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Aluminum Metal Matrix Composites with SiC, Al_2O_3 and Graphene – Review

U. Aybarc [a, b], D. Dispinar *, [c], M.O. Seydibeyoglu [a]
[a] Izmir Katip Celebi University, Turkey
[b] CMS Izmir, Turkey
[c] Istanbul University, Turkey
* Corresponding author. E-mail address: deryad@istanbul.edu.tr

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Abstract

Light weight, low density with high mechanical properties and corrosion resistance, aluminum is the most important material and is commonly used for high performance applications such as aerospace, military and especially automotive industries. The researchers who participate in these industries are working hard to further decrease the weight of end products according to legal boundaries of greenhouse gases. A lot of research was undertaken to produce thin sectioned aluminum parts with improved mechanical properties. Several alloying element addition were investigated. Yet, nowadays aluminum has not met these expectations. Thus, composite materials, particularly metal matrix composites, have taken aluminum's place due to the enhancement of mechanical properties of aluminum alloys by reinforcements. This paper deals with the overview of the reinforcements such as SiC, Al_2O_3 and graphene. Graphene has recently attracted many researcher due to its superior elastic modulus, high fatigue strength and low density. It is foreseen and predicted that graphene will replace and outperform carbon nanotubes (CNT) in near future.

Keywords: SiC, Al_2O_3, Graphene, Aluminum metal matrix composites, Metal matrix composites

1. Introduction

Aluminum alloys have high corrosion resistance, high thermal conductivity, sufficient strength characteristics, recyclability, ductility, durability and especially low density [1-5]. Therefore, it can be widely used in many areas of industry such as aerospace, architectural construction, marine industries and particularly in the automotive applications [6, 7]. Nowadays, especially in the automotive industry, demands are increasing day by day and aluminum does not satisfy some case. So that production industry has begun to look for alternative engineering materials. Figure 1 shows the engineering material classification.

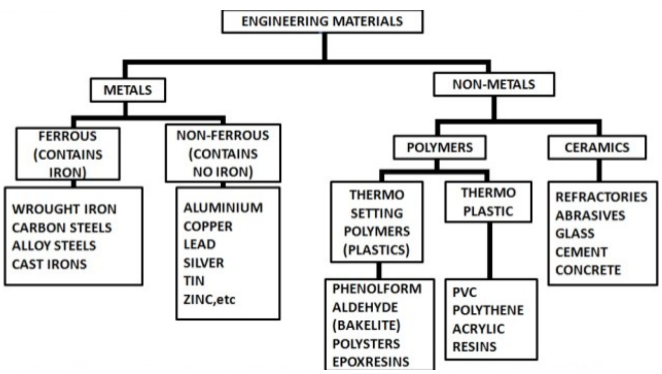

Fig. 1. Classification of engineering materials [8]

One of the engineering materials is composite. Composite materials consist of two or more materials. One of these materials is called reinforcement and other one is called matrix [9]. Fibers, particulates or whiskers are examples of reinforcements and metals, plastics or ceramics are examples of matrix material. In metal matrix composites systems, aluminum and its alloys have been drawn attention especially for last 20 years [9-12]. Silicon carbide (SiC) and aluminum oxide (Al_2O_3) are the most commonly used reinforcements [11]. So that this paper deals with the literature review about aluminum metal matrix composites in which SiC and Al_2O_3 were used as reinforcements materials. In addition, recent works in graphene reinforcements are also considered.

2. Aluminum metal matrix composite with Al_2O_3

Al_2O_3 is one of the commonly used reinforcement material for aluminum metal matrix composites [11]. Table 1 shows the summary of different investigations dealing with aluminum metal matrix composites with Al_2O_3 reinforcement.

