Mechanical Property Evaluation on Aluminium Based Metal Matrix Composite Reinforced with Grahite and Nickel Coated Graphite

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Abstract— **The selectively reinforced composites provide significant improvement in wear resistance. As important, the low co-efficient of thermal expansion (CTE), has allowed redesign of structural members, using tighter tolerances resulting on higher pressure and improved heat transfer properties. The lower reciprocating mass also adds to improved performance. To yield better performance than it's as cast part the percentage of reinforcement added in the composite fabrication plays a vital role. But due to chemical bonding phenomenon this percentage is limited to only a few numerals. But if this numeral is increased the better can be the result of the so fabricated composite. Although the hybrid aluminium MMC takes this part in some of the areas it is still advice able that these types of specialized reinforcement addition can yield much better results than its hybrid counterpart. The solution is to develop a new material which has characteristics of both matrix and reinforcement. Thus coated particle reinforcement is the material which will be a substitute for all. The density of the reinforcement added is also a peculiar point of interest that has to be looked for. These selective reinforcement and simplified process results in density reduction and cost reduction right at the component level.**

Keywords—Aluminium matrix composite,reinforcement, stir casting , squeeze casting mechanicalproperty.

I. Introduction

Composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with aggregate properties different from that of the monolithic alloys. The individual components remain separate and distinct within the finished structure. In composites, materials are combined in such a way as to enable us to make better use of their virtues while minimizing to some extent the effects of their deficiencies. This process of optimization can release a designer from the constraints associated with the selection and manufacture of conventional materials. We can make use of tougher and lighter materials, with properties that can be tailored to suit particular design requirements. And because of the ease with which complex shapes can be manufactured, the complete rethinking of an established design in terms of composites can often lead to both cheaper and better solutions. The 'composites' concept is not a human invention. Wood is a natural composite material consisting of one species of polymer: cellulose fibers with good strength and stiffness: in a resinous matrix of another polymer, the polysaccharide lignin. Nature makes a much better job of design and manufacture than we do, although Man was able to recognize that the way of overcoming two major disadvantages of natural wood: that of size (a tree has a limited transverse dimension), and that of anisotropy (properties are markedly different in the axial and radial directions): was to make the composite material that we call plywood. Bone, teeth and mollusk shells are other natural composites, combining hard ceramic reinforcing phases in natural organic polymer matrices. But it is only in the last half century that the science and technology of composite materials have developed to provide the engineer with a novel class of materials and the necessary tools to enable him to use them advantageously.

II. Material Selection

A. Aluminium alloy6061

Aluminium alloy 6061 is a medium to high strength heat-treatable alloy with strength higher than 6065 AA. It has very good corrosion resistance and very good weldability. Although reduced strength in the weld zone, it has good coldformability in the temper T4, but limited formability in T6

Alloy 6061 is easily welded and joined by various commercial methods but direct contact by dissimilar metals can cause galvanic corrosion. Since 6061 is a heat-treatable alloy, strength in its - T6 condition can be reduced in the weld region. Selection of an appropriate filler alloy will depend on the desired weld characteristicsGrowing importance and its applications in almost all the fields is widening scope for researchers to get in depth in to the field of MMCs. One can't deny the fact that Aluminium is the best and is a ready substitute in place of matrix in an MMC.

B. Graphite

Among various particulate reinforcements, graphite (Gr) is expected to be one of the best reinforcement for composites due to its low density (1.3-1.95 g/cm3), best dry lubricating property, good chemical stability (resistant to chemicals), good thermal and electrical conductivity, good hardness, high melting point, good corrosion resistance and outstanding tribological properties.

Graphite is one of three natural forms of carbon (the other two are diamond and coal). It is found naturally in metamorphic rocks in the form of lump, crystalline flake, and amorphous.

