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RECENT DEVELOPMENT OF FRICTION STIR WELDING TOOLS FOR JOINING COPPER ALLOYS

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ABSTRACT

In the present work an attempt was made to develop low cost high temperature wear resistance hardfacing tools. The hardfacing was applied on mild steel rod using Tungsten carbide powder by Plasma transferred arc welding (PTAW) processes. A comparative study was done to study the performance of hard facing tools with conventional tools. In this work, friction stir welding of pure copper plate of 6 mm thickness was investigated with an aim to understand the performance of tool materials on weld microstructure and tensile properties. From this investigation, it is found that the joints fabricated using PTA hardfaced tool yielded superior tensile properties compared to other joints. The optimum level of heat generation, formation of fine grains and higher hardness in plasticized zone are the main reasons for the superior tensile properties of these joints.

Keywords: *Plasma transferred 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 same potential exists for FSW of hard metals such as titanium, stainless steel, and copper and nickel base super alloys. 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 [7].

Weld hardfacing 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 [8]. Nowadays chemical and fertilizer plants, nuclear, steam power plants space, aircraft components, and in numerous industries employ weld hardfacing processes [9]. 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

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and low diluted coatings. These coatings also exhibit high homogeneity, low oxide content, and low concentrations of other unwanted inclusions [10]. 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. The Plasma transferred arc process was used to form deposition from Tungsten carbide Powder (WC) was shown in Fig.1 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.

Table 1 Chemical 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	-
PWC	1.4	10.0	8.0	1.0	5.0	2.5	0.5	Bal	13.0

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. The tool fabrication by hardfacing method was shown in Fig. 1. PTA 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. The tool dimension was shown in Fig. 1c.

Pure copper plates of 6 mm thickness are machined into proper welding dimension of 175 mm × 150 mm (Length *Width) shown in Fig. 2(b). 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 was shown in Fig. 2(a).

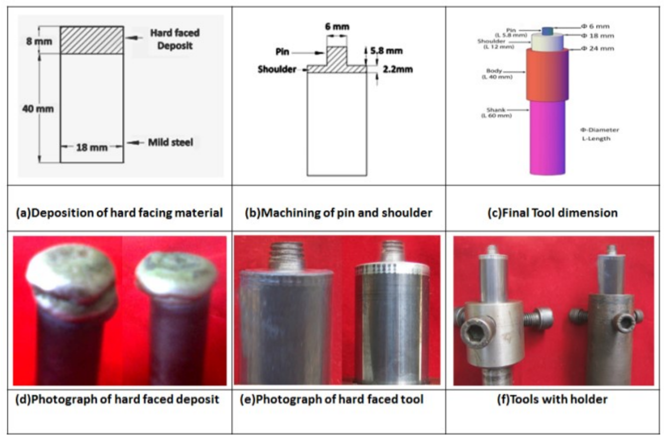


Fig. 1 Experimental Process

Table 2 Parameters Used for Hardfacing

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

In this investigation, the heat input was calculated using the expression proposed by Heuriter et al [11] 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 LABVIEW data acquisition system as shown in Fig. 3. The experimental results were compared with calculated heat input value. The experimental result compare with calculated heat input value were presented in Table 4 which shows the good agreement. The unnotched and notched tensile specimens were prepared as per the ASTM E8 M-04 guidelines [12].

The tensile test was carried out in 100 KN, servo controlled universal testing machine (Make: FIE – BLUESTAR, INDIA, Model: UNITEK 94100) with a cross head speed of 0.5 mm/min at room temperature. The 0.2% offset yield strength, ultimate tensile strength, and notch tensile strength were evaluated.

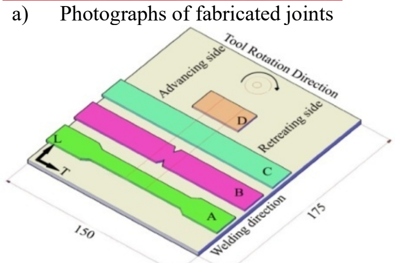
Vickers Micro hardness testing machine (SMIMADZV, Japan; model HMV-2T) was used to measure the hardness of weld with 0.5N load and 15s. Macro and micro-structural analysis have been carried out using a light optical microscope (VERSAMET-3) incorporated with an image analyzing software (Clemex-Vision). The polished samples were etched with a solution of 15ml hydrochloric acid, 100ml distilled water and 2.5g iron chloride was used to reveal the microstructure of the welded joints.

