



Mechanical Characterization of Nanomaterial Reinforced Aluminum-based Hybrid Nanocomposites

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ABSTRACT

Nanostructures are viewed as definitive fiber materials as a reinforcement for matrices because of their impressive properties. Because of their phenomenal mechanical properties Carbon nanotubes (CNTs), graphene (GR), and nanodiamond (ND) have made an enormous proportion of intensity in research over the world. Multiwalled carbon nanotubes (MWCNTs), Graphene, and Nano Diamond were utilized as reinforcements for the current work. Nanostructures with their extraordinary strength, minute size, and high aspect ratio were used as reinforcements in commercial-purity Al matrix. These nanocomposites were manufactured by various different routes such as casting and powder metallurgy techniques. Both of these methods are helpful for the preparation of MWCNTs/Al nanocomposites. These nanocomposites were manufactured with various weight fractions of reinforcements and characterized for their mechanical properties and indicated improved properties in contrast with the base Al matrix. Al/MWCNT nanocomposites, Al/MWCNT/GR hybrid nanocomposites and Al/MWCNT/GR/ND hybrid nanocomposites samples were tested for their mechanical properties such as Young's modulus, percentage elongation yield strength, and ultimate Strength. Mechanical characterization of these prepared composite samples demonstrated improved strength when compared with the casted samples.

Keywords: Carbon nanotubes, Graphene, Nanodiamond, nanocomposites, hybrid composites, tensile properties

1 Introduction

Nanotechnology is interdisciplinary of science, engineering and technology. It deals with nanoscale, which ranges from 1-100nm in at least one of the dimensions. Nanoscience and nanotechnology are the research areas which are concerned with minute things. Basic science, Human Science, materials science, and engineering are the various scientific fields that might be used in. Nanomaterials are more and more essential product of nanotechnologies. Among the invention of various nanometer size materials, one in all the foremost stable sp² carbon-bonded materials like helical microtubules of carbon fullerenes [1] and carbon nanotubes (CNTs) [2] have triggered the study in this field of nanocomposites. The 2 major types of Carbon Nano Tubes are – SWNT & MWNT (Single walled Nano tubes & Multi walled Nano tubes) – which may have very high structural perfection. CNTs were initially found from a method called CVD (Chemical vapor deposition) [3]. Since then, the synthesis strategies of nanotubes are advanced impressively. In the last few years, nanotubes have caught exceptional attention within the analysis space of composites [4]. Arc discharged technique is one of the methods to synthesize CNTs [5] and therefore the mechanical properties were ascertained to be valuable in producing the composites.

Synthesize of the C₆₀ structures have stirred sturdy interest in graphitic structures for example carbon sheets [6]. Their structures seem like geometric enclosures. They're product of carbon atoms, that establish polygonal faces like pentagonal and hexagonal within the cage [7,8]. Cage-like structures were initially found



to contain 60 carbon atoms. This structure resembles the shape of a football, with each surface of the pentagon being neighbouring to a hexagon. The carbon structure consists of tube-like structures or needle-like circular layers [9]; The hexagons are arranged around the needle axis on each carbon tube. Graphene (GR) is the most famous carbon nanomaterial of the century, possessing good properties such as in-plane structural stiffness and has its own application in composites. Research has demonstrated that work progresses to the total purpose of interest of GR as its exfoliation is crucial. GR is one of the cutting - edge nanomaterials, that was initial isolated at the University of Manchester by Professors [10]. From that point forward, various specialists were excited about this material since it has the flexibility to transform a huge vary of products due to its terribly superior capabilities when it is compared with the existing materials. The mechanisms of CNTs and GR are of primary interest to researchers, along with this Nano diamond (ND) is also a constituent of carbon and it is one of the encouraging nanomaterials for composite material reinforcement. ND is widely used for a particular reasonable ND base resource at the nano scale vary from 1 - 100 nm. [11,12,13]

NDs are produced by a method called as detonation synthesis (NDDS) [14]. NDDSs are equipped for forming isodiametric nanosized 'unbreakable aggregates' which will be used as a good modifying agent for giving increased mechanical characteristics of the filled polymers. Because of its small size and high number of surface atoms, ND has varied uses [15,16,17]. Carbon nanotubes are found to have a high Young's modulus of the order of 1 TPa, makes perfect reinforcement for composite materials. Treatment of CNT/Al composites, mechanical portrayal and the composite reinforcement are connected to numerous instruments and mechanisms [18]. Hybrid nanocomposites are the current decade's revolution, the most recent trend in composites by adding two or more fillers to the matrix, which exhibits an excellent result and created interest amongst all the researchers [19]. The present paper highlights the concept of Al-based hybrid nanocomposites with three nanoscale materials, namely multiwalled carbon nanotubes (MWCNTs), GR, and NDs. Casting and powder metallurgy methods have been adopted to compare the properties.

