EXPERIMENTAL STUDY TO EVALUATE THE MECHANICAL PROPERTIES OF ALUMINIUM REINFORCED WITH AL_2O_3 NANO PARTICLES

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ABSTRACT: Aluminium Matrix composites (AMCs) are light weight, high-strength materials with potential application in areas such as automobile, aerospace, defence, engineering and other industries. AMCs are projected to significantly reduce the overall weight of the vehicles and aircraft while maintaining satisfactory structural strength. Reinforcement of nano-sized range particles with aluminium matrix yields improved mechanical and physical properties in composite materials. The distribution of nano sized reinforcing particles also changes morphology and interfacial characteristics of nano composites. In this study pure aluminium and nano Al_2O_3 composites have been developed by using stir casting method. Different weight % of Al_2O_3 nano particles (from 0 to 12 % with step size of 3 %) were used for the analysis of composites. Microstructural study of the composites were characterized with the help of scanning electron microscopy (SEM) and it is found that nano particles (Al_2O_3) in aluminium metal matrix is distributed uniformly with agglomeration at some place. Various mechanical properties of composites like tensile strength, compressive strength, and hardness were measured. Results revealed that the tensile strength, compressive strength and hardness of composites increases with increase the weight % of Al_2O_3 particles. However the ductility of composite with nano Al_2O_3 particles reduced with increasing the weight % of Al_2O_3 particles.

KEYWORD Aluminium metal matrix nano composite; microstructural study by SEM; nanoparticle reinforcement; mechanical properties;

1. INTRODUCTION

Many of the engineering applications in the world today require materials with usual combination of properties that cannot be met by the conventional metal alloys, ceramics or polymers. This is especially true for the materials that are needed for aerospace and transportation applications. For example aircraft engineers are in quest for structural materials that have low densities yet strong, hard and impact resistant, and so on. Frequently materials having high strength have relatively high density, also increasing the results in decreasing impact strength. Engineers around the world have always been in search of better and better combination of properties in materials. Composite materials are artificially created by combining two or more materials which usually have dissimilar characteristics. The constituents of a composite material can be generally identified macroscopically. This is in contrast to usual metallic alloys whose phases can be identified only under higher magnification or microscopic examination.

Metal matrix composites (MMCs) have significantly improved properties such as high specific strength, specific modulus, damping capacity and good wear resistance compared to the unreinforced alloys. Aluminium metal matrix composites (AMCs) reinforced with particles and whiskers are widely used for high performance applications such as automotive, military, aero-space and electricity industries because of their improved physical and mechanical properties [1]. Mechanical properties of metal matrix composites are very sensitive to the method of processing being used. Fabrication techniques can be broadly categorized into two types first is solid liquid of processing technique and second is solid state of processing technique. . In solid state of processing mostly preferred method is powder metallurgy in which, the main drawback of liquid state of processing technique can be overcome that is non uniform dispersion of ceramic nanoparticles. But this uniform dispersion of nanoparticles makes it costly and lengthy process. Solid state processing routs is not mostly preferred because of the limitation in size and the complexity of components [6-7]

Although the solid state of processing produces better mechanical properties in MMCs, liquid state processing has some important advantages. They are as: better matrix-particle bonding, easier control of matrix structure, simplicity, low cost of processing, nearer net shape and the wide selection of materials [2]. Liquid state of processing technique includes two methods depending on the temperature of the particles at which they introduced into the molten metal. First is melt stirring process, the particles are incorporated above the liquidus temperature of the molten alloy, and the second is compo-casting method in which the particles are incorporated at the semi-solid slurry temperature of the alloy. In both processes, the vortex is used for introducing reinforcement particles. . In liquid state processing, mechanical and electromagnetic stirring and ultrasonic based dispersion is uses for the proper distribution of nanoparticles. However, the liquid state of processing technique has two major problems firstly, the particles tend to sink or float according to their density relative to the liquid metal , and secondly, the ceramic particles are generally not wetted by the liquid metal matrix. This problem is mostly faced in more viscous alloy because ceramic nanoparticles having higher tendency to agglomeration and clustering. Wettability can be defined as the ability of a liquid to spread on a solid surface and it represents the extent of intimate contact between liquid and solid [3].

