ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Effect of process parameter on synthesizing of TiC reinforced Al7075 aluminium alloy nano composites

Clement Tom Scaria, R. Pugazhenthi *

Department of Mechanical Engineering, VISTAS, Chennai, Tamilnadu, India

A R T I C L E I N F O

Article history:
Received 30 June 2020
Accepted 21 July 2020
Available online xxxx

Keywords:
Aluminium alloy
Nanocomposites
Al7075
TiC
Reinforcemet
Compressive strength

A B S T R A C T

In the present study TiC of differing its weight percentage (3%wt, 6 wt%, and 9 wt%) reinforced Al7075 aluminum alloy is synthesized by adopting stir casting method. However, achieving a consistent distribution of reinforcement of nanoparticles in the matrix alloy is more significant. Hence it is essential to explore the process parameters to achieve the uniform distribution of reinforcement in the matrix alloy such as stirring speed, stirring time, and by this, the influence of the mechanical property of aluminium alloy matrix composites has to be characterized. It has been observed that by increasing such parameters it resulted in better distribution of reinforcement particles in the synthesized composites, owing to that it enhances the microstructure and mechanical properties of composites such as the compressive strength increased to 232 Mpa, at stirring speed of 600 rpm and stirring time is maintained at 15 min. At this value, it is inferred that the TiC particles are consistently dispersed in the matrix alloy with an interfacial phase of $AlTi_2$.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Trends and Innovation in Mechanical Engineering: Materials Science.

1. Introduction

From the past decades, the utilization of lightweight composites and its alloys for various engineering applications has gained interest in research eternity. Despite several advantages, one critical limitation is that this material poses low strength and elastic modulus. A metal matrix composite has been specially developed to address these limitations. Metal matrix composites are a new class of material with lower density and are increased in the use of the automobile and marine industries for weight reduction purposes. Owing to its low density, tremendous corrosion resistance, castability, and mechanical properties the exploitation of aluminium and its alloys have become an attractive material for manufacturing low-density metal matrix composites. These materials are primarily utilized for buoyancy applications [1].

It has been observed from the literature that these composites are made of aluminium, steel, titanium, and magnesium alloys [2]. Hence aluminium matrix alloy paying attention majorly due to its lightest structural metal with a density of 2.8 g/cm3, which is extensively less in comparison to steel. It is also inferred that the synthesizing of magnesium is very tedious even though it has a low density compared with aluminum. Also, it possesses a lower ductility compared with aluminium alloy. This significantly considers that it can replace aluminum in existing applications for further weight savings [3]. However, the application of aluminium and its alloy is inadequate due to accelerated loss of strength with escalating the temperature, low elastic modulus, and lower wear resistance at elevated temperatures [4]. By adding suitable ceramic reinforcement particles can compensate for the above inadequacy.

The ceramics of varying particle sizes such as SiC, Al2O3, Y2O3, SiO2, and carbon nanotubes had been utilized for synthesizing metal matrix composites [5]. In addition to that, the processing method such as solid-state method (powder metallurgy, mechanical alloying and diffusion bonding) and liquid state method (pressure infiltration, stir casting, and spray deposition and in situ processing) has been used to develop such composites [6–7]. The synthesizing using solid particle reinforcement provides less optimal properties owing to the inadequate filling of interstitial spaces

* Corresponding author.
E-mail address: pugal4@gmail.com (R. Pugazhenthi).

https://doi.org/10.1016/j.matpr.2020.07.490
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Trends and Innovation in Mechanical Engineering: Materials Science.

Please cite this article as: C. Tom Scaria and R. Pugazhenthi, Effect of process parameter on synthesizing of TiC reinforced Al7075 aluminium alloy nano composites, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.07.490

between the matrix and the reinforcement, reaction between the matrix and reinforcement, the formation of detrimental inter metallic's originates decrease in mechanical properties. Despite these challenges, the liquid state method has been utilized for the present study.

In this study Al7075 aluminum alloy is used as matrix material and commercially available nano TiC of particle size < 200 nm from sigma Aldrich is worned as reinforcement for producing aluminum matrix composites using the stir casting method. However, achieving uniform distribution of nano reinforcement particles within the matrix is more significant which directly impacts the mechanical property of magnesium matrix syntactic foam. Hence it is imperative to manipulate the process factors to achieve consistent distribution of reinforcement in the aluminium matrix alloy such as stirrer design, stirring speed, stirring time, stirring temperature, and by using this the mechanical property of aluminium matrix composites has to be characterized.

