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Characterization on Aluminum Alloy 7050 Metal Matrix Composite Reinforced with Graphene Nanoparticles

S.Venkatesan[a], M. Anthony Xavior[b]*

[a,b]*School of Mechanical Engineering, Vellore Institute of Technology, Vellore. 632 014, India*

Abstract

Metal matrix composites based on aluminum were developed for light weight applications particularly in aerospace and automobiles sectors. This research article focuses on the development and characterization of Aluminum alloy 7050 matrix composites reinforced with Graphene nanoparticles. Liquid metallurgy techniques such as stir casting and squeeze casting processes were adopted for fabricating the composites. Certain parameters like melting temperature, stirring speed and graphene content with three levels were considered for the fabrication experiments. Taguchi's L27 Orthogonal array is used to evaluate the yield strength, tensile strength and hardness of AA7050-graphene composites fabricated by stir and squeeze casting. Based on the experimental results, analysis of variance (ANOVA) was conducted to determine the level of influence of the parameters on the strength properties such as yield, tensile strengths and hardness of the specimens.

Keywords: Aluminum alloy7050; Graphene; ANOVA; Hardness; Yield strength; Tensile strength.

1. Introduction

Composite material consists of more than one material which is delivered more strength than the individual material [1]. Aluminum metal matrix composites significantly enhanced the mechanical properties compared to the unreinforced aluminum alloys. The main reason for preferring the aluminum composite is excellent mechanical properties such as high strength and low weight which is most used aerospace applications [2]. Matrix material 7xxx series is one of the best suitable materials in the aluminum family. Among 7xxx series material AA7050 is excellent

* Corresponding author. Tel.: +919443687391
E-mail address: manthonyxavior@vit.ac.in

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in strength to weight ratio which is preferred in aeronautical and aerospace applications with more than 90% of them in as-cast state. Various reinforcements are used in metal matrix composites to improve the properties of the composites.

Mechanical properties of composites are defined based on some of the parameters namely size, shape and percentage composition of reinforcement and matrix material. More research work carried out on the carbonous materials to obtain excellent mechanical properties with reinforcing fewer amounts of carbonous materials. In the carbonous family graphene is most attractive reinforcement material due to its Young's modulus 0.5-1 TPa and tensile strength 130 GPa [3-5]. Some research works were reported on the usage of graphene as reinforcement in different forms such as particulate, nanoplatelets and nanosheets. Aluminum matrix reinforced with graphene nanosheets through powder metallurgy technique [6], graphene nanoplatelets through mechanical alloying [7], graphene nanoflakes by cryomilling methods [8], powder processing route [9], and squeeze casting [10] were reported in the literature.

Many researchers had suggested that fabricating aluminum alloy based composites through liquid metallurgy method is economically feasible. In the stir casting process non-uniform distribution of the reinforcements exist which results in blow holes and porosity. Distribution of graphene particles in aluminum matrix is more challenging one because of their interfacial contact area when compared to the other reinforcement materials. Since the addition of graphene nano-particles to aluminum alloy matrix influences the mechanical and tribological properties of the composites, the wt% of graphene can be decided based on the application requirement.

Some of the researchers have reported about developing Aluminum Matrix Composites (AMC) through stir casting process and the challenges associated in eliminating porosity and blowholes in the castings [11]. It is not possible to eliminate porosity and blow holes in the casting process but researchers have tried to reduce such defects through modified stir casting method. The electromagnetic stir casting method was found to result in slight improvement in the mechanical properties [12]. Baradeswaran and Elayaperumal [13] investigated the mechanical properties of aluminum reinforced with graphite content and inferred that there is a decrease in hardness with increasing graphite content. This is due to increasing brittle nature of graphite particles, which easily tends the composites to fail in brittle manner.

Later on Meysam Tabandeh at el. [14] investigated on aluminum matrix reinforced with graphene content and observed that increasing the graphene content more than 1% into aluminum matrix decreased the hardness values significantly. Its difficult to distribute the reinforcement uniformly into the matrix and consequently a decrease in mechanical properties of composites were observed. Brinell hardness result shows that the hardness of the composite decreases with increasing graphene content. Highest strength of alloy7050 were obtained through duplex aging at different subsequent temperature conditions [15].