3. Results and Discussion

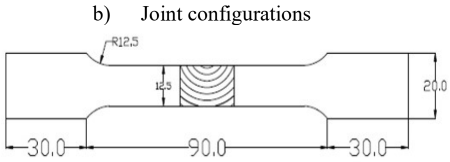
3.1 Transverse tensile properties

Transverse tensile properties such as yield strength, tensile strength and percentage of elongation of the joints were evaluated and are presented in Table 3. Since the dimension of tensile specimens both smooth and notch involving the entire joint shown in Figure 2c and Figure 2f.

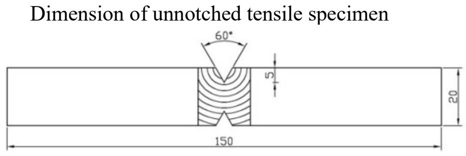
a) Photographs of fabricated joints



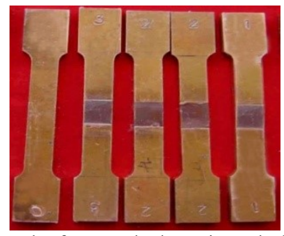
b) Joint configurations



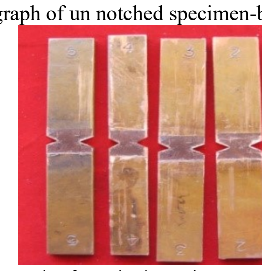
c) Dimension of unnotched tensile specimen



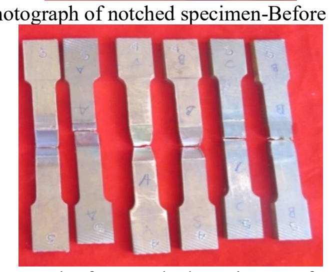
d) Dimension of notched tensile specimen



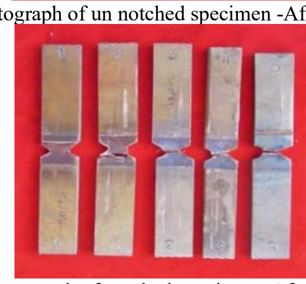
e) Photograph of un notched specimen-before test



f) Photograph of notched specimen-Before test



g) Photograph of un notched specimen -After test



h) Photograph of notched specimen- After test

Fig. 2 Fabrication of joints and tensile specimen

Table 3 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 Ration (NSR)	Joint efficiency (%)	Location of Failure
HSS	150	180	35	190	1.05	58.06	SZ
PWC	250	280	17	330	1.127	80.17	TMAZ -AS

In welding of pure copper using HSS tool the tensile strength and joint efficiency were observed in 180Mpa and 58.06%. Both values are higher for tungten carbide PTA hardfacing tool. This was due to sufficient heat generation and sufficient metal transportation supplied to the welding zone. The fracture occurred in PWC joint specimen TMAZ-AS because the lower hardness was observed in that region. But the HSS tool joints fractured in the stir zone region because entrapment of foreign particle due to tool wear take place. so lower tensile strength was 260MPa observed.

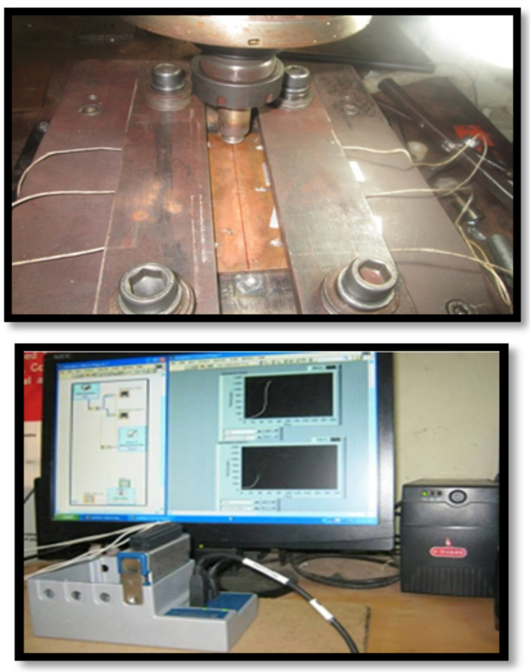
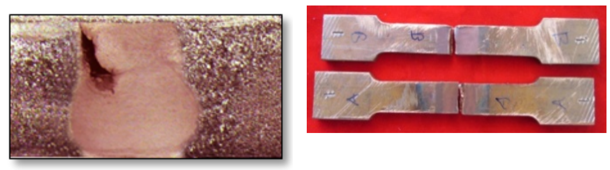


