SYNTHESIS AND CHARACTERIZATION OF ALUMINIUM 2024 WITH TUNGSTEN CARBIDE METAL MATRIX COMPOSITE BY IN-SITU METHOD

S. Nallusamy, M. Rajaram Narayanan, S. Saravanan
Dr. M G R Educational and Research Institute – India

Abstract. The objective of this research is to estimatethe effect of friction stir processing on microstructure and properties of aluminium alloy (Al-2024)/tungsten carbide (WC) metal matrix in-situ composite by low cost stir casting technique. Friction stir processing is used to modify the cast microstructure of aluminium alloy 2024 with tungsten carbide metal matrix composite. The fabricated composite specimens were subjected to a series ofmechanical and microstructural analysis. The observed results were compared with the results of base alloy material. Scanning electron microscope, optical microscopy and micro hardness test were carried out to analyze the microstructureand the dispersion of the reinforced particles in the composite alloy specimens.From the results it was found that, the mechanical properties like hardness value increases due to surface modification when compared with the base aluminium alloy.

Keywords: metal matrix composite, tungsten carbide, FSP, mechanical properties, SEM

Introduction

Aluminium matrix composites have gained more attention and research focus due tothe excellent properties like specific strength, superior wear resistance and low thermalexpansion. Aluminium matrix composites (AMCs) are widely replacing conventional aluminium alloys in many componentsin aerospace, automobile and marine applications (Singh, 2016; Nallusamy & Kartikeyan, 2016). Research is being carried out to improve theproperties of AMCs using novel fabrication methods and reinforcements of AMCs areconventionally produced by liquid metallurgy routes such as stir casting, squeeze casting andcompo casting techniques (Suganthini Rekha et al., 2015; Baradeswaran & Perumal, 2014; Karthkeyan & Nallusamy, 2017).AA 2024 is a precipitation hardenable alloy which is used for strategic applications becauseof good weldability and high strength to weight ratio. Tungsten carbide also referred to as cemented carbide, is a composite material-manufactured by a process called powder metallurgy. Tungsten carbide powder, generallyranging in proportion between 70 – 97% of the total weight, is mixed with a binder metal,usually cobalt or nickel, compacted in a die and then sintered in a furnace.In a stir casting process, the reinforcing phases are distributed into molten matrix bymechanical stirring. Mechanical stirring in the furnace is a key element of thisprocess. The resultant molten alloy, with ceramic particles, can then be used for die casting,permanent mould casting, or sand casting. Stir casting is suitable for manufacturingcomposites with up to 30% volume fractions of reinforcement (Nallusamy, 2016a; 2017; Kumar et al., 2014). The cast composites aresometimes further extruded to reduce porosity, refine the microstructure, and homogenize the-distribution of the reinforcement.

A major concern associated with the stir casting process isthe segregation of reinforcing particles which is caused by the surfacing or settling of thereinforcement particles during the melting and casting processes. The final distribution of theparticles in the solid depends on material properties and process parameters such as thewetting condition of the particles with the melt, strength of mixing, relative density, and rateof solidification.The distribution of the particles in the molten matrix depends on thegeometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer inthe melt, melting temperature, and the characteristics of the particles added (Purnawan et al., 2017; Jeevananthamet al., 2017; Singh, 2016). An interesting recent development in stir casting is a two-step mixing process. In thisprocess, the matrix material is heated to above its liquids temperature so that the metal ismelted. The melt is then cooled down to a temperature between the liquids and solidus pointsand kept in a semi-solid state. At this stage, the preheated particles are added and mixed. Theslurry is again heated to a fully liquid state and mixed thoroughly. This two-step mixingprocess is used in the fabrication of aluminium (Tony Thomas et al., 2014; Nallusamy, 2016b; Shin et al., 2014). Based on the above study, in thisresearch work AA2024 with tungsten carbide(WC)aluminium matrix composites are fabricated using in-situ casting method and theeffect of friction stir processing on microstructure and properties of the AMCs were studied.

