Synthesis and Mechanical Behaviour of Aluminium Reinforced with Alumina-Graphite Based Hybrid Composites

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Abstract The development of metal matrix composites (MMCs) represent a new generation of engineering materials in which a strong ceramic reinforcement is incorporated into a metal matrix to improve its properties including specific strength, specific stiffness, wear resistance, corrosion resistance and elastic modulus. Thus, they have significant scientific, technological and commercial importance. During the last decade, because of their improved properties, MMCs are being used extensively for high performance applications such as in automobile, aerospace, military and sports industries. Aluminium oxide and silicon carbide powders in the form of fibers and particulates are commonly used as reinforcements in MMCs and the addition of these reinforcements to aluminium alloys has been the subject of a considerable amount of research work. The objective of developing aluminium reinforced with alumina-graphite based hybrid composites by stir casting is to study their potential for application in structural component and the mechanical properties of these hybrid composites is therefore essential for the present study. There is an effort to understand the microstructure study of hybrid composites including particle distribution and defects like porosity when analyzed by FE-SEM in order to correlate with the observed mechanical properties measured in terms of hardness and tensile properties.

Keywords — Alumina-Graphite, FE-SEM, Hardness, hybrid composites, MMCs, Stir casting, Tensile Property

I. INTRODUCTION

Particle-reinforced metal matrix composites have been fabricated traditionally, by several processing routes such as powder metallurgy [1], deformation processing and various solidification processing techniques including spray deposition [2]. The cheapest technique for the synthesis of composites is by stir-casting where reinforcing particles or powders are stirred into molten alloy and the resulting slurry is cast to obtain ingots of composite [3-5].

Typically, MMCs have been synthesized mainly through solid state processing and liquid state processing. The most cost-effective method for the production of MMCs is by the use of stir-casting route, here reinforcement is incorporated into alloy melt and the subsequent slurry is solidified in the mold to get the ingots of the composite. The reinforcement particles show deprived wetting with matrix, unless, chemical reaction happens between the particles and the matrix which promotes their wetting. It is difficult to stir into the melt nano size particles of poor wettability as the surface forces dominate the particle transfer into the melt. The finer the particles, more dominating will be the surface forces, which increases as square of radius while weight and buoyancy, the other two forces involved in particle transfer, increases as cube of radius.

The vortex method is the widely used technique to get and retain better distribution of the reinforcement in the matrix. In this technique, the matrix is first taken to molten state, the melt is stirred vigorously until vortex is formed. The particles are then incorporated from the side of the

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vortex. Advantage of the stirring are: (a) particle transfer through the melt and (b) keeping the particles in a state of suspension.

Ray S have reviewed about synthesis of MMCs, here, author have concentrated on the problems to be tackled while producing quality cast products. Also, author tried to correlate those problems with the process variables and characteristics of the process. Microstructure study has been made towards nucleation behaviour on the basis of estimated interface energies. It is observed that the porosity in the MMCs is the major parameter which is damaging the property. The author has observed the chemical reactions between the particles and the matrix during processing and suggested the ways of controlling these chemical reactions to achieve better uniformity.

A hybrid composite is a composite which have different types of reinforcement particulates/fibers. The incorporation of several different types of particulates/fibers led to the development of hybrid composite. The behaviour of hybrid composite is a weighed sum of the individual components in which there is a more favorable balance between the inherent advantages and disadvantages. Also, using a hybrid composite that contains two or more types of reinforcements, the advantages of one type of particulates/fibers could complement with what are lacking in the other. As a consequence, a balance in cost and performance can be achieved through proper material design.

When more than one reinforcement materials are present in base material is called a hybrid composite. Al/Al_2O_3/Gr-MMC are one of the important hybrids composite among MMCs, which have Al_2O_3 and Gr particles with Aluminum matrix. The SiC is harder than Tungsten carbide (WC) and Graphite particles provide high resistance to wear in the hybrid composite. Recently modern industry rapidly introducing different composites due to their unique properties such as low density and very light weight with high temperature strength, hardness and stiffness, high fatigue strength and wear resistance, in order to meet the challenge of liberalization and to maintain global competitiveness in the market. Side by side modern manufacturing engineers are also trying to introduce the better properties in the composite like, hybridizing our usually available conventional composites such as Al/SiC-MMC, Al/Gr-MMC and Al/Al2O3-MMC etc [6-14]. The hybrid metal matrix composite like Al/ (Al_2O_3+Gr)-MMC is one of the composites which have many unique properties over Al/Al_2O_3-MMC or Al/Gr-MMC.

