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EFFECT OF TOOL MATERIALS ON JOINT CHARACTERISTICS OF FRICTION STIR WELDED OF AA7075-T6 ALUMINIUM ALLOY JOINTS

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ABSTRACT

In this present investigation, 6 mm thick rolled plates of AA7075-T6 aluminium alloy were used as the base material. AA7075-T6 aluminium alloy plates were friction stir butt welded using commercially available tools high carbon tool (HCS) and Super High Speed Steel (SHSS). Further in this investigation one more tools was developed using hard facing process. Tungsten carbide was used to deposit hard faced layer onto the mild steel rod by Plasma transferred arc hard facing (PTA) process. Using each tool, one joint was friction stir welded under same welding conditions. From this investigation, it is found that the joints fabricated using PTA hard faced 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.

Key words: *Plasma transferred arc hard facing, Friction Stir Welding, Mild steel, tensile properties and Microstructure.*

1. Introduction

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 [1]. Nowadays chemical and fertilizer plants, nuclear, steam power plants space, aircraft components, and in numerous industries employ weld hardfacing processes [2].In recent years, one of the hardfacing methods used for those purposes is plasma transferred arc hardfacing process. This method stands out for its high quality, metallurgical bonded with substrate and low diluted coatings [3]. These coatings also exhibit high homogeneity, low oxide content, and low concentrations of other unwanted inclusions[4] since they offer the following advantages: (1) lower micro chemical redistribution like ‘dilution effect’ in the deposit (2)excellent bonding with the substrate and (3) ability to give dense, defect-free deposits [5].

Friction stir welding (FSW) was invented at The Welding Institute (TWI), UK in 1991. Friction stir welding is a continuous, hot shear, autogenously process involving a non-consumable rotating tool of harder material than the substrate material [6]. FSW can be considered as a hot working process in which a large amount of deformation is imparted to the work piece through the rotating pin and the shoulder. Frequently, the weld nugget appears to comprise equiaxed, fine, dynamically recrystallized grains whose size is substantially less than that in the parent material [7]. The formation of defect-free friction stir processed (FSP) zone is affected by the material flow behavior under the action of rotating non consumable tool. However, the material flow behavior is predominantly influenced by the FSW tool profiles, FSW tool dimensions, and FSW process parameters [8].

Initial application of these high strength AA7075 Aluminium alloy was used to aircraft primary structures. However, this class of aluminium alloy is difficult to join by conventional fusion-welding techniques because the dendrite structure

Formed in the fusion zone can seriously deteriorate the mechanical properties of the joint [9].Other crucial aspects are the brittle solidification phases presence and the porosity formation subsequent to fusion welding [10]. It is extremely sensitive to weld solidification cracking as well as heat-affected zone (HAZ) liquation cracking due to the presence of copper.

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While it is possible to overcome the problem of weld solidification cracking using a suitable non heat-treatable aluminium alloy filler the resulting joint efficiencies are unacceptably low. Therefore, use of alloy AA7075 is currently limited to applications that do not involve welding [11]. Hence, in this investigation an attempt has been made to understand the influence of tool material on Heat input, material flow behaviour, microstructure formation and tensile strength properties of friction stir welded AA 7075-T6 aluminium alloy joint and comparing conventional tools with hard facing tool.

Table 1. Chemical composition of tool materials

Tool Used	C	Cr	Fe	Mn	Mo	Si	V	W	Co	WC
HCS	1.5	12	84.0	0.50	0.80	0.30	0.9	-	-	-
SHSS	1	4	-	-	5	-	2	6	5	-
PWC	1.4	10.0	3.0	1.0	5.0	0.5	0.5	-	48	Bal

2. Experimental Work

The commercially available mild steel rod was used as substrate for the deposition of the hard facings material. Here Tungsten carbide powder deposit hard faced layer onto the mild steel rod was donoted as PWC by Plasma transferred arc process and self fluxing powder NiCrBSi was added for further increase of the coating adhesion and avoids the temperature mismatch between the particle and substrate. Hard facing were produced using optimized process parameters with powder composition consisting of 60 mass percent (%) WC and 40 mass percent (%) NiCrBSi. The chemical composition of hard facing powder and conventional tool material are presented in table 1. Argon gas was used as plasma gas, shielding gas as well as powder transporting gas. PTA Hard facing 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.

Rolled plates of 6 mm thick AA7075 aluminium alloy were cut to the required size (175 mm × 150 mm) by power hacksaw cutting and milling. The standard dimension of the rotational tool with a pin (Ø6×5.8mm) and a shoulder (Ø18mm) is used for all the tool material. Samples were welded at a constant rotation speed of 1400 rpm and welding speed varied depends on tool materials. Single pass welding procedure was followed to fabricate the joints using conventional tool and hard facing tool.

