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Analysis of hardness test for aluminium carbon nanotube metal matrix and graphene

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ABSTRACT

Metal Matrix Composites (MMCs) have evoked a keen interest in recent times for potential applications in aerospace and automotive industries owing to their superior strength to weight ratio and high temperature resistance. Reinforcement to the aluminium metal by carbon nanotubes along with graphene enhances the mechanical properties like strength of the aluminium composite material. It is important to understand the variation in hardness before and after reinforcement to the aluminium. In this paper hardness test is analyzed along with experimental procedure for aluminium.

Keywords: Metal matrix composite; Reinforcement; Mechanical properties; Carbon nanotube; Aluminium

Abbreviations: MMC-metal matrix composites

1. INTRODUCTION

Carbon nanotube aluminium matrix can be prepared by powder metallurgy (Gehad Goudah et al. 2010). The widespread adoption of particulate metal matrix composites for engineering applications has been hindered by the high cost of producing components. Although several technical challenges exist with casting technology yet it can be used to overcome this problem. Improved mechanical properties can be obtained by uniform distribution of aluminum nanotube composite material (Umma et al. 2012). Achieving a uniform distribution of reinforcement within the matrix is one such challenge, which affects directly on the properties and quality of composite material.

Figure 1
Ball milling setup

Figure 2
After ball milling (or) mixture of pure aluminium

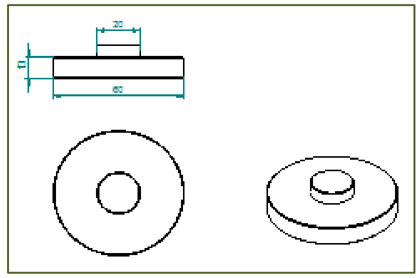

Figure 3
Bottom plate

Carbon nanotube aluminium matrix can also be prepared by catalytic chemical vapour deposition method (Shrivastava et al., 2008). Amongst the various metal matrix composites, a large portion of research & development work appears to have been dedicated to aluminum alloy based composites. By using high energy ball mills carbon nanotubes reinforced metal matrix composites uniformness can be obtained (Senthil Saravanan et al., 2010). Investigation on Alumina-based nano composites reinforced with niobium and/or carbon nanotubes (CNT) were fabricated by advanced powder processing techniques and consolidated by spark plasma sintering to know improvement in fracture toughness of CNT-reinforced samples is because of either damage to CNTs or possibly non-optimal interfacial bonding between CNT-aluminum (Thomson et al., 2011). Due to ease of preparation, low processing cost involved and possibility of a wide range of properties, aluminum alloy based composites have been a subject of great interest to the researchers and technologists. Such composites are prepared using different aluminum base alloys and Carbon nanotubes (CNTs) as reinforcement. The CNTs are among the exciting new materials to have been discovered in the past 30 years. And most of the researchers were interested to work by using as reinforcement in preparing the composites.

CNT-reinforced metallic composites are quickly emerging as attractive materials combining light weight with superior strength and stiffness especially by using powder metallurgy techniques as being a promising way for the fabrication of nanotube reinforced metal matrix composites (Mohamed Mahmoud Emara et al., 2013). Composite materials are multiphase materials obtained through the artificial combination of different materials in order to attain properties that the individual components by themselves cannot attain. If a relatively graphitic kind of carbon fiber is used, the thermal conductivity can also be enhanced significantly. The improvement of physical properties for composites of Al – CNT has been compared with pure aluminum. The combination of low coefficient of thermal expansion (CTE) and high thermal conductivity makes them veryattractive for electronic packaging applications. Carbon nanofibers and nanotubes are promising to revolutionise several fields in material science and are a major component of nanotechnology (RupeshKhare et al., 2005). Besides good thermalproperties, their low density makes them particularly desirable for aerospace electronics and orbiting spacestructures. Al6061 alloys as matrix and Multiwall Carbon Nanotube (MWCNT) as reinforcement (0, 0.5, 1.0, 1.5,2, 2.5 & 3weight percentage) have been fabricated by powder metallurgy process. Compared to the metal alone, a carbon fiber metal-matrix nanocomposite is characterized by higher strength-to-density ratio (i.e., specific strength), a higher modulus-to-density ratio (i.e., specific modulus), better fatigue resistance, better high-temperature mechanical properties (a higher strength and a lower creep rate), a lower CTE, and better wear resistance. However, aluminum a suitable matrix material as it is cheaper and can be processed easily using powder metallurgy route which is also cost effective and captive route compared to other fabrication routes.

