

## Effect of Cylindrical Tool Pin Profile of Friction Stir Welded Composite with Similar and Dissimilar Joints

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**Abstract:** This research made an effort to find the resistivity of a cylindrical shape tool pin on 5 different materials such as AA6061 alloy, AA7075 alloy, AA6061 reinforced Activated Carbon (AC) composite, AA7075 reinforced AC and AA6061/AC-AA7075/AC dissimilar joints. The FSW process parameters like spindle speed, axial load, tilt angle and tool pin profile are taken as constant and the process are carried out in five different materials. Ultimate Tensile Strength and Hardness test are taken in the welded joints to validate the best joint. The defect free joint were obtained in the AA6061 reinforced activated composite plates of similar joint. Microstructure and EDAX test are taken in the best joint based on the mechanical test results.

**Key words:** Friction stir welding, AA6061, AA7075, microstructure, hardness, tensile strength

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### INTRODUCTION

In recent days metal matrix composites fabricated using two types of carbon reinforcement and aluminium matrix. Microstructural investigation shows chemical formation of  $Al_4C_3$  compound. After thermal ageing at  $300^\circ C$ , alumina was formed and Si and Ti of SiC fibres moved into the matrix (Orbulov *et al.*, 2008). AA 6061 has some distinct properties like good strength, good fatigue strength, corrosion resistance and good weldability (Sozhamannan *et al.*, 2012; Rajesh *et al.*, 2016). AA6061 is also widely used in many aerospace applications. The fabrication process of aluminium metal matrix composites with different process in temperature and different holding time are investigated. The results obtained shows adequate wetting of ceramic particles by liquid metal through homogenous dispersion and improved mechanical properties. This was examined in microstructure analysis, hardness and density distribution (Kalaiselvan and Murugan, 2013). Mechanical behaviour was observed and wear properties examination was conducted on Al6061/ 9 wt.%  $B_4C_p$  composite fabricated by stir casting technique. Microstructure confirms uniform dispersion of  $B_4C_p$  in Al6061 matrix. Mechanical properties were improved by adding  $B_4C_p$  as reinforcement in comparison with base material. Wear rate also, decreased by adding  $B_4C_p$  reinforcement (Ugunder *et al.*, 2014).

The essential FSW parameters which influence the tensile property of AA6061- $B_4C_R$  composite weld were examined. FSW parameters were analysed using developed mathematical model. The result indicates the

weld using Tool Rotational Speed (TRS) of 1000 rpm, Welding Speed (WS) of 1.3 mm/sec, axial force of 10 kN and the reinforcement of 12% attains higher tensile strength compared with the other joints (Lakshminarayanan and Balasubramanian, 2008). Investigated different FSW process parameters are used for welding AZ31B magnesium alloy (Ramanan *et al.*, 2017). It was observed TRS has definite impact on properties of weld. Tool material at TRS of 1120 rpm got maximum values as compared to TRS and also to those of HSS material (Dorban *et al.*, 2016). Comparative study on different welding processes like GTAW, GMAW and FSW were carried out in AA6061 aluminium alloy. The tensile properties and micro hardness for butt welded plates of 6 mm thickness with AA4043 (Al-5Si) as filler metal were investigated (Deepati *et al.*, 2014). The test results show superior mechanical property for FSW joints fine metals in the welded zone that are evident by microstructure and fracture surface morphology (Trimble *et al.*, 2012). AA6061/ $B_4C$  hybrid composites were fabricated and butt joined using FSW. A tool made of high carbon high chromium steel with square pin profile and a rotational speed of 1000 rpm, WS of 80 mm/min and axial force of 10 kN was fixed (Singh, 2012). Some weld has efficiency of 89.4% was achieved in the composites. The micro vickers hardness and tensile strength of FSW of AA6061-T6 and AA6082-T6 dissimilar alloys of 6 mm thickness using Taguchi  $L_9$  technique were analysed (Zhang *et al.*, 2011). The different design parameters adapted were TRS (800, 1100 and 1400 rpm), WS and tool profiles for investigating the properties of joints. From the