2 Materials and Methods

2.1 Materials

Among all the accessible materials, Al-based MMCs are found to be appropriate materials for structural applications in the field of aircraft and automotive industries, since they possess number of the excellent properties like lightweight, ductility, highly conductive, corrosion resistant and high strength-to-weight ratio. Since entire spotlight has dependably been on PMCs, and exceptionally less work has been achieved out on the MMCs of nanomaterials (MMNCs). MMNCs with carbon - bonded nanomaterials as reinforcement can be expected to indicate a spectacular improvement in the values of stiffness and hardness. Al is considered as the essential entrant for carbon bond nanomaterials reinforcement. Present research work utilizes commercial-purity Al as a matrix. Table 1 indicates the chemical compositions for commercial purity Al.

Table 1: *Composition of commercial-purity Al (wt.%)*

| Al | Fe | Si | Ni | Zn | Mn | Cu | Mg |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 99.77 | 0.095 | 0.083 | 0.015 | 0.013 | 0.011 | 0.005 | 0.005 |

Al-based matrix composite materials possess wide range of applications in the field of aviation, spacecraft, and automobile industries because of their low density. Particulates-reinforced MMC is one among the novel basic structural materials, and persistent development has been observed in recent years because of its exceptional properties and in-depth application prospects within the future. Based on the size and shape of the reinforcement materials and among the several available nanomaterials, here the carbon nanotubes MWCNTs, GR, and ND are considered. CNTs are self-assembling nanostructures; they have received much consideration as exemplary systems for nanoscience and for various applications, along with

composites the other applications embrace battery electrode materials, field emitters, nano-electronics and nanoscale sensors. The CNT's system has a particular interest in its unique structure and properties, they have very low size (~ 0.42 nm in diameter) and the mechanical properties of the same are as shown in Table 2.

Table 2: Properties of SWCNT and MWCNT

| Property | SWNT (Single walled Nano Tubes) | MWNT (Multi walled Nano Tubes) |
|------------------------------|------------------------------------|-----------------------------------|
| Young's modulus (GPa) | 1054 | 1200 |
| Tensile strength (GPa) | 150 | 150 |
| Density (g/cm ³) | 2.1 | 2.6 |

The production of GR is presently a hot research theme, as the manufacturing process of GR defines its mechanical properties & as a consequence of its applications. It ought to even be noted that there's no single technique for synthesis of GR that yields the foremost ideal properties for each sensible application; hence, a number of production methods of GR have been reported [20]. NDs are synthesized by the different methods such as, high-energy ball milling using high-pressure high-temperature diamond microcrystal, method of detonation, plasma-assisted chemical vapour deposition (CVD), laser ablation etc. Table 3 represents the properties of nanomaterials.

Table 3: The structured properties of nanomaterials

| | Dimensions | Length | Thickness | Diameter | Density (g/cc) |
|-----------|------------|---------------------|---------------------|-----------|----------------|
| Fullerene | OD | < 1 nm | < 1 nm | < 1 nm | ~ 1.7 |
| SWCNTs | 1D | μm level | - | 0.75–3 nm | ~ 2.1 |
| MWCNTs | 1D | μm level | - | < 100 nm | ~ 2.1 |
| GR | 2D | - | < 1 nm | - | ~ 2.2 |
| ND | 2D | μm level | μm level | - | ~ 2.62 |

2.2 Fabrication of Nanocomposites

For the successful processing of composites, uniform distribution of reinforcement in the metal matrix is the main criterion [21,22]. The processing methods which are adopted subjected to make sure negligible injury to composites [23–26]. Since the reinforcements are nanomaterials, the most important task is to disperse nanomaterials systematically within matrix; Based on the nature of the process incorporated, reinforcement of nanomaterials may even be subject to high temperature and stress or molten metals may come into contact. This could cause chemical change, which might successively cause loss of nanomaterials through carbide formation and will have an effect on the properties of the composites favourably or adversely. The methods generally used for the processing of Al matrix composites are as follows.

