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Investigation of MWCNT Reinforced (Al-10Ni4Co) Metal Matrix Composite Processed Through Powder Metallurgy Technique

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Abstract - **Nowadays the requirement for newer materials with improved properties for applications in automotive and aerospace industries are increasing and the composite materials are the solutions. In this work, characterization of 85.5 % pure aluminum with 10 % nickel and 4% cobalt, reinforced with various proportions of Multi Walled Carbon Nanotubes [MWCNT] is studied. Al-Ni-Co Metal Matrix Composite (MMC's) are prepared by Powder Metallurgy (P/M) technique with 0.5, 0.75 and 1% of MWCNT addition. To investigate the effects of adding MWCNT particles, microstructural analysis, determination of mechanical properties and thermal conductivity are studied as per ASTM standards. From the Scanning electron microscope analysis, uniform distribution of MWCNT particulates are visualized inside the matrix of aluminum, nickel and cobalt. From the mechanical characterization techniques, it is observed that increase in addition of MWCNT, micro-hardness and compression strength increases, whereas thermal conductivity decreases. Thus the composite which will be used for the applications where light weight with high strength and hardness is required like airframe and aerospace applications.**

Index Terms - **MWCNT particles, Powder Metallurgy, SEM, Micro Scopic Analysis, Micro Structural Analysis.**

1.INTRODUCTION

Material selection is in most cases a contradictory decision-making process. Light-weight materials will most likely not possess sufficient strength, and brittle materials will not necessarily be good in fatigue resistance, stiffness or toughness. It is also almost impossible to find a single monolithic material with the required property profile for engineering applications. Moreover, material properties are greatly affected by the working environment (such as temperature, pressure, humidity, etc.) and the nature of loading (gradual, fluctuating, impact, fatigue, etc.). There is need, therefore, to combine two or more materials, as alloys or composites so as to utilize the different useful properties offered by the different materials.

For that a new Aluminium Metal Matrix Composite (Al-10Ni-4Co) combined with a reinforcement of Multi Walled Carbon Nano Tubes (MWCNT) is introduced and the above difficulties were overcomed by this experimentation process. Hence a new MMC with a high strength to weight ratio can be obtained by powder metallurgy techniques like blending, compacting and sintering and analyzed to identify that the composite would satisfy the engineering needs in various applications like small helicopters, automobiles, space and aircrafts. As a result of this experimentation, a new metal with increased compressive strength and hardness is found.

Composite Material

Composite materials are heterogeneous solid that consist two or more materials which are different, metallurgically and mechanically bonded for the purpose of rectifying the weakness in one material with the better properties of another material.

Since the early 1960s, there has been an increasing demand for materials that are stiffer and stronger, yet lighter in aeronautic, energy, civil engineering and in various structural applications. Unfortunately, no monolithic engineering material available is able to satisfy them. This need and demand certainly led to the concept of combining different materials in an integral composite structure.

Reinforcement

Types of Reinforcement

A reinforcement phase usually exists with substantial volume fractions (10% or more). Hence, three common types of composites depending on the size and/or aspect ratio and volume fraction of reinforcing phase can be described as:

a. Particle strengthened
b. Discontinuous fiber reinforced
c. Continuous fiber reinforced composites

In these, the function of each component can be different: in particle- strengthened composites, the matrix bears the main load and small dispersed particles obstruct the motion of dislocations in the matrix; and the load is distributed between the matrix and particles. In Fiber Reinforced Composites (FRC), the fibers bear the main load and the function of the matrix is confined mainly to load distribution and its transfer to the fibers.

In order to suit the varying needs of applications requiring materials with enhanced properties at lighter weight for application in aerospace and automotive fields, novel materials reinforced with ceramic particles were developed. However, the performances of these composites depend upon the matrix material, processing techniques, type of reinforcement and the processing parameters.

Multi-Walled Carbon Nanotubes

Multi-walled carbon nanotubes (MWCNTs) are a special form of carbon nanotubes in which multiple single-walled carbon nanotubes are nested inside one another. It is shown in the Fig.1.1. Although MWCNTs are still classed as a 1- dimenional form of carbon, the unique properties that are seen within single- walled and double-walled carbon nanotubes are not as prominent. The number of nanotubes that are within a MWCNT can vary - from as little as 3, to over 20. At the same time the diameter of both the internal nanotube and the external most nanotube can vary - from 2nm for the innermost tube, to over 50nm for the outer wall. Just like single-walled nanotubes, they exhibit exceptional electrical, thermal, and mechanical properties.