Table 1.
The summary of aluminum composites with Al_2O_3

Researchers	Additive materials	Additive materials Particle Size	Ratio of additive materials (%)	Preheat conditions	Production method	References
K.K. Alaneme M.O. Bodunrin	Al_2O_3	28 μm	6, 9, 15, 18	250 °C for 5 minutes	Stir casting	[13]
S. Mula P. Padhi S.C. Panigrahi S.K. Pabi S.Ghosh	nano Al_2O_3	10 nm	2	-	Ultrasonic chamber	[14]
M. Kok	Al_2O_3	16 μm 32 μm 66 μm	7, 15, 23	400 °C for 10 minutes	Stir casting	[15]
S.A. Sajjadi H.R. Ezatpour H. Beygi	micro Al_2O_3	20 μm	1, 3, 5, 10	1100 °C for 20 minutes	Stir casting	[19]
	nano Al_2O_3	50 nm	1, 2, 3		Stir casting	
L. Singh B. Ram A. Singh	Al_2O_3	75 μm 105 μm 150 μm	3, 6, 9	300 °C for 1 hour	Stir casting	[17]
D. Sujan Z. Oo M.E. Rahman M.A. Maleque C.K. Tan	Al_2O_3	400 μm	5, 10, 15	-	Stir casting	[18]

Alaneme et al. [13] investigated the effect of different ratio of Al_2O_3 as 6, 9, 15 and 18 volume percent. The particle size of Al_2O_3 was selected as 28 μm. The reinforcements were preheated at 250°C for 5 minutes in order to improve wettability and stirring process (30 rpm for 10 minutes) was used for incorporation of particles. They observed that composites had low porosity levels and a good uniform distribution of the alumina particulates. They determined that some mechanical properties (tensile strength, yield strength, and hardness) were increased by increasing ratio of additives but some mechanical properties (strain to fracture and fracture toughness) were decreased by increasing ratio of additives.
Mula et al. [14] investigated the production of aluminum metal matrix composite with 2% wt. nano-sized Al_2O_3 by ultrasonic chamber. At first, ball mill was used to produce nano-sized Al_2O_3 from nearly 75μm Al_2O_3 powder. Then, non-contact ultrasonic casting method was used to produce nano composites samples. They analyzed microstructure and mechanical properties and determined that tensile strength and hardness increased respectively nearly 57% and 92% by adding nano sized dispersoids.
Kok [15] studied the effect of Al_2O_3 with three different sizes and volume ratio in aluminum. The composite was produced by using pressure after vortex method. It was concluded that increasing volume ratio and decreasing particle size lead to increasing amount of porosity. And, thus, composite with 66 μm has the most homogeneity than that of 16 μm and 32 μm.
Sajjadi et al. [16] investigated the various processing parameters and different particle size of Al_2O_3 as 20 μm and 50 nm. They determined that wettability of particles was correlated with size and percentage of reinforcement. By increasing percentage and decreasing particle size of reinforcement, wettability was

decreasing. The heat-treated particle and stirring system conditions increase the wettability and homogeneous distribution of particles. In addition, hardness and porosity were increased by increasing the amount of nano Al_2O_3.

Singh et al. [17] investigated the effect of different particle size (75, 105 and 150 micron) and wt. % of alumina (3, 6 and 9%) and process parameters (15, 20 and 25 minute stirring time). They used the Taguchi technique for design of experiment. They concluded that hardness was increased from 29 to 58 HRB by increasing the stirring time and weight percentage but decreased by increasing particle size. Similarly, tensile strength (increased from 96 N/mm^2 to 147 N/mm^2) and impact strength (increased from 12 Nm to 30,59 Nm) were increased by increasing stirring time and reinforcement wt %. However, mechanical properties were decreased by decresing particle size.

Sujan et al. [18] studied both Al_2O_3 and SiC reinforced aluminum matrix composite by stir casting method. It was revealed that the density of composite increased from 2,73 to 3,02 with increasing amount of reinforcement from 5 to 15% wt. Similarly, hardness and tensile strength increased relatively from 31 to 42 HR and from 262,2 to 282,9 MPa with increasing amount of reinforcement. They concluded that reinforced materials improve physical and mechanical properties of matrix metals. However, Al_2O_3 reinforced aluminum has higher wear rate compared to SiC reinforced aluminum.

3. Aluminum metal matrix composite with SiC

Another commonly used reinforcement material for aluminum metal matrix composites is SiC [11, 20-23]. Table 2 shows the summary of different investigations dealing with aluminum metal matrix composites with SiC reinforcement.