Consequently, it results in poor dispersion of the ceramic particles, high porosity and low mechanical properties of the composite. This represents a great challenge of synthesizing cast MMC's. Poor wettability means the molten matrix cannot wet the surface of reinforcement particles as a result they simply float on the surface owing to surface tension, large surface area, high interfacial energy and presence of oxide film on the melt surface. Improvement in wettability to certain extent can be achieved by several methods like Increasing the surface energy of the solid, Decreasing the solid-liquid interfacial energy, Decreasing the surface tension of the liquid mechanical stirring, preheating the particles to remove adsorbed gases from particle surface, addition of alloying elements, use of surface coatings on reinforcement particle etc. [4-5]. another problem is distribution of reinforcement particles in molten matrix. Due to density difference between matrix and reinforcement, these particles have tendency to float or settle in the molten metal matrix and it will be the main cause of agglomeration and clustering of the particles into the formed composite. To overcome this problem, the injection of particles into molten metal take place with the inert carrier gas that is helpful in improving the distribution. Therefore, it is essential to develop a method for producing Al-MMC's taking account of incorporation and distribution reinforcing particles in the molten matrix [2].

KAINER K U. et. Al. [8] studied the reinforcement of Ceramic alumina nanoparticles into the aluminium alloy metal matrix by using liquid processing route in particular stir casting method. Ceramic nanoparticles reinforced by varying percentage 6% to 12% by weight in step of in step of 3%. For each composite, ceramic nanoparticles preheated to the 200^0c to increase the wettability of the nanoparticles. Then microstructural characteristics of composites are investigated by SEM photograph that is taken by the scanning electron microscope, it is found that alumina nanoparticles distributed uniformly with agglomeration at some place. Mechanical properties are highly sensitive to the microstructure and these are indirectly related to solidification parameters and processing conditions. G.G. sozhamannam et. Al. [12] studied that, the Sic (silicon carbide) nanoparticle reinforced with the aluminium metal matrix at the different temperature and different holding time by using the stir casting method. Because by changing the temperature and holding time distribution of nanoparticles in composite matrix changes and then make a comparision in mechanical properties of the different specimen. The distribution is examined by microstructure analysis, hardness distribution and density distribution. From the microstructure analysis it is found that there is increase in particles clustering corresponding to an increase in processing temperature and also the clustering tendency is more in the higher holding time than in the low holding time. The ultimate strength of composite increases when processing temperature increases from 700-800^0C and then decreases from 800-900^0C

The mechanical properties of the composites are affected by the size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface [9]. AGHAJANIAN et. Al. [10] studied the Al_2O_3 particle reinforced AMCs, with varying particulate volume fraction and reported the improvement in elastic modulus, tensile strength, compressive strength and fracture properties with an increase in the reinforcement content. The interface between the matrix and reinforcement plays a critical role in determining the properties of MMCs. Stiffening and strengthening rely on load transfer across the interface. Toughness is influenced by the crack deflection at the interface and ductility is affected by the relaxation of peak stress near the interface. M. Karabalaei Akbari, et. al. [11] studied the mechanical properties of aluminium alloy and nano Al_2O_3 composites fabricated by powder metallurgy route. Results revealed that by increasing in Al_2O_3 percentage, the results show that tensile strength of the composites increases with increasing weight fraction of the particles.

Zhao et. al. [13] characterized the properties and deformation behaviour of aluminium matrix nano-composites. Result of this study reveals that the elongation enhanced with increasing particulate volume fraction, which are markedly higher than those of Al composites synthesized by micro size particles. Ali Mazahery, et. al. [14] characterized cast A356 alloy reinforced with nano SiC particles composites and reported that hardness of the composites is higher than that of the un-reinforced alloy. It is maximum at 3.5 % of SiC nanoparticles. The higher hardness of the composites could be attributed to the fact that SiC particles act as obstacles to the dislocation motion. In this study, AA 5083 alloy micron and nano SiC composites has been fabricated by Ultrasonic assisted Stir casting method. Different weight % of micron SiC particles and Nano SiC particles were used for the experimental analysis of composites.