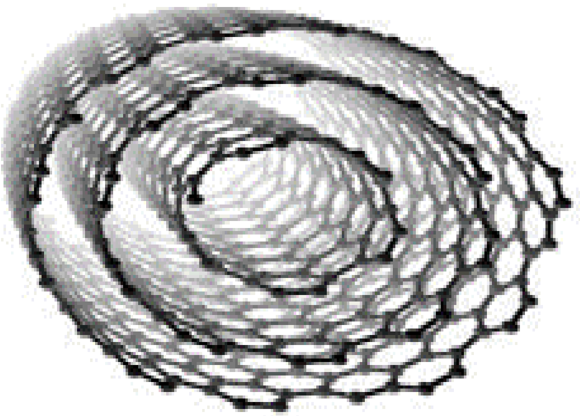


Fig. 1.1. MWCNT

By hybridizing multi-walled carbon nanotubes (MWCNTs) reinforced Al matrix composites, in this composite was fabricated to achieve excellent mechanical properties and low coefficient of thermal expansion. Composite materials contain a matrix with one or more physically distinct, distributed phases, known as reinforcements.

The reinforcement is added to the matrix in order to obtain the desired properties like toughness, thermal conductivity, coefficient of thermal expansion and wear resistance. Wear resistance materials are also currently in demand for automotive and aerospace applications besides lightweight and good mechanical properties.

1.2 Powder Metallurgy

Powder metallurgy is the name given to the process by which fine powdered materials are blended, pressed into a desired shape (compacted), and then heated (sintered) in a controlled atmosphere to bond the contacting surfaces of the particles and establish desired properties.

Fig. 1.2. Powder Metallurgy component

The process, commonly designated as P/M, readily lends itself to the mass production of small, intricate parts of high precision, often eliminating the need for additional machining or finishing (Klar 1998). There is little material waste, unusual materials or mixtures can be utilized, and controlled degrees of porosity or permeability can be produced. Major areas of application tend to be those for which the P/M process has strong economic advantage or where the desired properties and characteristics would be difficult to obtain by any other method. The material of powder metallurgy component is shown in Fig.1.2.

1.2.1 Importance of Powder Metallurgy

PM parts can be mass produced to net shape or near net shape, eliminating or reducing the need for subsequent machining.

PM process wastes very little material - about 97% of the starting powders are converted to product.

PM parts can be made with a specified level of porosity, to produce porous metal parts.

1.2.2 Stages of Powder Metallurgy

First the primary material is powdered and divided into many small individual particles. It is shown in the Fig.1.3.

Two or more metal and or non metals are mixed or blended together to form a homogeneous mixture.

The blended mix is introduced into a mold cavity or a die and pressed to produce a weak cohesive mass called as green compact.

The green compact is then subjected to very high temperature and pressure for a known time to get a hardened mass.

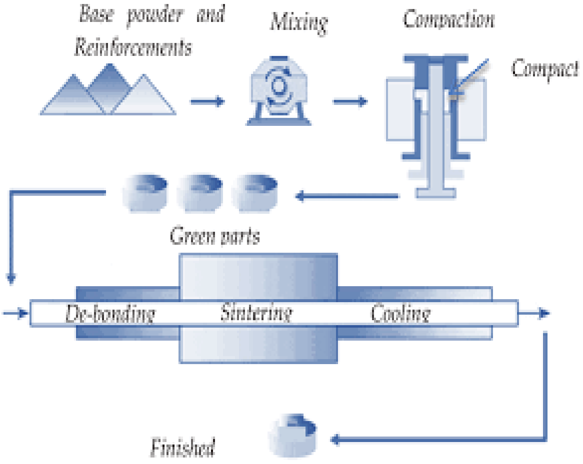


Fig. 1.3. Powder Metallurgy process

2.RESEARCH LITERATURE

In the present study, industrial waste has been used as reinforcement in pure aluminium to enhance the physical and mechanical properties. This can be effectively obtained by the creation of Aluminium Metal Matrix Composites (AMMC). The present research work is focused on the synthesis of grinding sludge (GS) based AMMC by powder metallurgy. The composites contain pure Al matrix reinforced with three different weight percentages of grinding sludge constituents (6, 16 and 29 wt%). After that, the microstructure, density, hardness and compressive strength at room temperature are investigated. The presence of AlFe and $AlFe_3$ inter-metallic compounds has been examined using SEM (scanning electron microscope) area mapping and XRD (X-ray Diffraction)[1].