test results it was concluded that the value of hardness and the tensile strength were improved for cylindrical threaded tool profile at rotational speed 1400 rpm and WS 120 mm/min (Bahrami *et al.*, 2014). TRS and translation speeds were parameters taken for FSW of AZ31B and Al6061 dissimilar metals. Good quality weld was obtained by placing aluminium on advancing side. The tensile strength of the weld showed joint efficiency between 18 and 55% at room temperature and between 58 and 78% for higher temperatures (200°C) (Gargatte *et al.*, 2013). FSW of AA 6061-T6 and Mg AZ31B dissimilar alloys were taken with varying ranges of process parameters such as TRS and transverse speed. Sound welded joints were obtained with Mg on advancing side with tool offset to Mg 0.3 mm and the tensile strength of the joints could reach up to 70% of that of Mg base metal (Darwins *et al.*, 2018). Investigating the mechanical properties on FSW of dissimilar aluminum alloys (AA 5083-AA1100) using H-13 steel tool and responses from different process parameters were reported. It was seen that TRS and traverse speed have significant effect on tensile property (Choi *et al.*, 2007). An analytical model was developed to find heat generation on FSW using taper cylindrical pin profile. Observation shows that low temperature was generated using pin profile compared to straight cylindrical pin profile under a given set of working conditions (Ramanan *et al.*, 2017). Investigating experimentally tool forces produced during FSW of AA2024-T3 using a rotating dynamometer and developed a finite element model for force generation. Tool pin designs signify the tool failure and identify a suitable design and material which can process the work piece more efficiently (Li *et al.*, 2016). Influence of tool geometry and penetration depth during FSW of aluminium alloy and carbon joints was investigated use the parameter taken for welding process were axial load and current consumption during welding. Macro and microstructural tests were carried out for welded joints and also mechanical characterization was determined. After investigation it was concluded that when tool penetrates to a certain depth the fracture load was increased (Dinakaran *et al.*, 2017).

Heat generated between tool and specimen in FSW of AA6061-T6 Al alloy was calculated. Results indicate mainly, heat was generated near tool shoulder, maximum heat was generated in the upper portion of weld and minimum along the thickness of the direction. Simulation method was used to predict the temperature field and the material flow behaviours of experiments (Rajakumar *et al.*, 2011). FSW tool pin influence on SiC nano particles reinforced composites were investigated using five different geometry tool pins. SEM shows threaded tapered pin tool produced uniform distribution of particle. Accumulations of reinforcement were seen in the stir zone of specimen in four-flute cylindrical pin tool. Lowest

microhardness was obtained in threaded tapered and four-flute cylindrical tool pins and the highest tensile strength was recorded in the triangular pin tool. From the literature study no authors were worked on FSW process on these composites. In this research to find the resistivity of a cylindrical shape tool pin on five different materials such as AA6061 alloy, AA 7075 alloy, AA 6061 reinforced Activated Carbon (AC) composite, AA7075 reinforced AC and AA6061/AC-AA7075/AC dissimilar joints.

## MATERIALS AND METHODS

### Experimentation

**Friction stir welding:** FSW is carried out in the plate of dimensions 100×50×6 mm in a modified vertical milling machine. The butt welding is carried out in AA6061 alloy, AA7075 alloy, AA6061 reinforced activated carbon composite plates, AA7075 reinforced activated carbon composite plates and dissimilar plates AA6061 reinforced activated carbon composite plates/AA7075 reinforced activated carbon composite plates (Zhang *et al.*, 2011). Based on the literature tool selected for performing welding is high speed steel tool with round shape pin profile with 70 mm, shoulder diameter 16mm and probe length of 5.8 mm. The parameters considered for friction stir welding are spindle speed, axial load, tool pin profile, specimen and tilt angle. Among this four parameters specimen will be varied other three parameters are kept constant. The values chosen are spindle speed 1200 rpm, tilt angle zero, cylindrical shape tool pin profile and axial load 10 kN. Friction stir welding process is shown in Fig. 1. The specimen after welding were taken to tensile and hardness test as per ASTM standards