Stir casting technique involves incorporation of ceramic/metallic particulate into liquid aluminium melt and allowing the mixture to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminium alloy melt [15-21]. The simplest and most commercially used technique is known as vortex technique or stir-casting technique. The vortex technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by the rotating impeller. In homogeneity in reinforcement distribution in these cast composites could also be a problem as a result of interaction between suspended ceramic particles and moving solid-liquid interface during solidification [22-31]. Generally, it is possible to incorporate up to 30% ceramic particles in the size range 5 to 100 micrometer in a variety of molten aluminium alloys.

The present study involves developing a Aluminium based hybrid composites by reinforced with Alumina-Graphite using stir casting is to study their potential for application in structural component and the mechanical properties of these hybrid composites is therefore essential for the present study. There is an effort to understand the microstructure of the composites including particle distribution and mechanical properties.

II. EXPERIMENTS

In this research, Al 1100 was chosen as the matrix of the composite because of its (a) density, which make it useful for lightweight components, (b) low melting point, which make it easier for casting purpose, (c) easy availability, which makes instant availability for experimentation and (d) low cost, it was alloyed with magnesium since it promotes wetting between the molten alloy and the reinforcement of alumina (Al_2O_3) and graphite (Gr) was used in order to retain these particles inside the melt.

The melting unit consists of an electrical resistance heating vertical furnace designed for a temperature of 1200°C. One end of the muffle was kept open and the other end was closed with a hole at its centre. A suitable steel structure was fabricated to assemble the furnace, leaving sufficient clearance from the floor for placing a mould conveniently right below the furnace. Melting of the Al 1100 was carried out in a clay graphite crucible that has been repeatedly cleaned to avoid contamination. The graphite crucible (No-6) has a cylindrical tapered shape with an average inner diameter of 80 mm and a hole of 12 mm in diameter at the centre of its bottom. The graphite crucible is placed inside the furnace and the bottom hole of the crucible is plugged tightly by inserting a graphite stopper in it through the bottom of the furnace. The stopper is held in place with the help of a lever arrangement as shown in Fig.1.

The use of axial stirrer for agitating the molten metal or alloy would result in both axial and radial flows and their relative magnitudes could be controlled by the design of stirrer to suit a desired condition of mixing. In present investigation Flat blade stirrer were used in an effort to

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retain maximum amount of oxide particles and to result in uniform distribution of particles in the melt-particle slurry to be cast. Permanent split type of mould made of MS is used for casting the composites in the present study. Three cavities of 12 mm diameter and one bigger cavities of 36 mm diameter and length of 80 mm cavities are provided in the mould also a groove is made at the bottom of die for bottom rising of the molten metal as shown in Fig.2.

Al 1100 was used as the matrix material and it was alloyed with 2 wt% magnesium to impart wetting to the Al_2O_3 and Gr particles added as reinforcements, Al_2O_3 added in amounts of 3, 6, 9 and 12 wt% whereas 2 wt% graphite is maintained constant. About 700 g of commercially pure Al 1100 was melted and superheated to a desired processing temperature in a clay-graphite crucible inside the muffle furnace. Before any addition, the surface of the melt was cleaned by skimming. The weighed amount of powders was added into molten Al 1100 at a processing temperature of 900°C and the rate of addition of particles was controlled at an approximate rate 6-8 g/min. A coated mechanical stirrer was used to disperse the Al2O3 and Gr particles in the melt. The speed of the stirrer was kept constant at 300 rpm. A magnesium lump of 2 wt% was wrapped by aluminium foil and plunged into the melt-particle slurry after the addition of Al_2O_3 and Gr particles. When the desired time of the stirring elapsed, reduce the stirrer speed. After completion of processing steps, the graphite stopper at the bottom of the crucible is removed by using the lever to pour the melt-particle slurry into split type graphite coated and preheated permanent steel mould.

