strength and elongation. Notched specimens were prepared to evaluate notch tensile strength and notch strength ratio (notched tensile strength/un-notched tensile strength) of the joints. Tensile testing was carried out using 100KN, electromechanical controlled universal testing machine (FIE-Blue star, India; model UNITEK-94100). The unnotched and notched tensile specimens were prepared as per the ASTM E8 M-04 guidelines [13]. In this investigation, the heat input was calculated using the expression proposed by Heuriter et al [14] and the equation was given by

$$\text{Heat input } (q) = (2\pi/3S) * \mu * p * \omega * R_s * \eta$$

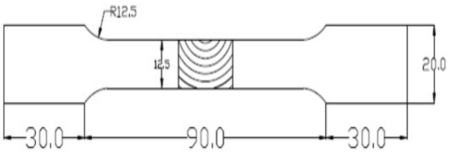
Thermocouples were used for sensing the thermal histories and it was recorded using LABVIEV data acquisition system was shown in Fig.3 and the experimental result compare with calculated heat input value.

Vickers Micro hardness testing machine (SMIMADZV, Japan; model HMV-2T) was used to measure the hardness of weld with 0.5N load and 15s.Micro structural examination was carried out using an optical microscope (MEJI, Japan; model MIL-7100) incorporating image analysing software (Metal vision). The specimens for metallographic examination were sectioned to the required size from the joint comprising weld metal, HAZ and base metal regions, and polished using different grades of emery papers. Final polishing was done using a diamond compound (1 lm particle (size) in the disc polishing machine. The specimens were etchedwith a solution of 15ml hydrochloric acid, 100ml distilled water and 2.5g iron chloride was used to reveal the microstructure of the welded joints.

(a) Photographs of fabricated joints



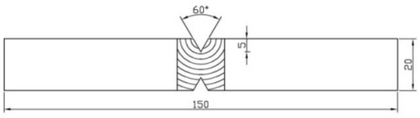
(b) Joint configurations



(c) Dimension of unnotched tensile specimen

(d) Photograph of un notched specimen-before test

(e) Photograph of un notched specimen -After test



(f) Dimension of notched tensile specimen

(g) Photograph of notched specimen-Before test

(h) Photograph of notched specimen- After test

Fig. 2 Fabrication of joints and tensile specimen

Table 4. Mechanical properties of base metal

Material	Yield Strength (MPa)	Tensile Strength (MPa)	Notch Tensile Strength (MPa)	Notch Strength Ratio	Hardness of base metal @0.5kg load (HV)	Elongation in 50 mm gauge length (%)
Copper alloy	280	350	420	1.02	130	30

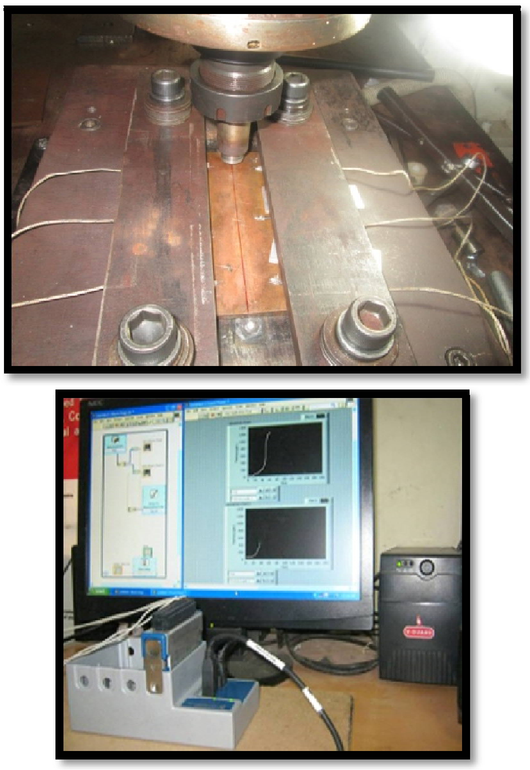


Fig. 3 Temperature measurement using LABVIEW

Table 5. FSW Process Parameters used to fabricate the joints

Material	Rotational speed (rpm)	Welding speed (mm/min)	Axial force (KN)	Shoulder diameter (mm)	Pin diameter (mm)
Pure Copper	1200	25	8.7	18	5.8

3. Results and Discussion

3.1 Transverse tensile properties

The transverse tensile properties such as yield strength, tensile strength, percentage of elongation, notch tensile strength, and notch strength ratio of copper alloy joints were evaluated. In each condition, three specimens were tested, and the average of the results is presented in Table 6.