- I. Casting technique
- II. Powder metallurgy technique

Initially, 1 Kilogram of commercial purity Al was allowed to melt in a resistance-heated muffle furnace and casted in a clay graphite crucible. The temperature of the melt was raised to a value of 993 K. Then the Al-MWCNT's composites were prepared by stir casting technique with different weight percentages like 0.5 wt.%, 1 wt.%, 1.5 wt.%, and 2 wt.%. The Commercially available pure Al ingot in the furnace was allowed to melt, CNTs added to the melt and mixed with the assistance of a stirring bar. MWCNTs of 0.5 wt.%, 1 wt.%, 1.5 wt.%, and 2 wt.% of CNTs were added to the molten Al to derive the composites. A 98% pure Al with 200-mesh powder was produced by the atomization method with 75 μm size and MWCNTs which are used as reinforcement material are procured from Nanoshell, produced by the chemical vapor

deposition method. The conventional powder metallurgy technique was utilized for syntheses of Al/MWCNTs which includes the steps like blending, compaction, and sintering.

The amorphous carbon will influence and even impede the interaction between the nanomaterials, before the first stage of composite preparation, the surface should be clean. Purification is therefore considered an essential phase. In order to achieve that the raw product of nanomaterials was sonicated in ethanol solution for time of 20 min at room temperature and finally allowed to dry at 120°C. Ethanol solution at diluted condition was employed to dissolve the catalytic particles and reinforcement particles (CaCO_3). As 1gm of CaCO_3 once reacts with the 1.26 g of ethanol throughout the purification and also the latter quantity should be able to get close to 4 cm³ 30% ethanol, mutually catalytic particles and the reinforcement can sufficiently be dissolved in increasing volumes of 4 cm³ 30% ethanol.

Initially MWCNTs were allowed to disperse in a solvent (ethanol) & sonicated with the help of Ultra sonication equipment for time of 20 min and then draw off by placing on the copper grid to obtain pure MWCNTs. Thus, obtained MWCNTs are free from impurities and can be used as reinforcement. The mixtures of Al and MWCNTs powders were uniaxially hard-pressed in a die under a pressure of 130 kN. The purpose of powder mixture compaction is to derive billets of size 20mm diameter. The derived product immediately after pressing is called green compact. These Green compacts undergo process called Sintering for which they are placed in a furnace, which involves heating of the green compact specimen at high temperature in a controlled atmosphere condition (nitrogen), This helps for prevention of oxidation of parts. The process helps for increasing the bond structure involving the particles and consequently helps for strengthening of the powder-metal compact. The most important factors which govern the sintering process are atmosphere, temperature, and time. Vacuum sintering furnace (resistance type) was used with voltage: 220V–380V; max. temperature: 1600° C; working temperature: 800°C; heating rate: 0–20° C/min. Hot extrusion is generally performed at temperatures of 50–70% of melting point of the metals, the pressure value ranges from 35 to 700 MPa.

For lubrication purpose Oil and graphite powders can be utilized for lower temperature conditions and at higher temperatures glass powders are used. This helps the die life to be upgraded. Al/MWCNT samples were extruded at 560°C from 20-mm to a diameter of 8 mm and a length of 120 mm with 85% degree of reduction. Pressure of 100 MPa was used for hot extrusion (30 KN force) which applied through a hydraulic press. In the same manner, Al/MWCNT, Al/MWCNT/GR and Al/MWCNT/GR/ND hybrid nanocomposites were fabricated.

2.3 Tensile testing

The test samples were prepared in accordance with the ASTM 8 standard and a Universal Testing Machine (UTM) was utilized to conduct the Tensile test. The specimen used for the tensile test was having a gauge length of 40 mm, diameter 13 mm and the reduced diameter of 8 mm. the test was carried out under static loading conditions to determine the yield strength and tensile strength of the material. Both the Hot extruded and casted samples of Al/MWCNT, Al/MWCNT/GR, and Al/MWCNT/GR/ND Hybrid nanocomposites were machined on a lathe to achieve a reasonable required surface finish. These samples of dimension of diameter 4-mm and gauge length 40 mm were commercially tested on a UTM for its mechanical properties.