From the literature survey, it is being understood that a relevant work on aluminum alloy 7050 based composites have been reported. But most of the reported work focused on the property evaluation through any one method like powder metallurgy or solid processing method. Comparison about the property of AA7050-graphene composites produced through stir and squeeze casting methods has not been addressed. In this research work an attempt is made to evaluate yield strength, tensile strength and hardness properties of AA5050-graphene composites produced by stir and squeeze casting processes.

2. Experimental work

Aluminum Alloy 7050 and graphene were purchased from Impex Maxwell, India and Angstron Materials Inc., USA respectively. Aluminum alloy AA7050 is melted in the form of liquid metal used by electric induction furnace at temperature of 775, 800 and 825°C and rotational speed of the stirrer is 300, 400 and 500 RPM and graphene weight percentage chosen as 0.3. Before pouring the liquid metal into the die is preheated at a temperature of 300°C to remove the moisture content in the die also eliminated the occurrence of casting defects of blow holes.

These composites are fabricated through typical process of stir and squeeze casting methods. Earlier researchers reported on investigation of AA2024 produced through squeeze casting method. Squeeze pressure leads to the formation of fine microstructure and higher applied pressures caused to decrease in percentage of porosity also tensile strength were improved [16].

Taguchi technique explored the correlation among hardness and tensile strength of aluminum composite. The composites obtained in the optimum conditions were melting temperature, applied pressure and holding time [17]. In the squeeze casting methods, the applied pressure maintained in the range of 100 to 110 MPa till the solidification of the casting. The samples have been taken separately for stir and squeeze casting processes. After solidification the castings are examined through Instron testing machine. Specimens are prepared through Electric Discharge Machine (EDM) wire cut process with the standard dimensions of ASTM E8 with dog bone shape. Taguchi's L27 Orthogonal array is used to evaluate the yield strength, tensile strength and hardness of AA7050-graphene composites fabricated by stir and squeeze casting. Tensile test is conducted according to the standard of ASTM E8 under different parameters of yield strength, tensile strength and hardness in the room temperature.

3. Results and Discussion

The observed data of hardness, yield strength and tensile strength of AA7050-graphene composites produced by stir and squeeze casting specimens were presented in Table 1. This observed data used for the statistical analysis. ANOVA was carried out to identify the significance of parameters considered in the testing. ANOVA was conducted to identify the significance of the parameters considered for the experimentation based on multiple performance characteristics.

Table 2 indicates the summary of ANOVA, influenced parameters of mechanical characteristics namely hardness, tensile and yield strength of the AA7050 and AA7050- 0.3 wt% of graphene composite fabricated by stir and squeeze cast processes. Based on the results, which were observed that graphene wt% (24.21%) have significant contribution when compared to the other two parameters namely stirrer speed (12.24%) and temperature (9.37%). Increase in graphene wt% caused to increase hardness values but elongation values are reduced irrespective of the fabrication process. Recommended graphene wt% is 0.3 wt% as reported by earlier researcher [18-19] for the proportion of graphene content in the aluminum matrix. Interaction effect of graphene with stirrer speed and temperature was observed as 23.4% and 17.23% respectively during the stir cast process.

In the stir casting process, temperature of 775ºC is recommended to obtain good hardness value. Similarly for squeeze casting process, optimum temperature of 825ºC is recommended to obtain good hardness value. Such a high temperature of 825ºC is used to improve the fluidity of flow for obtaining a good casting. There is no blow holes obtained in the squeeze casting. When the temperature exceeds 825ºC oxide is formed. In the stir casting process, 400 rpm is observed as optimum value for obtaining good hardness value. Exceeding 400 rpm or higher stirrer speed leads to increase in hardness due to porosity formed in the microstructure due to oxide skin formation over the surface. The reason being vigorous rotational speed of stirrer empowers oxide layers, gases and impurities to be appropriated in the liquid metal [20].