Optical Microscope and mechanical properties were evaluated by Vickers hardness tester and compression test. The test results revealed that increase in hardness and compressive strength of the composite was evidenced with increasing reinforcement level. The fabricated composites showed a good sintering response and the density achieved was maximum. Optimal microstructure showed homogeneous distribution of reinforcement particles in the composites. The wear rate of composites gets decreased with increased wt% of SiC due to formation of mechanical mixed layer (MML) and resist the direct contact of mating parts[2].

A strategy utilizing carbon nanotubes (CNTs) was put forward to prepare Titanium–zirconium–molybdenum (TZM) composites, which comprised Mo– 0.5Ti–0.1Zr–0.03CNTs (wt.%), via high–energy ball milling (HEBM), followed by spark plasma sintering (SPS). The microstructural evolution of the TZM composite powders and the sintered samples were characterized by X–ray diffraction (XRD) and scanning electron microscopy (SEM). Their Vickers hardness and compression mechanical properties were also investigated[3].

To our knowledge, this is the first study that investigates the effect of HTC on iron matrix composites. Microstructure, hardness, compression and corrosion behaviors of composites were investigated. According to the results, mechanical properties of composites were enhanced with the increasing of HTC/HTC* amount. However, high corrosion resistances were gained with the using of the low amount of HTC (0.25 and 0.50 wt%) and HTC* (0.25 wt%)[4].

Aluminum matrix composites consisting of Al2024 and Fe-based metallic glass powders were prepared via powder metallurgy by using an optimized matrix to reinforcement particle size ratio, the influence of glassy particle size on mechanical properties and dry sliding wear behavior of the composites were investigated. The composites showed dense structure and homogenous three- dimensional distribution of the reinforcements independent of particle size. The particle size has negligible influence on yield strength, while ultimate tensile strength and ductility gradually decrease with increasing particle size. Reduced specific wear rate was observed when particle size increases, most likely because of the evolution of the surface topography during sliding where the wear of matrix is protected when particles are large[5].

Carbon nanotubes (CNTs)-reinforced aluminum composites have attracted attention due to their high specific strength low density, which makes them suitable for the use in aerospace and automobile industries. In this review, preparation methods of Al/CNTs composites for achieving a homogeneous desperation of the CNT in the Al matrix are summarized. In addition, the effect of processing methods on carbon nanotube distribution and enhancement of mechanical properties such as toughness, wear behavior and hardness of the nanocomposites are reviewed. Improvement of mechanical characteristics was observed by the incorporation of carbon nanotubes in aluminum matrix. The strengthening factors gained by the carbon nanotubes addition are the interface of metal and CNTs and the chemical and structural stability of CNTs[6].

The composites were made by via powder metallurgy practice, where the reinforcement TiN is added in to Al matrix by 5, 10 and 15 percentage by weight. The drive of this paper is to study the microstructure and wear mechanism of produced composites. The SEM equipped with EDS facility has been used for the study of microstructure of composites. The wear behaviour and tribo-chemistry of the both matrix and composites has been studied as a function of sliding distance and load. The pin-on-disc has been used to analysis of the wear rate. The study reveals that the wear resistance of composites produced decreases with increase in load. However the wear resistance of Al is less than the wear resistance of composites produced. Also the wear resistance of composited increases with the increase in the addition of reinforcement[7].

The aluminum matrix with different compositions using a combination of stir casting and semisolid extrusion. The microstructure and mechanical properties of the produced nanocomposites were evaluated. The results showed that the presence of Nickel acts as an appropriate metallic carrier for SiC nanoparticles, which causes uniform dispersion and spherical grains. Consequently, the coexistence of SiC nanoparticles and Nickel resulted in UTS of above 304 MPa and elongation of 5.8%. However, the addition of Titanium caused the formation of flake-like intermetallic, which decreased the elongation of the nanocomposites. The method introduced in this study for the incorporation of SiC ceramic nanoparticles can be used as a promising process instead of conventional methods, which are expensive and time-consuming[8].