Table 2.
The summary of aluminum composites with SiC

Researchers	Additive materials	Additive materials Particle Size	Ratio of additive materials	Preheat conditions	Production method	References
Md. H. Rahman H.M. Mamun Al Rashed	SiC	53-74 µm	0, 5, 10, 20	800 C for 2 hours	Stir casting	[24]
M. Singla D.D. Dwivedi L.Singh V.Chawla	SiC	320 grit (~44 µm)	5, 10, 15, 20, 25, 30	1100 C for 1-3 hours	Stir casting	[25]
S.P. Dwivedi S.Sharma R.K.Mishra	SiC	15 µm	0, 5,10, 15	500 K for 1 hour	Mechanical and electromagneti c stir casting	[26]
K. Karvanis D. Fasnakis A. Maropoulos S. Papanikolaou	SiC	325 mesh (~44 µm)	3, 6, 9, 12, 15	1076 C 1 hour 30 minutes	Centrifugal casting machine	[27]
S.B. Prabu L. Karunamoorthy S.Kathiresan B. Mohan	SiC	60 µm	10	800 ◦C for 2 hours	Stir casting	[28]
D. Sujan Z. Oo M.E. Rahman M.A. Maleque C.K. Tan	SiC	-	5, 10, 15	-	Stir casting	[18]
T. Ozben E. Kilickap O. Cakir	SiC	30-60 µm	5, 10, 15		Pressure casting	[29]
K.L. Meena Dr.A. Manna Dr.S.S. Banwait Dr. Jaswanti	SiC	220-300-400 mesh (~69-40-37 µm)	5, 10, 15	1100°C for 1 hour 30 minutes	Stir casting	[30]

Rahman et al. [24] investigated the effect of SiC reinforced aluminum metal matrix composites. They investigated the effect of different contents of SiC such as 0, 5, 10 and 20 wt%. They used mechanical stirrer for 10 minutes at 500 rpm. They concluded that the reinforcement increased hardness, tensile strength and wear resistance with 20 wt% SiC content. These values were 45,4 Vickers, 77,5 MPa and nearly 0,005 cumulative mass loss (g/m), respectively. It was clearly seen that mechanical properties of composite increase by increasing the amount of SiC.

Singla et al. [25] studied the effect of different amount of SiC (5%, 10%, 15%, 20%, 25%, and 30% wt) on the hardness and impact strength. They used preheated aluminum scraps at 450^{o}C for 3-4 hours and preheated SiC particles at 1100^{o}C for 1-3 hours and applied two steps of stirring process. At first step, they heated aluminum scraps above the liquidus then cooled just below liquidus to get semi-solid state then added SiC particles and mixed manually. At second step, they reheated and stirred by automatic stirrer. They came to conclusion that the hardness and impact strength increase by increasing in weight percentage of SiC. They got maximum hardness as 45,5 BHN and maximum impact strength as 36 N-m with 25% weight fraction of SiC.

Dwivedi et al. [26] investigated the effect of amount of SiC particle as well as two different stirring methods: mechanical and electromagnetic. They used direct melt reaction for each stirring methods and same percentage of SiC particles: 0, 5, 10 and 15%. The conclusions show that mechanical properties such as hardness, toughness, fatigue life increase with increasing the addition of SiC and they concluded that the best mechanical properties and homogeneous can be obtained by using electromagnetic stirring method.

Karvanis et al. [27] investigated the effect of SiC particle on mechanical properties of aluminum metal matrix composites by using a centrifugal casting machine. They observed that the compressive and tensile strength and also the hardness increase with increasing the percentage of SiC particles. Tensile strength increased from 72,3 MPa to 119,3 MPa, compressive strength increased from 140,8 MPa to 196,3 MPa with increasing of reinforcement percentage.

Prabu et al. [28] studied the effect of different stirring speeds at 500, 600 and 700 rpm and durations of 5, 10 and 15 minutes for aluminum metal matrix composite with 10 wt% SiC with an average particle size of 60 µm. They determined that the stirring speed and time causes clustering of SiC particles and got better distributions of reinforcement material after 10 minutes stirring at 600 rpm. This research shows that the hardness value of composite is non-uniform for short stirring time and speed such as 5 minutes and 500 rpm respectively. Same conclusions can be seen at higher speed such as 700 rpm. Thus, they determined the mechanical properties can be directly affected by stirring speed and time. They came to conclusion that better hardness of composite could be obtained at 10 minutes stirring time and 600 rpm stirring speed.

Sujan et al. [18] investigated both Al_2O_3 and SiC reinforced aluminum matrix composite by stir cast method. They used different weight fraction of SiC such as 5, 10 and 15% and determined that hardness and tensile strength increased 30, 45 and 50 HR and 258,8, 293,3 and 310,5 MPa, respectively. Samples were subjected to wear test at a fixed time and adhesive paper at different grinding speeds such as 300 and 400 rpm. They found that wear resistance increased with increasing amount of SiC particles but decreased with increasing grinding speed.

