DEVELOPMENT AND CHARACTERIZATION OF AL-SIC-GRA METAL MATRIX HYBRID NANO-COMPOSITES -A REVIEW

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Abstract: Aluminium matrix hybrids Nano-composites (AHNCs) are a new generation of composite materials that have the capabilities of achieving the demands of advanced engineering applications. These challenges are met owing to enhanced mechanical properties, acquiescence to conventional fabrication technique and opportunity of reducing manufacturing cost of AHNCs. The performance of AHNCs is typically dependent on choosing the correct combination of reinforcing materials since the different parameters are connected with the reinforcing particulates. Very few amalgamations of reinforcing particulates have been abstracted in the development of AHNCs. The present study attempts to review the various combinations of reinforcing materials used in the fabrication of AHNCs. It is also discussed how the reinforcement affects the development of aluminium hybrid metal matrix nano-composites. Moreover, the major techniques for fabricating these hybrid composite materials are also mentioned.

Key words: Aluminium; Silicon carbide; Graphene (GRA), Graphene Platelets (GNPs), Hybrid composite; Nano-composite; Characterization;

1. Introduction:

The importance of composite materials has a large significance. Composite materials have noted importance in industries. Metal matrix composites (MMCs) are sub-classification of composite materials developed for achieving the highest possible strength to weight and weight to stiffness ratios in a less cost light material [1]. Metal matrix composites are fast substituting monolithic metallic materials. They are used in automobile, aerospace, marine sports, defense and dalliance industries. The aluminium metal matrix composites are mainly used due to their low weight, durability and high strength [2].

Aluminium hybrid composites denote a classification of metal matrix composites maintaining properties such as high strength, stiffness, low density, regulated co-efficient of thermal expansion and superior wear resistance and good stability at increased temperature [3]. Aluminium nano-composites with hybrid reinforcement is novel and new generation materials noted to offer adapt property combinations required in a vast range of engineering, industries applications [4]. Today aluminium hybrid Nano composites are widely used in a many number of fields and new required applications are being continuously developed. Characteristics of aluminium based hybrid composites are automotive and industrial unit components manufacturing use of impact, resistant of scratch, light weight and high heat malformation performance [5].

2. Reinforcement materials

The various reinforcement materials used for the development of aluminium hybrid nano composites are silicon carbide (SiC), boron carbide (B_4C), tungsten carbide (WC), alumina (Al_2O_3), and graphite (Gr). SiC and alumina extensively studied reinforcement materials as compared to other synthetic reinforcing materials [6]. Conventional aluminium MMCs with the reinforcement of silicon carbide (SiC) or alumina (Al_2O_3) have shown improved specific stiffness and strength over the monolithic alloy materials. But this happens at the outflow of ductility, light weight and fracture toughness. Researchers were still identifying the best combination of reinforcement for developing the aluminium hybrid composites. In this way the Al-SiC MMCs with the hybrid reinforcement of graphene nano-platelets were developed. The Al-SiC reinforced with Graphene platelets GNPs) have extensive applications in the field of medicine and aerospace industry due to its attractive properties [7].

3. Micro-structural features

The main focuses during manufacturing of composites are to attain the uniform distributions of particles in the ceramic matrix alloy. And also it is crucial to intercept agglomeration or segregation of ceramic particles during the progression of solidification. Rajmohan, et al. [8] studied the microstructural developments of aluminium/10%SiC/Mica hybrid MMCs fabricated by using the stir-casting method. The microstructure shows good bonding among matrix and reinforcement materials in the micrograph. The wear tracks give out that addition of mica exhibits less wear loss compared to without reinforced alloy. Devaraju et al. [9] studied the microstructure of aluminium alloy reinforced with the SiC + Al_2O_3(alumina) developed by friction stir-processing. Hybrid composite microstructure showed that SiC, Al_2O_3(alumina) are uniformly dissolved into the nugget zone (NZ). It is to be noted that the incorporated of Al_2O_3 particles with silicon carbide, increases the micro hardness and also increases the dry slid wearing resistance of Al alloy 6061-T6 nano hybrid composite. Ravindran et al. [10] analyzed the properties and microstructure of Al nano-hybrid composites with the adding of solid lubricant. The Al nano hybrid composites had silicon carbide (SiC) (5 wt.%) with wide ranged graphite content up to 10 wt.%. Authors concluded that those properties increased with increasing nano reinforcement materials. The aluminium composite with nano hybrid reinforcement had exceptional mechanical properties other than the Al/5 % silicon carbide (SiC) composite.