Table 6. Tensile properties of FSW joints fabricated using different tool materials

Joint Type	Yield strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Notch Tensile Strength (MPa)	Notch Strength Ratio (NSR)	Joint efficiency (%)	Location of failure
HSS	150	180	22	190	1.05	58.06	SZ
MWC	220	240	22	270	1.125	68	SZ
PWC	250	300	24	350	1.166	85	TMAZ-AS

The yield strength and tensile strength of unwedded parent metal are 280 MPa and 350 MPa, respectively. However, the tensile strength of HSS and MWC joints are 180 MPa and 250 MPa, respectively. Which was lower compared to PWC joint. However, the tensile strength of PWC joints 300MPa.Elongation of the unwelded parent metal is 30%, respectively. However, the elongation of HSS and MWC Joints are 22% and 26%, respectively..In which elongation of PWC was 24%.

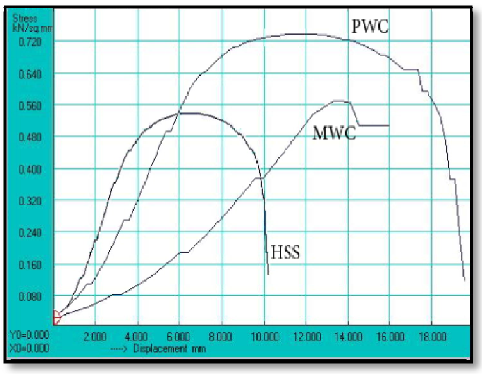
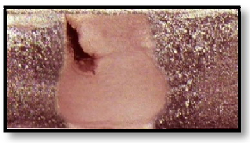


Fig.4 Stress v_s displacement

Another notch tensile parameter,NSR, is found to be greater than unity (>1) for all the joints. This suggests that the copper alloy is insensitive to notches and it is a "notch ductile materials". The NSR is 1.02 for unwelded parent metal, but it is 1.05, 1.233 and1.166 for HSS, MWC and PWC joints respectively. Joint efficiency is the ratio between tensile strength of welded joint and tensile strength of the unwelded parent metal.

The joint efficiency of HSS and MWC joints is approximately 58% and 71% and the joint efficiency of PWC joints is 85%. Of the three types of welded joints, the joints fabricated by PWC exhibited a relatively higher strain tolerance as compared to the other joints as shown in Fig.4.

Tool used	**Top surface of weld**	**Cross sectional macrograph** **AS RS**
HSS		
MWC		
PWC		

Tool used	**Failed tensile specimen**	**Observation**
HSS		(i) Surface defect - The area between the shoulder diameter and pin diameter is reduced which in turn reduced thematerial flow from the leading to trailing edge (ii) Location of failure: SZ
MWC		(i) Defect free. (ii) Location of failure: SZ
PWC		(i) Defect free. (ii) Location of failure: TMAZ-AS