2. Experimental methodology

Commercially available Al7075 aluminium alloy and TiC of particle size < 200 nm from sigma Aldrich is used as reinforcement to formulate aluminium matrix composites. Stir casting method has been employed for synthesizing such composites, the stir casting setup is shown in Fig. 1. Necessitate amount of aluminium alloy is melted in a crucible at 750 °C. The required amount of preheated TiC reinforcement particles with various mass percentage were mixed into the melt under inert atmosphere (Co2 and Sf6) to prevent oxidation and burning due to the presence of magnesium in it. The stirrer has been used to stir the slurry with dissimilar speed for the different mass fractions in order to get the homogenous circulation of reinforcement in the matrix alloy. A vacuum apparatus has been enclosed along with the cylindrical die of 30 mm diameter and 250 mm length is placed at the bottom of the furnace and a vacuum of 15 bars is introduced into the die before pouring of the slurry into the die. These eliminate the matrix porosity during pouring. The slurry is poured into the die and it is allowed to cool atmospheric temperature [8].

Fig 1. Stir casting setup.

3. Result and discussions

3.1. Effect of processing temperature on synthesizing of aluminium composites

The effect of the processing temperature of aluminium composites is illustrated by the contact time between the reinforcement particles and aluminium molten alloy with various holding time. These mainly influence the change in the viscosity of matrix alloy. The change in viscosity is calculated theoretically by using Arrhenius equation

$$\eta = \eta_0 \exp\left(\frac{E}{RT}\right) \cdot \left(\frac{E}{RT}\right) \quad (1)$$

where E is the activation energy for viscous flow and η0 is the viscosity of Al7075 aluminium alloy at the melting temperature, T is the temperature in K, and R is the gas constant (8.3144 J mol − 1 K − 1) [8]. The viscosity of the liquid aluminium matrix with the dissimilar mass percentage of TiC reinforcement is calculated with Einstein function as follows [9].

$$\frac{\eta}{\mu_u} = 1 + 2.5C + 10.5C2 + A\exp(BC) \quad (2)$$

In which A = 0.0023, B = 16.6, C is the mass fraction of the TiC particles. For C = 0.15, 0.20 and 0.23 the value of $\frac{\eta}{\mu_u}$ is 1.333, 1.921and 2.150 respectively.

It has been observed that the appreciable viscosity is increased by 33% than matrix alloy with the addition of reinforcement. The viscosity of composites slurry increases if the particle size of reinforcement in the nanoscales level [10]. At this stage, the reinforcement particles tend to immerse in the molten slurry owing to its higher density. Due to continuous stirring of liquid, it forms a sturdy cutting off the flow that exceeds by the reinforcement particles which enhance the wettability of synthesized composites. This is utilized to maintain the uniform particle distribution in the matrix alloy.

3.2. Influence of stirrer design to ensure the homogeneous distribution of reinforcement in the matrix alloy

To enhance the homogeneous distribution of reinforcement in matrix alloy and to improve the mechanical properties of aluminium composites the stirrer diameter is considered to be a significant factor. If the diameter of the stirrer is short then the solid particles persist and it fluctuates at the outside of the vessel incite of the inadequacy of reinforcement at the center. When the diameter of the stirrer is substantial, solid particles are prevailing un-dispersed in the axis of the furnace bottom. Hence the optimal diameter of the stirrer is the size has to be decided at which the solid particles are impregnated in both the central and minimal parts at the equivalent speed. From the literature, it is inferred that the stirrer width will be equal to 0.4D, where D is the diameter of the furnace, and the blade width should equal to 0.1–0.2D is developed for the present study as cited in the literature [11].

3.3. Effect on stirring speed and stirring time on the microstructural characterization of aluminium composites

To improve the mechanical properties of aluminium composites the particle distribution in the matrix alloy and its process parameter related to process methodology must be considered. The process parameters such as stirring speed (400,500 and 600 rpm) and stirring time minutes (5, 10, and 15) are considered for the dissemination of reinforcement particles in aluminium matrix composites. Microstructure characterization illustrates that the passage of ceramic reinforcement particles in the alumnium matrix alloy. It clearly evident that by increasing the stirring speed will not attain the equivalent distribution of reinforcement particle in the matrix alloy the stirring time also contributes to another deciding factor. It is noted that the accumulation of reinforcement particles found in some confined region in the aluminium matrix alloy at 5 and 10 min stirring. The interface particle separation increased by increasing the speed of the stirrer. It was not found effective by using 5 and 10 min stirring time. This is because some regions were recognized without the presence of TiC nanoparticles in the matrix alloy. Finally, to improve the homogeneous distribution of reinforcement particles it is decided to increase the stirring time (15 min) and speed (600 rpm) respectively. The superior microstructure has been viewed from the synthesized composites as shown in Fig. 2.

