IOP Conference Series: Materials Science and Engineering

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To cite this article: B Suresh Babu *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **988** 012045

IOP Conf. Series: Materials Science and Engineering **988** (2020) 012045 doi:10.1088/1757-899X/988/1/012045

Investigations of the effect of the tool rotational speed on friction stir welded joint on aluminium metal matrix hybrid composite

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Abstract. Aluminium alloy based hybrid composites with ceramic reinforcements has caught the interest of research nowadays. The addition of more than one reinforcement in aluminium alloy matrix leads to the fabrication of Aluminium Metal Matrix Hybrid Composite (AMMHC). The need for the present investigation arrives from the above considerations in exploring the potential of joining the newly developed AMMHC for automobile applications. The stir casted Al 6063 with reinforcement 5% wt. Silicon Carbide (SiC) and 5% wt. Boron Carbide (B_4C) was prepared and joined by friction stir welding (FSW) route. The prime experimental work has been tried out in the FSW process by varying Tool Rotational Speed (TRS) from 800-1200 rpm. The effect of TRS on AMMHCs was studied by evaluating macro and microstructural parameters followed by microhardness and ultimate tensile strength. It was seen that the1000 rpm of TRS gives better properties than other processing conditions. This effect of TRS revealed that fine particle dispersion followed by higher join strength can be obtained for AMMHC. This fabrication of AMMHC and the FSW processing parameter was recommended for automobile component applications.

Keyword: Al 6063, Silicon Carbide, Boron Carbide, Stir casting, Friction Stir Welding

1. Introduction

Composite is a multi-phase material composed of reinforcements (fibers, particulates and flakes) embedded in a matrix material (polymers, metals, and ceramics). These constituents are united at the macroscopic value level only and or not soluble in each other. The reinforcements are held by the base matrix to obtain the desired shape and to transfer the load to the fibers [1]. The mechanical properties of metal matrix are found to be enhanced with the addition of reinforcements [2]. Aluminium metal matrix composite reinforced with Silicon Carbide 10% wt and Boron carbide 10 % wt. particulates are a new

range of the materials. The presence of reinforcements (SiC, B_4C and Al_2O_3, etc.) in Hybrid Metal Matrix Composites (HMMC) has resulted in the improvement of wear resistance, tensile strength, and strength to weight ratio than that for unreinforced alloys [3-7]. Hybrid Aluminium Metal Matrix Composites (HAMMCs) have been appropriate for applications that necessitate characteristics such as combined tensile strength, heat conductivity, damping properties and co-efficient of heat expansion. Corrosion resistance and wear resistance enhance their tribological applications in pistons, brake drum, brake disc and the cylinder block in automotive. An experiment has been conducted to study the mechanical properties of Al6061–SiC composites having 0, 2, 4, 6 wt. % & 20 μm particle size prepared by the modified stir casting method [8]. The hardness of the composite is better, compared to its cast matrix alloy. The positive effect of % reinforcement of boron carbide on the tensile property of aluminium HMMCs. The strength and hardness values were found to increase with the increase in the wt. % of particle reinforcement [9]. Al 6063 and Al 1070 matrix with 10 wt. % and 32 μm particle size of reinforcement B_4C produced by modified stir-casting technique. Due to the poor wetting of B_4C by liquid aluminium, a perfect bonding would not be formed at the matrix and reinforcement interface in Aluminium and B_4C HMMCs produced at lower temperatures [10].
The physical and mechanical performance of Al_2O_3 and B_4C reinforcement with Aluminium 7075 matrix prepared by using a modified stir casting method were studied. The HMMC comprises the base matrix Aluminium 7075 with different concentrations of two particles reinforcements Al_2O_3 and B_4C. In the first study, B_4C was kept with a constant weight percentage and wt% of Al_2O_3 was varied along 2,4,6,8 and 10. In the second study, wt% of Al_2O_3 was constant and that of B_4C was kept at 5 wt% for the sample specimens [11]. In another study, the metallurgical and mechanical properties were analysed from ZrO_2 and the coconut shell ash particles in Aluminium 6082 MMCs. The weight percentage of coconut shell ash particles, ZrO_2 were varied from the value of 0 to 10 wt% and fabricated by stir casting techniques [12]. There was a focus on different factors to improve the wettability between matrix interface and reinforcement [13]. The weight percentage of SiC and B_4C particulates were highly influential factors on tensile strength. It can be identified that SiC and B_4C particles were effective in improve the tensile strength of hybrid metal matrix composites [14]. It was due to the strengthening mechanism of the reinforcement. Friction Stir Welding (FSW) joints of AA2095 and found that retained 100% of the base material ductility and more than 95% of the base material strength [15]. From the literature, the study has carried out to fabricate Al 6063 based hybrid composites with reinforcements SiC and B_4C using the conventional stir casting method. The hybrid composites further processed with the FSW process and the performance was analysed to find out metallography and mechanical properties. The hybrid composites were compared with unreinforced alloy in terms of physical properties and check the suitability for structural components in automotive applications [16-22].