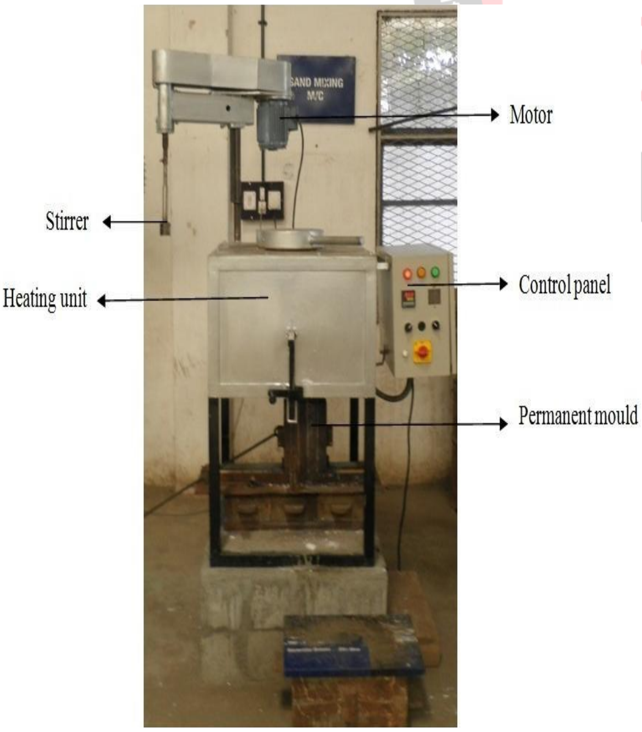

Fig.1: Photograph showing experimental set-up for stir casting used for solidification Processing of different cast composites and cast unreinforced base alloy

Fig.2: Photograph showing mould assembly

There after they were cooled in air before sampling for various testing samples. Microscopic examinations of the forged composites for metallographic examination under scanning electron microscope (SEM) and Transmission Electron Microscope (TEM). The tensile tests were carried out at ambient temperature for forged in-situ nano-composites and unreinforced alloy. No degassing practice of the melt or the slurry was carried out at any stage of processing. The composite has been designated on the basis of its constituents and the first letter A indicates the base metal of Al 1100 and the next letter M indicates the alloying element of magnesium, which was kept constant at 2 wt%. AM is followed by a letter G indicates the graphite powder was kept constant at 2 wt% is added and Q indicates the alumina powder followed by the number indicating the wt% of alumina powder added. Microscopic examinations of the hybrid composites for metallographic examination under scanning electron microscope (SEM) and mechanical tests were carried out at ambient temperature for composites and unreinforced alloy.

III. RESULTS AND DISCUSSION

The size and particle shape of the Al_2O_3 particles in the powder has been observed under SEM and the results are shown in Figure 3 the size is in the range of 23 μm and the shape of the smaller particles are spherical while the larger particles have some hat irregular in shape.

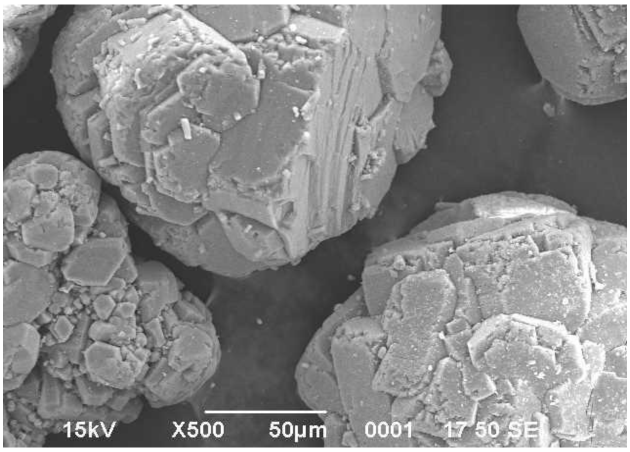

Fig 3: SEM micrographs showing size and particle shape of the alumina powder

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The powder has been examined for their X-ray diffraction (XRD) pattern using X-ray diffractometer in the two theta range of 5-80° using CuKα radiation target and nickel filter, step size and dwell time were suitably adjusted, which was used for identification of various phases with the help of inorganic JCPDS (Joint Committee on Powder Diffraction Standards) X-ray diffraction data card (PDF NO-) which conform that it belongs to Al_2O_3 is as shown in Fig 4.