3 Results and Discussion

MWCNTs, GR, and ND possesses high aspect ratio, high modulus, and high strength hence these plays a vital role as a reinforcement. The load from the Al matrix can be transmitted successfully to nanofibers, similar to the randomly oriented short fibers with high strength and modulus. Likewise, high surface area of the the nano materials (CNT)s makes an interface region, which possesses the properties not same as those of the bulk matrix. The commercial-purity Al matrix material was processed and synthesized using casting and powder metallurgy route. The tensile test specimens were having a dimension of 4 mm in

diameter, 100 mm in length and with a gauge length of 50 mm. INSTRON machine was used to carry out tension test. The Figure 1 shows the prepared specimen as per standard ASTM E8 standard.

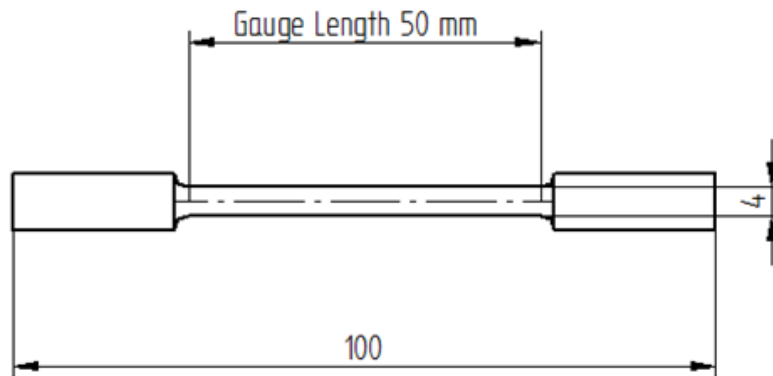


Figure 1: Tensile test specimen

Similar processing conditions and tests were employed for Al/MWCNT, Al/MWCNT/GR, Al/MWCNT/GR/ND hybrid nanocomposites. The Table 4 indicates strength of commercial-purity Al synthesized by casting and powder metallurgy. These properties support basis for assessing the mechanical behavior of the Al/MWCNT nanocomposites.

Table 4: Tensile properties of commercial-purity Al

| Property | Casted | PM |
|---------------------------------|--------|-----|
| Hardness (BHN) | 40 | 44 |
| % Elongation | 19 | 17 |
| Young's Modulus (GPa) | 69 | 71 |
| Yield Strength (MPa) | 80 | 81 |
| Ultimate Tensile Strength (MPa) | 125 | 126 |

Table 5 depicts the tensile properties of Al/MWCNT nanocomposites; the results illustrates that in comparison with casted samples powder metallurgy samples showed sufficient transfer of the load from the matrix to fiber as shown by increasing trend in Young's modulus and yield strength values with increase in weight percentage of fiber. The ultimate strength of the cast samples does not increase due to the non-homogeneous dispersion of reinforcements in the composite and specimen breakage at the grips during the tension test. With increase in reinforcement weight percentage of MWCNTs in Al/MWCNT nanocomposites a downward trend was observed for ductility for both cast and powder metallurgy samples. There was a variation in the hardness up to 1.5 wt.%; thereafter there was no significant change. This was due to the saturation of the reinforcement in the matrix.

Table 5: Tensile properties of Al/MWCNT nanocomposites

| Composition | Young's Modulus (GPa) | | Yield Strength (MPa) | | Ultimate Tensile Strength (MPa) | | % Elongation | |
|-------------------|-----------------------|----|----------------------|-------|---------------------------------|-----|--------------|------|
| | Casted | PM | Casted | PM | Casted | PM | Casted | PM |
| Al/1wt.% MWCNTs | 77.5 | 82 | 95.95 | 97 | 151 | 153 | 9.1 | 8 |
| Al/1.5wt.% MWCNTs | 82.72 | 86 | 98.6 | 99 | 152 | 157 | 8.43 | 7.88 |
| Al/2wt.% MWCNTs | 84.67 | 85 | 98.2 | 101.3 | 150 | 157 | 7.92 | 7.46 |

The results for the 1 wt.% MWCNT-reinforced commercial-purity Al composites depicts that, the value of Young's modulus increased by 12.31% & 15.49% for the specimens prepared from casted and powder metallurgy routes, respectively. The yield strength of the casted and powder metallurgy composite samples

also improved by 19.93% and 19.75% respectively. The results for Young's modulus, yield strength, and ultimate strength for 1.5 wt.% Al/MWCNT nanocomposites showed an increase in the value of 19.88%, 23.25%, and 21.6% for the cast composite samples and 21.12%, 22.22%, and 24.60% for the samples prepared using powder metallurgy respectively.