Ozben et al. [29] studied the mechanical properties of aluminum metal matrix composite with different ratio: 5, 10 and 15% wt SiC reinforced. They obtained maximum hardness and impact toughness as 65 HB and nearly 0,6 Joule respectively with 15 wt% SiC. However, they determined that maximum tensile strength obtained in 10 wt% SiC and over this interface bond between particles and matrix was inadequate. They came to conclusion that increasing of reinforcement ratio improve the mechanical properties such as hardness and impact toughness but tensile strength indicated different properties for same reinforced additives.

Meena et al. [30] investigated SiC reinforced aluminum with different weight fraction (5, 10, 15, and 20%) and particle size (220, 300 and 400 mesh) by using melt stir technique. They determined that the hardness, tensile strength and impact strength were increased but elongation at fracture was decreased by increasing reinforced weight fraction.

4. Aluminum metal matrix composite with graphene

Graphene is a two-dimensional carbon material and attract scientist' attention because of high mechanical and chemical properties for last several years [31-36]. Table 3 shows the summary of different investigations dealing with aluminum metal matrix composites with graphene reinforcement.

Venkatesan et al. [34] investigated the mechanical properties of aluminum with different weight of graphene particles additions (0.33, 0.55 and 0.77%) by using stir casting technique. They applied stirring speed of 400 rpm for 5 to 10 seconds at 820^{o}C. They concluded that hardness increased from 45 BHN to 57.1 BHN with decreasing graphene content from 0.77 to 0.33% respectively. They came into conclusion that composite with 0.33% weight fraction gave optimum results.

Jagadish [37] investigated the effect of different amount of graphene such as 0.25, 0.5, 0.75, 1% to produce aluminum matrix composite. Powder metallurgy was used and found that aluminum without any reinforced showed higher hardness and impact strength. Hardness test results indicated that composite without any reinforcement was maximum as 62.5 HRC and composite with 0,5% graphene was minimum as 52.0 HRC. Same situation could be seen at Charpy test results: impact energy was decreased with increasing amount of graphene. On the other hand, aluminum with 0,75 wt % graphene shows maximum tensile strain and stress.

Bartolucci et al. [32] studied on powdered aluminum and composites with graphene platelets and multi walled carbon (MWNT) nanotube. They used milling, hot isostatic press and hot extrusion to produce composites. In their study, they compared pure aluminum with aluminum composites (0.1 wt% graphene and 1 wt% MWNT). They found that MWNT promoted the tensile strength up to 12% and graphene decreased the hardness and strength.

Table 3.
The summary of aluminum composites with graphene

Researchers	Additive materials	Ratio of additive materials	Production method	References
S. Venkatesan M.A. Xavior	Graphene	0.33, 0.55 0.77	Stir casting	[34]
B. S. Jagadish	Graphene	0.25, 0.5, 0.75, 1	Powder metallurgy	[37]
S.F. Bartolucci J. Paras M. A. Rafiee J. Rafiee S. Lee D. Kapoor N. Koratkar	Graphene	0,1	Hot isostatic pressing, and hot extrusion	[32]
P. Kumar S Aadithya K Dhilepan N Nikhil	Graphene (and SiC; fixed 5% wt.)	1, 3, 5	Ultrasonic assisted stir casting	[10]
M.M. Narwate K.K. Mohandas	Graphene (aluminum with 10%fixed TiO2)	0.5, 0.75, 1.0	Stir casting	[35]

Kumar et al. [10] investigated hybrid composites which consist of different ratio of micro SiC and nano graphene and they also produced aluminum composite with 5% SiC for comparison. They used ultrasonic assisted stir casting. At first, they melted aluminum for matrix material at 900°C then decreased temperature at 680°C to fabricate composite. They began to stir at 630°C for 5 minutes then reheated at 900°C and then used ultrasonic cavitation for 10 minutes. They poured slurry in metallic mould which was preheated to 500°C. They concluded that hardness of composite with 3% graphene has maximum impact strength with increasing amount of graphene.
Narwate et al. [35] investigated the effect of different amount of graphene (0.5, 0.75 and 1.0 wt.%) with 10% TiO_2 reinforced aluminum. They melted matrix material at 750°C and generated vortex by stirring at 220 rpm for 5 minutes. After vortex was formed stirring process was continued and they added graphene for 5-10 minutes. They concluded that composite with 1,0% graphene had maximum hardness as 50 HRB and ultimate tensile stress was maximum value as 112.7 MPa for composite with 1,0% graphene.