Fig. 3 Temperature measurement using LABVIEW

3.2 Macrostructure

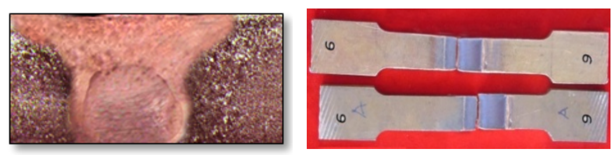
Fig.4 show the effects of tool materials on macrostructure of the friction stir welded joints. All the joints fabricated were examined at low magnification (10x) using stereo zoom microscope to reveal the quality of weld nugget region. The cross-section of macrographs of the FSW joints was presented. Even though MWC tool produced defect free joint, the strength and joint efficiency is low. PWC tool were completely free from macro level defects. From the macrostructure analysis, it can be inferred that the formation of defect free FSP zone is a depending on the tool material and process parameters.

HSS



(i) Name of the defect: Pin hole
(ii) Location of the defect; Advancing side
(iii) Reason : Insufficient heat generation and insufficient metal transportation
(iv) Location of failure: Along the defect

PWC



(i) Name of the defect: Defect free.
(ii) Location of the defect: Nil
(iii) Reason: Adequate heat input
(iv) Location of failure: TMAZ-AS

Fig. 4 Macrostructure of weld cross-section

3.3 Microstructure

The microstructures of SZ formed at various welding Tools are shown in Fig. 5 &6. Compared with the BM, the NZ has much smaller equiaxed grain due to dynamitic recrystallization. Therefore, the variation of recrystallized grain size with welding tools in FSW depends on the peak temperature of FSW thermal cycle is the dominant factor in determining the recrystallized grain size. It is due to the stirring action at plastic condition of the metal during FSW. Regardless of welding condition, while using HSS tools produced brittle structure because the entrapments of tool material in stir zone region. Thus, resulting in a degradation of mechanical properties.

But PTAH tools produced stir zone having finer grains. HSS tool the tool hardness is lower, then the friction between tool and base metal will be lower. This condition leads to low heat generation and resulted in defects such as pin holes in weld nugget region.

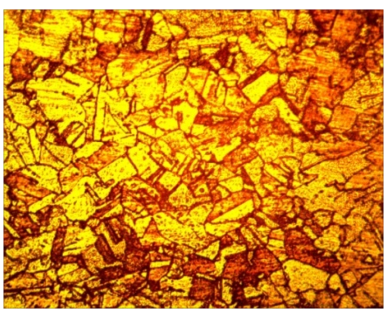
3.4 Tool material properties

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.

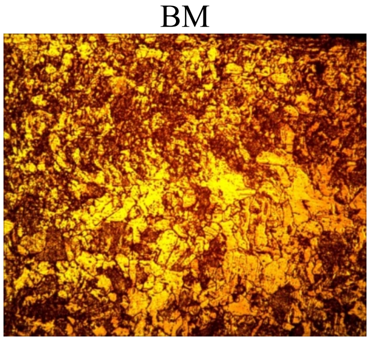
Table 4 Tool Materials Properties

Tool material	Hardness (HV)0.5kg load	Co-efficient of friction (μ)	Heat Input (J mm^{-1})
HSS	500	0.28	560
PWC	1050	0.71	800

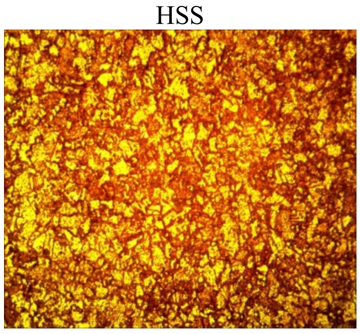
From Table 4, it is understood that the heat input is having directly proportional relationship with the tool hardness. The HSS tool generates heat energy of 560 Jmm^{-1} which is relatively less than PWC hardfacing tool materials consider for this investigation. The PWC tool producing sufficient heat energy of 800 Jmm^{-1}, due to hardness, co efficient of friction and uniform distribution of dendrite structure in microstructure is higher compared with conventional tool. The heat input calculated value confirmed with lab view software shown in Fig. 3.