1.1. Properties of Carbon Nanotubes

a) CNTs have about 1 to 5 TPa of Young's Modulus CNTs have excellent electrical properties and are used as reinforcement to metals in order to enhance electrical properties.
b) CNTs have extremely high thermal conductivity that allows metal matrix carbon nanotubes to be used for thermal management.
c) The thermal properties of CNT metal matrix composites can be improved based on the distribution and bonding of CNTs with the matrix.

1.2. Properties of Graphene

In Aluminum metal matrix nanocomposite Graphene reinforcement is also added which also have some distinctive properties
a) Modulus, fracture strength ~130 GPa
b) Low density ~2 g/cm3
c) Thermal conductivity ~3000 W/m-K in plane—but highly anisotropic; ~ 2 W/m-K out of plane
d) Electrical conductivity: ballistic electron transfer; high mobility
e) High specific surface area (limit: 2630 m2/g)

Table 1

Percentage combinations of Aluminum+Graphene+Carbon Nanotubes

Weight percentage of reinforcement to matrix	Matrix weights (ALUMINIUM) in gms (% mixture)	Reinforcement-1 (GRAPHENE) in gms (% mixture)	Reinforcement-2 (Carbon Nanotubes) in gms (% mixture)
0.2 WT%	19.96 (99.80%)	0.02 (0.1%)	0.02 (0.1%)
0.4 WT%	19.92 (99.60%)	0.04 (0.2%)	0.04 (0.2%)
0.6 WT %	19.88 (99.40%)	0.06 (0.30%)	0.06 (0.30%)
0.8 WT %	19.84 (99.20%)	0.08 (0.40%)	0.08 (0.40%)
1 WT%	19.80 (99%)	0.1 (0.50%)	0.1 (0.50%)

Table 2

Percentage combination of Aluminum, Graphene

Weight pecentage of reinforcement to matrix	Matrix weight (ALUMINIUM) in gms (% mixture)	Reinforcement-2 in gms (% mixture)
0.20%	19.96 (99.80%)	0.04 (0.2%)
0.40 %	19.92 (99.60%)	0.08 (0.4%)
0.60 %	19.88 (99.40%)	0.12 (0.6%)
0.80%	19.84 (99.20%)	0.08 (0.8%)
1 %	19.80 (99%)	0.2 (1%)

Table 3

Percentage combination of (Aluminum, Graphene, Carbon Nanotubes) sintering

Weight percentage of reinforcement to matrix	Matrix weight (ALUMINIUM) in games (% mixture)	Reinforcement-1 (GRAPHENE) in gas (% mixture)	Reinforcement-2 (Carbon Nanotubes) in gms (% mixture)
0.8 WT %	19.84 (99.20%)	0.08 (0.40%)	0.08 (0.40%)
1 WT%	19.80 (99%)	0.1 (0.50%)	0.1 (0.50%)

Table 4

Percentage combination of(Aluminum, Graphene) sintering

Weight percentage of reinforcement to matrix	Matrix weight (ALUMINIUM) in gms (% mixture)	Reinforcement-2 (Graphene) in gms (% mixture)
0.80%	19.84 (99.20%)	0.08 (0.8%)
1 %	19.80 (99%)	0.2 (1%)

Table 5

Hardness for (AL+GRAPHENE+CARBON NANOTUBES) cold pressed composites

Weight percentage of reinforcement to matrix	Pure aluminum	0.2 WT%	0.4 WT%	0.6 WT%	0.8 WT%	1 WT%
Rockwell Hardness No	35	35	38	37	41	41

Table 6

Hardness for (AL+GRAPHENE) cold pressed composites

Weight percentage of reinforcement to matrix	Pure aluminum	0.2 WT%	0.4 WT%	0.6 WT%	0.8 WT%	1 WT%
Rockwell Hardness No	35	33	31	30	33	34

Table 7

Hardness for (AL+GRAPHENE+CARBON NANOTUBES) sintered specimens

Weight percentage of reinforcement to matrix	0.8 WT%	1 WT%
Rockwell Hardness No	40	41