Friction stir processing (FSP) is a method of changing the properties of a metal through intense localized plastic deformation. This deformation is produced by forcibly inserting a non-consumabletool into the workpiece, and revolving the tool in a stirring motion as it is pushed laterally through the workpiece as shown in Fig.1. It is carried out by rotating and plunging a speciallydesigned cylindrical, shouldered tool with a small diameter pin into the plate that is clampedfirmly to the bed. Frictional heat causes the metal to soften and allows the tool to traverse along the plate (Kamusheva & Karamanov, 2016; Kanthavel et al., 2016; Nallusamy & Kartikeyan, 2017). In friction stir processing, a rotating tool is used with a pin and a shoulder to a singlepiece of material to make specific property enhancement, such as improving the material'stoughness or flexibility, in a specific area in the micro-structure of the material via fine grainof a second material with properties that improve the first. Friction between the tool andworkpieces results in localized heating that softens and plasticizes the workpiece. A volume of processed material is produced by movement of materials from the front of the pin to theback of the pin. During this process, the material undergoes intense plastic deformation andthese results in significant grain refinement (Oyetunji et al., 2016; Jeevananthamet al., 2016; Nallusamy & Majumdar, 2016).FSP changes physical properties withoutchanging physical state which helps engineers create things such as high-strain-rate-superplasticity. The grain refinement occurs on the base material improving properties ofthe first material, while mixing with the second material. This causes for the base material'sproperties. This allows for a variety of materials to be altered to be changed for things thatmay require other difficult to acquire conditions. The processes branch of friction stirwelding (FSW) which uses the same process to weld two pieces of different materialstogether without heating, melting, or having to change the material's physical state (Salih et al., 2015; Nallusamy, 2015).

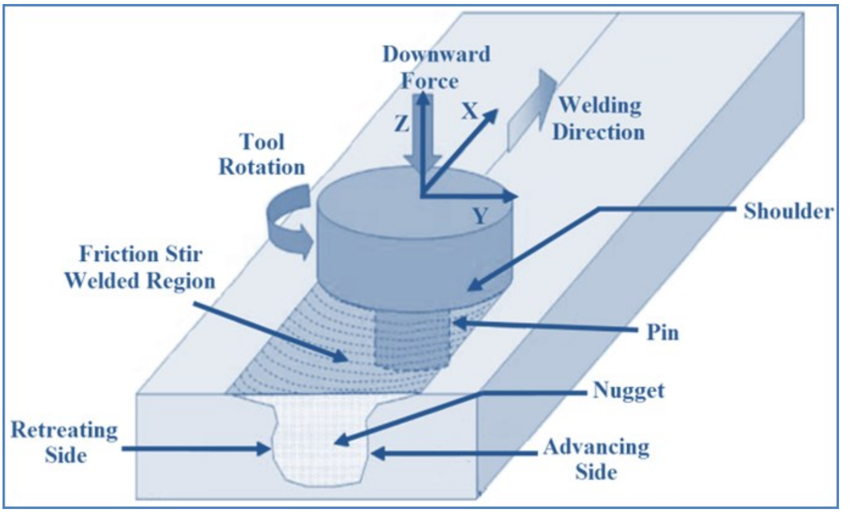


Figure 1. Friction stir processing under FSW

Experimental

Material preparation

Aluminium alloy plates, tungsten carbide are the materials used primarily in thepreparation of composites.Stir casting process starts with placing empty crucible in the muffle. Initially heatertemperature is set to 500°C and then it is gradually increased up to 900°C. Hightemperature of the muffle helps to melt aluminium alloy quickly, reduces oxidation level andenhance the wettability of the reinforcement particles in the matrix metal.Aluminium alloy 2024 is used as matrix material and the required quantity of aluminium alloy istaken from the raw material. About 997 grams of aluminium 2024 is dropped into the crucible and aluminium alloy is cleaned to remove dust particles. The preheated aluminium is thenpoured on to the crucible for melting at 638ºC. During melting nitrogen gas is used asinert gas to create the inert atmosphere around the molten matrix. Required quantities ofreinforcement powder are weighed on the weighing machine. Tungsten carbide with weightof 200grams after preheating at a temperature of 1000ºC for 20 minutes is then dropped in to thecrucible. It is then the temperature of the system must have reached 760^0C.