5. Conclusion

Due to their attractive mechanical properties, aluminum metal matrix composite has been an important engineering material for industry. Therefore, researchers have given close attention to reinforcement materials. It can be clearly understood that the type and amount of reinforcements directly determine the mechanical properties of composite material. However, the incorporation of reinforcement still is the major concern. Particularly the wettability and formation of porosity has to be evaluated. Stir casting method emerges as the best means of introducing particles into aluminum matrix. With its enhanced properties, the use of graphene as reinforcement for aluminum alloys appears to have the potential to produce higher toughness with minimum additions compare to ceramic particle additions.

References

[1] Campbell, J. (2015). *Complete Casting Handbook: Metal Casting Processes, Metallurgy, Techniques and Design*. Elsevier Science.
[2] Dispinar, D., et al. (2010). Degassing, hydrogen and porosity phenomena in A356. *Materials Science and Engineering: A*. 527(16), 3719-3725.
[3] Tan, E., Tarakcilar, A. & Dispinar, D. (2015). The effect of melt quality and quenching temperature on the Weibull distribution of tensile properties in aluminium alloys. *Materialwissenschaft und Werkstofftechnik*. 46(10), 1005-1013.
[4] Tan, E., Tarakcilar, A.R. & Dispinar, D. (2012). Correlation between Melt Quality and Fatigue Properties of 2024, 6063 and 7075. *Supplemental Proceedings: Materials Properties, Characterization, and Modeling*. 2, 479-485.
[5] Yuksel, C., et al. (2016). Quality Evaluation of Remelted A356 Scraps. *Archives of Foundry Engineering*. 16(3), 151-156.
[6] Al Hawari, A., et al. (2014). *A Life* Cycle Assessment (LCA) of Aluminum Production Process. World Academy of Science, Engineering and Technology. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*. 8(4), 704-710.
[7] Tsakiridis, P. (2012). Aluminium salt slag characterization and utilization–a review. *Journal of hazardous materials*. 217, 1-10.
[8] Kalpakjian, S., Schmid, S., Kok, C. (2009). *Manufacturing, engineering and technology SI*. London: Prentice Hall, Pearson Education Ltd.
[9] Kandpal, B.C., Kumar, J. Singh, H. (2014). Production Technologies of Metal Matrix Composite:-a review. *International Journal Of Research in Mechanical Engineering & Technology*, 2249-5770.
[10] Garg, H.K., et al. (2012). Hybrid Metal Matrix Composites and further improvement in their machinability-a review.

International Journal of Latest Research in Science and Technology. 1(1), 36-44.

[11] Ramnath, B.V., et al., (2014). Aluminium metal matrix composites- a review. *Rev. Adv. Mater. Sci*. 38(5).

[12] Reddy, B., Das, K. & Das, S. (2007). A review on the synthesis of in situ aluminum based composites by thermal, mechanical and mechanical–thermal activation of chemical reactions. *Journal of Materials Science*. 42(22), 9366-9378.

[13] Alaneme, K. & Bodunrin, M. (2013). Mechanical behaviour of alumina reinforced AA 6063 metal matrix composites developed by two step-stir casting process. *Acta Technica Corviniensis-bulletin of engineering*. 6(3), 105.

[14] Mula, S., et al., (2009). On structure and mechanical properties of ultrasonically cast Al–2% Al 2 O 3 nanocomposite. *Materials Research Bulletin*. 44(5), 1154-1160.

[15] Kok, M. (2005). Production and mechanical properties of Al2O3 particle-reinforced 2024 aluminium alloy composites. *Journal of Materials Processing Technology*. 161(3), 381-387.

[16] Ezatpour, H., Beygi Nasrabadi, H., Sajjadi, S.A. (2011) Microstructure and mechanical properties of Al/Al2O3 micro and nano nanocomposites fabricated by a novel stirr casting. in 2th conferences on applications of nano technologie in sciences, engineering and Medicines-NTC 2011.