Table 8

Hardness for (AL+GRAPHENE) sintered composites

Weight percentage of reinforcement to matrix	0.8 WT%	1 WT%
Rockwell Hardness No	35	37

Table 9

Vickers Micro Hardness for (AL+GRAPHENE+CARBON NANOTUBES) cold pressed composites

Weight percentage of reinforcement to matrix	Pure aluminum	0.2 WT%	0.4 WT%	0.6 WT%	0.8 WT%	1 WT%
Vickers Micro Hardness no	40.1	39.7	40.9	42.6	42.4	44.6

Table 10

Vickers Micro Hardness for (AL+GRAPHENE) cold pressed composites

Weight percentage of reinforcement to matrix	Pure aluminum	0.2 WT%	0.4 WT%	0.6 WT%	0.8 WT%	1 WT%
Vickers Micro Hardness no	40.1	37.2	38.4	41.6	42.4	43.6

Table 11

Hardness for (AL+GRAPHENE+CARBON NANOTUBES) sintered specimens

Weight percentage of reinforcement to matrix	0.8 WT%	1 WT%
Rockwell Hardness No	43.9	45.5

Table 12

Hardness for (AL+GRAPHENE) sintered composites

Weight percentage of reinforcement to matrix	0.8 WT%	1 WT%
Rockwell Hardness No	43.4	43.9

1.3. Physical properties can be 'chemically tuned

a) Barrier material—impermeable if defect-free

b) High temperature 'base' (support) material (in reducing or neutral conditions)

1.4. Different methods to manufacture MMNCs

In recent years the potential of metal-matrix nano composite (MMNC) materials for significant improvement in performance over conventional alloys has been recognized widely. However, their manufacturing costs are still relatively high. There are several fabrication techniques available to manufacture the MMNC materials there is no unique route in this respect. Due to the choice of material and reinforcement and of the types of reinforcement, the

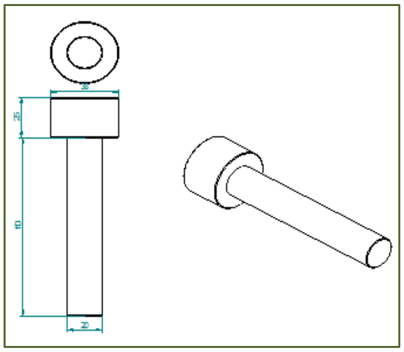

Figure 4

Plunger

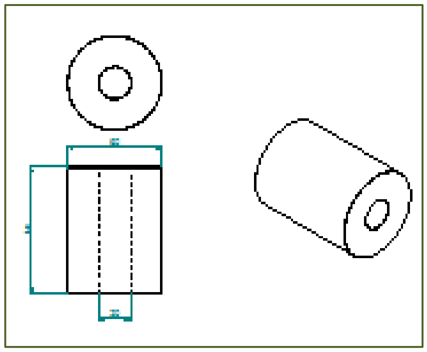

Figure 5

Die Body (All dimensions are in mm)

Figure 6

Disassemblies of Compression die

Figure 7

Assembly of compression. (Bottom plate, Punch and (Bottom plate, Punch and body)

fabrication techniques can vary considerably. The processing methods used to manufacture reinforced MMNCs can be grouped as follows:

1) Solid-phase fabrication methods
   i) Diffusion-bonding method
   ii) Powder Metallurgy Technique
2) Liquid-phase fabrication methods
   i) Liquid-metal infiltration
   ii) Squeeze casting
   iii) Spray co-deposition
   i) iv)Compo casting
3) Vapor state method
   i) Physical vapor deposition (PVD)

1.5. Powder metallurgy

Powder metallurgy is science of producing metal powders and making finished / semi finished objects from mixed or alloyed powders with or without the addition of nonmetallic constituents. This is one of the most common routes to synthesize a metal-matrix composite. The reinforcements used in this process are generally particulates or whiskers-reinforced MMCs. The powder metallurgy is one of the popular solid state methods used in production of metal matrix composites. The matrix and the reinforcement powders are blended to produce a homogeneous distribution. In this process, prepared powders of both matrix and reinforcement phases are mixed and blended together. This mixture is put in a mould of required shape and appropriate pressure is applied to compact the powder. Then the compacted form of the powder is heated at a sufficiently high temperature in an inert atmosphere to develop proper bonding between the matrix and reinforcement through solid state diffusion. This is the sintering process. Hot pressing can also be used to directly press the blended mixture of powders.