It was also seen for the Al composite strengthened by 2 wt.% MWCNT. The modulus and yield strength of the young show an increase in the matrix value of 22.7% and 22.75% for the casted samples, and 19.71% and 25.06% for the samples prepared with powder metallurgy route. Even though improvement was observed for ultimate strength of the matrix, there exists a reduction in the value compared to the Al/MWCNT composites for 1 wt.% and 1.5 wt.%. The increase in strength prompts to a reduction in ductility. Samples prepared from casting route also showed good results for strength and stiffness compared with the powder metallurgy sample.

Because of higher porosity levels and lack of microscopic coherence between Al and MWCNT, higher numbers of cracks in the composite produced by the cast sample during tensile deformation compared to the powder metallurgy samples as observed from Figure 2. However, Short average length and smaller width of the individual cracks were observed in case of Al/MWCNT films because the suppression effect caused by the MWCNTs made it difficult to propagate the cracks. In addition, the effect of MWCNTs on crack propagation restraint is indicated in Figure 3, it is observed that in the vicinity of broken or exposed CNTs indicated as dark ellipses, whereas in the powder metallurgy samples, the crack width is smaller than in the cast samples.

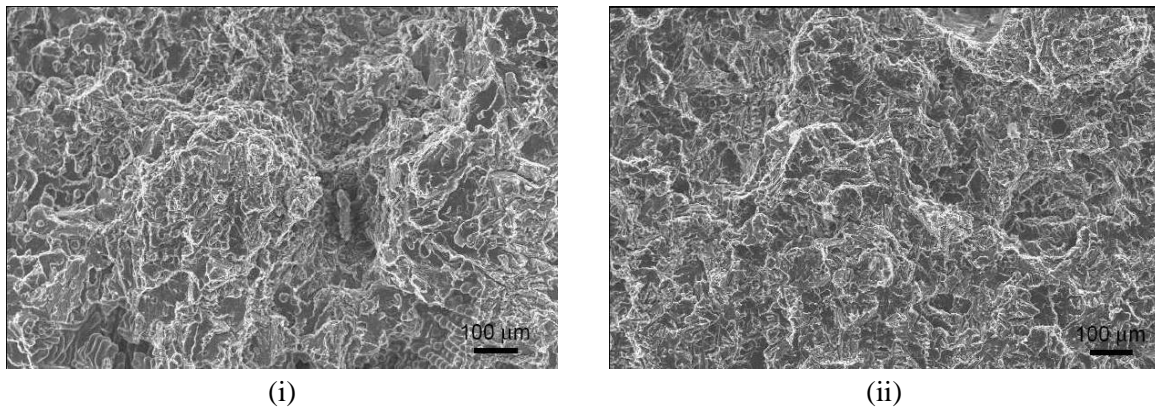


Figure 2: SEM image of the fracture surface of an Al with 1 wt.% MWCNT for tensile test samples:
i) casted samples (ii) powder metallurgy samples

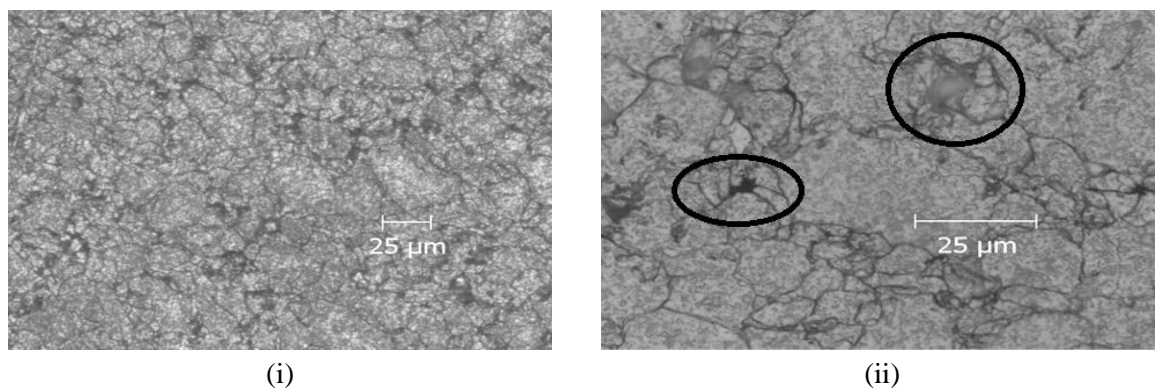


Figure 3: SEM image of the reinforcement distribution of an Al with 1.5 wt.% MWCNT composite samples:
i) casted samples (ii) powder metallurgy samples