Table 2 indicated that temperature (51.2%) exhibits higher contribution on hardness followed by graphene (7.3%) and stirrer speed (1.8%) for the squeeze cast process. Hence temperature has a significant effect on hardness characteristic when compared to the graphene and stirrer speed for squeeze casted samples. Liquid metal temperature is high which improves the fluidity of liquid metal. The graphene particles are reinforced into the AA7050 matrix, which have a suitable response of enhancing the composite hardness behaviour.

Table 1 L27 Experimental observations from AA7050-graphene composites

Sl no	Temperature (°C)	Stirring speed (RPM)	Graphene (wt %)	Stir casting						Squeeze casting					
				Hardness (HBN)	Yield strength (N/mm^2)	Tensile strength (N/mm^2)				Hardness (HBN)	Yield strength (N/mm^2)	Tensile strength (N/mm^2)			
						Trial 1	Trial 2	Trial 3	Mean			Trial 1	Trial 2	Trial 3	Mean
1	775	300	0.3	97	206	235	237	236	236	107	225	253	249	248	250
2	775	300	0.5	105	202	231	232	229	231	105	221	245	246	247	245
3	775	300	0.7	108	197	225	224	228	226	108	217	239	243	241	241
4	775	400	0.3	96	207	236	237	240	238	96	227	252	249	248	243
5	775	400	0.5	106	202	235	231	234	233	106	225	242	240	241	241
6	775	400	0.7	110	197	226	230	227	228	110	221	238	243	239	240
7	775	500	0.3	94	200	231	235	232	233	104	223	252	249	255	252
8	775	500	0.5	95	195	227	228	226	227	106	215	247	242	246	245
9	775	500	0.7	98	186	220	219	218	219	103	216	246	244	239	243
10	800	300	0.3	96	204	235	234	236	235	106	228	252	249	249	250
11	800	300	0.5	97	195	230	229	225	228	108	225	245	249	248	247
12	800	300	0.7	98	199	221	227	225	224	104	223	245	244	246	244
13	800	400	0.3	97	206	240	236	241	239	107	227	252	249	255	252
14	800	400	0.5	99	204	232	228	230	230	105	224	252	249	246	249
15	800	400	0.7	98	197	224	225	226	225	104	221	243	244	248	245
16	800	500	0.3	97	207	239	244	240	241	108	225	244	246	248	246
17	800	500	0.5	99	194	227	222	226	225	110	222	241	245	243	243
18	800	500	0.7	95	190	217	224	219	220	111	217	238	242	243	241
19	825	300	0.3	97	202	235	237	236	230	107	231	252	256	257	255
20	825	300	0.5	98	198	229	224	225	226	111	229	252	249	249	250
21	825	300	0.7	99	195	221	225	223	223	116	226	248	245	248	247
22	825	400	0.3	96	202	241	237	236	238	110	224	258	255	255	256
23	825	400	0.5	95	199	229	233	231	231	117	222	252	249	255	252
24	825	400	0.7	94	195	227	222	226	225	114	219	250	249	248	249
25	825	500	0.3	96	211	242	238	239	240	113	221	259	257	258	258
26	825	500	0.5	95	196	231	226	227	228	115	220	252	251	257	254
27	825	500	0.7	94	189	220	222	218	220	116	219	252	249	249	250

This hardness behaviour is to be predictable since aluminum is a soft material and graphene particulates are hard, contributing positively to the hardness of the composites. The existence of graphene reinforcement caused to improve the restriction to plastic deformation of the aluminum matrix during the hardness test as reported by Charles [21].