2. Materials and Methods of hybrid composites preparation

Al 6063 alloy was used as a matrix material. It is having 2.69 g/cm3 density, 615ºC melting point and better weld-ability in nature. The measured chemical composition values of Al 6063 are as shown in Table 1. The hard reinforcement phase of SiC and B_4C was taken for this experimentation, are having 3.21, 2.52 g/cm^3 density, 2730, 2763ºC melting point respectively. The average grain size of both the reinforcement is 45 μm and it has better strength at elevated temperature.

Table 1. Chemical Composition - Aluminum alloy (6063)

Elements	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti	Al
Measured weight %	0.9	0.6	0.35	0.1	0.1	0.1	0.1	0.1	Bal

The proposed AMMHC was produced by using stir casting technique under optimal process parametric conditions. Figure 1 shows a typical stir casting set up, in which aluminium alloy was melted in an induction crucible at 725°C. The melt was agitated at 300 rpm with the help of a mechanical stirrer to form a vortex. The mixtures were preheated at 500°C with 5wt% SiC and 5wt% B_4C particles along with a wettability element of 10 grams K_2TiF_6 flux added into the vortex at a constant feed rate following the four-step addition and stirred for few minutes. After the stirring process, the molten mixture was poured down into the preheated die cavity and solidification was allow for few seconds. At this same processing condition, all the prepared AMMHCs in the size of 100 x 100 x 10 mm plates were fabricated as shown in Figure 2.

Figure 1. Stir casting set up

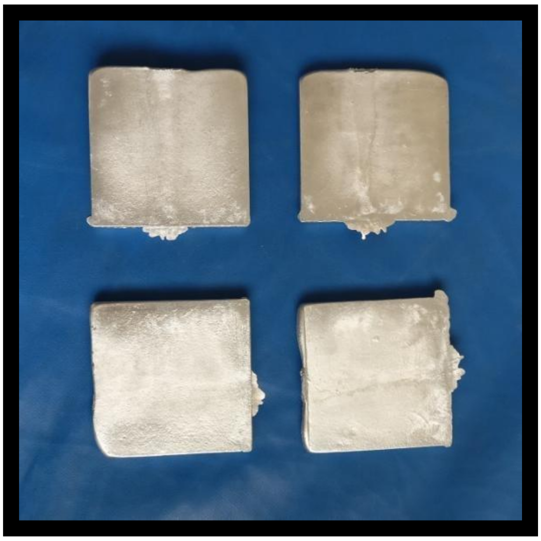


Figure 2. AL 6063 with 5wt% SiC and 5wt%B_4C hybrid composites

The mechanical properties of the fabricated AMMHC were analysed. The proper dispersion of SiC and B_4C particles in the matrix and the absence of porosity in the hybrid composite samples were observed visually during specimen preparation. Vickers microhardness of about 93 HV and ultimate tensile strength of 225 MPa were found to exist for all the specimens. It was also seen that the improved properties were found to exist for 5wt% SiC and 5wt% B_4C particulates in Al 6063 hybrid composite than plain Al 6063. Further, the prepared high strength AMMHC was taken for FSW for the joining process.