It has been observed from the microstructure that the TiC particles are uniformly distributed in Aluminum matrix alloy without residual pore. The microstructure of Al7075 aluminium alloy consists of hypoeutectic Ti-Al solid solution grains along with eutectic particles surrounded by Ti-Al supersaturated solid solutions. The presence of Silicates in HGM particles reacts with magnesium matrix alloy to forms an $AlTi_2$ interface [12]. Hence these acts as a strengthening mechanism of synthesized composites. Owing to that it increases the compressive properties of aluminium matrix composites found to be increased.

3.4. Effect on stirring speed, stirring time on the hardness of aluminium matrix composites

The Rockwell hardness values of the synthesized composites are shown in the table. Higher hardness of the composite relative to that of the aluminium matrix could be attributed to the reduced grain size and existence of TiC reinforcement particles. This acts as an obstacle to the motion of dislocations. It is understood that the increase in hardness of developed composites is due to the improvement of microstructural, interface bonding and lowering of porosity. This is to be expected since aluminium alloy is a soft material and the reinforcement particles being hard which contributes positively to the hardness of the aluminium composite. The presence of stiffer and stronger reinforcement leads to an increase in the constraint to plastic deformation of the matrix during the hardness test. But the constraint to plastic deformation depends on the distribution of the reinforcement particle in the matrix alloy. If the particle distribution is accumulated in a particular region and absence in some region will show a remarkable change in hardness value at a different location in the specimen. This could not be observed in the synthesized composites as shown in Table 1. The hardness values of the Al7075 with various percentage of Tic reinforcement is shown in the Fig. 3.

3.5. Effect on stirring speed, stirring time on compressive strength of aluminium matrix composites

The compressive strength of developed composites is performed as per the ASTM E9 standard. In this, both the matrix and the reinforcement particles afford the compressive strength of the manufactured composites. However, the increase in compressive strength is due to the homogenous distribution of TiC particles and the occurrence of the $AlTi_2$ interface between matrix and reinforcement particles. A typical stress–strain characteristic consisted of linear region, plateau region, and followed by densification region was observed in the stress–strain curve similar to that the curve obtained for metal foams. In the linear region, the maximum stress, i.e., the compressive strength of aluminium matrix composites, has been deformed linearly and then plastically and it appears as metallic foam [13]. The initiation of plastic deformation has been followed by a stress drop and entered into the plateau region. The stress drop is owing to the relative properties of the reinforcement and matrix in syntactic foams. The plateau region has been associated with buckling and collapse of grain size cell walls. This tends to fracture and expose the volume enclosed by TiC particles during compression. The magnitude of strain is essentially confiding on the porosity level of the aluminum matrix composites under the magnitude region. The energy absorption of the aluminium matrix composites can be improved either by increasing the plateau strength or porosity [14]. It is inferred that an increase in the proportion of reinforcement increases the compressive properties of TiC reinforced aluminium composites as shown in Table 2.

The Fig. 4 shows the compression strength of the Al7075 without any reinforcement with 3%, 6%, and 9% of reinforcement of Tic, which shows that without reinforcement the compression strength of the Al7075 is 160 MPa, Al7075 with 3% of Tic compressive strength value is 184 MPa, Al7075 with 6% of Tic compressive strength value is 208 MPa, and Al7075 with 9% of Tic compressive strength value is 323 MPa which shows that the reinforcement of Tic improves the compressive strength of the material.

Fig. 2. Microstructures of Al7075 aluminium composites reinforced with TiC of varying weight percentage of 3, 6, and 9%

Please cite this article as: C. Tom Scaria and R. Pugazhenthi, Effect of process parameter on synthesizing of TiC reinforced Al7075 aluminium alloy nano composites, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.07.490

Table 1
Hardness of the Al7075 with various percentages of Tic reinforcement.

Materials	Hardness (HRC)
Al7075	99.56
Al7075 + 3% TiC	102.96
Al7075 + 6% TiC	108.76
Al7075 + 9% TiC	116.06

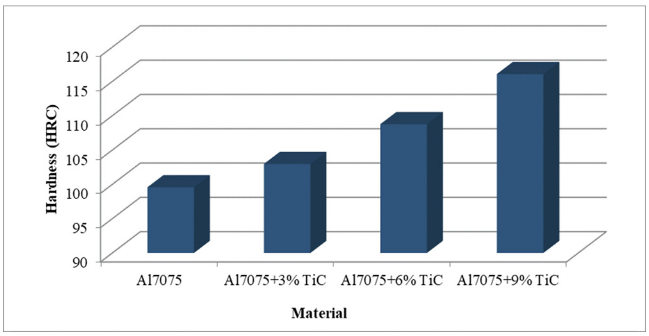

Fig. 3. Hardness values of the Al7075 with various percentage of Tic reinforcement.