Figure 4 shows the fracture image obtained from SEM. it is one of the tools for understanding materials behaviour & reinforcements to the fractures surface of the composites, it can fetch much information related to the material. Fracture surface investigations obtained by SEM provide information about the failure mechanism and the reinforcement role. The MWCNT pullout, crack bridging and MWCNT deflection are easily visible in the fracture surface SEM image, which provides information about the strengthening mechanisms involved.

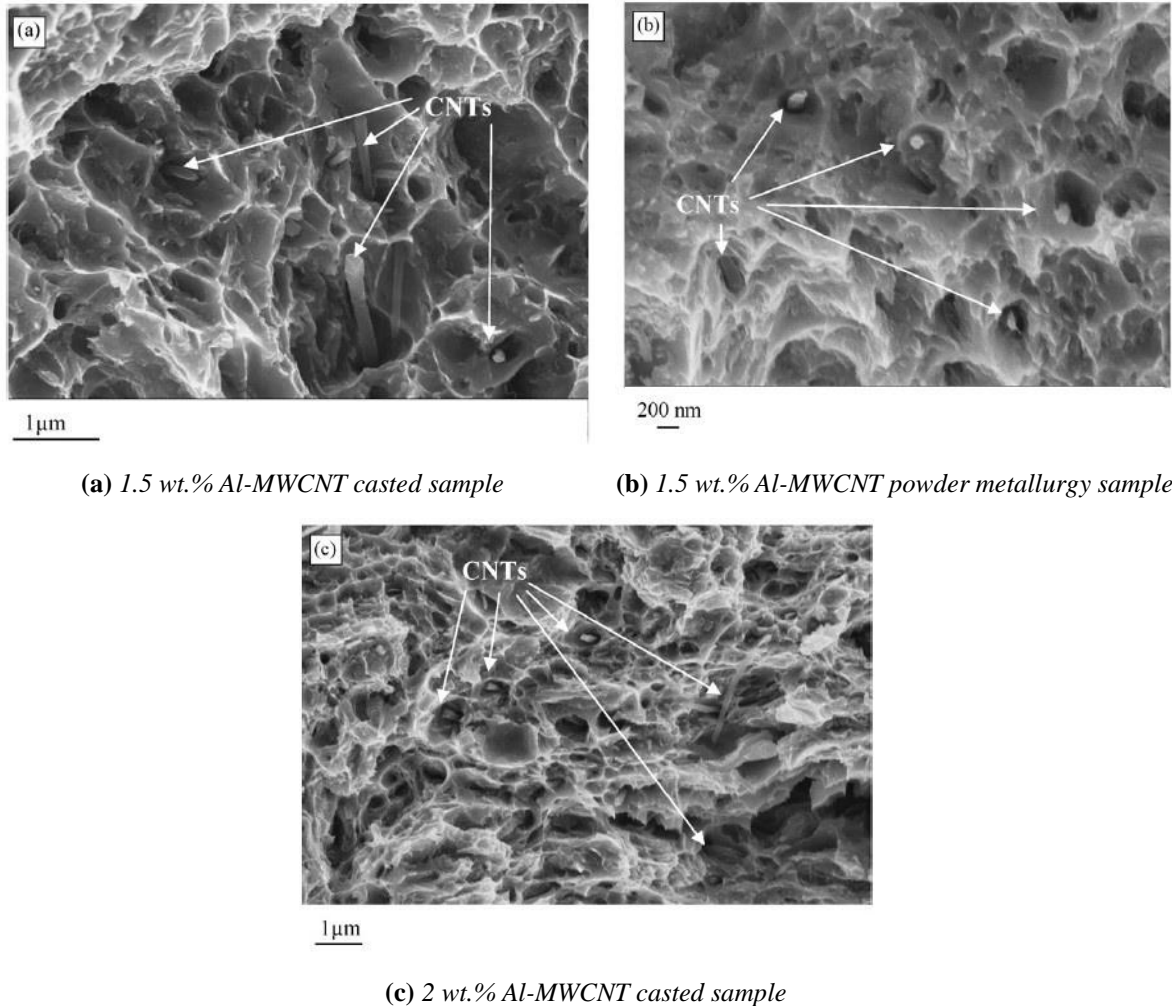


Figure 4: Fracture surfaces of 1.5 wt.% Al-MWCNT samples which shows individual MWCNTs dispersed in the matrix

Figure. 5 shows a heavily etched bulk composite sample that was not tensile tested. CNTs are adjusted in the direction of extrusion, which in the final composite can lead to anisotropic properties. In this sample, the voids formed around the CNTs are less present, proving that they are due to tensile testing.