3. Friction stir welding procedure

The manufactured stir cast plates were cut into 6 mm thin plate by using wire cut electrical discharge machine. Then the plates were cut to the required size of 100 x 50 x 6 mm as shown in Figure 3. Burrs were removed, edges were flattened using a grinding machine and polishing was done with an emery sheet. Before carrying out the FSW, all the specimens were cleaned to avoid any surface contaminations. To fabricate FSW joints with three passes, the test plates were positioned rigidly in milling machine. The backing plate used as mechanical clamps prevented the plates from vibrations during the FSW process. FSW process was conducted by changing the TRS (N) through 800, 900, 1000, 1100, 1200 rpm and remaining process parameters as welding speed (S) of 30 mm/min and axial force (F) of 10kN with hot tool steel as a tool material were kept as constant. This process parameters and operating conditions were fixed based on literature study findings and pilot experimental run. During the test, the heat input (q) was determined by the following equation 1.

$$q = (2\pi/3S)\ \mu\ R\ F\ N\ \eta \qquad \text{(Eq.1)}$$

Where;
R= Tool pin radius (m),
μ = Coefficient of friction,
η = Welding efficiency.

IOP Conf. Series: Materials Science and Engineering **988** (2020) 012045 doi:10.1088/1757-899X/988/1/012045

For the given TRS of 800, 900, 1000, 1100, and 1200 rpm, heat input was measured to be 1.20638, 1.35716, 1.50795, 1.65875, and 1.80955 kJ/mm respectively. From the calculation, it was inferred that the heat input is directly proportional to the TRS. If the TRS increases, heat input increases correspondingly. FSW process has been performed for all specimens of Al 6063 with 5wt% SiC and 5wt% B_4C with variations on TRS. Testing of metallurgical and mechanical properties were taken further with the specimens by following ASTM standards. Figure 4 represents test samples for before testing.

Figure 3. Prepared AMMHC plates for FSW process

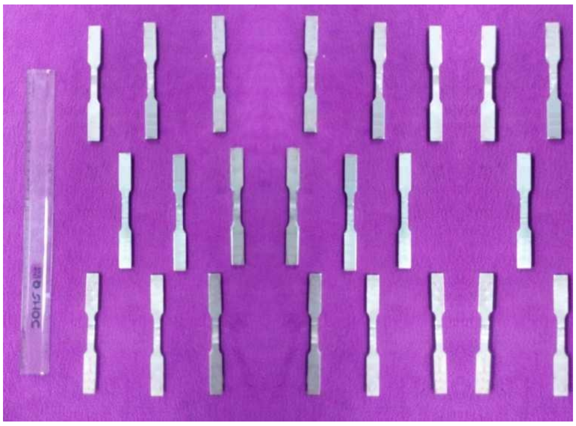


Figure 4. Tensile strength test samples for FSW joints

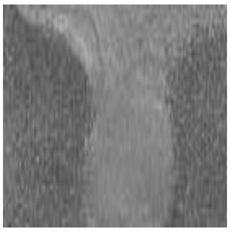
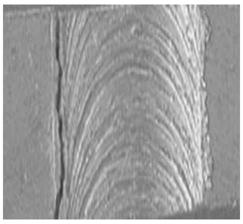
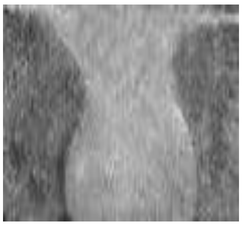
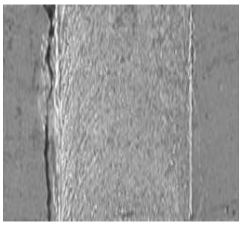
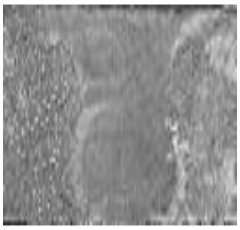
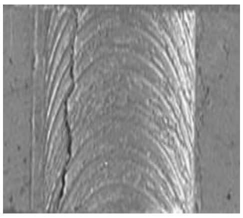
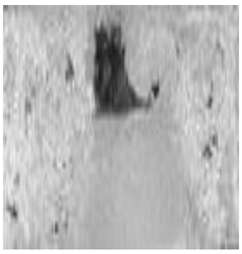
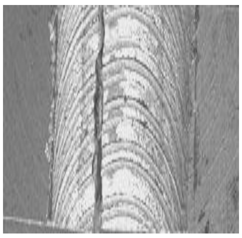
4. Results and discussions