Fig.5 Macrostructure of weld cross-section

3.2 Macrostructure

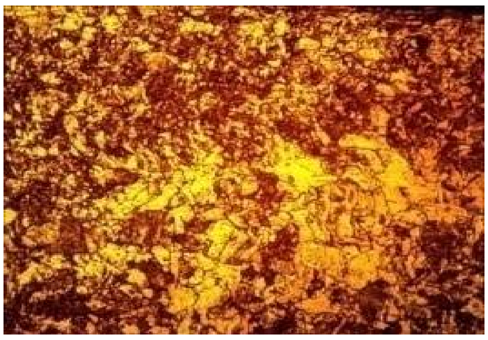
Fig .5 shows the influence of tool material on macrostructure of the friction stir welded joints. It is generally known that the fusion welding accompanied by the defects like porosity, slag inclusion, solidification cracks, etc., deteriorates the weld quality and joint properties. Usually, friction stir welded joints are free from solidification related defects since, there is no melting takes place during welding and the metals are joined in solid state itself due to the heat generated by the friction and flow of metal by the stirring action. However, FSW joints are prone to other defects like pin hole, tunnel defect, piping defect, surface defect, groove defect, Zig-Zag line and cracks, etc., due to improper flow of metal and insufficient consolidation of metal in the FSP (weld nugget) region. All the joints fabricated were examined at low magnification (10x) using stereo zoom microscope to reveal the quality of weld nugget region.The weld cross-section appears like ‘basin-shape ‘and no volumetric defect is observed. The macrostructure of the weld can be split into several distinct regions such as stir zone (SZ), a region either side of the stir zone which can be termed the thermo mechanically affected zone (TMAZ), heat-affected zone (HAZ), and the base metal (BM) itself.

3.3 Microstructure

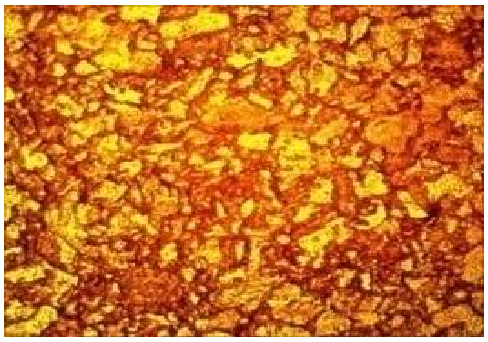
Microstructure of all the joints was examined at different locations, but most of the tensile specimens failed in the weld metal region, and the optical micrographs was taken at the weld metal region alone are displayed in Fig. 6 for comparison purpose. The base metal contains coarse and inhomogeneous grains with uniformly distributed very fine precipitates. The stir zone of HSS Fig 6 (a) and MWC Fig. 6(b) joints contain coarser grain structure and this may be due to in sufficient heat generation. The only difference between these two joint and PWC joint is the fine grain microstructure was obtained. However, the weld region of PWC joint Fig. 6(c) contains very fine, equiaxed grains due to the dynamic recrystallisation that occurred during FSW process.

3.4 Tool material properties

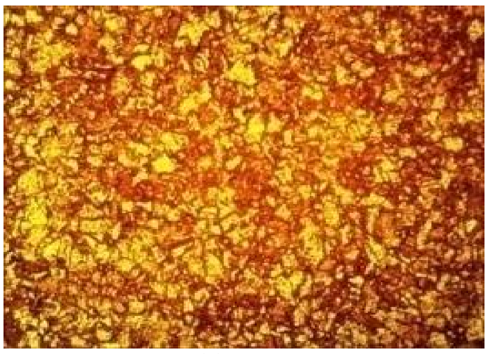
The heat generation is liable for the sound weld characteristic like less distortion, defect free stir zone formation, residual stress formation, etc. Hence determination of heat generation and thermal histories of friction stir welding process leads to achieving sound joint. In FSW, The tool material properties especially, heat generation due to friction is mainly dependent on tool material hardness. The tool material decides the quantity of heat supplied to the base materials to be joined.



(a)HSS



(b)MWC



(c)PWC

Fig.6 Stirzone microstructure

Hence in this investigation an attempt was made to determine average µ value by conducting Pin On Disc wear test (copper was used as disc and Tool material were used as pin).Table 7 present, the measured µ value for each combination of tool-work piece material and calculated heat input values. The tool material decides the quantity of heat supplied to the base materials to be joined. From table 7, it is understood that the heat generation is having directly proportional relationship with the tool hardness and µ.