Once thereinforcement ceramic of tungsten carbide is dropped in to the molten aluminium themolten matrix is left undisturbed for two minutes. When matrix was in the fully molten condition, stirring is started after two minutes. Stirrer rpm is gradually increased from 0 to 300rpm with the help of speed controller. Temperature of the heater is set to 630°C which isbelow the melting temperature of the matrix. A uniform semisolid stage of the molten matrixwas achieved by stirring it at 630°C.Pouring of preheated reinforcements at the semisolidstage of the matrix enhance the wettability of the reinforcement, reduces the particle settlingat the bottom of the crucible. Reinforcements are poured manually with the help of conicalhopper with flow rate of reinforcements about 0.5 grams per second. Dispersion timewas taken as five minutes and after stirring five minutes at semisolid stage slurry was reheated andhold at a temperature 900°C to make sure slurry was fully liquid. Since the melting point oftungsten carbide is way high above 1000ºC. So the WC particles remain suspendeduniformly throughout the matrix adding to the properties. Stirrer rpm was then graduallylowered to the zero.

The stir casting apparatus is manually kept side and then moltencomposite slurry is poured in the metallic mould. Mould is preheated at temperature 500°Cbefore pouring of the molten slurry in the mould. This makes sure that slurry is in moltencondition throughout the pouring. While pouring the slurry in the mould the flow of theslurry is kept uniform to avoid trapping of gas. Then it is quick quenched with the help of airto reduce the settling time of the particles in the matrix. After solidification the die isremoved to get the casted plate specimen.The precursor of this technique, friction stir weldingis used to join multiple pieces of metal without creating the heat affected zone typicalof fusion welding. When ideally implemented, this process mixes the materialwithout changing the phase and creates a microstructure withfine, equiaxed grains.This homogeneous grain structure, separated by high-angle boundaries,allows some aluminium alloys to take on superplastic properties. Friction stir processing alsoenhances the tensile strength and fatigue strength of the metal.

Polishing of the specimen was carried out with P220 grit ALO paper with water as a lubricant. Speed of the grinding wheel is 100/100 rpm and the time taken for grinding until plane is one minute. Etching of the specimen was carried out with the etchant of Keller‘s reagent. Highlights features in aluminium and aluminiumalloys and is sometimes effective at showing grain boundaries mixed as 1.0 mlhydrogen fluoride and 1.5mlhydrochloric acid in 2.5 mlnitric acidwith 95 ml water. The tool specifications used in friction stir processing is shown in Table 1.

Table 1. FSP cutting tool parameters

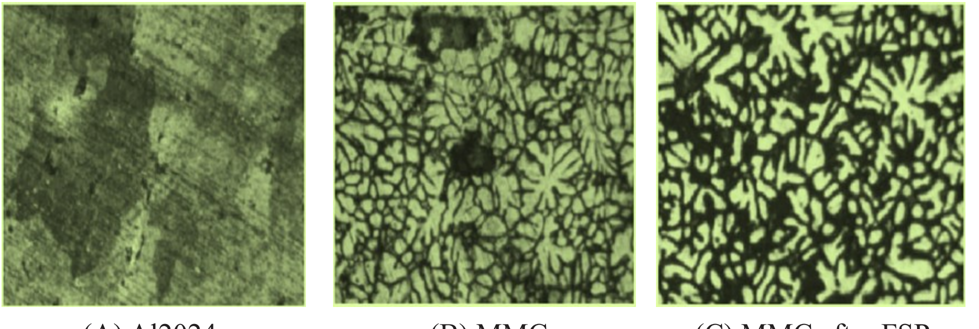
Material	AA 2024
Size of the Plate	100 mm x 100 mm x 10 mm
Reinforcement Particle	WC with 4-10 μm
Tool Material	EN 31 tool steel
Heat Treatment	Soaking period with 800oC about 2.5 hours. Quenching oil tempering with 100oC about 1 hour.
Rake Angle	2.5 degree

Results and discussion

Microstructural characterization was carried out on metallographically polished samples to investigate morphological characteristics of grain and secondary phase. Inversed-microscope analysis and scanning electron microscope (SEM) analysis were conducted for both Al 2024 alloy and aluminium with titanium carbide composite material.