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C. Nickel Coated Graphite

Nickel Coated Graphite is a graphite powder that has been completely encapsulated with a layer of nickel by thermal decomposition process, carbonyl vapour deposition method. Here, nickel coated graphite powder is made by carbonyl vapour deposition

Nickel-Coated Graphite is an extremely important material for the manufacture of electronic shielding (EMC) devices. It is also used for friction applications. It is used as lightweight filler for conductive gaskets (extruded, molded, sheet and Form-In-Place) and sealants. Other applications include plasma spray, friction products, graphitic aluminum, high temperature solid lubrication material (< 500°C), - wettability of reinforcement by liquid matrix.”

III. OBJECTIVE OF THE PAPER

The modern industry is in need of newer materials that will be more economical and that suits almost all field of application. Fabricating or developing a novel material is essential in this industrial era, as the present world is in search of Quality products with less cost. With all sectors gaining improvements in their own path, material science technology is also rushed to find out the Best material. As we are in such a critical need we have to find out a material that saves money and weight but achieving more performance. For example now a day’s airplane or aerospace industry could have not been possible without implementation of composite concept. Undoubtedly various other sectors such as automotive, marine, consumer products also enjoy the benefits. Confining our discussion to few specific areas of application such as automobile parts, wear subjected areas, corrosion resistant areas, temperature prone zone of application, conduction zones we have seen a lot of literatures and work being carried out in the area of metal matrix particularly in case of matrix employing Aluminium as the primary alloy. Aluminium Metal Matrix employing ceramic particles such as SiC, TiB2, Al2O3 too have enough studies and literatures. Not only Literatures but many have come in to real world applications too. Also of owing importance in modern industrialization manufactures are compelled to produce more competitive products. Materials designed need to be capable of accepting the fluctuating loading conditions, must suit the environment of operation, must resist wear, corrosion, chemical reactions, etc., Also they must be more economical! Many researchers have concluded that more percentage addition of reinforcement have yielded much brittle composites than the low percentage added one. Also the property enhancement seems to be improved to only a few fractions or percentage. Thus, efforts are being done to find better property enhancement of fabricated composites with less percentage of reinforcement addition

IV. EXPERIMENTALSETUP AND PROCEDURE

The selectively reinforced composites provide significant improvement in wear resistance. As important, the low co-efficient of thermal expansion (CTE), has allowed redesign of structural members, using tighter tolerances resulting on higher pressure and improved heat transfer properties. The lower reciprocating mass also adds to improved performance.

To yield better performance than it’s as cast part the percentage of reinforcement added in the composite fabrication plays a vital role. But due to chemical bonding phenomenon this percentage is limited to only a few numerals. But if this numeral is increased the better can be the result of the so fabricated composite.Although the hybrid aluminium MMC takes this part in some of the areas it is still advice able that these types of specialized reinforcement addition can yield much better results than its hybrid counterpart.The solution is to develop a new material which has characteristics of both matrix and reinforcement. Thus coated particle reinforcement is the material which will be a substitute for all. The density of the reinforcement added is also a peculiar point of interest that has to be looked for. These selective reinforcement and simplified process results in composite fabrication. The first step in experimental work is to fabricate the composite by appropriate method so that the testing can be done as per standards. The following sections give a clear idea about the mode of fabrication and the route through which the cast samples has undergone.

A. Casting

Casting is a manufacturing process by which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process.Casting materials are usually metals or various cold setting materials that cure after mixing two or more components together; examples are epoxy, concrete, plaster and clay. Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods.

B. Reinforcement used

The following table gives the description, specification and images of reinforcements

Powder Name	Size (mesh)	Density (gcm-3)	Purity (%)
Graphite	400	2.1	96
Nickel	400	8.9	99.9
Nickel coated Graphite	-300	1.26	99

C. Preheating

Reinforcement powders were preheated to a temperature of above 450°C. Preheating removes the moisture from the powder added and allows it to take part in the reaction completely.