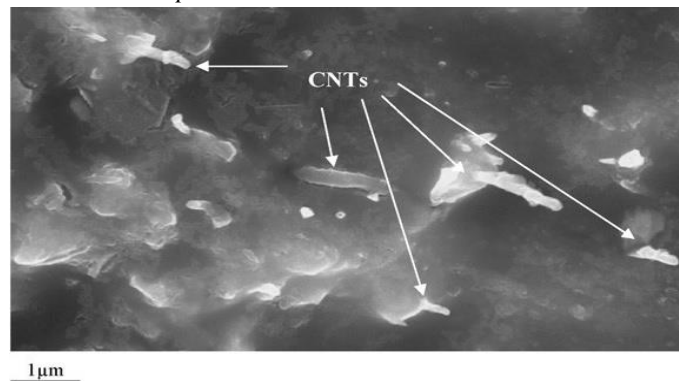


Figure 5: A cross section for 2 wt.% Al-MWCNT extruded sample subjected to tensile testing and deeply etched showing individual MWCNTs aligned in the extrusion direction

The results shown in Table 6 states that, Young's modulus for 1 wt.% MWCNT/GR reinforced commercial-purity Al composites increased by 14.67% for cast and 16.8% composite samples prepared by powder metallurgy route. Similarly, when yield strength is considered, it is observed that there is an increment of 20% and 21% for the composite samples prepared by casted and powder metallurgy routes respectively. For the 1.5 wt.% the value of Young's modulus, yield strength, and ultimate strength of Al/MWCNT nanocomposites, showed an increase of 21.22%, 24.29%, and 22.8% for the casted composite samples, and 22.05%, 22.8%, and 26% for the powder metallurgy samples, respectively.

Table 6: *Tensile properties of Al-based MWCNT/GR hybrid nanocomposites*

| Composition | Young's Modulus (GPa) | | Yield Strength (MPa) | | Ultimate Tensile Strength (MPa) | | % Elongation | |
|---------------------------|-----------------------|----|----------------------|-----|---------------------------------|-----|--------------|------|
| | Casted | PM | Casted | PM | Casted | PM | Casted | PM |
| Al/1wt.% of MWCNTs & GR | 78 | 82 | 98 | 100 | 152 | 162 | 9 | 8.32 |
| Al/1.5wt.% of MWCNTs & GR | 84 | 91 | 99 | 112 | 159 | 170 | 7.9 | 7.1 |
| Al/2wt.% of MWCNTs & GR | 85.5 | 94 | 98 | 114 | 162 | 167 | 8 | 7.6 |

It was also seen for the Al composite strengthened by 2 wt.% MWCNT / GR. The Young's modulus and yield strength showed an increase from the matrix value for the casted samples by 22.7% and 22.75%, and for the powder metallurgy samples by 20% and 26%. The ultimate strength showed an improvement from the matrix value, however, when compared to the 1 wt. % and 1.5 wt. % Al / MWCNT / GR composites, there was a reduction. The increase in strength leads to a reduction in ductility. Compared to the powder metallurgy samples, the casted samples also showed good strength and rigidity. This is achieved by the uniform distribution of MWCNT & GR reinforcements in PM technology compared with the casting method.

Early results of the GR reinforcement of MWCNT / GR alone cannot produce very high mechanical properties. If the ND is used together with MWCNT and GR as one of the reinforcements, very good mechanical properties are expected. [21]. Compared to the base metal, the mechanical properties of the composites are expected to be enhanced even with the low volume fraction of the reinforcement provided there is adequate wetting between the reinforcement and the matrix for load transfer. The tensile properties of Al/MWCNT/ND nanocomposites are shown by table 7 the results depict that the composite Young's modulus and yield strength increases with an increase in the wt.% of the fiber, indicating a sufficient transfer of the load from the matrix to the fiber in samples prepared from powder metallurgy route compared to the casted samples. The ultimate strength in the casted samples does not increase basically due to the non-homogenous dispersion of the composite reinforcements as well as breakage of the sample in the grips during the tension test. In both the cases (casted and PM) The ductility of composite samples showed a decreasing trend with an increase in the wt.% of reinforcement MWCNTs in nanocomposites Al/MWCNT/ND.