Table 2. Parameters used for PTA hard facing

Parameter	PTA
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
Electrode diameter(mm)	-

Rolled plates of 6 mm thick AA7075 aluminium alloy were cut to the required size (175 mm × 150 mm) by power hacksaw cutting and milling. The standard dimension of the rotational tool with a pin (Ø6×5.8mm) and a shoulder (Ø18mm) is used for all the tool material. Samples were welded at a constant rotation speed of 1400 rpm and welding speed varied depends on tool materials. Single pass welding procedure was followed to fabricate the joints using conventional tool and hard facing tool. In this investigation, the heat input was calculated using the expression proposed by Heuriter et al [12] and the equation was given by

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

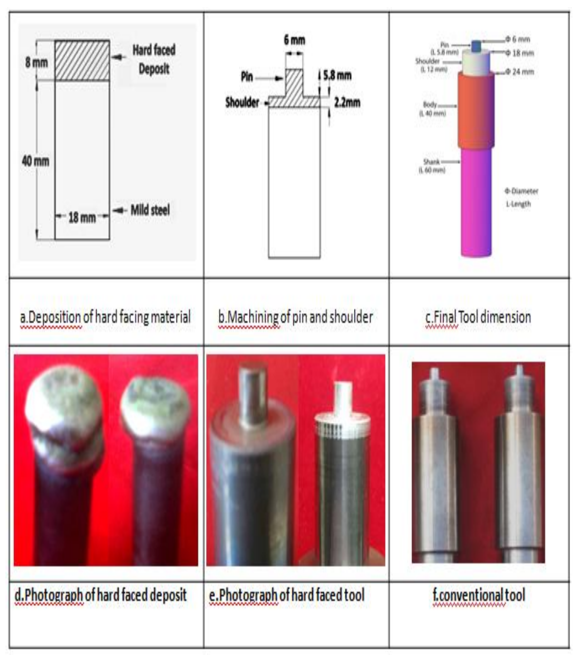
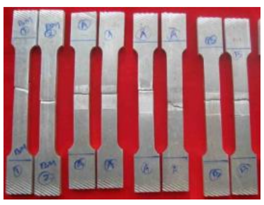


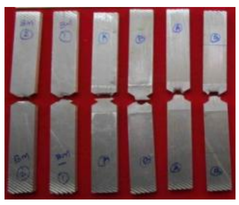
Fig.1 Schematic representation of hard faced tool fabrication

(a)Un notched specimen-before test

(b) Notched specimen-Before test



(c) Un notched specimen - After test



(d) Notched specimen-After test

Fig.2 Fabrication of joints and tensile specimen

Thermocouples were used for sensing the thermal histories and it was recorded using LABVIEV data acquisition system and 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 [13]. The tensile test was carried out in 100 KN, servo controlled universal testing machine 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 using 10% NaOH to show general flow structure of the alloy. A standard Keller's reagent made of 5 ml HNO_3 (95% concentration), 2 ml HF, 3 ml HCl, 190 ml H_2O was used to reveal the microstructure of the welded joints.

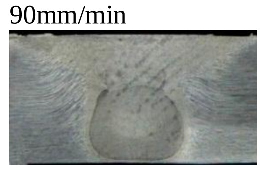
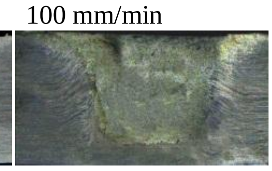
Joint made using	Macrostructure	Macrostructure
HCS		
	RS-1400rpm WS-60mm/min	RS-1400rpm WS-70mm/min
SHSS		
	RS-1400rpm WS-90mm/min	RS-1400rpm WS - 100 mm/min
PWC		
	RS-1400rpm WS-150mm/min	RS-1400rpm WS-160mm/min

Fig.3 Macrostructure of weld cross-section.

3. Results and discussion

3.1Tensile Properties

Transverse tensile properties such as yield strength, tensile strength and percentage of elongation of the joints were presented in Table 3. Since the dimension of tensile specimens both smooth and notch involving the entire joint shown in Fig 2a and Fig 2b. In welding of Aluminum alloy using HCS and SHSS tools the tensile strength and joint efficiency were observed in 250, 360 Mpa respectively and 56 %, 73.46 % respectively. Both values are higher for Tungsten carbide PTA hard facing tool. This was due to sufficient heat generation and sufficient metal transportation supplied to the welding zone. The fracture occurred in PTAH specimen nearer to HAZ because the weld strength is almost equal to base metal strength. The conventional SHSS tool joints fractured in the area where the lower hardness was recorded AS-TMAZ region.