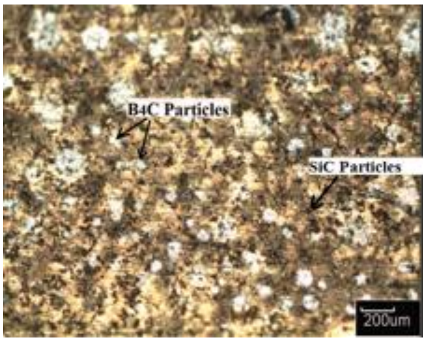
AMMHC specimens were fabricated by varying the TRS (800, 900,1000,1100,1200 rpm) with constant welding speed and axial force. The welded joints were tested for micro/macrostructure examination, microhardness and tensile strength as discussed below.

4.1. Metallography analysis

All the FSW joints were analyzed at low range magnification 10x using an optical microscope to check the quality of the weld portion. The observations made from the macrostructure study of the FSW joints on Al 6063 MMHCs are presented in Table 2. The FSW joints produced at TRS of 800 and 1200 rpm contain tunnel and cavity defects at the retreating side of the weld region. The joints fabricated using TRS 900, 1000 and 1100 rpm were found to be free from macro-level defects. If TRS was increased, the stirring action and heat input were also increased, thus the size of the SiC and B_4C particulates were found to be reduced and resulted in the growth of mechanical strength in the stir zone. The fineness and the dispersion of SiC and B_4C particles mainly depended on the TRS which in turn decided the strength of the joints. The mechanical properties and fracture locations of the welded joints are dependent on the TRS and other welding parameters to a large extent. If the joints are related to defects such as pinhole, tunnel and cracks in the weld region, the joints fail at the defective area. If the FSW joints are defect-free, the failure locations get shifted towards the retreating side. In the present study, a TRS value of 1000 rpm gives better dispersion of particles in the base metal than another process parametric conditions. It was evident from microscopy and scanning electron microscopy study that the uniform dispersion and absence of micro defects were observed as shown in figure 5 (a, b).

Table 2. Effect of TRS on macrostructure of AMMHC FSW joints

TRS(rpm)	Macrostructure		Fracture location		Remarks
	RS	AS	RS	AS	
800					Tunnel defect identified in the retreating side and advanced side Insufficient heat generation
900					No defect is observed. Good heat generation
1000					No defect is observed. Good heat generation
1100					No defect identified. Sufficient stirring process
1200					Tunnel defect at the retreating side An abnormal of stirring in the plasticized metal



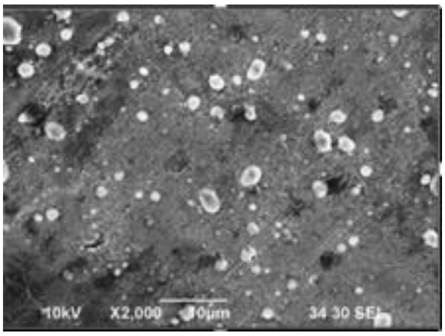


Figure 5. TRS (1000 rpm) on weld region (a) Microstructure of AMMHC (b) SEM of AMMHC

4.2. Microhardness measurement

The microhardness was measured for all AMMHC specimens. It was observed that there is a considerable increment in the hardness along the weld zone when compared to the base material AMMHC. Mainly, the thermal exposure during the FSW governs the hardness of the joints. Due to the heat distribution during the FSW process, hardness drop was observed in heat-affected and the thermomechanical affected area. The maximum microhardness of AMMHC was observed at the nugget zone which is about 105.5HV at 1000 rpm TRS. From the centre of the bead, the hardness was found to decrease gradually with increasing distance from the stir zone. The same trend was observed in all the cases of hardness profiles shown in Figure 6. The microhardness value of the nugget zone was observed in the range of 98 HV to 105.5 HV for five different TRS values of samples (800-1200 rpm). The lowest hardness was recorded at TRS of 800, 900 rpm and higher TRS of 1100, 1200 rpm. On the whole, the maximum microhardness value of 105.5 HV was recorded for the joint made using the TRS of 1000 rpm due to the presence of reinforcement in the matrix and absence of defects in the stir zone.