The size and particle shape of the graphite particles in the powder has been observed under SEM and the results are shown in Fig. 5 the size is in the range between 1 μm and 20 μm and it is observed that smaller and longer particles are irregular in shape.

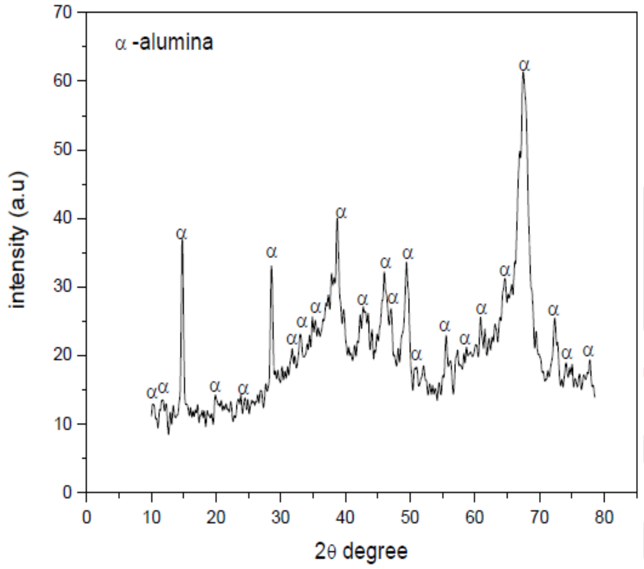

Fig.4: XRD pattern of alumina particles

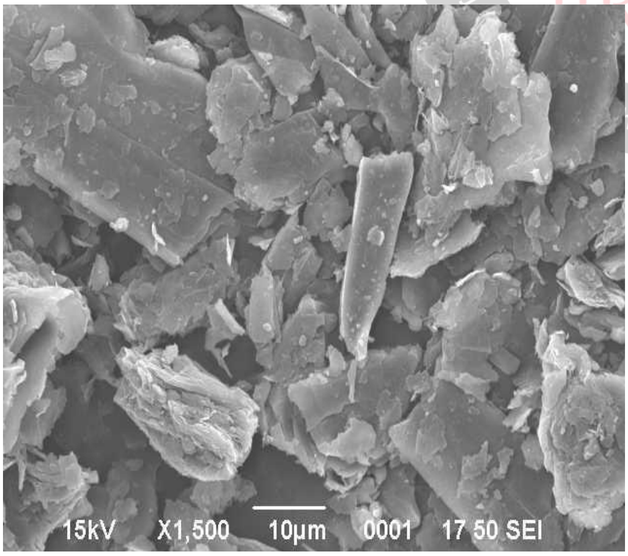

Fig.5: SEM micrographs showing size and particle shape of the graphite powder

The powder has been examined for their X-ray diffraction (XRD) pattern using X-ray diffractometer in the two theta range of 10-70° using CuKα radiation target and nickel filter, step size and dwell time were suitably adjusted, which was used for identification of various phases with the help of inorganic JCPDS (joint committee on powder diffraction standards) X-ray diffraction data card (PDF No-41147) which shows the Graphite particles are fairly pure is as shown in Fig 6.