[17] Singh, L. Ram, B. & Singh, A. (2013). Optimization of process parameter for stir casted aluminium metal matrix composite using Taguchi method. *International Journal of Research in Engineering and Technology*. 2(08), 375-383.

[18] Sujan, D., et al. (2012). Physio-mechanical properties of Aluminium metal matrix composites reinforced with Al2O3 and SiC. World Academy of Science, Engineering and Technology. 68.

[19] Ezatpour, H., et al. (2001). microstructure and mechanical properties os Al-Al2O3 micro and nano composites fabricated by a novel stir casting route. in 2nd Conferences on Application of nanotechnology in Science, Engineering and Medicine, Mashhad-Iran.

[20] Konopka, Z. & Pasieka, A. (2014). The Influence of Pressure Die Casting Parameters on the Mechanical Properties of AlSi11/10 Vol.% SiC Composite. *Archives of Foundry Engineering*. 14(1), 59.

[21] Konopka, Z. & Pasieka, A. (2014). Tribological Properties of AlSi11-SiCp Composite Castings Produced by Pressure Die Casting Method. *Archives of Foundry Engineering*. 14(3), 37.

[22] Łągiewka, M. & Konopka, Z. (2015). Properties of AlSi9Mg Alloy Matrix Composite Reinforced with Short Carbon Fibre after Remelting. *Archives of Foundry Engineering*. 15(3), 39.

[23] Pasieka, A. & Konopka, Z. (2013). The Influence of Pressure Die Casting Parameters on Distribution of Reinforcing Particles in the AlSi11/10% SiC Composite. *Archives of Foundry Engineering*. 13(3), 64.

[24] Rahman, M.H. & Al Rashed, H.M. (2014). Characterization of silicon carbide reinforced aluminum matrix composites. *Procedia Engineering*. 90, 103-109.

[25] Singla, M., et al., (2009). Development of aluminium based silicon carbide particulate metal matrix composite. *Journal of Minerals and Materials Characterization and Engineering*. 8(06), 455.

[26] Dwivedi, S.P., Sharma, S. & Mishra, R.K. (2014). Comparison of microstructure and mechanical properties of A356/SiC metal matrix composites produced by two different melting routes. *International Journal of Manufacturing Engineering*.

[27] Karvanis, K., et al. (2016). Production and mechanical properties of Al-SiC metal matrix composites. in IOP Conference Series: Materials Science and Engineering. IOP Publishing.

[28] Prabu, S.B., et al., (2006). Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite. *Journal of Materials Processing Technology*. 171(2), 268-273.

[29] Ozben, T., Kilickap, E. Cakır, O. (2008). Investigation of mechanical and machinability properties of SiC particle reinforced Al-MMC. *Journal of materials processing technology*. 198(1), 220-225.

[30] Meena, K., Manna, A. & Banwait, S. (2013). An analysis of mechanical properties of the developed Al/SiC-MMC's. *American Journal of Mechanical Engineering*. 1(1), 14-19.

[31] Akçamlı, N., Gökçe, H. & Uzunsoy, D. (2016). Processing and characterization of graphene nano-platelet (GNP) reinforced aluminum matrix composites. *Materials Testing*. 58(11-12), 946-952.

[32] Bartolucci, S.F., et al. (2011). Graphene–aluminum nanocomposites. *Materials Science and Engineering: A*. 528(27), 7933-7937.

[33] Casati, R. & Vedani, M. (2014). Metal matrix composites reinforced by nano-particles— a review. *Metals*. 4(1), 65-83.

[34] Venkatesan, S., Xavior, M.A. (2000). *Mechanical behaviour of Aluminium metal matrix composite reinforced with graphene particulate by stir casting method.*

[35] Narwate, M.M. & Mohandas, K. (2016). A Study on Mechanical and Tribological Properties of Aluminum Metal Matrix Composite Reinforced With TiO2 and Graphene Oxide. *International Journal.* 4(4), 729-732.

[36] Wang, J., et al. (2012). Reinforcement with graphene nanosheets in aluminum matrix composites. *Scripta Materialia*. 66(8), 594-597.

[37] Jagadish, B.S. (2015). Synthesis and characterization of aluminium2024 and graphene metal matrix composites by powder metallurgy. School of Mechanical and Building sciences, VIT University, Vellore, Tamil Nadu, India, 2, p. 14-18.