Fig. 4.1 Preheating of Particulate Reinforcements

D. Stir casting route

Stir casting set-up mainly consists a furnace and a stirring assembly. In general, the solidification synthesis of metal matrix composites involves producing a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. The next step is the solidification of the melt containing suspended dispersoids under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix. In preparing metal matrix composites by the stir casting method, there are several factors that need considerable attention, including

1. The difficulty in achieving a uniform distribution of the reinforcement material.

2. Wettability between the two main substances.

3. Porosity in the cast metal matrix composites.

4. Chemical reactions between the reinforcement material and the matrix alloy.

In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimized. The porosity levels need to be minimized, and chemical reactions between the reinforcement materials and the matrix alloy must be avoided.

E. Squeeze casting method

The above disadvantage can be overcome by this method. It is a primary process of composite production, where by the reinforcement ingredient material is incorporated into the molten metal by stirring.

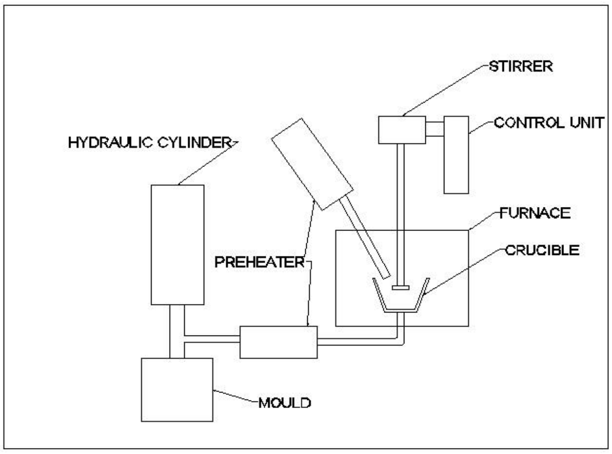


Fig. 4.2 Schematic view of setup for Fabrication of AMC through squeeze casting technique

One of the major challenges when processing MMCs is achieving a homogeneous distribution of reinforcement in the matrix as it has a strong impact on the properties and the quality of the material. To obtain a specific mechanical/physical property, ideally, the MMC should consist of fine particles distributed uniformly in a ductile matrix and with clean interfaces between particle and matrix. MMCs are generally processed with liquid metal routes such as stir casting. Stir casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Stir Casting is the simplest and the most cost effective method of liquid state fabrication.

After stirring, the melt is allowed for gravity flow in to the mould and the squeezer is set on for to squeeze the mould to get more uniform distribution of reinforcement. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies.

Fig. 4.3 Squeeze casting machine used

F. Experimentation

Initially, the furnace was turned on to heat to a temperature above 850°C and a holding time up to 1hr. Aluminum alloy blocks were dropped in to the furnace allowing it to

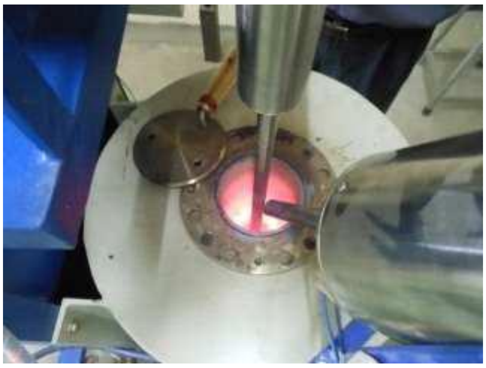


Fig. 4.4 Melting of Aluminium

melt in the furnace. Meanwhile the powders which are to be added as reinforcement were preheated at 450°C.

The reinforcement is slowly added in to the aluminum matrix melt through a dispenser while maintaining a constant stirring of 400 rpm for 6-7secs with a motorized stirrer. The temperature rate of the furnace should be controlled at 760 ± 10°C in final mixing process. After completing the process the slurry has to be ensured for proper distribution of the reinforcement in to the matrix and is taken into the mould and die setup within twenty seconds by opening the drain plug so that the melt flows through the pathway which is preheated to a temperature of 650°C. The mould's inner surface is coated with a non-sticky coating material for easy separation of cast piece form the mould.

