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Investigation of Mechanical Behavior of Ultra Light Weight Nano Composite for Aero-Crafts

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Abstract: ***Now a day's demands on aerospace application have much crisis to be satisfied by composite materials. The problem behind in demand is processing and characteristics of nano materials with appropriate methodology. The Nano composite material is composed of a discrete reinforcement and distributed in a continuous phase of matrix, In Aluminum matrix nano composite (AMnC) one constitutes is aluminum which forms networks i.e. matrix phase and another constitute serve as reinforcement which is generally ceramic or non metallic hard material. The basic reason of metals reinforced with hard ceramic particles or non-metallic are improved properties than its original material like strength, stiffness etc. Stir casting has been used to synthesize Al/SiC and Graphite with economically. The main objective of the paper is to make Ultra-light weight nanocomposite material with volume fraction upto 30% using stir casting by varying proportional ratio from 5% to 30%. The mechanical properties of nano-composites from stir casted Aluminum-Silicon Carbide-Graphite composites have been studied using Metallographic and mechanical analysis techniques. This paper presents detailed approach of nano composite materials, process parameter and Characteristics reinforced by nano-particles for aero space vehicles spars.***

Keywords: Aluminum, Silicon carbide, Graphite, Metal matrix nano composites, Stir casting, reinforcement.

1. Introduction

Now days with the modern development need of developments of advanced engineering materials for various engineering applications goes on increasing. To meet such demands metal matrix nano composite is one of reliable source. Nano composite material is one of the reliable solutions for such requirement. In nano composites, materials are combined in such a way as to enable us to make better use of their parent material while minimizing to some extent the effects of their deficiencies. The simple term 'nano composites' gives indication of the combinations of two or more nano material in order to improve the properties. In the past few years, materials development has shifted from monolithic to nano composite materials for adjusting to the global need for reduced weight, low cost, quality, and high performance in structural materials. Driving force for the utilization of AMMnC in areas of aerospace and automotive industries include performance, economic and environmental benefits. In AMMnC one of the constituent is nano aluminum, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminum and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC, Al_2 O_3 and graphite etc.

2. Processing of AMNC

A key challenge in the processing of composites is to homogeneously distribute the reinforcement phases to achieve a defect-free microstructure. Based on the shape, the reinforcing phases in the composite can be either particles or fibers. The relatively low material cost and suitability for automatic processing has made the particulate-reinforced composite preferable to the fiber-reinforced composite for automotive applications.

2.1 Stir casting

In a stir casting process, the reinforcing phases are distributed into molten matrix by mechanical stirring. Stir casting of metal matrix composites was initiated in 1968, when S. Ray introduced alumina particles into an aluminum melt by stirring molten aluminum alloys containing the ceramic powders. Mechanical stirring in the furnace is a key element of this process. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting is suitable for manufacturing composites with up to 30% volume fractions of reinforcement.

The cast composites are sometimes further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement. A major concern associated with the stir casting process is the segregation of reinforcing particles which is caused by the surfacing or settling of the reinforcement particles during the melting and casting processes. The final distribution of the particles in the solid depends on material properties and process parameters such as the wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification .The distribution of the particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added.

3. Objective of the Paper

The main objective of this paper is to study the operating parameter of the nano composite as its control the properties of the nano composite material. Second objective is manufacture particulate aluminum metal matrix nano composite (PAMMnC) with varying compositions of reinforcement particles of graphite and SiC by using stir casting method. Third objective is to investigate the mechanical behavior of fabricated nano composites.

A. Nano Composite Material:

For nano composite material selection of Matrix and reinforcement are of prime importance. For this research work it had selected material as follows.

B. Matrix

Nano aluminium 2000, 6000 and 7000 series are used for fabrication of the automotive parts. PAMnC under study consist of matrix material of aluminium alloy Al6061 whose chemical composition is superior. An advantage of using aluminium as matrix material is casting technology is well established, and most important it is light weight material.

C. Reinforcement

Nano SiC and graphite of mesh size 10^{-9} are used as reinforcement. **SiC**: Silicon carbide particulates have attained a prime position among the various PAMC. This is due to the fact that introduction of Sic to the aluminum matrix substantially enhances the strength, the modulus, the abrasive wear resistance and thermal stability. The density of Sic (3.2g/cm) is nearer to that of aluminum (2.7g/cm3). The resistance of Sic to acids, alkalis or molten salts up to 800 degree Celsius makes it a good reinforcement candidate for aluminum based MMC. Addition of Silicon carbide particle results in Excellent Mechanical properties this produces a very hard and strong material.