Table 7: *Tensile properties of Al-based MWCNT/GR/ND hybrid nanocomposites*

| Composition | Young's Modulus (GPa) | | Yield Strength (MPa) | | Ultimate Tensile Strength (MPa) | | Elongation (%) | |
|------------------------|-----------------------|----|----------------------|-----|---------------------------------|-----|----------------|-----|
| | Casted | PM | Casted | PM | Casted | PM | Casted | PM |
| Al/1wt.% MWCNTs+GR+ND | 79 | 84 | 97 | 106 | 156 | 165 | 9.6 | 8 |
| Al/1.5wt.% WCNTs+GR+ND | 86 | 93 | 100 | 115 | 164 | 178 | 6.8 | 7 |
| Al/2wt.% WCNTs+GR+ND | 88 | 99 | 99 | 117 | 166 | 180 | 7 | 5.9 |

For 1 wt. percent MWCNT / GR / ND strengthened commercial-purity Al composites, the results show that Young's module increased by 14 percent and 16.22 percent for the composite samples of cast and powder metallurgy respectively. The yield strength of the casted and powder metallurgy composite samples also improved by 21.3% and 22.23% respectively. For the 1.5 wt.% the value of Young's modulus, yield strength and ultimate strength for Al/MWCNT nanocomposites increased by 22.98%, 24% and 23.6% for the casted composite samples and by 22%, 23% and 26% for the samples prepared by powder metallurgy route.

For the Al composite reinforced by 2 wt.% of MWCNT / GR / ND, the Young modulus and yield strength increased from the matrix value by 24% and 25.8% for the cast samples and by 26% and 27.8% for the powder metallurgy samples. It showed improved results when the reinforcement used as ND was 2%. The final strength showed a betterment in the matrix value compared to the Al/MWCNT & Al/MWCNT/GR composites of 1 wt.% and 1.5 wt.%. The strength increases lead to ductility reduction. The casted samples also showed good strength and stiffness compared with the powder metallurgy samples. Composites carrying 2 wt.% MWCNT/GR/ND resulted higher tensile strength because of the existence of less micro voids and good interface strength. In addition, due to the same reason, the strength of the samples prepared by casted Al/MWCNT/GR/ND composites showed lower results compared to samples prepared by powder metallurgy route. The proper distribution of reinforcement throughout the matrix shows improved results in yield strength to the base matrix. When the temperature exceeds Al's melting point MWCNTs are also predicted to react with Al.

4 Conclusion

The first part described the material used and the composite manufacturing processes. The casting and powder metallurgy technique are utilized to produce CNTs reinforced Al composites. The latter half reported the impact of 2 different reinforcements (hybrid) along with MWCNTs, namely GR and ND. The mechanical characteristics of Al/MWCNT, Al/MWCNT/GR and Al/MWCNT/GR hybrid nanocomposites reported in the third part. The current research resulted that the addition of MWCNT, GR and ND into commercially pure Al nanocomposites manufactured by casting and powder metallurgy techniques improves the physico-mechanical properties of the composites, such as density, hardness, tensile strength and ductility. Compared to the Al matrix Al / MWCNT nanocomposites showed an increment in the value of Young's modulus by 19% and 21% increment in the value of yield strength. The hybrid nanocomposites Al/MWCNT/GR and Al/MWCNT/GR/ND 1.5wt.% of the reinforcement showed betterment in yield strength by 21.65% and 23% respectively, Young's Modulus by 24% and 26% respectively when compared with the base Al matrix. Nanocomposites Al / MWCNT, Al / MWCNT / GR and Al / MWCNT / GR / ND were fabricated using powder metallurgy route. Compared to the casted samples, the mechanical characterization of these composite samples showed much better strength. 1.5 wt.% fraction of reinforcement showed increases of 24%, 26%, and 29.2% and 25%, 28%, and 31% in yield strength compared with the Al matrix and casted samples, respectively.

5 How to Cite this Article:

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