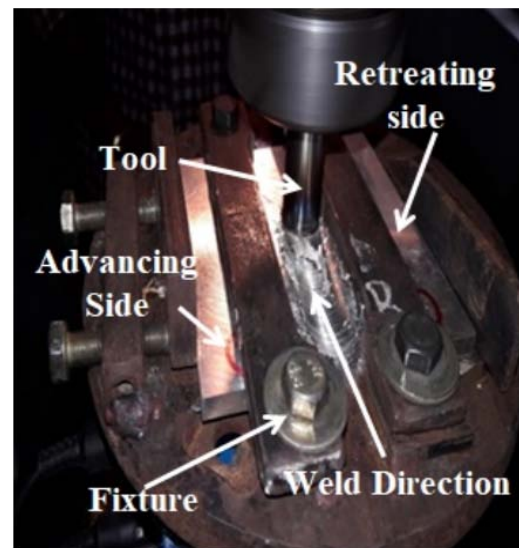


Fig. 1: Friction stir welding process

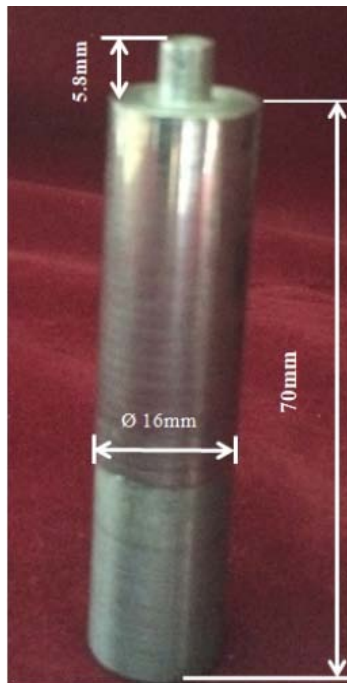


Fig. 2: Cylindrical tool used for FSW process

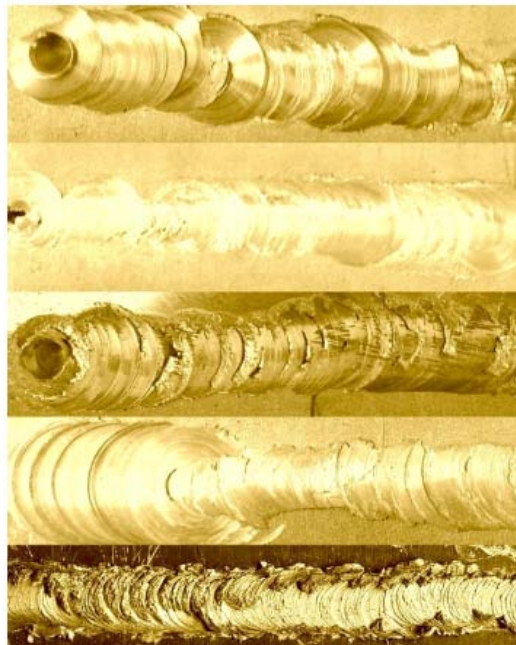


Fig. 3: Friction stir welded composite plates

(Dorbane *et al.*, 2016). Figure 2 shows the dimension of cylindrical tool used for welding. Figure 3 shows friction stir welded different composite plates by using cylindrical tool profile (Table 1).

Table 1: Parameters and levels

Parameters	Range
Spindle speed	1200 rpm
Axial load	10 kN
Tilt angle	Zero
Tool pin profile	Round
Plates	AA6061, AA7075, AA6061-AC, AA7075-AC, AA6061-AC/AA7075-AC

## RESULTS AND DISCUSSION

The friction stir welded composite plates are tested as per ASTM standards for ultimate tensile strength and hardness (Singh, 2012). The specimen taken for ultimate tensile strength is shown in Fig. 4. The values obtained after testing is narrated in Table 2.

The effects of FSW process parameters such as spindle speed, axial load, plates and tilt angle on hardness is analysed by using the experimental values. Figure 5 shows the estimated response for UTS and hardness with input parameters. It is seen that hardness tends to increase with axial load of 11 kN with increase in UTS between 180 and 220 MPa (Choi *et al.*, 2007). Similarly square shape pin profile produces high hardness of above 75 HN other tool pins fails at various samples (Li *et al.*, 2016). The spindle speed produces high hardness with various plates. From this it is evident plates with similar joints produces high hardness. Figure 6 shows the EDAX analysis of welded joints at high axial load. From results confirmed that austenitic composite weld joints contain some Cu and Zn compounds. Formation of these metallic compounds degrades the strength of the joints (Rajakumar *et al.*, 2011).

The above results show the square shaped tool gives the best result in hardness and ultimate tensile strength. Taper shape pin profile results the moderate among all the five tools used in this research. The hexagon will produce least among the five types of tools used for welding and there will be minor difference between the round shaped tool and threaded round tool (Kant and Sangwan, 2014).

Base materials used in the research confined grains elongated in the rolling direction and a great number of eutectic and intermetallic particles are shown in Fig. 7. In SEM images the thermo mechanically affected zone on either side displayed grains that are extremely deformed, expressing a evidently discernible stirred zone/thermo mechanically pretentious zone and thermo mechanically affected/heat affected zone boundaries (Rani *et al.*, 2018; Kadian and Biswas, 2017).