The effect of SiC amount on structural, physical and mechanical properties of Al matrix composite (AMCs) was investigated. Al6061 alloy and three composites were fabricated by powder metallurgy technique (0, 7.5, 10 and 13 wt.% of SiC). The prepared composites were characterized by X-ray diffraction, optical microscopy and Vickers hardness. Physical properties (Density) of the prepared Al6061-SiC composites were measured. The microstructures show a homogeneous distribution of SiC nanoparticles into the aluminium matrix. We have found a significant increase of hardness and density of the composites with the increase of silicon carbide quantity. However, it is noticed that the porosity of Al-SiC composites decreases with the increase of SiC amount[9].

In this investigation, five aluminum matrix nanocomposites were obtained by the hot pressing at 800 MPa and 600 °C. The electrolysis coating technique was utilized to prepare the nano-nickel powder. The fabricated nanocomposites were characterized by studying their chemical composition, microstructure, hardness, and thermal expansion coefficient. The scanning electron microscope of the microstructure of the electroless nickel powder shows that the Ni particles have nano-size where it was less than 100 nm. The EDAX analysis of the fabricated composite that contains 25 wt. % (Al_2O_3) in different regions was established. No elements rather than Al, Cu, Ni, and O were observed. The hardness of the aluminum matrix increases as the content of the Al_2O_3 increases. In addition, the thermal expansion coefficient was reduced by increasing the Al_2O_3 content for reasons related to the low thermal expansion of the alumina reinforcement 7.2x10^{-6} mm/ºC compared with aluminum that has 23.1x10^{-6} mm/ºC[10].

Aluminium matrix reinforced with Al_2O_3–carbon (2.5, 5, 7.5 and 10 wt.%) in equal proportion was prepared by stir casting. Phase, microstructure, EDS, density, hardness, impact strength and tensile strength of prepared samples have been investigated. X-ray diffraction reports the intermediate phase formation between the matrix and reinforcement phase due to interfacial bonding between them. Scanning electron microscopy shows that Al matrix has uniform distribution of reinforcement particles, i.e. Al_2O_3 and carbon. Density decreases due to variation of reinforcement because ceramic reinforcement has low density. Hardness decreases due to variation of carbon since it has soft nature. Impact strength was found to increase with addition of reinforcement[11].

The aluminum matrix composites are widely used in automobile sectors, aerospace, and other engineering applications. The aim of this present study is to develop aluminum reinforced SiC-TiC hybrid metal matrix composites by liquid stir casting process. It also investigates the effect of hybrid ceramic reinforcements on the microstructural, mechanical and tribological behavior of composites. In present study, for composites SiC content is fixed as 1 wt% and TiC content is varied as (1, 1.5, 2 and 2.5 wt%). It is found that increase in the reinforcement content of SiC-TiC particles increases the hardness and decreases the density of composites. Improvement in wear resistance is also seen at higher reinforcement content. It is expected that this composite is beneficial in the development of lightweight composites for aerospace applications[12].

Vickers microhardness test was conducted to find out the microhardness. Using pin-on-disc wear-tester experiments were conducted with a velocity of 1.2 m/s over a sliding distance of 2.5 km of load 5 N. Scanning Electron Microscopy (SEM) analysis was carried out to investigate the worn surface. Experimental results showed that the Vickers microhardness number have been increased to 66 by addition of 15% ZnO, which was double that of the matrix material. Wear experiments revealed improved wear resistance by the addition of ZnO particles. SEM analysis exposed that abrasion, delamination and oxidation were the predominant wear mechanisms for the matrix material and AA7068-5% ZnO composite and adhesion and oxidation for composites reinforced with 10% and 15% ZnO particles[13].

A range of porosity values was achieved between 34% to 43% for different combinations of aluminum matrix and alumina reinforcement phase. The crystallite size of the alumina reinforcement phase in Al-3 wt% alumina and Al-15 wt% alumina composite foam was estimated as 23.51 nm and 23.24 nm while the crystallite size of the aluminum matrix was determined as 15.72 nm and 15.44 nm for the same samples. The Field Emission Scanning Electron Microscope (FESEM) images indicated micro-size pores, which were connected via channels. The composite foam with 3 wt% of Al_2O_3 nanoparticles had a more uniform microstructure and more channels than other samples. The Vickers hardness values of the composites foam increased with an increase in wt% of alumina particles. This amounts to an approximately 93% increase in hardness when 15 wt% alumina particles are added to the aluminum foam. The sample with 3 wt% Al_2O_3 nanoparticles showed enhanced compressive strain up to 50% with high compressive strength up to 45 MPa and a uniform microstructure[14].