The present investigation has been focused on particulate composite formation by reinforcement of Al_2O_3 nanoparticles into aluminium matrix by using stir casting method. Microstructural study of the composites were characterized with the help of scanning electron microscopy (SEM). And then Tensile strength, Compressive strength and Hardness of Al- Al_2O_3 composite sample are evaluated with varying composition:-

1- Pure aluminium
2- Al + 3% of Al_2O_3
3- Al + 6% of Al_2O_3
4- Al + 9% of Al_2O_3
5- Al + 12% of Al_2O_3

After determining the experimental values of these mechanical properties, the comparison is made between the composite of different composition

2. EXPERIMENT PROCEDURE

2.1 Choice of Material

The matrix material used in this study is pure aluminium with 99.50% of purity. And used nanoparticle is Al_2O_3 (Alumina) with Purity: 99.85%, 100% alfa phase, Average particle size 150 nm (from BET SSA and SEM), Specific surface area (SSA) -10 m^2/g. these Al_2O_3 particles with varying amounts of 3, 6, 9 and 12wt% are being used as reinforcing material in preparation of composite.

Fig 1 (a) pure aluminium ingot

fig 1 (b) Al_2O_3 nano powder

Fig 1 of raw material

2.2 Stir casting

The aluminium Al_2O_3 metal matrix nano composite was prepared by stir casting route. For this we took different composition of composite that are given below

- 1 kg of pure aluminium
- 1 kg of pure aluminium + 30 gram of Al_2O_3
- 1 kg of pure aluminium + 60 gram of Al_2O_3

- 1 kg of pure aluminium + 90 gram of Al_2O_3
- 1 kg of pure aluminium + 120 gram of Al_2O_3

The alumina nanoparticles were preheated before to remove the moisture. Conventional pure aluminium was melted in furnace and melting temperature was raised up to 720^0C. The melt temperature was maintained at 700^0C during the addition of Al_2O_3 nanoparticles. Then the melt was stirred with the help of mechanical stirrer (zirconia coated steel impeller) and stirring was maintained 5 to 7 minute after the addition of nanoparticles in melted aluminium metal. The dispersion of nanoparticles was achieved by the vortex method. The melt with reinforced particulates were poured into the preheated mould. The pouring temperature was maintained at 680^0C. The melt was then allowed to solidify in the mould.

2.3 Scanning electron microscope:

Microstructural characterization studies were conducted on unreinforced and reinforced samples. This is accomplished by using scanning electron microscope. The composite samples were metallographically polished prior to examination. Characterization is done in etched conditions. Etching was accomplished using Keller's reagent. The SEM micrographs of composites were obtained using the scanning electron microscope. The images were taken in both secondary electron (SE) and back scattered electron (BSE) mode according to requirement. Microscopic studies to examine the morphology, particle size and micro structure were done by a JEOL 6480 LV scanning electron microscope (SEM) equipped with an energy dispersive X-ray (EDX) detector of Oxford data reference system. Micrographs are taken at suitable accelerating voltages for the best possible resolution using the secondary electron imaging.

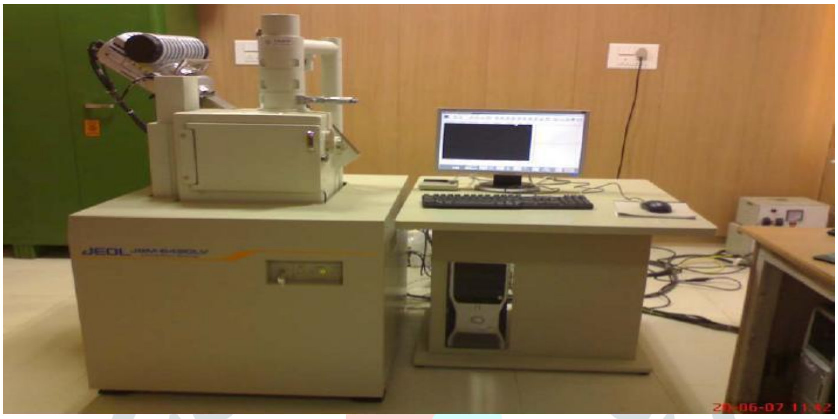

Fig 2 :-JEOL JSM-6480LV scanning electron microscope

2.4 Tensile testing

Tensile strength and compressive strength measurements were carried out on the pure aluminium and composite samples by using universal testing machine. Tensile strength investigation was carried out to investigate the effect of the variation in percentage of reinforced nanoparticles on the tensile strength. The size of tensile testing specimen is given below fig.4 [b]. Maximum capacity of UTM is 10 ton. Power is supplied to perform testing by means of electric motor.