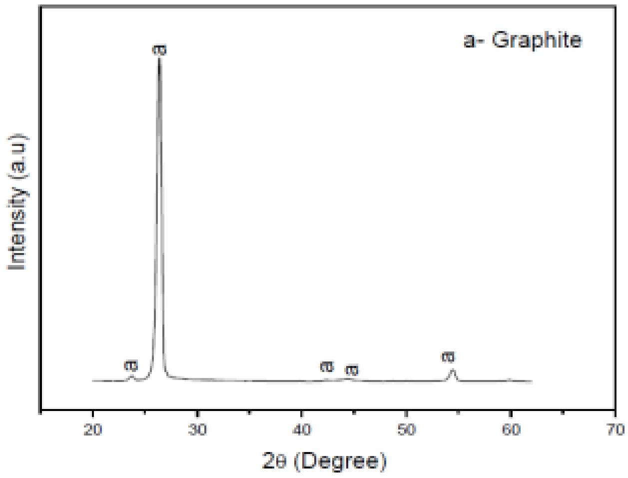

Fig.6: XRD pattern of graphite particles

Different hybrid composites have been synthesized by adding powder as given in Table.1 and these hybrid composites have been designated by using the letters AM to indicate Al 1100-Mg alloy followed by a letter G and Q indicates particle contents of graphite and alumina. The digit of 3, 6, 9 and 12 wt% represents the percentage of alumina added respectively. The hybrid composite designated as AMG2Q3 indicates that it has been synthesized by addition of alumina by 3 wt%. During processing powder mix has been dispersed by stirring into the molten alloy, which has been maintained at 900°C and the resulting slurry has been cast in permanent steel mould to get hybrid cast composite ingot. Al 1100-Mg alloy has been prepared by addition of 2 wt% of magnesium into Al 1100 melt and these alloys are designated as AM.

Table 1: Nominal Composition of the cast composites

Designation of alloy/hybrid composites	Magnesium (wt.%)	Alumina (Al_2O_3) (wt.%)	Graphite (Gr) (wt.%)
AM	2	0	0
AMG2Q3	2	3	2
AMG2Q6	2	6	2
AMG2Q9	2	9	2
AMG2Q12	2	12	2

The chemical compositions of commercial Al 1100 and commercial magnesium used for making composites are shown in Table 2. Iron, silicon and manganese are the major elements other than the Al in ingots of Al 1100, iron and silicon are the major impurities observed in the ingots of magnesium.

The SEM micrographs reveals the presence of some oxides, inter metallic compound Al_3Mg_2 (bright needles) distributed in the matrix and also some dark spots due to porosities. All these microstructures Fig.7 (a) AMG2Q3 (b) AMG2Q6 (c)

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AMG2Q9 and (d) AMG2Q12 respectively contain similar phases but their volume fraction varies depending upon the amount of Al_2O_3 additions and also composite shows presence of individual particles and no significant clustering is observed. It is observed that the porosity (dark spots) in the hybrid composite increases with increasing addition of Al_2O_3 particles. This is often attributed to attachment of particle with bubble during processing. This attachment takes place during particle transfer by stirring as mentioned earlier. It may also happen during solidification as the dissolved gases start nucleating on the heterogeneous surfaces of particles. Often these bubbles are not able to float out rapidly due to increased density because of attached particles and get entrapped during solidification, enhancing the porosity in hybrid cast composite.

Table 2: Chemical composition of the Al 1100 and commercial magnesium ingots

		Material	
		Al 1100-Ingot	Mg-Ingot
Chemical Composition	Fe	0.132	0.020
	Mn	0.052	0.002
	Cr	-	0.001
	Cu	0.041	0.016
	Zn	0.022	0.002
	Si	0.074	0.006
	Ti	-	0.001
	Mg	0.005	Bal.
	Al	Bal.	0.023

Brinell hardness has been measured for unreinforced alloy and cast composites developed by addition of Al_2O_3 and constant 2 wt.% Gr, with 10 mm hardened steel ball indenter using 500 kg load. Eight indentations have been taken for each sample; the distance of 0.8 cm have maintained from one indentation centre to another indentation centre. The average hardness of the hybrid cast composites increases with increasing addition of Al_2O_3 particles to base alloys as observed in Fig 8. The hybrid composites developed by addition of 12 wt.% of powder have higher hardness than the hybrid composite developed by addition of 3, 6 and 9 wt.% of Al_2O_3 powder. However, the alloy without any Al_2O_3 powder added has the lowest hardness. As the reinforcement contents increased in the matrix material, the hardness of the composites also increased as observed in Fig 9.

The yield strength increases with increasing addition of Al_2O_3 powder for 3 wt% and then decreases with increasing addition of powder as shown in Fig 10. The same trend is observed in the tensile strength also, beyond 3 wt% addition of Al_2O_3 powder tensile strength decreases as shown in Fig 11. The ductility of alloy shows maximum 11.78% of elongation, as the addition of powder increases to 3 wt% and then ductility decreases to 8.25% as shown in Fig. 12. The percentage elongation of the hybrid cast composites decreases with increasing addition of Al_2O_3 particle is observed.