Composites with light metals as the matrix and ceramic particles as the reinforcements are being acknowledged widely during the past decade for their superior mechanical properties, the most successful among them have been Aluminium/Alumina (Al/Al_2O_3) composite where Alumina particulates are reinforced in Aluminium matrix. Present work deals with fabrication and characterization of Al/Al_2O_3 ultra-fine composites with 10, 20, 30 and 40% Al_2O_3. These ultrafine composites are fabricated using uniaxial hot press under 10^{-5}mbar vacuum pressure at 400 °C sintering temperature and 3-tonne load for 2 h experimental condition. Effect of Al_2O_3 volume fraction on microstructural and mechanical properties of the composite are studied through optical microscopy. Phase analysis and microstructure investigations revealed that the consolidated material consists of Al as a matrix phase and Al_2O_3 phases with size below 1 µm homogeneously dispersed in a continuous matrix. Taking into consideration the results of above experiment, Al/Al_2O_3 system Functionally Graded (FG) Material is successfully hot pressed using powder metallurgy (PM) route under similar experimental conditions[15].

Scanning electron microscope (SEM) was used to characterize the morphology and microstructure of the produced composites as well as wear mechanisms. Energy-dispersive X-ray spectroscopy (EDX) test was used to investigate the elemental composition of the composites. The results showed that adding graphite to the aluminum matrix composite containing eggshell has a positive impact on the tribological properties of the composite up to a certain limit (1.5 wt%). However, the additional increase in graphite content has an adverse effect. Hybrid composites with 3 wt% eggshell show the best compressive strength and hardness, whereas hybrid composite with 9 wt% eggshell has the lowest compressive strength and hardness. The mass loss of the hybrid composite increases with the increase in the graphite weight percentages regardless of the eggshell weight percentages. The combination of SEM micrographs and EDX showed signs for three wear mechanisms: abrasive, adhesive and delaminated wear in the examined composites[16].

Significant research has been focused on the development of carbon nanotube (CNT) reinforced aluminum nanocomposites, which are quickly emerging because of their lightweight, high strength and other mechanical properties. The potential applications of these composites include the automotive and aerospace industries. In this study, powder metallurgy techniques are employed to fabricate aluminum (Al)/CNT nanocomposites with different raw material properties with optimized conditions. We successfully fabricated three different samples, including un-milled Al, un-milled Al with CNT and milled Al with CNT nanocomposites, in the presence of additional CNTs with various experimental conditions using a planetary ball mill. Scanning electron microscopyand field emission scanning electron microscopy are used to evaluate the particle morphology and CNT dispersion. The CNTs are well dispersed on the surface of the fabricated milled Al with CNT nanocomposites than un-milled Al with CNT nanocomposites for milling. The fabricated Al/CNT nanocomposites are processed by a compacting, sintering and rolling process. Vickers hardness measurements are used to characterize the mechanical properties. The hardness of the Al/CNT nanocomposites are improved milled Al with CNT nanocomposite compared other fabricated composites[17].

Existing aluminium metal matrix composites (Al MMCs) can attain both high tensile yield strength (>500 MPa) and high elastic modulus (>90 GPa) but usually at the expense of tensile strain-to-fracture (~5% or less).

Here we report the development of a novel class of Al MMCs that can offer tensile yield strength of 515 ± 17 MPa, elastic modulus of 95.6 ± 1.7 GPa and tensile strain-to-fracture of 10.4 ± 0.8%. Our design hypothesis is to reinforce the Al matrix with ex situ introduced carbon nanotubes (CNTs) for primary strengthening but at the same time we craft a high number density of in situ formed ultrafine γ-Al_2O_3 nanoparticles to improve dimple fracture. Together they act in concert to render outstanding tensile properties. The strengthening and failure mechanisms of the as-fabricated Al-CNTs-γ-Al_2O_3 MMCs are characterized in detail. The design concept proposed and validated in this study can be informative for the fabrication of other high-performance carbon-reinforced MMCs[18].