Table 3. Tensile properties of FSW joints fabricated using different tool materials

Joint made using	Yield strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Notch Tensile Strength (MPa)	Notch Strength Ratio (NSR)	Joint efficiency (%)	Location of failure
HCS	230	250	23	300	1.161	56.05	TMAZ -AS
SHSS	310	360	22	440	1.222	73.46	TMAZ -AS
PWC	340	470	17	495	1.227	88.90	HAZ-AS

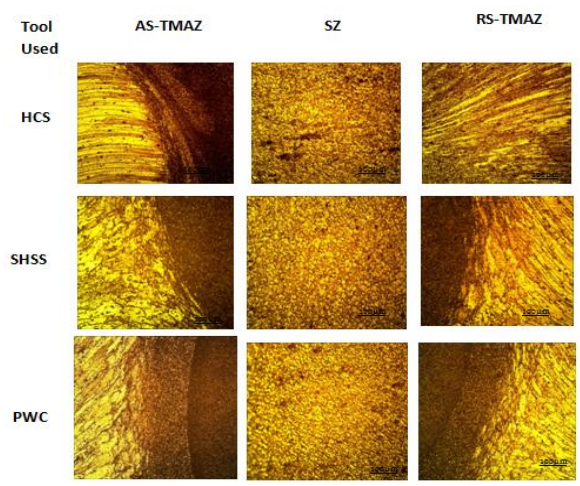


Fig.4 Optical Micrographs of AA7075-T6 aluminium alloy with different tools

3.2. Macrostructure

Fig.3 shows that effect of tool materials on macrostructure of the friction stir welded joints. All the joints fabricated in this investigation 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 SHSS tool produced defect free joint, the strength and joint efficiency is low. PTAH 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.

3.3. Microstructure

The microstructure of base metal consists of acicular eutectic precipitates MgZn2 embedded in aluminum matrix. It is due to the stirring action at plastic condition of the metal during FSW. Regardless of welding condition, while using HCS tools it will produce defect structure because insufficient heat generation and coarser grains are formed in stir zone region. But PTAH tools produced stir zone having finer grains.

Shoulder influenced region and pin influenced region grains having some difference because of the cooling rate. Grains are oriented towards the stir zone and distinguished boundary region between SZ and TMAZ in advancing side but grains are come out in retreating side. There is no indication of grains between SZ and TMAZ in retreating side shown in fig 4.

Table 4. Tool Materials Properties

Tool material	Hardness (HV) 0.5kg load	Co-efficient of friction(μ)	Heat Input (J mm^{-1})
HCS	390	0.20	310
SHSS	640	0.21	443
PWC	910	0.43	540

3.4 Temperature profile

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 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.

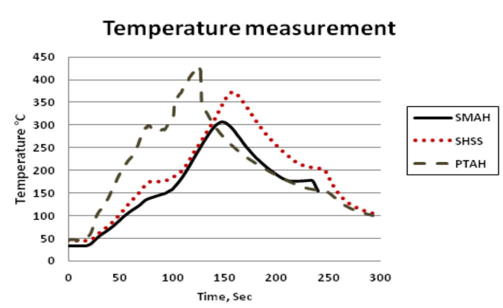


Fig. 5 Temperature profile.

From table 4, it is understood that the heat input is having directly proportional relationship with the tool hardness. The HCS and SHSS tool generates heat energy of 310 Jmm-1 and 443 Jmm-1 which is relatively less than PTA hard facing tool materials consider for this investigation. The PTAH tool producing sufficient heat energy of 540Jmm-1, due to hardness and co efficient of friction is higher compared with conventional tool. The heat input calculated value confirmed with lab view software shown in Fig 5.

3.5. Micro hardness

Micro hardness was measured at mid-thickness region across the weld and the values are presented in Fig 6. The base metal recorded a hardness of 140 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 is inversely propositional to the grain size. (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 80 HV was recorded in the joint fabricated with HCS tool. The joint fabricated with a PTAH tool was recorded the hardness value of 160 HV in the SZ region.

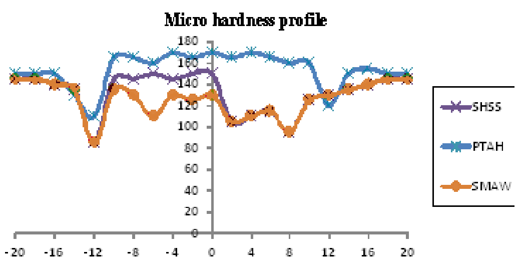


Fig. 6 Hardness profile

4. Conclusion

In this investigation, an attempt was made to study the influence of tool materials on the mechanical and metallurgical properties of friction stir welded AA7075-T6 aluminum alloys. From this investigation, the following important conclusions are derived:

- Of the Three tools, the PWC tool generated higher heat input 540 Jmm-1. The reason was PWC tool having higher hardness and higher coefficient of friction. The SHSS tool generated sufficient heat energy of 443 Jmm^{-1}, but HCS tool generated lower heat energy 310 Jmm^{-1}.
- Of the Three tools, the PWC tool fabricated joint exhibited very high strength values and the enhancement in joint efficiency approximately 30% compared to HCS tool joints, and 15% compared to SHSS tool joints.
- 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.
- The joints fabricated by PWC tool Hardness was recorded (160 HV) higher in the weld metal (SZ) region compared to the TMAZ, HAZ and BM regions. Hardness was recorded in the SHSS tool joints (140 HV) and the very lower hardness was recorded in the HCS tool joint (120 HV).

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