Fig. 4.5 Removal of cast samples from die

The ram of the squeezer is now pushed forward so that the entire melt is subjected to a pressure of 50 tones with a setting time of 8-10 secs and allowed to solidify. This squeezing enhances the distribution of reinforcement uniformly in to the matrix there by minimizing the formation of pores in the cast samples.

G. Die Casting

The samples were fabricated as two sets: the first being the samples having reinforcement of NCG with 0, 5 and 10 wt% addition into the matrix melt and the second being the mixed addition of Ni powder and Graphite powder in the proportion of 0, 5 and 10 wt% in to the melt matrix.

H. Cast samples

The cast samples are identified by marking in it the composition of mixtures added for

Fig. 4.6 Cast Samples

Preparing.

I. Specimen preperation

Based on the test requirement samples so casted are machined under standard conditions using prescribed and calibrated machines. Machining is done using the centre lathe to prepare the round specimens as per the ASTM standards.

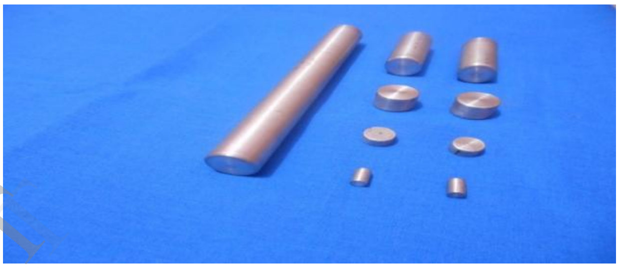


Fig. 4.7 Specimens for various tests

V. MICROSTRUCTURAL CHARACTERISATIONAND RESULT

Samples were examined on a Scanning Electron Microscope (SEM) with EDS JSM - 5610LV setup. The micro structural characterization was done to investigate the shape and size of the powder particles.

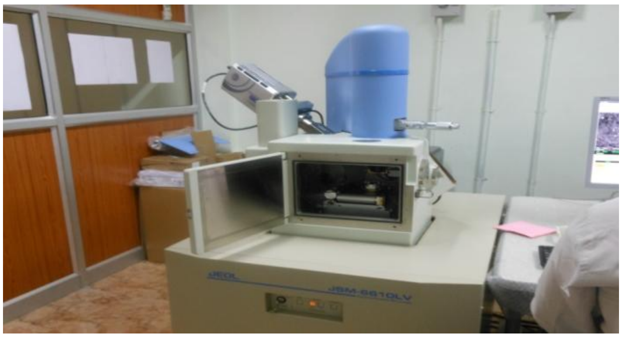


Fig.5.1 Scanning Electron Microscope (SEM) used

A. SEM Image on graphite powder

As received Graphite and Nickel powders were characterized by SEM after spreading down the powders on a sticky surface tape. The spreading of powders should be done carefully so that no cluster forms.

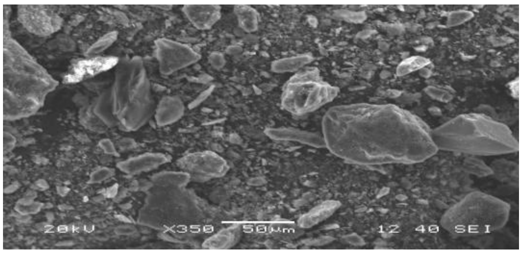


Fig. 5.2 SEM image of Graphite powder

This is achieved by blowing the powder with mild pressure as it is being deposited. Fig. 5.2 show the microstructures of as received powders of pure Graphite and Nickel. Micrographs indicate the dendritic structure of Nickel and the irregularly shaped graphite particles.