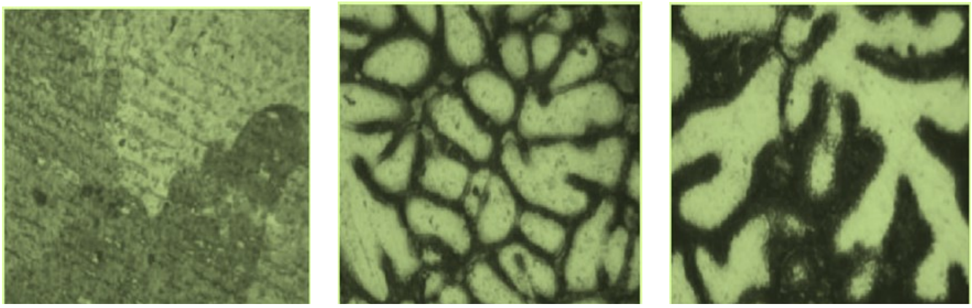
Optical microscope analysis

Figs. 2A and 3A shows the irregular boundary structure and have interconnected and coarse grain structure. Clogged black smoky appearance is observed in stir casted MMCs shown in Figs. 2B and 3B. From the optical microscope images it was observed that stir casting lead to dispersion of tungstencarbide throughout the matrix. But the smoky appearance signifies the presence ofagglomeration of reinforcement in the matrix. After FSP the refined microstructureof grains and grain boundaries indicate more even distribution of reinforcement in the matrixwith enhanced microstructure is shown in Figs. 2C and 3C.



(A) Al2024 (B) MMC (C) MMC after FSP

Figure 2. Microscopic images under 100X magnification

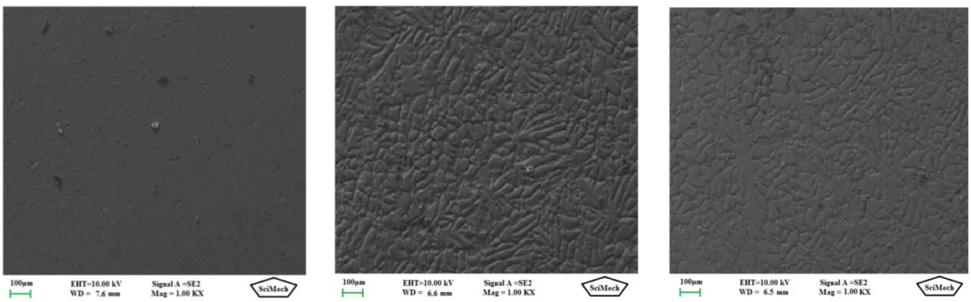


(A) Al2024 (B) MMC (C) MMC after FSP

Figure 3. Microscopic images under 400X magnification

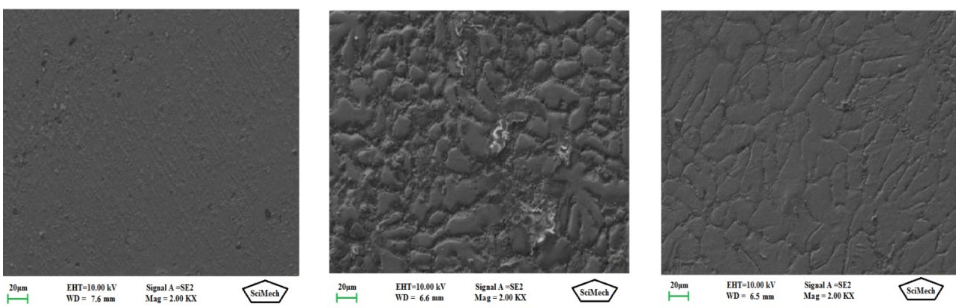
SEM analysis

Comparative SEM analysis on three samples wascarried out. Figs. 4 and 5 showthe SEM analysis images ofaluminium 2024, stir casted AA2024 with WC material under 1000X and 2000X magnifications.