Fig 3. (a) universal testing machine

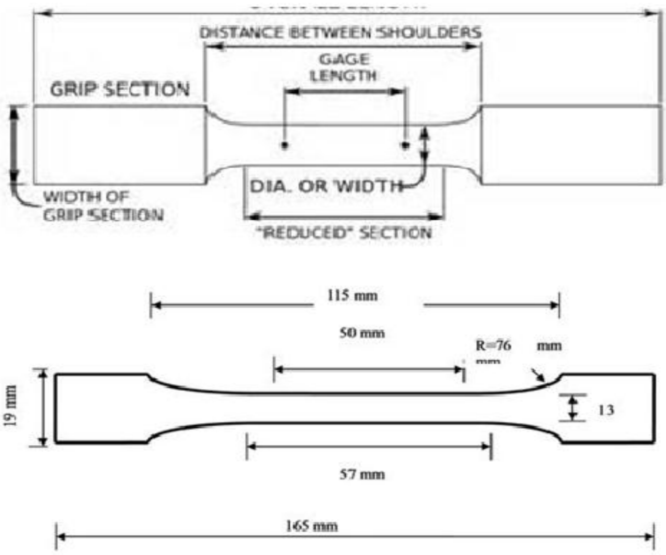

fig 3 (b) specimen size for tensile and compression

2.5 Hardness testing

Bulk hardness measurements were carried out on the pure aluminium metal and composites samples by using standard brinnel hardness test machine. brinnel hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Power supply to the ram is given by the electric motor and ram consists a ball of 5" diameter that is pressed against the test specimen to create an impression on it for the specific load and then the average diameter of impression measured. After measuring all the required data for the hardness calculation uses given formula to determine the hardness of composite material of different composition.

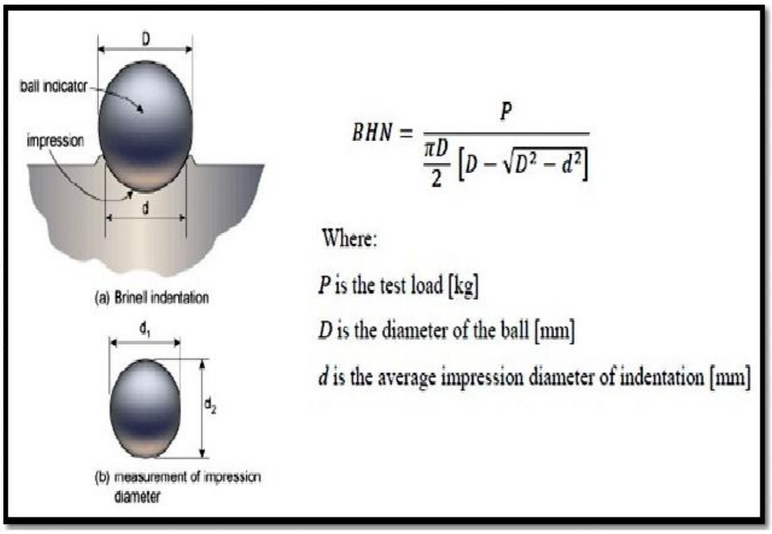

Fig 4 (a) brinell hardness testing machine **fig 4 (b) formula used to calculate hardness**

3. Result and discussion

3.1 microstructural study

Fabrication of metal–matrix composites with alumina particles by casting processes is usually difficult because of the very low wettability of alumina particles and agglomeration phenomena which results in non-uniform distribution and poor mechanical properties. In the current work, an attempt has been made to prepare pure aluminium metal matrix composites with nano size alumina particles by stir casting method with four stages mixing combined with preheating of the reinforcing particles. The magnitude of alumina powder used in the composites was 3, 6, 9 and 12wt. %.

SEM photographs were obtained using Scanning Electron Microscope. Fig. 6(a-d) shows the SEM photographs of pure Al with 3 wt. %(Fig. 6 a) 6 wt. %(Fig.6b), 9 wt. %(Fig.6c) and 12wt %(Fig.6d) particulates. Fig. 6d (12wt %) reveals good distribution of particles and very low agglomeration compare to 9 wt. % Al_2O_3 (Fig.6 c), 6 wt.% (Fig.6b)Al_2O_3 and 3 wt. % (Fig 6a) Al_2O_3particulates.