Table 7. Tool materials properties

Tool material	Hardness (HV)0.5kg load	Co-efficient of friction (μ)	Heat Input (J mm^{-1})
HSS	430	0.28	390
MWC	730	0.53	680
PWC	910	0.71	790

From table 7, it is understood that the heat input is having directly proportional relationship with the tool hardness. The HSS tool generates heat energy of 390 Jmm^{-1} which is relatively less than PWC hardfacing tool materials consider for this investigation. The PWC tool producing sufficient heat energy of 790 Jmm^{-1}, due to higher hardness obtained by presents of tungsten carbide, co efficient of friction is higher compared with conventional tool. The heat input calculated value confirmed with lab view software shown in Fig. 8.

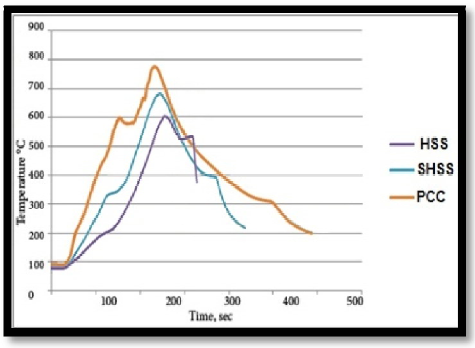


Fig.7 Temperature profiles during FSW

3.5. Micro hardness

Micro hardness was measured at mid-thickness region across the weld and the values are presented in Fig.8. The base metal recorded a hardness of 130 HV. The hardness of the SZ is considerably higher than that of the base metal irrespective of the tool material used. There are two main reasons for the improved hardness of the SZ. (i) The grain size of SZ is much finer than that of base metal; grain refinement plays an important role in material strengthening. On, hardness increases as the grain size decreases. (ii) The small particles of intermetallic compounds are also a benefit to hardness improvement.The difference in hardness between the HAZ and SZ is attributed to the grain refinement in the SZ. The lowest hardness 80Hv was recorded in the joint fabricated with HCS tool. Advancing Side (AS) recorded appreciably lower hardness values compared to Retreating Side (RS).

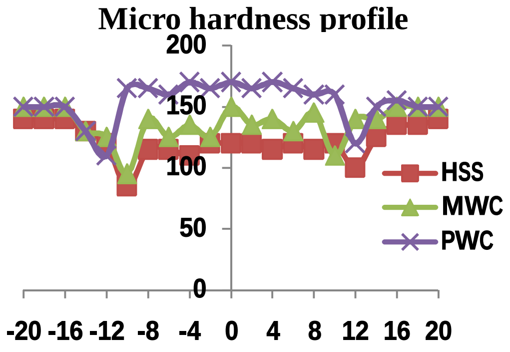


Fig. 8 Hardness profile across the weld center line

Because, there is no refilling of material from retreating side due to plasticized material. The joint fabricated with a MWC and PWC tool was recorded the hardness value of 150 HV and 170Hv respectively in the SZ region.

4. Conclusions

In this investigation, an attempt was made to develop low cost and high wear resistance tool material using SMA and PTA hardfacing techniques to friction stir weld copper alloys. From this investigation, the following important conclusions are derived:

(i) Of the three tools investigated, HSS tool produced surface defect on the welded joint and the pin underwent excessive deformation; MWC tools able to weld copper alloy without defect but the threaded pin profile was worn out completely; PWC tool (PTA hardfaced tungsten carbide tool) was able to withstand the high temperatures and forces during FSW of copper alloys and yielded defect free joint

(ii) Of the Three tools, the PWC tool fabricated joint exhibited very high strength values and the enhancement in joint efficiency approximately 25% compared to HSS tool joints, and 15% compared to MWC tool joints

(iii) The PWC tool joint produced Defect free fine grained microstructure of weld nugget and uniformly distributed finer particles in the weld nugget regions are found to be the important factors responsible for the higher tensile strength compared to all other joints.

(iv)The joints fabricated by PWC tool Hardness was recorded (170 HV) higher in the weld metal (SZ) region compared to the TMAZ, HAZ and BM regions. Hardness was recorded in the MWC tool joints (150 HV) and the very lower hardness was recorded in the HSS tool joint (80 HV).

Acknowledgement

Authors are grateful to Centre for Materials Joining& Research (CEMAJOR), Department of Manufacturing Engineering, Annamalai University for extending all the necessary facilities to carry out this investigation.

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