(A) Al2024 (B) MMC (C) MMC after FSP

Figure 4. SEM analysis under 1000X magnification



(A) Al2024 (B) MMC (C) MMC after FSP

Figure 5. SEM analysis under 2000X magnification

AA 2024 shows irregular boundary structure and interconnected and coarsegrain structureshown in Figs.4A and 5A. Oxide layers, non refined grain structures are observed in casted MMC and are shown in figure 4B and 5B respectively. Addition of reinforcement resulted in changes in the morphology of the phase from coarsein-terconnected dendrites to fine equiaxed microstructure with homogenous distribution ofprimary α phase. Broken dendrite structure is observed in MMC with lot of debris likestructures throughout the grain boundaries. SEM images gives detailed and more clearexplanation on dispersion of reinforcement in the matrix and agglomeration at certain sites.After FSP the grain structures have expanded and are more refined as shown in figure 4C and 5C. SEM imagesgives detailed and more clear explanation on dispersion of reinforcement in the matrix andagglomeration at certain sites before FSP. It can be inferred that reinforcement is distributed moreeven in the matrix after FSP which in turn enhance the physical property of MMC also.

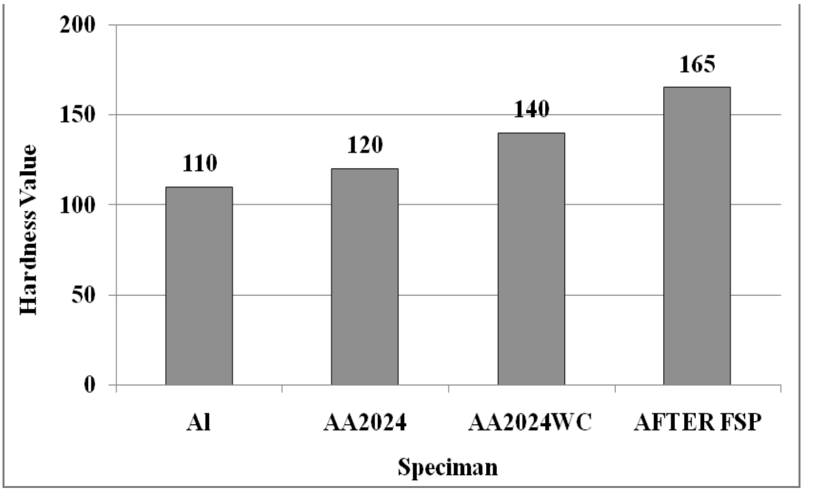


Figure 6. Micro hardness values of specimens

Micro hardness analysis

Average micro-hardness of pure aluminium, AA 2024, Al-WC MMC before FSP and Al-WCMMC after FSP were calculated and shown in Fig. 6. From the graph there is a progressive increase of hardness value.Micro-hardness has significantly increased which means there is a significant increase in thesurface toughness of the aluminium alloy with tungsten carbide metal matrix composite material.

Conclusion

Al-WC metal matrix composite was prepared with defect free and uniformly dis-tributed up to aconsiderable depth by using In-situ technique.The different analysis-like opticalmicroscopy, SEM analysis and microhardness test were conducted. Based on the results observed the followingconclusions were made: (i) Aluminum metal matrix composite was efficiently manufactured by In-situ Method and uniform distribution of ceramic particles along the material surface was achieved by friction stir-processing; (ii) Friction stir processing is used as a tool to enhance the uniform distribution of particle along the surface of matrix, which resulted in mechanical as well as micro structural modification; (iii) After FSP the refined microstructureof grains and grain boundaries signifies more even distribution of reinforcement in the matrixwith enhanced microstructure; (iv) From the SEM analysis it was found that, the reinforcement is distributed more even in the matrix after FSP which in turn enhance the physical property of MMC; (v) In micro-hardness analysis it was observed that, there is a significant increase in thesurface toughness of the prepared composite material.

REFERENCES

Baradeswaran, A. & Perumal, E.A. (2014). Study on mechanical and wear properties of Al- 7075/Al_2O_3/graphite hybrid composites. *Composites B, 56,* 464 – 471.

Jeevanantham, S., David Rathnaraj, J., Robinson Smart, D., Nallusamy, S. & Manikanda Prabu, N. (2016). A study on characteristics of parameters influencing internal grinding process with MRR. *Indian J. Sci. & Tech., 9*(37*),* 01 – 07.

Jeevanantham, S., Sivaram, N.M., Robinson Smart, D., Nallusamy, S. & Manikanda Prabu, N. (2017). Effect of machining parameters on MRR and surface roughness in internal grinding using EN8, EN31 steel. *Int. J. Appl. Eng. Res., 12*, 2963 – 2968.