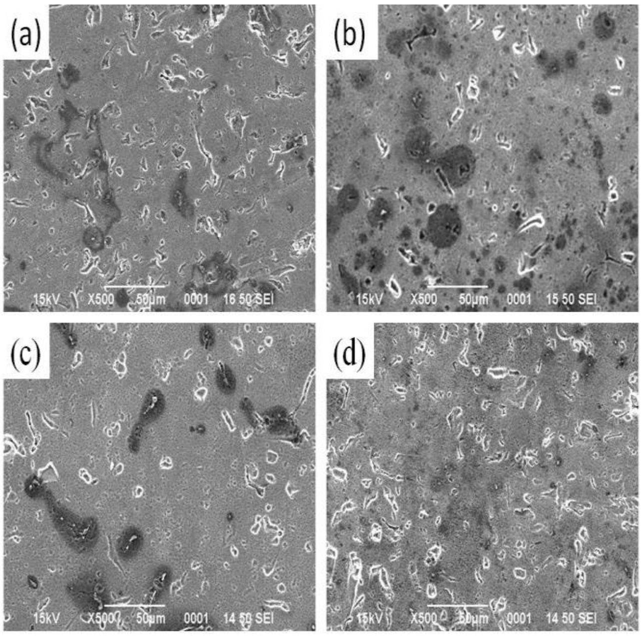

Fig.7: SEM micrographs (500X) of different hybrid cast composites developed by increasing Amounts of Al_2O_3 powder designated as (a) AMG2Q3 (b) AMG2Q6 (c) AMG2Q9 and (d) AMG2Q12 respectively

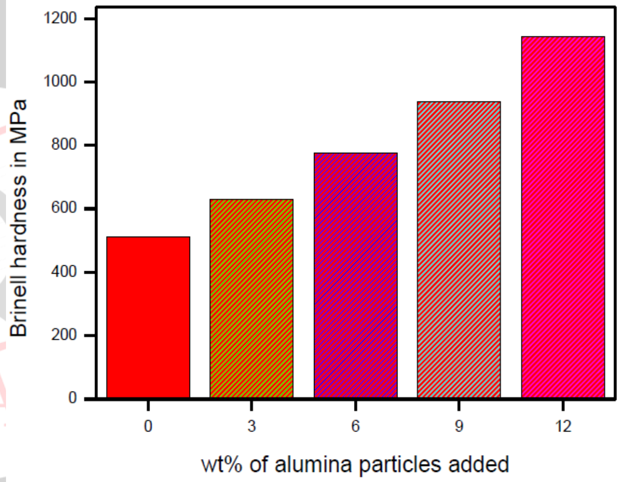

Fig. 8: Variation of average hardness of unreinforced base alloy and hybrid cast composites developed by addition of Alumina (bar graph)

Generally, in a hybrid composite, loss of strength and ductility is caused by debonding of the particles due to shear stress generated by difference in flow behaviour across the interface between the matrix and the particle. The magnitude of the shear stress depends on the size of the particle. The larger is the particle, the larger is the shear stress and the debonding takes place at lower strain. If debonding takes place in the elastic region of strain, there will be no improvement in the tensile strength of the hybrid composite but a lowering will be observed due to loss in the area of cross section. In the cast alloy it is presumed that the failure has been caused by debonding of the oxide inclusions generated due to oxidation during processing at high temperature.

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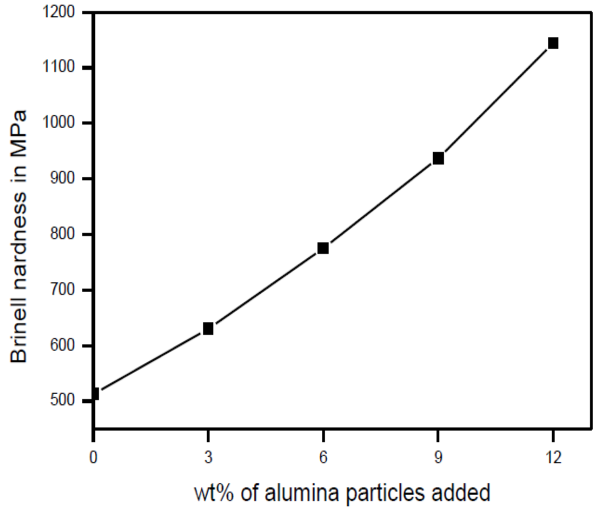