Table 2
Compressive strength of the Al7075 with various percentages of Tic reinforcement.

Materials	Compressive strength (MPa)
Al7075	160 MPa
Al7075 + 3% TiC	184 MPa
Al7075 + 6% TiC	208 MPa
Al7075 + 9% TiC	232 MPa

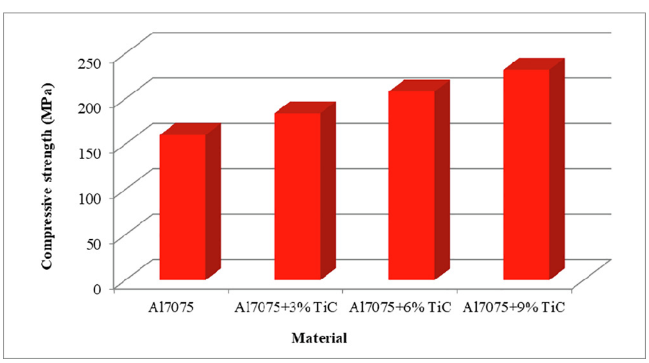

Fig. 4. Compression strength of the Al7075 with various percentage of Tic reinforcement.

4. Conclusions

The TiC particles reinforced Al7075 aluminium alloy matrix composites have been fabricated using the stir casting process. From the study, the microstructure characterization and compressive stress have been determined with the effect of stirring speed and stirring time. Based on the experimental results, the following conclusions have been made.

- The TiC particles are uniformly distributed in the matrix alloy without the sign of residual pore, owing to the influence of high stirring speed 600 rpm and stirring time 15 min.
- The hardness value is significantly increased by increasing the percentage of TiC reinforcement.
- The compressive strength of TiC reinforced aluminium composites has been increased due to the effect of harder reinforcement incurred in it.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Baradeswaran, S.C. Vettivel, A. Elayaperumal, N. Selvakumar, and R. Franklin, Mat. & Des. 63, (2014), pp. 620–629.
[2] R. Saravanan, M. Santhanam, S. Nadarajan, R. Pugazhenthi, J. Adv. Micro. Res. 10 (2015) 296.
[3] G. Anbuchezhiyan, B. Mohan, D. Sathyanarayanan, T. Muthuramlingam, J. Alloys and compd, 719 (2017) 125-132.
[4] R. Jino, R. Pugazhenthi, K.G. Ashok, T. Ilango, P.R. Chakravarthy, J. Adv. Micro. Res. 12 (2017) 89.
[5] G. Anbuchezhiyan, B. Mohan, T. Muthuramlingam, Arch. Civil Mech. Eng., 18(4) (2018) 1645-1650.
[6] S.A.A. Daniel, R. Pugazhenthi, R. Kumar, S. Vijayananth, Defence Technol. 15 (4) (2019) 545–556.
[7] G. Anbuchezhiyan, B. Mohan, S. Kathiresan, R. Pugazhenthi, Materi. Today Proc. 27 (2020) 1530-1534.
[8] A. Parthiban, C. Dhanasekaran, S. Sivaganesan, R. Pugazhenthi, Int. J. Mech. Prod. Eng. Res. Develop. 1 (2018) 284–288.
[9] R. Pugazhenthi, S. Sivaganesan, C. Dhansekaran, A. Parthiban, Int. J. Vehicle Struct. Syst. (IJVSS), 11(2) 2019.
[10] K. Jishu Chandran, R. Ganesh Manikandan, S. Baskar, Int. J. Ambient Energy (2020), https://doi.org/10.1080/01430750.2020.1725637.
[11] R. Pugazhenthi, D. Sreeram, S.S.V. Ananth, A. Devaraju, Mater. Today: Proc. 22 (2020) 701–704.
[12] S. Saravanan, A.G. Antony, V. Vijayan, M. Loganathan, S. Baskar, Int. J. Mech. Eng. Technol., 1(2019) 785-790.
[13] A. Rajasekaran, R. Pugazhenthi, Mater. Today: Proc., 22 (202020) 766-771.
[14] A. Parthiban, R. Pugazhenthi, R. Ravikumar, P. Vivek, IOP Conf. Series: Mater. Sci. Eng. 183 (1) (2017) 012013.

Please cite this article as: C. Tom Scaria and R. Pugazhenthi, Effect of process parameter on synthesizing of TiC reinforced Al7075 aluminium alloy nano composites, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.07.490