We can also have a clear idea about the uniformity of distribution of nickel powder around each particulate of graphite from the Fig.5.3

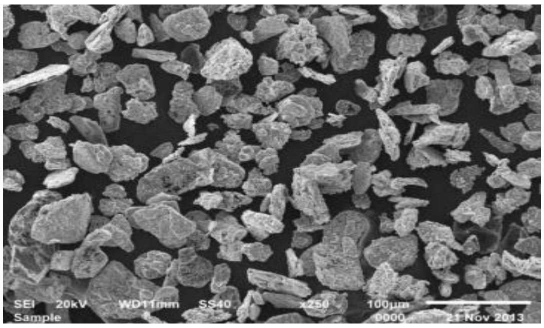


Fig. 5.3SEM image of Nickel Coated Graphite (NCG) powder sample

This uniformity of coating on graphite is very essential parameter that decides the good wetting of the reinforcement in to the matrix. With this there will be a reduction in contact angle θ which is a primary factor that influences the property enhancement in our work.

B. *Tensile testing*

To investigate the mechanical behavior of the composites the tensile tests were carried out using computerized uni-axial tensile testing machine as per ASTM standards. The results of tension tests of specimens machined to standardized dimensions from selected portions of a part or material may not totally represent the strength and ductility properties of the entire end product or its in-service behavior in different environments. The test methods have been used extensively in the trade for this purpose.

C. *Test Sample preparation*

The cast pieces are machined to the required dimensions as per ASTM E8 standard. Test samples are prepared as per the given dimensions in the Fig.10.2.1.1 and Fig.10.2.1.2.

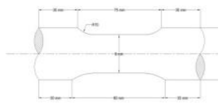


Fig. 5.4 Test Piece Showing Dimensions (mm)

Fig. 5.5 Prepared samples for Tensile Test

Tensile samples were prepared with a diameter of 16 mm and length of 140 mm. The length of the reduced section is 80 mm and the diameter at the gauge section is 12 mm.

D. *Conducting Test*

Tests were conducted on a uniaxial Tensile Testing computerized unit, FIE Universal testing machine series UNITEK 94100.

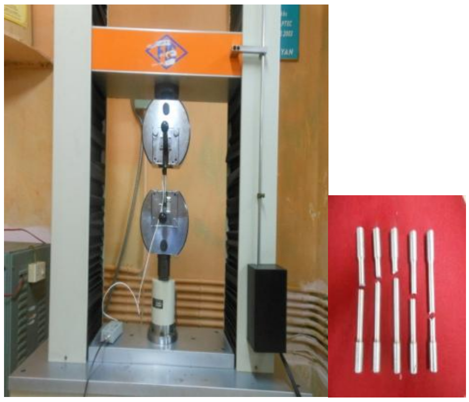


Fig. 5.6 Tensile Testing Machine

These are microprocessor based electromechanical machines with servo drive designed for testing and studying mechanical behavior of various materials like metals, polymers, composites etc.

E. *Discussionon Tensile test*

The tensile properties, such as, tensile strength, yield strength and % elongation were extracted from the stress-strain curves and are represented in Table. 5.1 and Fig. 5.7 and Fig. 5.8 respectively.

Table. 5.1 Showing the Tensile Test Results of Fabricated Composites

Sample	**Peak Load (kN)**	**Ultimate Tensile Strength, UTS (MPa)**	**Percentage Elongation**
Al 6061 as-cast	10.245	91	16.257
Al/ 5% Ni-Gr	10.01	88	7.857
Al/ 10% Ni-Gr	9.55	84	7.443
Al/5% NCG	20.095	178	12.6
Al/ 10% NCG	21.23	183	11.4

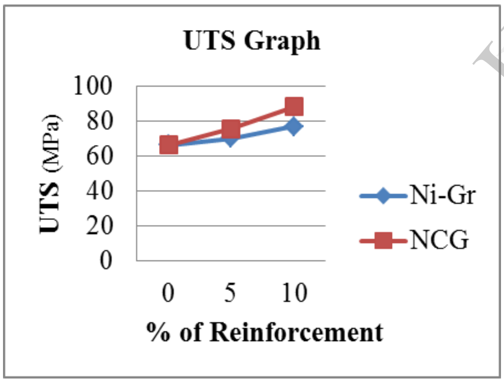
It is clear that tensile strength of composites containing 10 wt% of reinforcement particulates is higher when compared to as cast Al6061, while ductility of composite is lesser that unreinforced alloy.