Alumina: Addition of alumina particle has shown increase in tensile strength and it has good compatibility with aluminium alloy.

Graphite: Addition of graphite particle results in low friction of composite as it is good dry lubricant hence reduces wear and abrasion.

4. Process Parameter

For manufacturing of composite material by stir casting knowledge of its operating parameter are very essential. As there is various process parameters if they properly controlled can lead to the improved characteristic in composite material.

A. Stirring Speed

Stirring speed is the important process parameter as stirring is necessary to help in promoting wetability i.e. bonding between matrix & reinforcement. Stirring speed will directly control the flow pattern of the molten metal. By keeping speed from 300-600 rpm.

B. Stirring Temperature

The processing temperature is mainly influence the viscosity of Al matrix. The change of viscosity influences the particle distribution in the matrix. It accelerates the chemical reaction b/w matrix and reinforcement. In our project in order to promote good wet ability operating temperature at 630°C which keeps Al (6061) in semisolid state.

C. Reinforcement Preheat Temperature

Reinforcement was preheated at a specified 500◦C temperature 30 min in order to remove moisture or any other gases present within reinforcement. The preheating of also promotes the wetability of reinforcement with matrix.

D. Addition of Magnesium

Addition of Magnesium enhances the wetability. However increase the content above 1wt. % increases viscosity of slurry and hence uniform particle distribution will be difficult.

E. Stirring Time

Stirring promotes uniform distribution of the particles in the liquid and to create perfect interface bond b/w reinforcement and matrix. The stirring time b/w matrix and reinforcement is considered as important factor in the processing of composite. For uniform distribution of reinforcement in matrix in metal flow pattern should from outward to inward.

5. Experimental Setup

This is the layout of the stir casting apparatus. It consist of conical shaped graphite crucible is used for fabrication of AMMnC, as it withstands high temperature which is much more than required temperature [680°C].Along that graphite will not react with aluminum at these temperature. This crucible is placed in muffle which is made up of high ceramic alumina. Around which heating element of wound.

The coil which acts as heating element is Kanthol-A1. This type of furnace is known as resistance heating furnace. It can work up to 900°C reach within 45 min. Aluminium, at liquid stage is very reactive with atmospheric oxygen. Oxide formation occurs when it comes in contact with the open air. Thus all the process of stirring is carried out in closed chamber with nitrogen gas as inert gas in order to avoid oxidation. Closed chamber is formed with help of steel sheet. This reduces heat loss and gas transfer as compare open chamber.

A K type Temperature thermocouple whose working range is -200°C to 1250°C is used to record the current temperature of the liquid. Due to corrosion resistance to atmosphere EN 24 is selected as stirrer shaft material. One end of shaft is connected to 0.5 hp PMDC motor with flange coupling. While at the other end blades are welded. 4 blades are welded to the shaft at 45°C. A constant feeding rate of reinforcement particles is required to avoid coagulation and segregation of the particles. This can be achieving by using hopper. Aluminium alloy matrix will be formed in the crucible by heating aluminium alloy ingots in furnace. A stirring action is started at slow rate of 30 rpm and increases slowly in between 300 to 600 rpm with speed controller. A mixture of reinforcements ($Al2O3$ + SiC + Graphite) is to be incorporated in the metal matrix at semisolid level near 640°C. Dispersion time is to be taken as 5 minutes. After that slurry is reheated to a temperature above melting point to make sure slurry is fully liquid and then it is poured in mould.

6. Mechanical Behaviour Investigation

This chapter has discussed about metallurgical testing, micro structure and its impact of nano composites. The mechanical testing was carried out with Norms and conditions of American society for testing and materials by following testing method.

A. Hardness Test

Rockwell Hardness Testing using 10 mm ball diameter with an applied load of 3000 kg for 30 second. The hardness of 25% weight reinforcement contributes better results. The improvement increased upto 30%. It found that when the amount of percentage of reinforcement increases, the hardness also increases. Because of fine distribution of SiC and Graphite shows the results in strength. The experimental verification was observed and tabulated as shown in table.