Fig. 4: Specimen for ultimate tensile strength

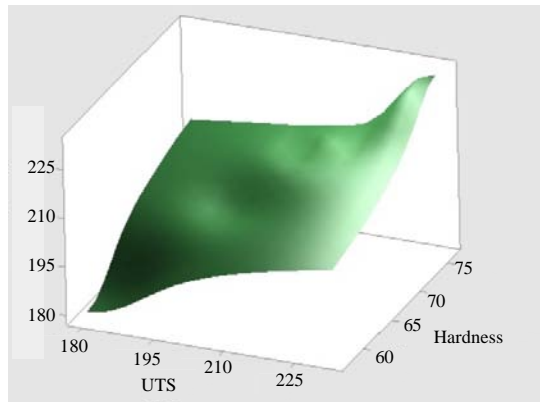


Fig. 5: Response surface plot for UTS and hardness

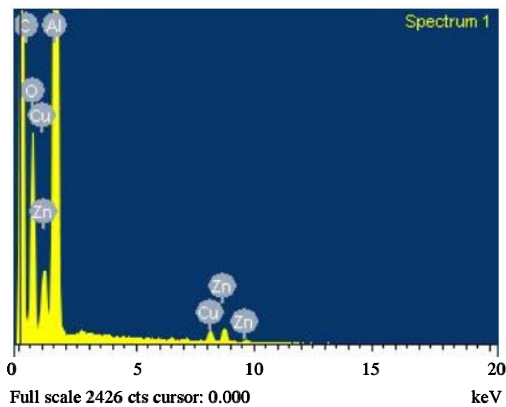


Fig. 6: EDAX in NZ in the joints after FSW at high axial load

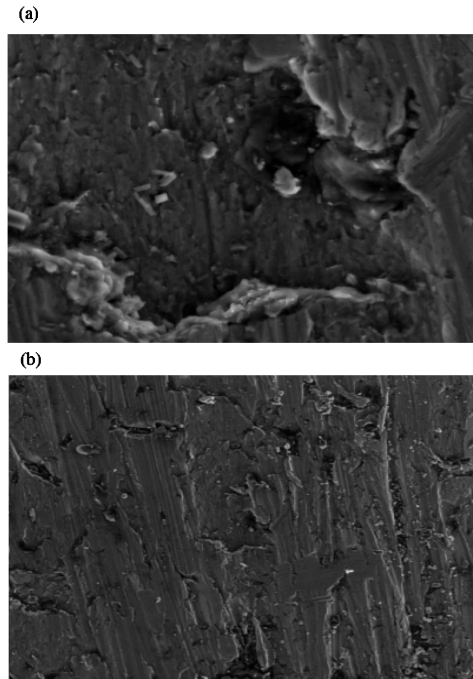


Fig. 7: a, b) SEM image of UTS and hardness

Table 2: Tested values after UTS and hardness

No.	Specimen	UTS	Hardness
R01	AA6061-AC	231.2	76.2
R02	AA6061	180.0	57.3
R03	AA7075	198.0	66.1
R04	AA7075-AC	207.0	72.8
R05	R01/R04	212.0	74.1

## CONCLUSION

From this study, the following conclusions are derived. It is found out that from all the tools used, square pin profile produces good mechanical property. Ultimate tensile strength 231.2 MPa and micro hardness value of 76.2 with weld parameter of axial load 10 kN, speed 1200 rpm and AA6061/PAC hybrid composite. From various reinforcement and matrix used AA6061/PAC has produced good tensile and hardness values. The plates were used to conduct the experiments for the prediction of ultimate tensile strength and hardness in friction stir welding confirmed its consistency and applicability with the experimental results. It is clearly shows that max UTS and hardness is obtained with cylindrical tool from the AA6061-activated carbon composite plates.

## REFERENCES

Bahrami, M., M.K.B. Givi, K. Dehghani and N. Parvin, 2014. On the role of pin geometry in microstructure and mechanical properties of AA7075/SiC nano-composite fabricated by friction stir welding technique. *Mater. Des.*, 53: 519-527.