Microplasticity takes place in MMCs, at a fairly low stress, which corresponds to a slight deviation from linearity in the stress-strain curve. This point is termed the proportional limit stress. Microplasticity in the composites has been attributed to stress concentrations in the matrix at the poles of the reinforcement and/or at sharp corners of the reinforcing particles. The initial microyielding stress decreases with increasing volume fraction, as the number of stress concentrating points increases.

Increase in strength is possibly due to the thermal mismatch between the metallic matrix and the reinforcement, which is a major mechanism for increasing the dislocation density of the matrix and therefore, increasing the composite strength.

However, the 10 wt% reinforcement addition of reinforced composite materials exhibited lower elongation than that of unreinforced specimens. It is obvious that plastic deformation of the mixed soft metal matrix and the non-deformable reinforcement is more difficult than the base metal itself.

As a result, the ductility of the composite drops down when compared to that of unreinforced material. Further, the percentage of addition of NCG had better results when compared with Ni-Gr addition which shows that NCG remains as a good substitute of reinforcement when compared to hybrid reinforcement.



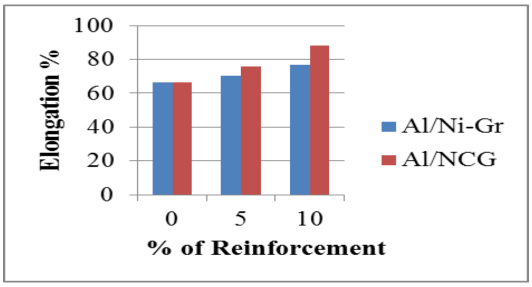


Fig. 5.7 Graph showing variation in UTS bef. and aft. addition of reinforcement

Fig. 5.8 Graph showing variation in %Elong bef. and aft. addition of reinforcement

It is clearly evident from the above graphs that not only the UTS but also the % elongation is more compared to the hybrid reinforcement and unreinforced alloy. This percentage increase in elongation is due to addition of coated graphite particulates.

F. Micro hardness Test

The term 'micro hardness test' usually refers to static indentations made with loads not exceeding 1kgf.

Fig. 5.9 Pictorial view of Vickers's Microhardness Tester used

The testing is done on a microscopic scale with higher precision instruments. Microhardness testing of the samples was done using a Zwick 3212 Direct Mass Loading type Hardness tester as shown in Fig. 5.9

G. Sample prepartion

The Micro-Vickers hardness values of the samples were measured on the polished samples using diamond cone indenter. The surface being tested generally requires a metallographic finish and it was done with the help of 100, 220, 500, 800, 1000 & 1500 grit size emery paper.

Fig. 5.10 Preparation of samples for Hardness Testing

Load applied on micro hardness machine was 0.3 kg and the time of indentation is 10 secs for all samples.

H. Discussion on Hardness

The results of the readings observed are tabulated in Table.5.1. It is evident from the table values that the impact of NCG reinforcement is better than Ni-Gr reinforcement as expected. The values of the Ni-Gr for both wt% additions happen to be greater than the as-cast sample but it could have been even better if the formation of intermetallic could have been avoided.

The below figures 5.11 and 5.12 shows the images of samples from composites fabricated with 5 wt% and 10 wt% of Ni-Gr reinforcement. These images show a very close and clear fact of separation of matrix from the bonded reinforcement..