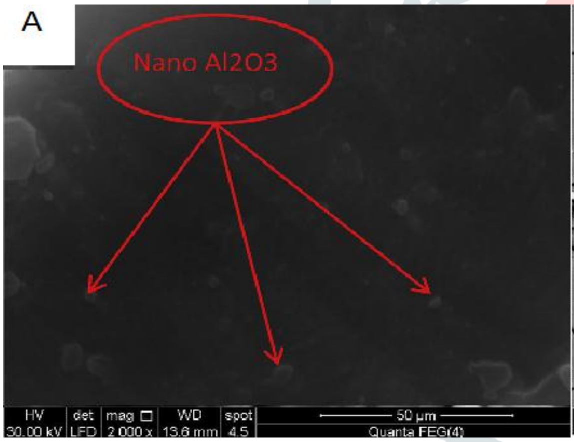

Fig 5 (a) pure Al + 3% of Al_2O_3

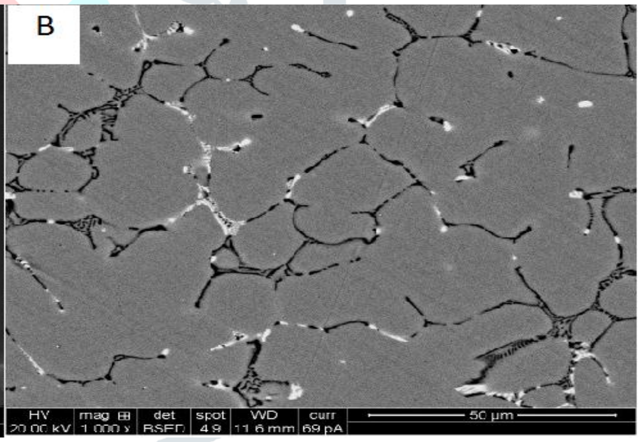

Fig 5 (b) pure Al + 6 % of Al_2O_3

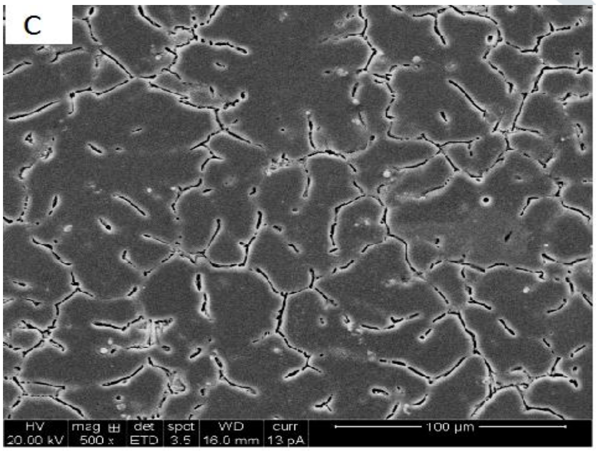

Fig 5 (c) pure Al + 9 % of Al_2O_3

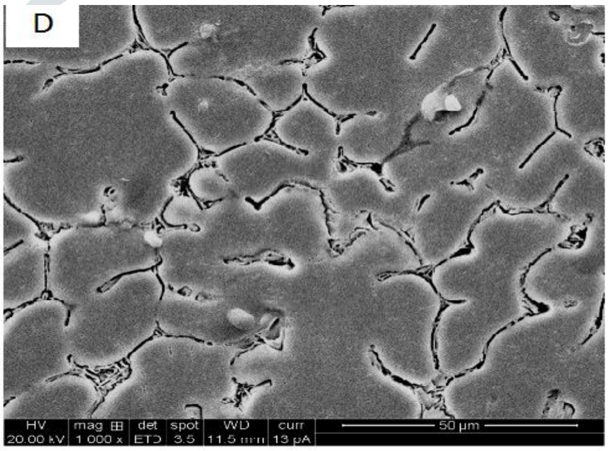

Fig 5 (d) pure Al + 12 % of Al_2O_3

3.2 Tensile and compressive testing result

To investigate the mechanical behaviour of the composites the tensile tests and compression test were carried out using uni-axial tensile testing machine as per ASTM standards. Two specimens were used for each test and average value is reported. Following observation are made from the given table and graph of tensile testing and compressive testing.