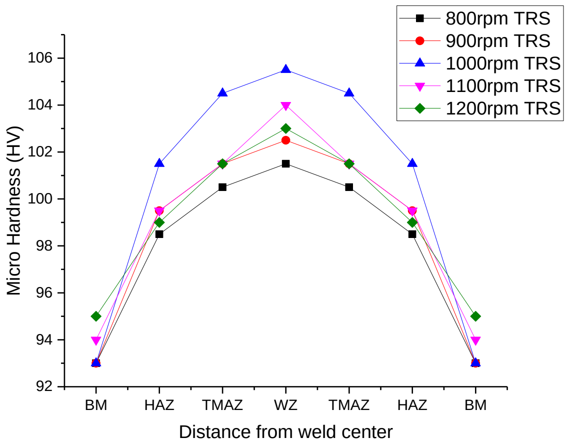


Figure 6. Effect of TRS on microhardness of weld zone

The hardness value in the weld nugget of Al 6063 metal matrix hybrid composites was found to be higher than the base metal. The variation in microhardness of the joints is due to changes in the heat input caused by frictional heat produced by rotating tool and subsequent alterations in the microstructure. When the spindle speed is increased to a certain level, the hardness values initially rise and later on, it is found to converge at higher spindle speeds. This behaviour corresponded to the development of more uniform temperature distribution within the weld region as the heat input is increased. It is also noticeable that the hardness of the nugget zone was decreased with increasing rotational speed.

4.3. Tensile Strength measurement

The outcome of TRS on the tensile strength of FSW stir cast AMMHC was shown in Figure 7. FSW joints were made by varying the TRS from 800-1200 rpm with other parameters kept as constant. TRS of 1000 rpm yielded higher tensile strength of 221 Mpa and TRS of 800, 900 rpm have exhibited lower tensile strength. When the TRS value was further raised from 1100, 1200 rpm, the tensile strength of the FSW joints also decreased respectively. Lower TRS value of 800, 900 rpm generated insufficient heat input, resulting in a lack of stirring leading to pinhole or tunnel defects in the nugget zone which were revealed from the macrostructure observations. It was observed to be the main cause of the inferior tensile strength. If the TRS value is increased from 800 rpm to 1000 rpm, the tensile strength of FSW joints increased from lower strength and reached maximum strength and down again at the higher TRS. This increase in the tensile strength was due to the increase in the heat input in the stir zone, because of higher frictional heat generation results in intense stirring, constant distribution of fine-grained silicon particulates and mixing of materials in the nugget zone. At higher TRS values of 1100 and 1200 rpm, the strength started to reduce due to a high level of heat generation leading to the release of excessively stirred material to the upper surface which resulted in producing microvoids in the stir zone.

Five TRS values were used to produce AMMHC. The joint fabricated at a TRS value of 1000 rpm yielded better tensile strength. The joints were made with TRS less than1000 rpm and higher than 1000 rpm showed comparatively lower tensile strength. Metallography structure observations showed that the FSW joints were made at higher TRS of 1200 rpm contained tunnel and cavity defects in the weld portion and resulted in low tensile strength. As TRS was increased, which resulting inferior tensile strength due to a rise in temperature that raises the coarsening effect of SiC and B_4C particles.