Kamusheva, A. & Karamanov, A. (2016). Pycknometric evaluation of crystallinity and porosity in pyroxene glass-ceramics from industrial wastes. *Chemistry, 25,* 21 – 34.

Kanthavel, K., Sumesh, K.R. & Saravanakumar, P. (2016). Study on tribological properties on Al/Al_2O_3/MoS_2hybrid composite processed by powder metallurgy. *Alexandria Eng. J., 55,* 13 – 17.

Karthikeyan, A. & Nallusamy, S. (2017). Experimental analysis on sliding wear behavior of aluminium-6063 with SiC particulate composites. *Int. J. Eng. Res. Africa, 31,* 36 – 43.

Kumar, Ravindranath, V.M. & Shankar, G.S.S. (2014). Mechanical and wear behaviour of aluminium metal matrix hybrid composites. *Procedia Mat. Sci., 5,* 908 – 917.

Nallusamy, S. (2015). Analysis of welding properties in FSW aluminium 6351 alloy plates added with silicon carbide particles. *Int. J. Eng. Res. Africa, 21,* 110 – 117.

Nallusamy, S. (2016a). Characterization of epoxy composites with TiO_2 additives and E-glass fibers as reinforcement agent. *J. Nano Res., 40,* 99 – 104.

Nallusamy, S. (2016b). Analysis of MRR and TWR on OHNS die steel with different electrodes using electrical discharge machining. *Int. J. Eng. Res. Africa, 22,* 112 – 120.
Nallusamy, S. (2016c). A review on the effects of casting quality, microstructure and mechanical properties of cast Al-Si-0.3Mg alloy. *Int. J. Performability Engineering, 12*, 143 – 154.
Nallusamy, S. & Karthikeyan, A. (2016). Analysis of wear resistance, cracks and frictional properties of metal matrix composites with SiC additives and Al_2O_3 as reinforcement. *Indian J. Sci. & Tech., 9*(35), 01 – 06.
Nallusamy, S. & Karthikeyan, A. (2017). Synthesis and wear characterization of reinforced glass fiber polymer composites with epoxy resin using granite powder. *J. Nano Res., 49*, 1 – 9.
Nallusamy, S. & Gautam Majumdar, (2016). Effect of stacking sequence and hybridization on mechanical properties of jute-glass fiber composites. *Int. J. Performability Engineering, 12,* 229 – 239.
Oyetunji, O.A., Nareetsile, F.M., Gontse, R. & Sheling, L. (2016). Synthesis and characterization of palladium complexes of some N,N,N',N'-tetrakis (2-pyridyl-methyl) alkanediamine ligands. *Chemistry, 25*, 862 – 873.
Purnawan, C., Wahynningsihr, S. & Aisyah, D.N. (2017). Synthesis of ToO2-M (Cd, Co, Mn) as a Photocatalyst degradation of methylene blue dye. *Chemistry, 26,* 737 – 753.
Salih, O.S., Ou, G., Sun, W. & McCartney, D.G. (2015). A review of friction stir welding of aliminium matrix composites. *Materials & Design, 86,* 61 – 71.
Shin, J.H., Choi, H.J. & Bae, D.H.(2014). The structure and properties of 2024 aluminumcompositesreinforcedwithTiO_2nanoparticles.*Mat.Sci.&Eng.A,607,* 605 – 610.
Singh, J. (2016). Fabrication characteristics and tribological behavior of Al/SiC/Gr hybrid aluminum matrix composites: a review. *Friction, 4*, 191 – 207.
SuganthiniRekha, R., Nallusamy, S., Vijayakumar, R. & Saravanan, S. (2015). Modeling and analysis of crank shaft with metal matrix composites. *Int. J. Appl. Eng. Res., 10*(62), 133 – 137.
Tony Thomas, A., Parameshwaran, R., Muthukrishnan, A. & Aravind Kumaran, M. (2014). Development of feeding and string mechanisms for stir casting of aluminium matrix composites. *Procedia Mat. Sci., 5,* 1182 – 1191.

✉ **Dr. S. Nallusamy (corresponding author)**
Department of Mechanical Engineering
Dr. M G R Educational and Research Institute
Chennai-600095, Tamilnadu, India
E-mail: ksnallu@gmail.com