Table 2 Summary of ANOVA – Mechanical Properties

Sl.No	Process Parameters	% influence on Mechanical properties					
		Hardness		Yield strength		Tensile strength	
		Stir cast	Squeeze cast	Stir cast	Squeeze cast	Stir cast	Squeeze cast
1	Graphene (wt%)	24.21	7.3	60.53	28.83	77.05	33.26
2	Stirrer speed (rpm)	12.24	1.8	5.45	5.76	7.33	0.21
3	Temperature (°C)	9.37	51.2	0.15	35.29	0.76	47.15

In the stir casting process, rotational speed of 400 rpm is observed to be the optimum value. If the speed exceeds 400 rpm, porosity is formed due to the formation of oxide layers, gases and impurities in the liquid metal. Better hardness value of the aluminum composite is based on the uniform dispersion of graphene particulates in the aluminum matrix based on rotational speed of the stirrer [22]. Hardness values are obtained as high and low values in some places due to the non-uniformity of graphene particle distribution of 0.7 wt% of graphene particles.

ANOVA for the yield strength of AA7050-graphene composite fabricated by stir cast and squeeze cast processes are recorded in Table 2, it is being observed that graphene wt% (60.53%) have significant contribution when compared to the other two parameters namely temperature (0.15%) and stirrer speed (5.45%) and negligible value of the interaction. Hence interaction effect is less significant in the stir cast process. Table 2 indicates that temperature (35.29%) exhibits higher contribution on tensile behavior followed by graphene wt% (28.83%) and stirrer speed (5.76%). Here also there is no interaction response on the yield behavior of aluminum composites. Hence temperature has a symbolic domination on yield behavior when compared to the stirrer speed and graphene wt% for squeeze casted samples. In the squeeze casting process, temperature is more influencing parameter to improve the fluidity of the cast.

In the stir casting process, temperature 775ºC is recommended to obtain good yield strength. Similarly for squeeze casting process, recommended temperature is 825ºC recommended to obtain good yield strength value. Temperature 825ºC is to improve the fluidity of flow to obtain good casting. There is no blow holes obtained in the squeeze casting. In the stir casting process, 400 rpm is observed as optimum value for obtaining good yield strength value.

Exceeding 400 rpm or higher stirrer speed leads to decrease in yield strength because of porosity formation in the microstructure due to oxide skin formed over the surface. Increase in graphene wt% caused to decrease yield strength irrespective of the fabrication process. Recommended graphene wt % of 0.3 has been reported by Wang [19] for developing MMCs based on Aluminum alloy matrix. Interaction effect of graphene with stirrer speed and temperature was observed as 9.3% and temperature with stirrer speed as 5.67% in the stir cast process.

ANOVA for the tensile strength of AA7050-graphene composite fabricated by stir cast and squeeze cast processes are indicated in Table 2, it is being observed that graphene wt% (77.05%) have significant contribution when compared to the other two parameters namely temperature (0.76%) and stirrer speed (7.33%) and negligible value of the interaction. Hence interaction effect is less significant in the stir cast process.

Table 2 indicates that temperature (47.15%) exhibits higher contribution on tensile behavior followed by graphene wt% (33.26%) and stirrer speed (0.21%). Here also there is no interaction consequence on the tensile characteristics of aluminum composites. Hence temperature has an important effect on tensile behavior while compared with the stirrer speed and graphene wt% for squeeze casted samples. Temperature has a reasonable influence in determining heat transfer as well as surface roughness of aluminum alloy. Surface roughness mainly depends on processing methods, melt treatment, mould material and cooling condition. Heat transfer of molten material is the significant factor which determines the mechanical properties. High pouring temperature resulted in decreasing heat flow and surface reported by Shayganpour [23]. In the squeeze casting process, temperature is the most influencing parameter, which improve the fluidity of the cast. Stir casting process temperature is to be maintained at 775ºC to obtain the maximum tensile strength of 230 MPa. Graphene content of 0.3 wt% and a stirrer speed of 400 rpm at a temperature of 775ºC is recommended for maximum tensile strength. Decreasing trend of tensile strength is observed for a temperature of 825ºC, stirrer speed higher than 400 rpm and graphene content more than 0.3 wt% in the composite fabricated through stir cast process. During squeeze casting process, 300 rpm is observed as optimum value for obtaining good tensile strength. Exceeding 300 rpm or higher stirrer speed leads to decrease in tensile strength because of the porosity formed in the microstructure. The main reason is active rotational speed of stirrer empowers oxide skins, gases and impurities to be appropriated in the liquid metal.