BM

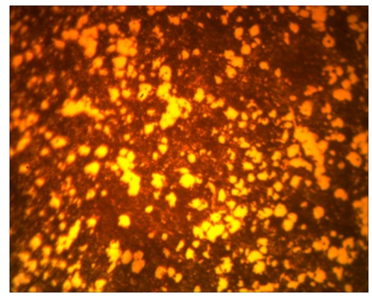


HSS

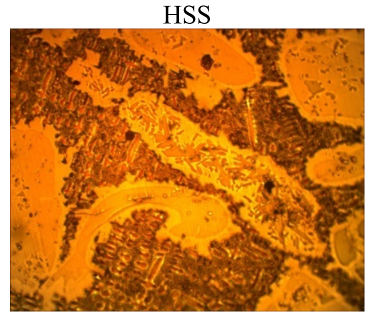


PWC

Fig. 5 Stir zone microstructure of copper alloy joints



HSS



PWC

Fig. 6 Microstructure of different Tools

4. Conclusions

In this investigation, an attempt was made to study the influence of tool materials on the mechanical and metallurgical properties of friction stir welded copper alloy joints. From this investigation, the following important conclusions are derived:

i. Of the two tools, the PWC tool generated higher heat input 800 Jmm^{-1}. The reason was PWC tool having higher hardness and higher co efficient of friction. But the HSS tool generated low heat energy of 560 Jmm^{-1}.
ii. Of the two tools, the PWC tool fabricated joint exhibited very high strength values and the enhancement in joint efficiency approximately 23% compared to HSS 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.

References

1. *Hwang Y M and Fan C H L (2010), "Experimental study on friction stir welding of copper metals", Materials Science and Engineering A, vol. 527: 5723–5727.*

2. *Steuwer A, Barnes S J, Altenkirch J, Johnson R and Withers P J (2011), "friction stir welding of hsla-65 steel: part ii. the influence of weld speed and tool material on the*

residual stress distribution and tool wear", The minerals, metals & materials society and ASM international

3. *Olivier Lorraina, Véronique Favierb, Hamid Zahrounic and Didier Lawrjaniecd (2010), "Understanding the material flow path of friction stir welding process using unthreaded tools", Journal of Materials Processing Technology, vol. 210: 603–609*

4. *Sun Y F and Fujii H (2011), "The effect of SiC particles on the microstructure and mechanical properties of friction stir welded pure copper joints", Materials Science and Engineering A, vol. 528: 5470–5475*

5. *Carter Hamiltona, Stanisław Dymekb and Marek Blicharskib (2008), "A model of material flow during friction stir welding", Materials characterization, vol. 59: 1206 – 1214*

6. *Cavalierea P, Nobilea R, Panellaa F W and Squillaceb A N (2006), "Mechanical and microstructural behaviour of 2024–7075 aluminium alloy sheets joined by friction stir welding", International Journal of Machine Tools & Manufacture, vol. 46: 588–594*

7. *Ouyang J H, Mei H, Valant M and Kovacevic R (2002), "Application of laser-based additive manufacturing to production of tools for friction stir welding"*

8. *Balasubramanian V, Varahamoorthy R, Ramachandran C S and Muralidharan C (2009), "Selection of welding process for hardfacing on carbon steels based on quantitative and qualitative factors", Int J Adv Manuf Technology, vol. 40: 887–897.*

9. *Srimath N and Murugan N (2011), "Prediction and Optimisation of Weld Bead Geometry of Plasma Transferred Arc Hardfaced Valve Seat Rings", European Journal of Scientific Research, vol. 51(2): 285-298.*

10. *Eitvydas gruzdys and Šarūnas meškinis (2011), "Influence of Plasma Transferred Arc Process Parameters on Structure and Mechanical Properties of Wear Resistive NiCrBSi-WC/Co Coatings", Materials Science (Medžiagotyra)" vol. 17(2):1392–1320.*

11. *Heurtier P (2006), "Mechanical and Thermal Modeling of FSW", J. Mater.Process. Technol., vol. 171: 348–357*

12. *ASTM E8 M-04. Standard test method for tension testing of metallic materials.*