The effect of carbon nanotube (CNT) amount in aluminium (Al)–CNT composites produced by adding CNT to Al alloy in various amounts on microstructure and hardness of CNT-reinforced aluminium metal matrix composites was investigated. CNT was added to Al matrix in different weight percentages. Two different ball materials, namely tungsten ball and aluminium oxide ball, were used for same composition of Al–CNT composites. The milled powders were compacted inside the compaction die and then sintered using microwave sintering process. The microstructural analysis of CNT-reinforced aluminium nanocomposite ball-milled powder is sintered and scanned using SEM. The Brinell hardness test is conducted for Al–CNT nanocomposite samples for both 60 and 100 Kgf loads, and it can be observed that the highest enhancement in hardness value has occurred in CNT 1.3 wt% reinforced into aluminium composites for both 60 and 100 Kgf load. Hence, it can be understood that the alumina ball-milled samples have slightly higher improvement in hardness than compared to tungsten ball-milled samples[19].

Carbon nanotubes (CNT) have received huge attention from the scientific community in the last two decades due to their unique structure and properties. They have been considered for potential applications in various areas of science and technology. One of the major applications of CNT is as reinforcement for fabrication of light weight high strength composite materials for use in automobile and aerospace applications.

Aluminium and its alloys are natural choices for such applications due to their low density, high specific strength and modulus. In the last decade, there have been significant advances in the processing of carbon nanotube reinforced aluminium matrix (Al-CNT) composites. New understanding has emerged due to research on several aspects such as damage to CNTs during processing, interfacial phenomena, novel methods of processing for improving CNT dispersion, tensile behaviour, numerical modelling and in situ tensile testing. This review summarizes the present status of the tensile properties of pure Al-CNT and Al alloy-CNT composites. The various processing routes for fabrication of Al- CNT composites have been compared in terms of the resulting microstructure, degree of CNT dispersion, extent of interfacial reaction and its effect on the tensile properties[20].

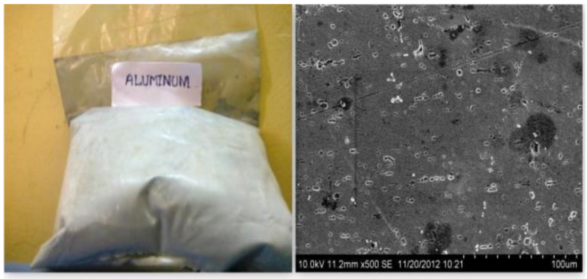
3. MATERIAL AND WEIGHT RATIO CALCULATION

As a result of a growing awareness of the interconnectivity of global environmental factors, principles of sustainability, industrial ecology, eco-efficiency, and green chemistry and engineering are being integrated into the development of the next generation of materials, products, and processes. For fabricating the environmental friendly composite material, the base material chosen for the preparation of MMC is 99.9 percentage pure aluminum, nickel and cobalt as a secondary material and MWCNT to reinforce the matrix. Aluminum is chosen to reduce the weight of the composite material and to provide the required ductility, nickel, cobalt and MWCNT is added to improve the strength and hardness of the MMC (Rahman & Rashed 2014).

3.1. Materials

3.1.1. Aluminum powder

Aluminum is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation make it an ideal material for use in conventional and novel applications. Aluminum has become increasingly important in the production of automobiles and trucks, packaging of food and beverages, construction of buildings, transmission of electricity, development of transportation infrastructures, production of defense and aerospace equipment, manufacture of machinery and tools and production of durable consumer products. As demand for more technologically complex and ecologically sustainable products increases, opportunities for aluminum will continue to expand. Depending on amount of impurities, aluminum is classified into extreme purity aluminum Aluminum is well known for its low density, 2.7 g/cm3, high reflectivity and high electrical and thermal conductivity. It is very resistant to atmospheric corrosion, due to instantaneous formation of an adherent oxide film, which protects the metal against further attack. The main effects of purity are upon electrical resistivity and thermal conductivity. Corrosion is one of the main reasons for failure of the engineering materials in service. Pure aluminum resists corrosion better than commercial one. That is why it is used for cladding alloys. Aluminum has a resistance to corrosion in some common environments, including the ambient atmosphere. It has been associated with the presence of a continuous oxide film on its surface (Totten & MacKenzie 2003).



Aluminum Powder SEM image

Fig. 3.1. Used Aluminum powder and SEM image (x500)

The strength and durability of aluminum alloys vary widely, not only as a result of the components of the specific alloy, but also as a result of heat treatments and manufacturing processes. The usage of PM aluminum parts has seen a significant recent growth, driven largely by the automotive sector’s desire for weight reduction. Camshaft bearing caps have emerged as a leading application for PM aluminum parts. Figure 3.1 shows the aluminum powder used in this study and its SEM image. Aluminum powders, produced by a variety of techniques, have physical and metallurgical characteristics related to their method of manufacture and tailored to their end use. Also, aluminum powders can be consolidated into larger structural components by several powder metallurgy processes (Davis 1999).