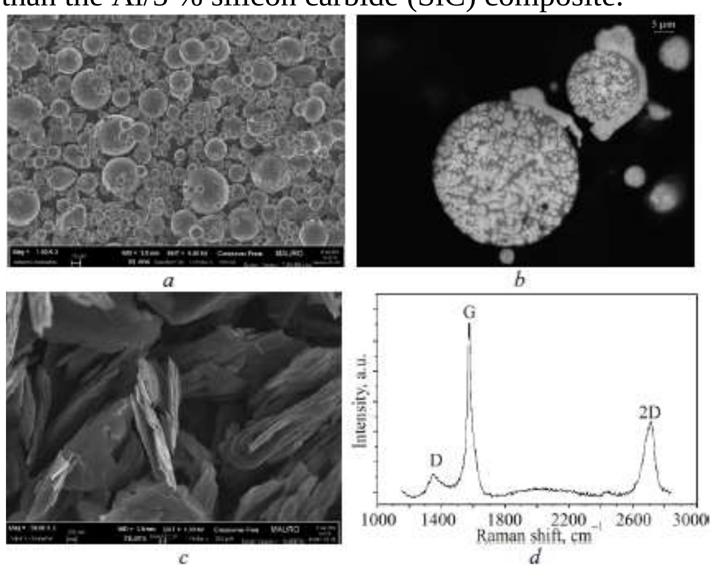

Fig. 1: (a,b)SEM micrographs of Al/Si/10Mg, (c) graphene nanoplatelets and (d) Raman spectra of graphene powder [13]

Suresha et al. [11] analysed the effect result of graphite addition on various properties of aluminium nano hybrid composites. Tribological studies have done to analyse the effect of load, sliding distance, sliding speed and graphite particulates on the wear of nano hybrid composite specimens. Sharma et al. [12] fabricated the aluminium-silicon carbide nano hybrid composite reinforced with different carbonaceous materials through solid state stir casting friction processing. The structural analysis discloses the exfoliation of graphene(GRA) to many layered graphene(GRA) under the influence of shear stresses in the time of plastic deformation. Saboori et al. [13] developed the AlSi10Mg–GNPs composites through the hot consolidation techniques. Studies have shown that hot consolidation is effective in produce dense materials containing a standardized dispersion of the Graphene (GRA) at the minimum for the lower reinforcement fraction. As per the results, the manufactured nano composites disclose higher ultimate tensile strength and hardness, which is related to the fundamental strengthening mechanisms. Unexpectedly, the plastic deformation capacity and ultimate tensile strength (UTS) of 1 wt.% GNP composites were lower uniform than the aluminium(Al) alloy, which is to be a result of graphene (GNP) porosity and agglomeration. Authors summarized that the reinforcement of 1% of GNPs is inspirational and can affect the final nano composite properties. Zeng et al. [14] studied the nano composites incorporate of aluminum-silicon matrix with 10 wt. % silicon carbide particles and different graphene oxide (GO) composition. The method established to be operative for the fabrication of hybrid aluminium metal matrix composites (HAMMCs) consist of an aluminium matrix with a GO distribution is uniform. The mechanical properties of the Al/Si-SiC-GO composite had a superior hardness compared to the aluminium MMC composite. The hybrid composites of Al/Si-SiC-GO composition had abrasive wear and adhesion wear, take place at low loads.

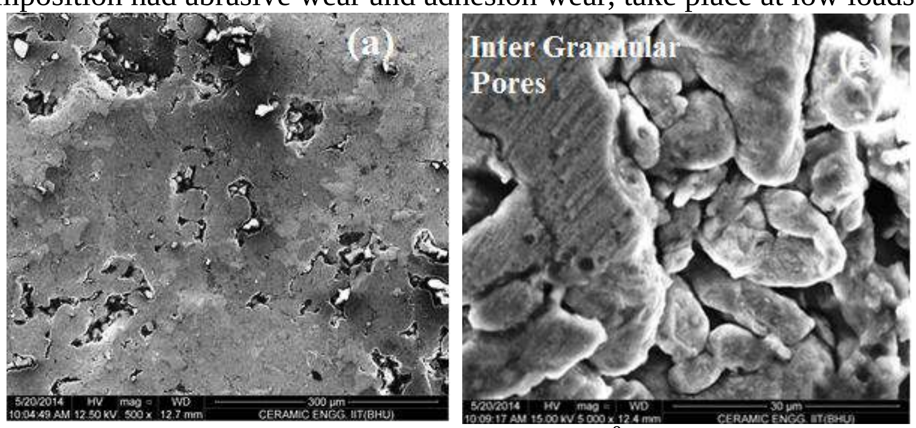

Figure 2: SEM micrograph of A5G550 (Al 15g +0.5g GRP at 550^0 C), Magnification: (a) 500X and b) 5000X [21]