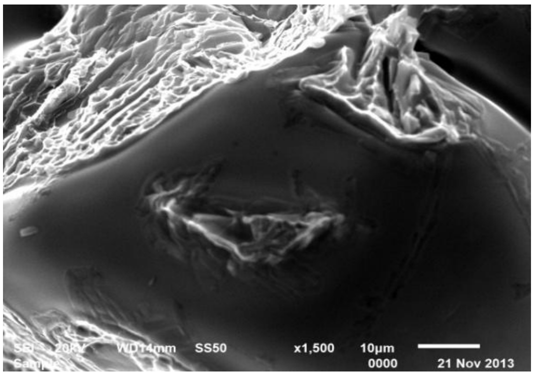


Fig. 5.11 Image of Al / 5% Ni-Gr

significant cause for the value of elongation to get reduced. As this factor, that is, as the percentage of reinforcement increases the percentage elongation reduces. Further, conclusions reveal that due to the inclusion of such hard materials than softer matrix material there seems to be an increase in the value of hardness.

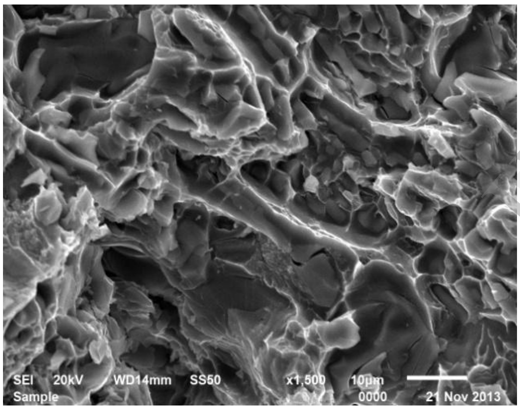


Fig. 5.12 Image of Al / 5% NCG

Examination of samples fabricated from coated particle reinforcement showed that the tendency of elongation of the substituted reinforcement had been similar to, as that of the unreinforced alloy which is evident from the percentage elongation .The image from Fig. 5.12 shows closely the presence of graphite inside the matrix that is intact due to the nickel coating on the surface of graphite.

The investigation images shows that the layer of separation is strained more because of the difficulty of making the separation at the more stressed regions.

VI. Conclusion

The tensile test values predicted good results for NCG reinforced composite than for ordinary reinforced ones.The NCG reinforced composites were able to achieve better hardness values than that of the as-cast samples and separately dispersed reinforcements. The SEM micrograph very clearly shows less formation of voids in NCG reinforced composites. This reduces the brittleness and retains the ductility to some extent and then allows for fracture.

Graphite being less dense was thought to float or get skimmed away by the melt when more percentage needs to be added. But with nickel coating on graphite we were able to achieve graphite particles a little denser than graphite. It is also due to this reason we are able to go in for higher percentage of graphite addition.The intact bonding between the reinforcement and the matrix plays a vital role in deciding the behavior of composite. We have achieved this intact layer by reducing the layer of segregation and improving performance. Generally, low Coefficient of Thermal Expansion (CTE) of metal matrix piles up with graphite particle and gives good result. The high rate of conductivity liberates the absorbed heat from the composite and as Graphite being a good conductor enhances the conductivity. Cost reduction in MMCs is a major point of focus which one can never take off from his sight. But composites produced as per the above work compensates in bearing the applied load and also reduces the percentage of particulate addition of hybrid reinforcements in the matrix Fabrication of MMCs has several challenges like porosity formation, poor weldability, poor wettability and improper distribution of reinforcement.

Achieving uniform distribution of reinforcement with good wetting nature is the foremost important work. Uniform wetted reinforcement of MMCs plays a major role in the improvement of mechanical and tribological properties. More homogenous distribution of reinforcement can be achieved by following metal coated reinforcements. As aluminum is less corrosive than steel the application of this metal in corrosive environment shows better results. Thought had been laid that as graphite is less dense was expected to float and would not get distributed into the matrix uniformly loosing the property of importance for which it was fabricated. But with more efforts on metal coated reinforcements we will be able to achieve more uniform distribution of reinforcements with little density.Effort can be done to also achieve more percentage of reinforcement addition so that still harder and better strength composites can be fabricated.

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