RHN Results for AMMnC

Load (3000kg)	Trial 1	Trial 2	RHN
Specimen 1	1200	1199	1200
Specimen 2	1199.5	1199	1199

B. Impact Test

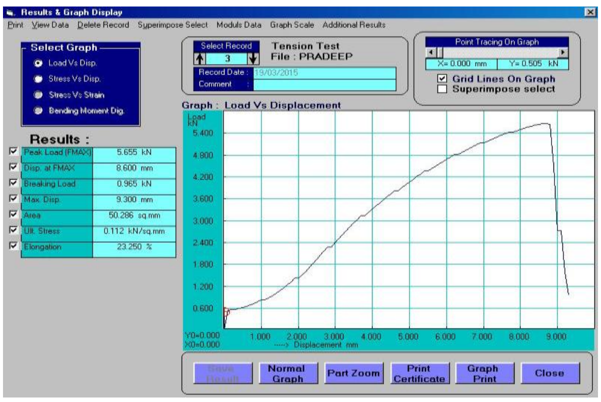
Charpy impact testing machine load used was 200kgf-m, used to check the impact strength of the nano composites. Standard ASTM specimens were used having notch of particular dimensions as indicated below: Cross section dimensions ±1% or ±0.075mm (0.003 inches). Radius of notch = ±0.025 mm (0.001 inches), Depth of notch = ±0.025 mm (0.001 inches), finish requirements = 2µ, width = 10mm, depth = 10mm. The result improvement is 20.9 % by reinforcement increments. The data shows that the observation of the impact test was tabulated as shown in table.

Impact Energy Results for AMMnC

LOAD (200kgf-m)	Trial 1	Trial 2	Impact energy in N/mm^2
Specimen 1	111.8	111.9	111.9
Specimen 2	111.1	111.1	111.1

C. Tension Test

Tensile tests were carried on specimens prepared with a gauge length of 32 mm and a diameter of 6 mm. For each composition, for standard tensile specimens were tested.



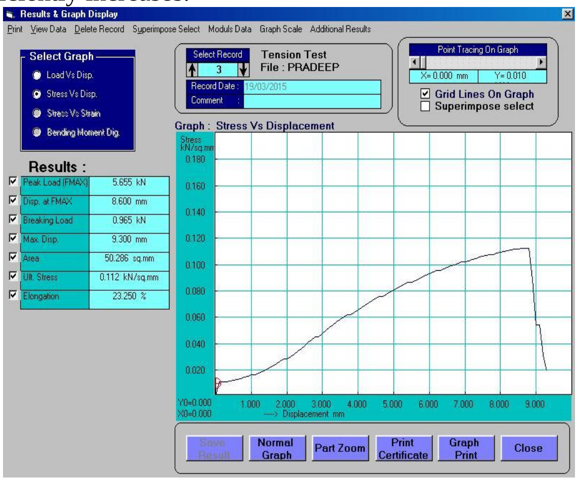
Load Vs Displacement

The obtained data is shown in following table.

Results of MMnC

Parameters	Results
PEAK LOAD (MAX)	5.655kN
DISP at MAX	8.600mm
BREAKING LOAD	0.965kN
MAX DISP	9.30mm
AREA	50.286 sq.mm
ULTIMATE STRESS	0.112kN/sq.mm
ELONGATION (%)	23.250%

The above figure represents that the strength increased to 30.6% that lower reinforcement. The peak load increased up to 1.8KN and percentage of elongation in reduced up to 20.5% compared to lower reinforcement. Ultimate stress increased up to 20.8% compared to various test composition results. It is quite evident that deformation in metals is because of the movement of dislocations and if we block these dislocations by some means the strength which is resistance against the applied force of the material, sufficiently increases.



Stress Vs Displacement

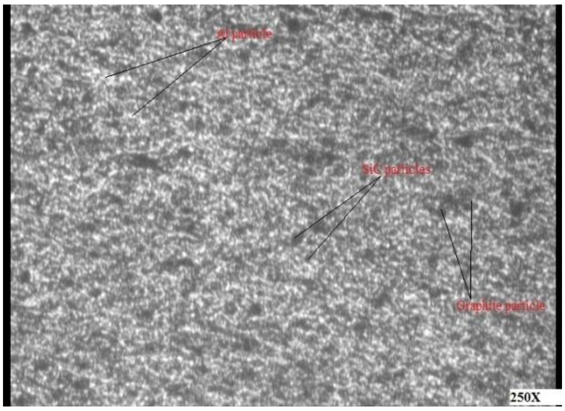
There is improvement in tensile loads and also capacitance to absorb the load within an elastic limit; these are sufficiently high in the vicinity of mechanical mixture of 20% silicon carbide, 5% of graphite and 75% aluminum. The experiments were tried by manual as well as using by the mechanical stirring but the results with the manual stirring were very poor because of the following reasons:

Lack of uniformity resulted because in certain sites of the melt, the stirring was higher as compared to others. The particle distributions were different in different areas which resulted in property variation. Potential sites for crack initiation: The accumulations of particles in certain areas of the composites were the potential sites for the crack initiation because in those areas either the particles were quite in the vicinity of each other or totally absent from those sites which resulted in the crack or deformation initiation.

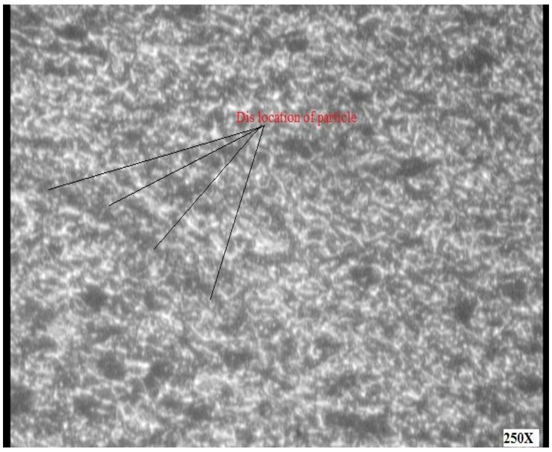
D. Micro Structure

The SEM images of aluminum matrix with addition 25wt% nano particles. From the micrographs it was observed that the nano SiC and Graphite particles are well distributed in the aluminum matrix though some clusters were formed. The scanning electron micrographs for the micro structure samples reveal that in around the 20 percent of the SiC and 5 percent of Graphite, particles are more uniformly embedded in the matrix than other compositions. The other micrographs which were polished show deep vallies in them because of the hard ceramic particles which emerged during polishing of the samples as shown in figure. It was found that some agglomeration of particles in that material which was composed and the reason for that material defects as follows:

- The material sizes varied on material composition because of fewer amounts of particles are added to the metal matrix.
- When the ceramic particles are polished with 0.5% of HF solution the polishing affects the surface of the ceramic particles.
- Precision of materials size are not uniform on composite.



Distributions of Nano Dots



Agglomerations of Nano Dots

7. Results

This nano composite material, the ultra-light weight nano composite material was fabricated by advanced stir casting method with density fraction upto 30% reduction. The research was measured that fabrication parameters and material characteristics of ULW nano composite.

The fabricated composition ratio is varying from 5% to 30% with silicon carbide and graphite nano particles as reinforcement agents. By testing these nano composite materials it found that 25% of reinforcement contributes better results among various compositions. The above all data are the 25% reinforced nano composites results. From the testing it can says that properties of nano composite increased upto 38% than its original properties. The final results of nano composites are shown in following table.

Results of AMMnC

Property	Nano Al	Nano Sic	Nano Graphite	Nano Composite Result
Density (gm/cm^3)	2.7	3.2	2.09 - 2.11	2.6
Melting Point (K)	923	3246	4188	1002.11
Young's Modulus (GPa)	300	410	100	300.2

8. Conclusion

This paper analyzed the light weight nano particles reinforced nano composites. Even though it has some crisis in synthesis of nano particles, it can conclude some facts as following:

- High energy ball mill is used to synthesize nano particles using top down approach. SEM analysis was carried out on the milled powder to get particle size and chemical composition.
- The stir casting technique is used to fabricate Nano composites.
- For uniform dispersion of material blade angle should be 45° or 60 ° & no of blade should be 4.
- For good wetability we need to keep operating temperature at semisolid stage i.e. 630 for Al. At full liquid condition it is difficult uniform distribution of the reinforcement in the molten metal.
- Preheating of mould helps in reducing porosity as well as increases mechanical properties. For further study we are going to check its mechanical properties.
- SEM micrographs shows that the nano particles are evenly distributed through some of the clusters were formed but good distribution was achieved.
- The tensile and hardness values were increasing with the increase in reinforcement. At 25wt% nano SiC and graphite reinforcement maximum tensile strength and hardness values has been observed.

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