4. Mechanical properties

4.1. Hardness

Yuminget al. [15] studied the metallurgy of silicon carbide (SiC) nanoparticles reinforced Al matrix nano-composites. The composite with 5 % Nano-SiC addition were prepared by deformation metallurgy process. It was observed that substantial microstructural refinement was achieved in the nano-size. During this process the agglomerated nanoparticles were broke and redistributed into the aluminum matrix and treated to become more uniform dispersion under the result of turbulent flow. The fabricated composites have improved hardness by 151%. Sajjad et al. [16] characterized the wear performance, surface morphology and modelling of graphite added hybrid aluminium composites. The hardness and wear properties of the 6% graphite particles reinforced in hybrid composite are high amongst all synthesized composites. They pointed that wear resistance of the hybrid composites can be increased by the combined effect of ZrO_2 and Gr. The experimental data and predicted values exhibited a high degree of association. It was accepted that the developed models can be used to expect the wear behavior within the range of investigation. Haiet al. [17] studied the processing, microstructure and hardness of Al_2O_3 nano-sized particle reinforced aluminum matrix composites. The nano-composites were fabricated by solid–liquid mixed casting combined along with ultrasonic treatment. Casting technology was operative in hindering the agglomeration of nano sized particles in the metal matrix. The ultimate tensile strength and hardness of 1% nano-Al_2O_3 reinforced 2024 alloy composite was enhanced by 37% and 81%, respectively. The better mechanical properties were credited to the homogeneous distribution of grain refinement and reinforcement of aluminum metal matrix. Sahin et al. [18] produced the 55% SiC reinforced aluminium metal matrix composites by using vacuum infiltration process. The density and micro-hardness of the SiC reinforced composite increased with high volume fraction of reinforcement and increasing particle content during this process porosity decreased. Furthermore, the rate of wear of the composite improved with increasing load and decreased with increasing particle content. Boopathi et al. [19] evaluated of mechanical properties for 2024 aluminium alloy reinforced along with silicon carbide and fly ash hybrid matrix composites. The compacted density of the metal composites decreased with the increasing fulfilled of the reinforcement. The better performance obtained by using Al/SiC and Al-fly ash composites, Al/SiC/fly ash composites. The properties improved with the increase in area fragment of reinforcement in metal matrix.

4.2. Tensile properties

Siva Prasad et al. [20] investigated the mechanical properties of aluminium hybrid composites fabricated by stir-casting process. Authors observed that the porosity and hardness of the hybrid nano composite increased with increasing reinforcement volume fraction and density decreased with increasing particle content. It can be noted that the yield strength and UTS increase along with an increase in the reinforcement particles, whereas percent elongation decreases with the increase in reinforcement. The improvement in strength of the hybrid nano composites is perhaps due to the dislocation density. Authors summarized that when compared to that of the base aluminum alloy, the sleet kinetics of the composites was accelerated by adding the reinforcement. Garg et al. [21] studied the structural and mechanical properties of graphene reinforced aluminum metal matrix composites. The microstructure shows the dense phase microstructure with some minute amount of channel pores and the reinforced particles were also clearly visible. The strength increased with high concentration of graphene (GRP) reinforcement ranging from 0.1 % to 0.5% stipulate increase in load bearing capacity of the samples. Rabiei et al. [22] analyzed to the fracture behavior of particle reinforced aluminium metal matrix nano composites. The toughness of different AMMCs is evaluated and compared with the Hahn–Rosenfield model prediction. Authors concluded the developed model is only valid for predicting toughness of composites with nano particle reinforcements. The analytical results were matched with the experimental fracture toughness resulted from the modified model for extremely large particle reinforced composites. Alaneme et al. [23] studied the mechanical behavior of aluminium hybrid composites. The light weight Al/Mg/Si-RHA-Al_2O_3 hybrid composites have assessed porosity levels as low as the alumina reinforced grade. The hardness of the Al/Mg/Si-RHA-Al_2O_3 hybrid composites decreases with the increase in RHA content. The strength decreases of 8% and 13% and specific strengths were lower and observed for the 3 and 4 wt% Rice Husk Ash (RHA) containing hybrid composites. The percent elongation, fracture toughness and specific strength of the 2 wt% Rice Husk Ash (RHA) containing hybrid nano composite was higher than that of the alumina reinforced and all other hybrid composite compositions. Milan et al. [24] studied the fracture toughness properties and tensile of SiC reinforced Aluminium alloys. Authors evaluated the influence of particles volume fraction, particle size and matrix strength on the monotonic fracture properties of Al alloys reinforced with silicon carbide (Sic) particles. From the mechanical tests, the high volume particle reinforcement

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increases the strength and decreased ductility. However, strength decreased with an increase in particles size and increased the composite ductility. Johny James et al. [25] studied the properties of hybrid aluminium metal matrix composite (AMMC) reinforced with silicon carbide and TiB_2. The hardness results show that the dispersion of reinforcement silicon carbide and TiB_2 increases hardness value. Authors reported that addition of SiC reinforcement to base metal increases 20% strength to the composite but addition of TiB_2 decrease in 50 - 60% strength.