3.1 Microstructural examination

AA7050-graphene composite samples were subjected to microstructural examination to evaluate its properties. Samples are polished using fresh emery papers with different grades to obtain fine surface finish. Keller's reagent was applied on the specimen for etching the surface to view the microstructure. The strengthening effects were firstly enhanced and then deteriorated by increasing graphene content. The forms of bonding at the interface of aluminium matrix composites during molecular mixing process as there are functional groups on the carbon fillers which is beneficial to the load transfer between matrix and reinforcement. Interfaces and strong interfacial bonding between the graphene reinforcement and the aluminium alloy AA7050 metal matrix play an important role in determining tensile strength of the composites.

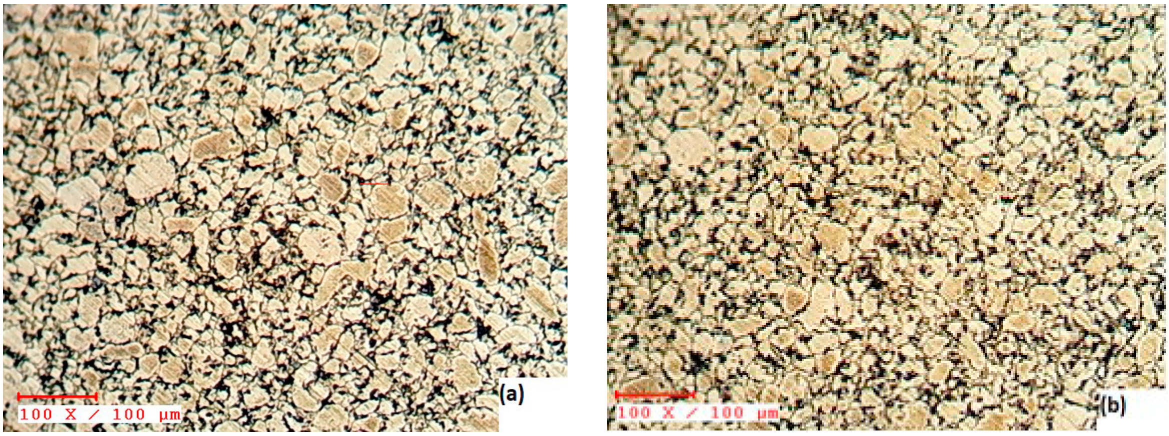

Fig. 1 SEM images of (a) Stir cast (b) Squeeze casting of AA7050-graphene composite material

SEM images reveal that the interface information of GNP/Al composites also shows that the interfaces are continuous and free of gaps or impurities. The microstructural studies were carried out using Zeiss metallurgical microscope to confirm the uniform distribution of graphene nanoparticles in aluminum matrix. The uniform distribution of graphene particles in the matrix depends on the process parameters of stir casting and squeeze casting methods. Fig. 1 (a) and (b) indicates the SEM images of the composite fabricated by stir cast and squeeze cast processes.

4. Conclusion

The AA7050-graphene composite was successfully produced by stir and squeeze cast techniques. Mechanical properties were increased due to the addition of graphene which act as effective reinforcement in aluminum matrix for both the processes. Maximum mechanical properties are obtained with the 0.3 wt% graphene content through squeeze cast processes which also eliminated casting defects such as blow holes and porosity. From ANOVA, it was observed that the presence of graphene is the most influencing parameter on tensile strength of AA7050-graphene composite fabricated by stir cast process. Similarly, from the analysis of squeeze cast specimen, it was noted that melting temperature is the most influencing parameter on tensile strength of AA7050-graphene composite. Further it was observed that the presence of graphene influences more on hardness of AA7050-graphene composite fabricated by stir cast process. Similarly for squeeze cast specimen, it was noted that melting temperature is the most influencing parameter on hardness. It was observed that the presence of graphene is the most influencing parameter on yield strength of composite fabricated by stir cast process. Similarly for the squeeze cast specimen, it was noted that melting temperature is the most influencing parameter on yield strength.

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