- Pure aluminium metal matrix have lower tensile and compressive strength.
- The tensile strength and compressive strength of composites are increases as the percentage of reinforcement increases from 3 to 12wt. % of nano-Al_2O_3 particles.
- The highest tensile and compressive strength was observed in case of 12wt. % of Al_2O_3 nanoparticles.
- It is also clear from the given data that ductility of the composite decreases as the percentage of reinforcement of nano-Al_2O_3 particles increases due to this percentage of elongation decreases with increase in reinforcement.

The strengthening mechanism for MMNCs has been studied and one of the major attributes is the higher dislocation density in MMNCs [15]. The difference of the thermal expansion coefficients between the matrix and the uniformly dispersed nano-Al_2O_3 could induce high dislocation density, and these nano-Al_2O_3 inclusions can work as the barriers for dislocations movement. It is believed that the properties of MMNCs would be enhanced considerably even with a very low volume fraction due to the high dislocation density of matrix metal.

TABLE-1 Variation of tensile strength of composites with different wt. % of nano Al_2O_3 particles.

S.NO.	Material Composition	Ultimate Tensile Strength (MPa)	Extent of Improvement in Tensile Strength In Percentage
1	Pure Aluminium	149.615	-
2	Al+3% of Al_2O_3	162.545	8.642%
3	Al+6% of Al_2O_3	168.086	12.345%
4	Al+9% of Al_2O_3	182.86	22.22%
5	Al+12% of Al_2O_3	193.945	29.629%

TABLE-2 Variation of compressive strength of composites with different wt. % of nano Al_2O_3 particles.

S.No.	Material Composition	Compressive Strength (MPa)	Extent of Improvement in Compressive Strength In Percentage
1	Pure Aluminium	229.041	-
2	Al+3% of Al_2O_3	240.123	4.83
3	Al+6% of Al_2O_3	251.206	9.67
4	Al+9% of Al_2O_3	254.900	11.29
5	Al+12% of Al_2O_3	262.288	14.51

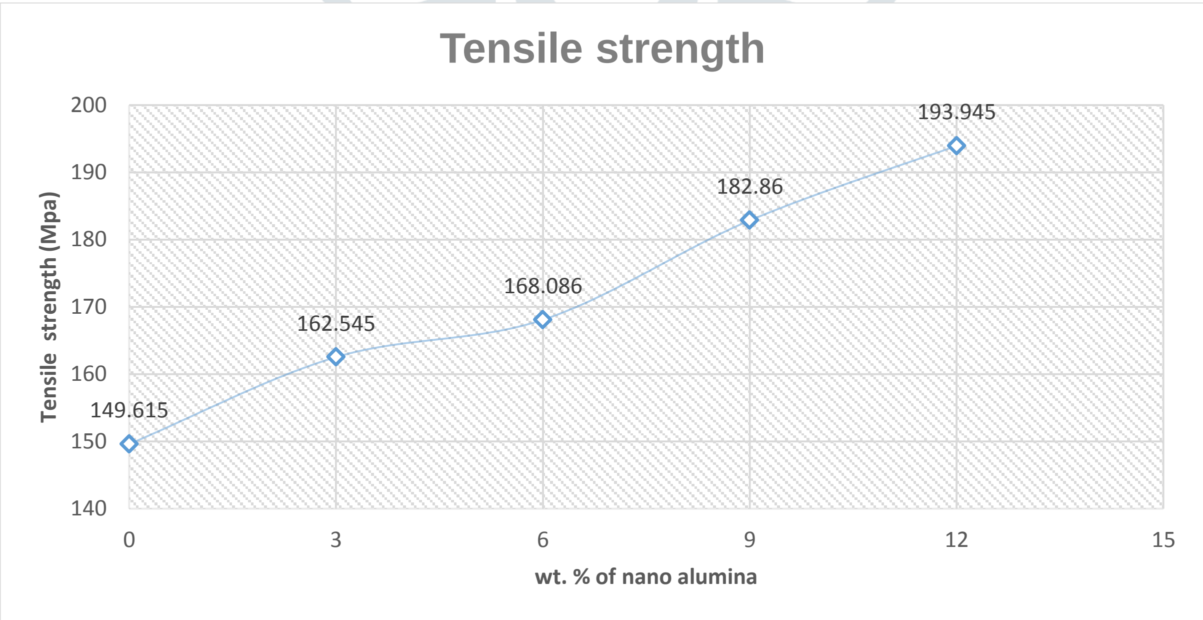

Fig. (6) Variation of tensile strength of composites with different wt. % of nano Al_2O_3 particles.