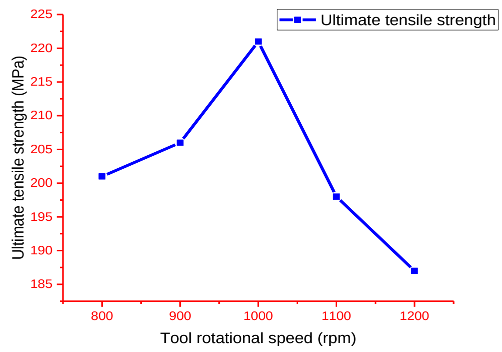


Figure 7. Effect of TRS on tensile strength of weld zone

5. Conclusions

This work deals with the preparation of Al 6063 metal matrix hybrid composites followed by an analysis of FSW processing effects. The following conclusion was drawn from the above study,

- The soft matrix of Al 6063 with 5wt% SiC and 5wt% B4C hybrid composites were fabricated through stir casting route and were obtained with a hardness of 93HV and tensile strength of 225 MPa.
- The FSW processing was performed by varying TRS along 800, 900, 1000, 1100, 1200 rpm and remaining parameters being kept constant for obtaining better joint.
- A defect-free weld region in the stir zone with very fine, uniformly distributed silicon carbide and boron carbide particles with TRS value of 1000 rpm.
- The maximum hardness of 105.5 HV and tensile strength of 181.5 MPa was found to be observed at 1000 rpm.
- It is seen that the stir casted AMMHC, followed by the FSW processing method can serve as an alternate material over conventional material for automotive applications in the future.

6. References

[1] Surappa, M 1981 *Journal of materials science* 16 [4] 983-93.
[2] Uvaraja, V and Natarajan 2012 N *International Journal of Advancements in Research and Technology* 34 2-8.
[3] Seah, K, Sharma, S and Girish, B 1997 *Composites Part A: Applied Science and Manufacturing* 28[3] 251
[4] Sharma, C, Dwivedi, D K and Kumar, P 2012 *Materials & Design* 36 379-390
[5] Santella, M, Engstrom, T, Storjohann, D and Pan 2005 *T-Y Scripta materialia* 53[2] 201-206.
[6] Prasad, S and Asthana, R 2004 *Tribology letters* 17[3] 445-453.
[7] Rajamanickam, N, Balusamy, V, Reddy, GM and Natarajan, K 2009 *Materials & Design* 30[7] 2726-2731.
[8] Kumar, G V, Rao, C and Selvaraj, N 2012 *Composites Part B: Engineering* 43[3] 1185-1191
[9] Gopal Krishna, U, Sreenivas Rao, K and Vasudeva, B 2012 *International journal of Mechanical Engineering and Robotics Research* 1[3] 290-295
[10] Kerti, I and Toptan, F 2008 *Materials letters* 62[8] 1215.
[11] Kaviyarasan, K., Pridhar, T., Sureshbabu, B., Boopathi, C. and Srinivasan, R 2018 *IOP Materials Science and Engineering* 402[1] 48-54
[12] T.Pridhar, C.Boopathi 2016 *Digest Journal of Nanomaterials and Biostructures* 11[3] 845 – 852
[13] Povirk, G, Needleman, A and Nutt, S 1991 *Materials Science and Engineering: A* 132 31
[14] Feng, C and Froyen, L 2000 *Journal of materials science* 35[4] 837-850
[15] Attallah, M M and Salem, H G 2005 *Materials Science and Engineering: A* 391[1] 51
[16] M P Joshi et al 2019 *IOP Conf. Ser.: Mater. Sci. Eng*. 561 012053
[17] Hillary JJM, Ramamoorthi R, Joseph JDJ, Samuel C S J 2020 *Journal of Composite Materials*. 254(17) 2327-2337.
[18] RaviKumar M, Reddappa H and Suresh R. 2018 *Mater Today: Proc* 5 5573–5579.
[19] Pazhouhanfar Y and Eghbali B 2018 *Mater Sci En*g A 710 172–180.
[20] Sabahi Namini A, AzadbehM and Shahedi Asl M. 2017 *Adv Powder Technol* 28 1564–1572
[21] Shi X, Hassanzadeh Aghdam MK and Ansari R 2018 *Proc Instit Mech Eng, Part L, J Mater: Des Appl* 233 1843–1853.
[22] Halil Karakoç, Şener Karabulut, Ramazan Çıtak 2018 *Composites Part B: Engineering* 148 68-80