- Choi, E.Y., M.C. Kang, D.H. Kwon, D.W. Shin and K.H. Kim, 2007. Comparative studies on microstructure and mechanical properties of CrN, Cr-C-N and Cr-Mo-N coatings. *J. Mater. Proc. Technol.*, 187: 566-570.
- Darwins, A.K., M. Satheesh and G. Ramanan, 2018. Experimental analysis of friction stir welding of dissimilar alloys AA7075 and Mg Ze42 using butt joint geometry. *Intl. J. Mech. Prod. Eng. Res. Dev.*, 8: 505-512.
- Deepati, A.K., S. Tikaderb, H. Chaturvedi and P. Biswas, 2014. Experimental investigation of mechanical properties on friction stir welding of dissimilar aluminum alloys. *Intl. J. Curr. Eng. Technol.*, 1: 242-246.
- Dinaharan, I., K. Kalaiselvan and N. Murugan, 2017. Influence of rice husk ash particles on microstructure and tensile behavior of AA6061 Aluminum matrix composites produced using friction stir processing. *Compos. Commun.*, 3: 42-46.
- Dorbane, A., B. Mansoor, G. Ayoub, V.C. Shunmugasamy and A. Imad, 2016. Mechanical, microstructural and fracture properties of dissimilar welds produced by friction stir welding of AZ31B and Al6061. *Mater. Sci. Eng. A.*, 651: 720-733.
- Gargatte, S., R.R. Upadhye, V.S. Dandagi, S.R. Desai and B.S. Waghmode, 2013. Preparation and characterization of Al-5083 alloy composites. *J. Miner. Mater. Charact. Eng.*, 1: 8-14.
- Kadian, A.K. and P. Biswas, 2017. Effect of tool pin profile on the material flow characteristics of AA6061. *J. Manuf. Proc.*, 26: 382-392.
- Kalaiselvan, K. and N. Murugan, 2013. Role of friction stir welding parameters on tensile strength of AA6061-B<sub>4</sub>C composite joints. *Trans. Nonferrous Met. Soc. China*, 23: 616-624.
- Kant, G. and K.S. Sangwan, 2014. Prediction and optimization of machining parameters for minimizing power consumption and surface roughness in machining. *J. Cleaner Prod.*, 83: 151-164.
- Lakshminarayanan, A.K. and V. Balasubramanian, 2008. Process parameters optimization for friction stir welding of RDE-40 aluminium alloy using Taguchi technique. *Trans. Nonferrous Met. Soc. China*, 18: 548-554.
- Li, Y., Q.I. Li, D. Li, W. Liu and G.G. Shu, 2016. Fabrication and characterization of stir casting AA6061-31% B<sub>4</sub>C composite. *Trans. Nonferrous Met. Soc. China*, 26: 2304-2312.
- Orbulov, I.N., A. Nemeth and J. Dobranszky, 2008. XRD and EDS investigations of metal matrix composites and syntactic foams. *Proceedings of the 13th European Conference on X-Ray Spectrometry*, June 16-20, 2008, Cavtat, Croatia, pp: 1-8.
- Rajakumar, S., C. Muralidharan and V. Balasubramanian, 2011. Influence of friction stir welding process and tool parameters on strength properties of AA7075-T<sub>6</sub> aluminium alloy joints. *Mater. Des.*, 32: 535-549.
- Rajesh, G.L., V. Auradi and S.A. Kori, 2016. Mechanical behaviour and dry sliding wear properties of ceramic boron carbide particulate reinforced Al6061 matrix composites. *Trans. Indian Ceramic Soc.*, 75: 112-119.
- Ramanan, G., J.E.R. Dhas and M. Ramachandran, 2017. Optimization of material removal rate and surface roughness for wire electric discharge machining of AA7075 composites using grey relational analysis. *Intl. J. Veh. Struct. Syst.*, 9: 309-312.
- Ramanan, G., J.E.R. Dhas, M. Ramachandran and G.D. Samuel, 2017. Influence of activated carbon particles on microstructure and thermal analysis of AA7075 metal matrix composites. *Rasayan J. Chem.*, 10: 375-384.
- Rani, M.G., V.S.P. Rao and K.R. Kotaiah, 2018. Prediction and optimization of machining parameters for cutting Al6061/MoS<sub>2</sub> MMC material by WEDM process. *J. Eng. Appl. Sci.*, 13: 8483-8488.
- Singh, S., 2012. Optimization of machining characteristics in electric discharge machining of 6061Al/Al<sub>2</sub>O<sub>3</sub>p/20P composites by grey relational analysis. *Intl. J. Adv. Manuf. Technol.*, 63: 1191-1202.
- Sozhamannan, G.G., S.B. Prabu and V.S.K. Venkatagalapathy, 2012. Effect of processing parameters on metal matrix composites: Stir casting process. *J. Surf. Eng. Mater. Adv. Technol.*, 2: 11-15.
- Trimble, D., J. Monaghan and G.E. O'Donnell, 2012. Force generation during friction stir welding of AA2024-T3. *CIRP. Ann.*, 61: 9-12.
- Ugunder, S., A. Kumar and A.S. Reddy, 2014. Microstructure and mechanical properties of AZ31B Magnesium alloy by friction stir welding. *Proc. Mater. Sci.*, 6: 1600-1609.
- Zhang, L., S. Ji, G. Luan, C. Dong and L. Fu, 2011. Friction stir welding of Al alloy thin plate by rotational tool without pin. *J. Mater. Sci. Technol.*, 27: 647-652.