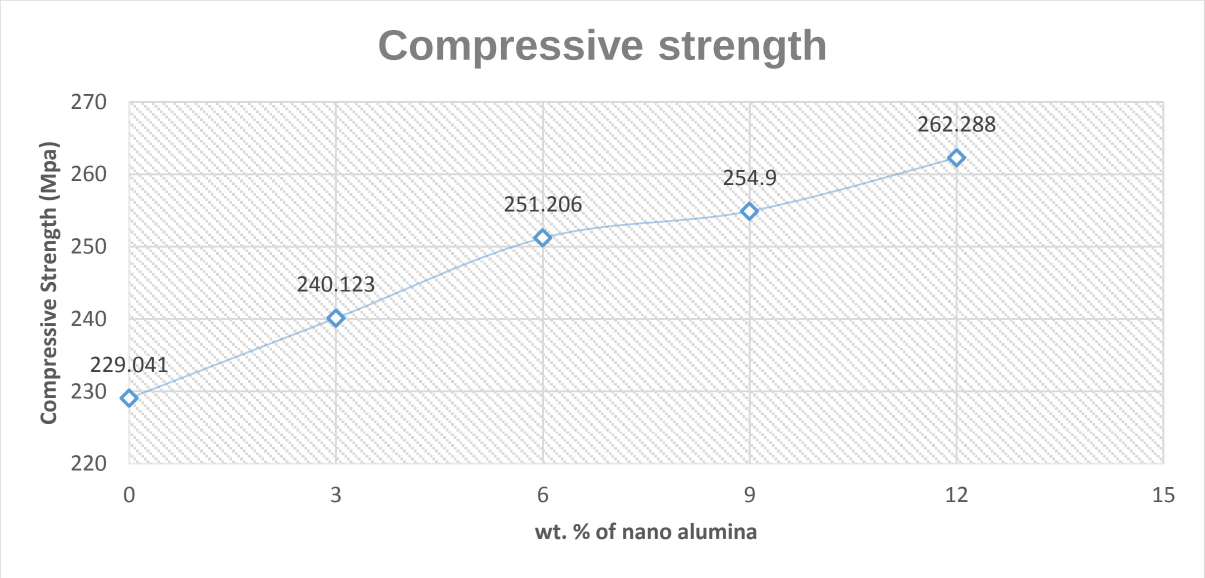

Fig. (7) Variation of compressive strength of composites with different wt. % of nano Al_2O_3 particles.