Prashant Kumar et al. [26] measured the mechanical properties of Al alloy reinforced with Silicon carbide and fly ash. Al Alloy as matrix material and reinforcement materials as SiC and fly Ash chosen respectively. The mechanical tests have been tested by varying the volume fraction of fly ash while keeping Silicon carbide constant. The experimental results revealed that the increase in the reinforcement of fly ash increased the mechanical properties of material.Senthil Murugan et al. [27] evaluated the properties of Aluminium oxide(Al_2O_3), Silicon carbide(SiC) reinforced Aluminium 6061 matrix hybrid composite fabricated by stir-casting. The yield strength and fracture strength of Al hybrid composites with various weight fractions were noted. Authors measured the tensile strength of Al composite and the highest tensile strength noted was 124 N/mm^2 at 20 wt% of Silicon carbide. Highest mechanical properties was obtained for AA 6061/ 20% of Silicon carbide and 7% of aluminium (Al_2O_3) hybrid composite because of the ceramic nature of SiC reinforcement. The silicon carbide will develop a strong interface bond with the metal matrix on increasing the amount of silicon carbide into the metal matrix and this bond in turn improves the properties of composites. Ravikumar et al. [28] studied the mechanical and wear characteristics of Aluminium-aluminium oxide-silicon carbide (Al-Al_2O_3-SiC) hybrid metal matrix composite fabricated using stir casting process. Microstructural studies of composite confirmed the uniform distribution of reinforcements in metal matrix. Tensile and hardness properties of hybrid composite were increased with increase in alumina particles. The dispersion of alumina and SiC in matrix material had meaningfully refines the mechanical properties. Pradeep Devaneyan et al. [29] studied the mechanical properties of Al 7075 matrix composite material reinforced with SiC and TiC produced by powder metallurgy method. By conducting the mechanical tests at various samples were tested and found out the properties were improved for various compositions. Aoshuang et al. [30] fabricated the aluminium metal matrix hybrid composites reinforced with silicon carbide (SiC) micro-particles and TiB_2 nanoparticles by powder metallurgy. The combination of SiC micro particles and TiB_2 nano particles were uniformly distributed in the aluminium matrix. This uniform microstructure helps to improve the performance of the hybrid metal matrix composites. The nano TiB2 particles have a better influence on the tensile properties of the hybrid metal matrix composites.

Table 1: Comparison of different aluminium hybrid metal matrix nano-composites available in the literature

Composition	Fabrication	Hardness (VHN)	Tensile strength (MPa)	Elongation (%)	References
Al 2024 + 10%SiC + 5%FA	Stir-casting	93 BHN	285	12.8	[19]
Al–Mg–Si + 6%SiC + 4%BLA	Stir-casting	67	125	12	[31]
Al 7075 + 10%SiC +3%B_4C	Stir-casting	85	--	--	[32]
Al + 7.5%SiC +7.5%Al_2O_3	Stir-casting	82	159	8	[33]
Al+SiC+2%Al_2O_3	Accumulative	83	149	7	[34]

	roll bonding				
Al+7% SiC+3% Al_2O_3	Stir-casting	95	240	--	[35]
Al+1%GNP	Powder metallurgy	90	--	--	[36]
Al+9%+ Si_3N_4+0.1% GNP	Powder metallurgy	82	334	-	[37]
Al+10%+ B_4C+0.6% GNP	Powder metallurgy	89	325	--	[38]
Al+6%+ SiC+2% Graphite	Stir-casting	49 BHN	230		[39]
Al + 2% GNP	Stir-casting	34.7	66.15	34	[40]
A356+GNP	Squeeze casting	--	350	6	[41]
AA6061 +1%SiCp+0.5%B_4C	Ultrasonic dispersion	90 BHN	225	16	[42]
AA6061+10%SiC+0.7%GNP	Stir-casting	50 BHN	220	--	[43]
Al + 1% Graphene	Powder metallurgy	75 VHN	270	10	[44]
Al-30%SiC-0.1%GNPs	Powder metallurgy	85±2.6 HV	271±7 Mpa (Compressive strength)	---	[45]

5. Conclusions

The present review focuses on different combination of reinforcements used in the development of hybrid aluminium nano-composites. The dual synthetic ceramics reinforced aluminium nano-composites showing good mechanical and tribological properties over the un-reinforced alloys. From this literature survey, found that very less research done on Al-GNPs MMC nano composite materials can be manufactured by either solid or liquid phase methods. Researchers obtained effective results, factors such as interface reaction, volume fraction of reinforcing material, type of reinforcing material and its distribution in the matrix must be taken into consideration during design, compositions, material selection and fabrication process. With the right selection made, it is genuinely believed that Al-SiC-GNPs metal matrix hybrid nano-composites have tremendous potential for application in Medical instruments, aerospace industry and automobile industries.

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