2. MATERIALS AND METHODS

2.1. Powder Weighing

Commercially pure Aluminum powder of 200 mesh size(approx 65-70 µm grain size), purity 98% as a matrix and commercially pure Multiwall Carbon nanotubes synthesized from carbon vapor deposition method and Graphene as reinforcement were procured from different company.

The Aluminums powder, CNTS and Graphene were weighed in electronic balance machine according to required weight percentage which is mentioned in tables 1 to 4.

2.2. Ball Milling

AL/MWCNTs powders were prepared by a mechanical mixing process. The mechanical mixing process produced relatively homogeneous mixture of MWCNTs, Graphene and AL powder. Several methods have been used for dispersing CNTs in aluminium powder such as dispersing in liquid medium by ultrasonic mixing, blending, mechanical milling, spray drying. Ball milling is leads to result in moderate to good dispersion with poor to excellent mechanical properties. Most of the studies have used ball milling for the powder preparation, Al/MWCNTs were placed in ball milling setup consists of steel ball of 10 mm diameter, the process of mixing is continued for duration of 30 min at 200 rpm in order to get uniform mixing for different composition Powder And Reinforcement Materials (Figures 1 & 2).

2.3. Die description

(Figures 3-5)

2.4. Compression (or) cold pressing

Compaction die is made of EN8 steel. Compaction die have punch, bottom plate and body. The powder mixture of a particular weight percentage of MWCNT, Pure aluminum Graphene and was compacted in the die assembly using a

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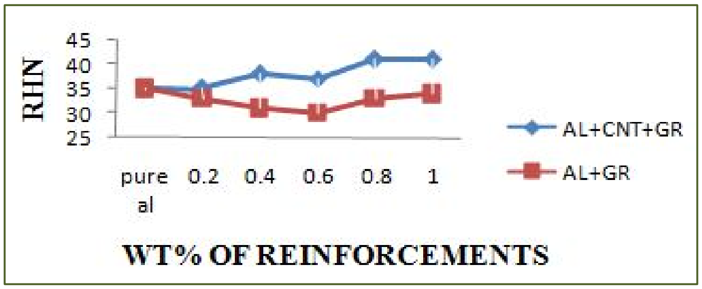