Fig. 9: Variation of average hardness of unreinforced base alloy and hybrid cast composites developed by addition of Alumina

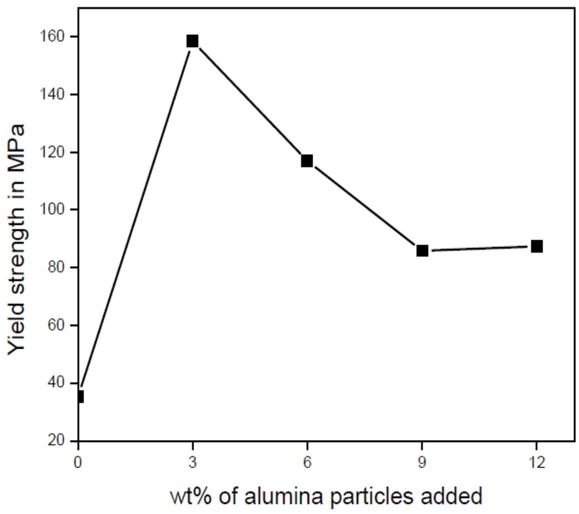

Fig.10: Variation of yield strength in alloy and hybrid composites

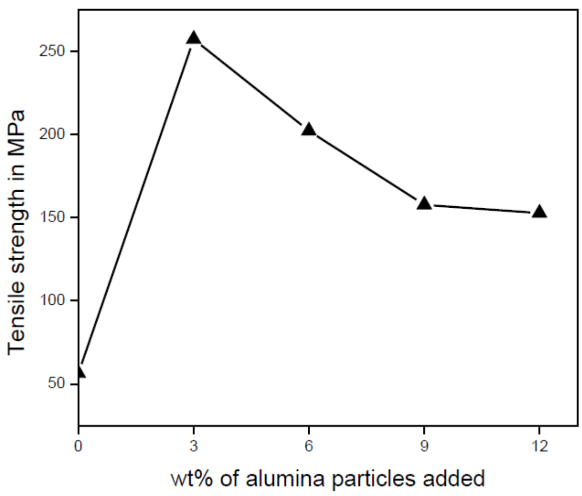

Fig 11: Variation of tensile strength in alloy and hybrid composites

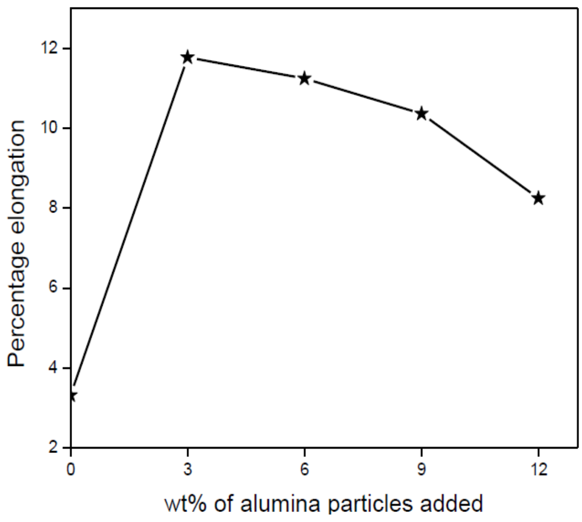

Fig 12: Percentage elongation variation in alloy and hybrid composites

IV. Conclusions

1. The stir casting technique was successfully adapted in the preparation of Al 1100 matrix material (with 2 wt.% magnesium to impart wetting) to the Al_2O_3 added in amounts of 3, 6, 9 and 12 wt.% whereas graphite is maintained constant at 2 wt.%.
2. XRD and SEM analysis shows the Al_2O_3 particles are fairly pure and have irregular angular shapes.
3. The microstructure of the composites under FESEM shows that the particles are mostly occurring individually and Porosity (dark spot) in hybrid composites increases with increasing addition of Al_2O_3 powder.
4. The hardness of the hybrid composites is found that increase with increase in reinforcement content.
5. The yield and tensile strength of the hybrid composites are found maximum at 3 wt.% of alumina added composite, but beyond this powder addition both yield and tensile strength decreases with increasing powder addition. Percentage of elongation is found to decrease with increase in addition of reinforcement.

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