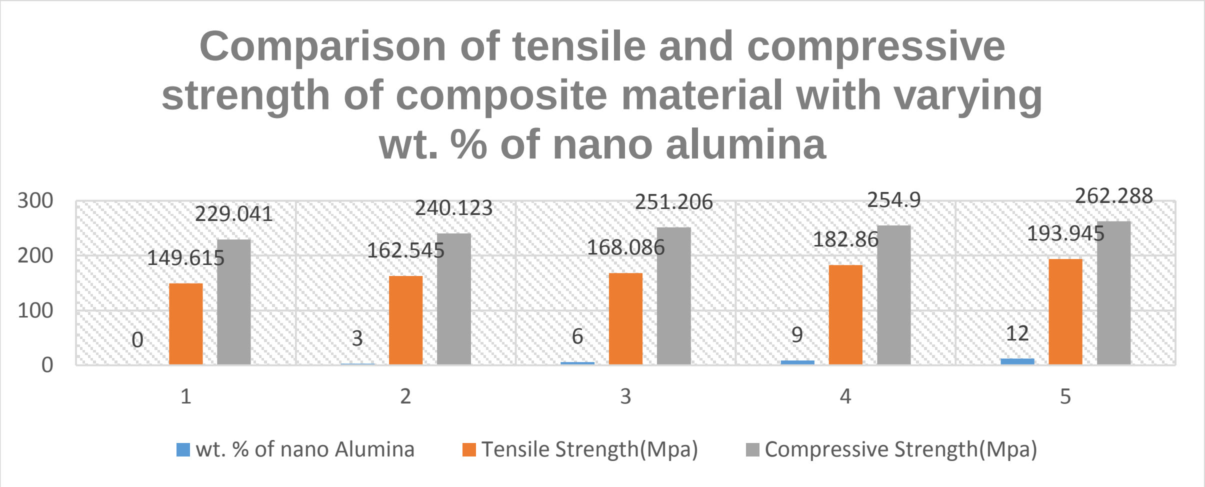

Fig. (8) Comparison of tensile and compressive strength of composite material with varying wt. % of nano Al_2O_3 particles

3.3 brinell hardness testing result

Fig (9) shows the comparison of hardness of pure aluminium metal matrix and composite material with composition of 3, 6, 9 and 12 wt. % of nano Al_2O_3-particles. The hardness of the composites is higher than that of the pure aluminium and hardness of the composites increases with increasing weight percent of the particles and its value is maximum for the 12 wt. % of Al_2O_3 nano particles. The higher hardness of the composite samples relative to that of the pure aluminium metal matrix could be attributed to the reducing grain size and existence of hard nano Al_2O_3-particles acting as obstacles to the motion of dislocation. At higher Al_2O_3 weight percent, scattering of hardness results increases because of non-uniform distribution of the reinforcement particles. It should be mentioned that agglomeration occurs as a result of higher viscosity of the molten metal and increasing tendency to clump the particles together due to high surface tension and poor wetting between the particles and the melt.

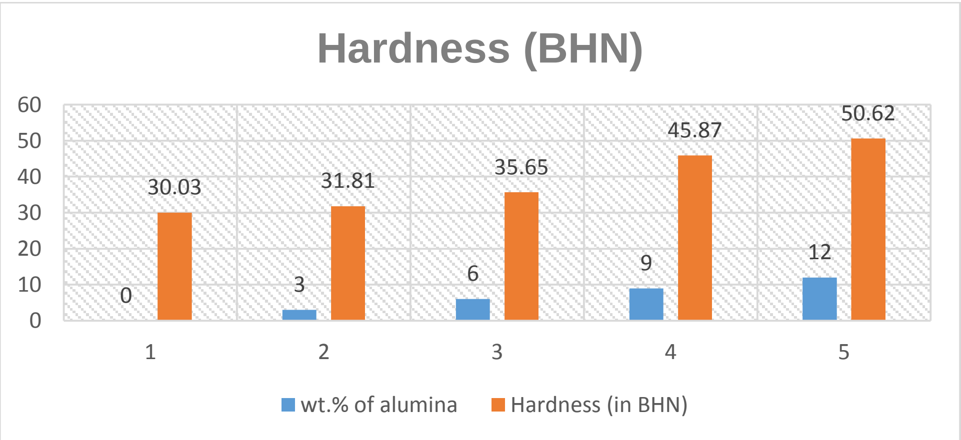

Fig (9) variation of Hardness of composites with different wt. % of alumina

4. CONCLUSION-

1:- Aluminium metal matrix and nano (3, 6, 9, and 12 wt. %) alumina particle composites have been successfully fabricated by stir casting process.

2:- From SEM images it is found that the nano particles are uniformly distributed in aluminium metal matrix with some agglomeration and clustering.

3:- Tensile strength of composites increases with increase in wt. % of Al_2O_3 particles. Al – 12% Al_2O_3 particle composites have the maximum tensile strength of 193.945 MPa.

4:- The compressive strength of composites increases with increase in wt. % of Al_2O_3 particles. Al- 12% Al_2O_3 particle composites have the maximum compressive strength of 262.288 MPa.

5:- Increase in tensile and compressive strength with increase in wt. % of Al_2O_3 particles are not uniform because of the some agglomeration and clustering of the nano-particles in composites.

6:- Hardness of composites increases with increase in wt. % of Al_2O_3 particles. And Composite with 12% nano Al_2O_3 particles have higher hardness of 50.62 BHN among all the composites.

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