Figure 8

Comparison of Hardness between (AL+CNT+GR) and(AL+GR) green compact

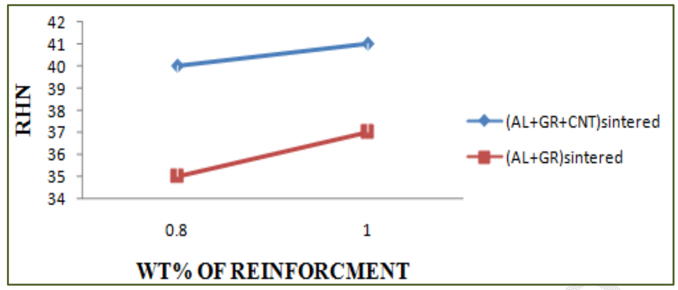

Figure 9

Comparison of Hardness between (AL+CNT+GR) and (AL+GR) sintered specimen

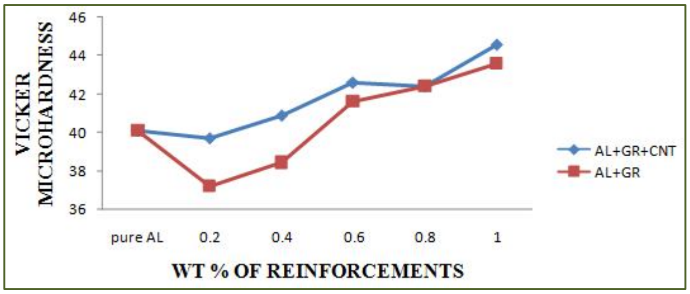

Figure 11

Comparison of micro hardness between (AL+CNT+GR) and (AL+GR) green compact

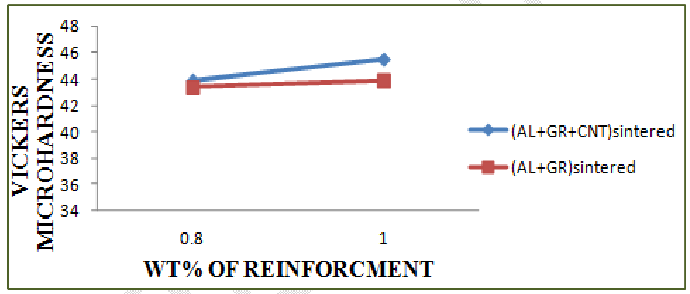

Figure 12

Comparison of micro hardness between (AL+CNT+GR) and (AL+GR) sintered specimens

Figure 10

Micro hardness testing machine

compression testing machine. Al and MCNTs powder was uniaxially pressed in die under a pressure of 140KN for 2min. Al, Graphene and CNTs were compacted at a load to form billet of 20 mm diameter and 25 mm height. The work part after pressing is called a green compact body (Figure 6 & 7).

2.5. Sintering and extrusion

Sintering is a heat treatment process performed on the compact to bond its metallic particle thereby increasing strength and hardness. The treatment is usually carried out at temperature between 0.7 and 0.9 times melting temperature of the base metal. Shrinkage of AL+CNT+GR and AL+GR was occurs during sintering as a result of pore size reduction. This depends to a large extent on the density of green compact which depends on pressure during compact. Sintering process is carried in the die where temperature is maintained across the body of the die of about 0.7 and 0.9 times melting temperature of aluminium that is around about 5800c and external load of about110 KN is applied through plunger. Extrusion is carried on same die where the bottom plate is replaced by 10mm bore plate, sintered specimen is squeezed through 10mm bore plate where we can obtain 10mm extruded rod.

3. RESULTS

3.1. Hardness measurement

Rockwell Hardness Testing using Diamond indenter (1.6mm or 1/16” diameter and 120degree apex angle) with an applied load of 150Kg for 30second.Three different specimens of different % of CNT and a pure Al specimen are to be taken from each sample at different sections for testing to ensure the validity of the results. Samples are cut about 10mm thickness. The surface of the specimens has to be grinded and polished to be ready for testing and this is done by the sample preparation technique. The measurements were performed at room temperature at a load of 150KN and 30 seconds of dwell time. All readings were taken in Rockwell Hardness Number (RHN). Three different indentations are made at different sites on each of the samples as shown in Figure and the average is taken as a final result. Various compositions of CNT/Al composite having 0.5, 1 and 1.5 % of Al were produced. The average hardness values of the samples were measured using Rockwell Hardness Number (RHN) (Figures 8 & 9; Tables 5-8).

3.2. Micro hardness measurement

Micro hardness is a depth sensing indentation test from which hardness of material are obtained at nanolevel. The load and depth of penetration are measured with high precision as the diamond indenter penetrates the sample. The micro hardness study is conducted on the machine which is shown in figure. The test is conducted for the value of test load 0.9807N (Figures 10-12; Tables 9-12).

4. DISCUSSION

From the figure 5.1 and 5.2 shows the comparison graph of hardness for cold pressing compacts and also sintered specimens in which it clearly shows the increase in hardness as reinforcement percentage increases. We also observe that hardness is slightly higher for AL+GR+CNT composites comparing to AL+GR composites. From the figure 5.3 and 5.4 shows the comparison graph of Vickers Micro hardness for cold pressing compacts and also sintered specimens in which it clearly shows the increase in hardness as reinforcement percentage increases. We also observe that Vickers Micro hardness is slightly higher for AL+GR+CNT composites comparing to AL+GR composites. The above result may be due to formation of more refined and compacted Microstructure for AL+GR+CNT comparing to AL+GR composite because Graphene in its 2D form doesn't makes refined and compaction structure with Aluminium.

5. CONCLUSION

As the weight percentage of reinforcement to metal matrix increases corresponding to that Rockwell hardness number increases and as the weight percentage of the reinforcement to metal matrix increases corresponding to that Vickers micro hardness is also increases. This shows that hardness is mainly depends on weight of the metal matrix and the number of reinforcements. Hence hardness can be increases by increasing number of reinforcements.

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