3.1.2 Nickel powder

Nickel in elemental form or alloyed with other metals and materials has made significant contributions to our present-day society and promises to continue to supply materials for an even more demanding future. Nickel has always been a vital metal for a wide variety of industries for the simple reason that it is a highly versatile material that will alloy with most other metals. Nickel is a versatile element and will alloy with most metals. Nickel alloys are alloys with nickel as principal element. Complete solid solubility exists between nickel and copper. Wide solubility ranges between iron, chromium, and nickel make possible many alloy combinations. Its high versatility, combined with its outstanding heat and corrosion resistance has led to its use in a diverse range of applications; such as aircraft gas turbines, steam turbines in power plants and its extensive use in the energy and nuclear power markets.

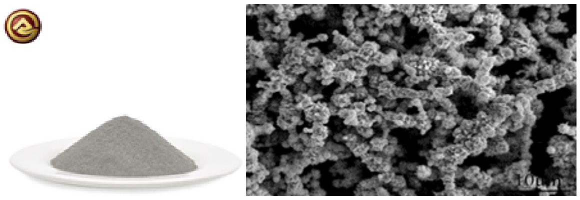


Fig. 3.2. Used Nickel powder and SEM image (x500)

3.1.3 Cobalt powder

Cobalt (Co) alloys have been in use since 1907 when Elwood Haynes obtained the first patents on cobalt–chromium compositions Historically, many of the commercial cobalt-base alloys are derived from the cobalt–chromium–tungsten and cobalt–chromium–molybdenum ternaries. Fig. 3.3 shows the used cobalt powder and SEM image (×500)

Cobalt alloys have good magnetic properties, corrosion resistance, wear resistance, and high temperature strength. These properties arise from the crystallographic nature of cobalt, the solid-solution-strengthening effects of Cr, W, and Mo, the formation of metal carbides, and the corrosion resistance imparted by Cr. Relatively harder Co-alloys is used for resistance to wear. On the other hand the tougher Cobalt compositions are used for high-temperature applications such as gas-turbine vanes and buckets. Co-based alloys are also used to produce artificial joints thanks to their excellent biocompatibility (Hassani *et al.*, 2016; Martinez- Nogues *et al.*, 2016). Although in terms of properties, nickel-based alloys have taken the majority share of the superalloy market, Co-alloys give superior hot corrosion resistance to gas turbine atmospheres, due to their high Cr content, and they show superior thermal fatigue resistance and weldability over Ni-alloys (Sato *et al.*, 2006).

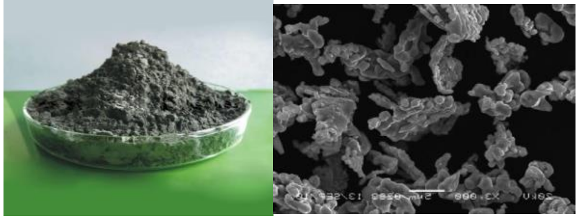


Fig. 3.3. Used Cobalt powder and SEM image (x500)

3.1.1. MWCNT

Multi Walled Carbon Nanotubes are hollow, cylindrically shaped allotropes of carbon that have a high aspect ratio (length to diameter ratio). Their name is derived from their structure and the walls are formed by multiple one-atom-thick sheets of carbon. MWNTs consist of multiple rolled layers of concentric nanotubes of graphene inside other nanotubes.

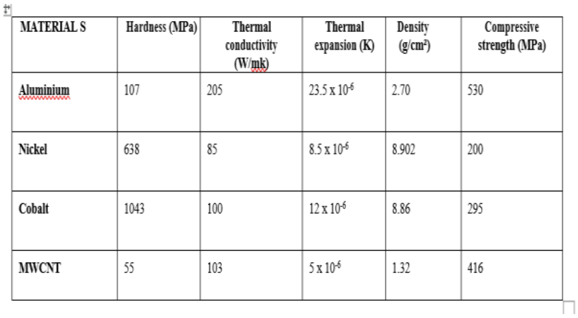
Multi walled Carbon nanotubes (MWCNTs), due to their superlative mechanical and physical properties, have shown a high potential to improve properties of polymeric composites. Adding CNTs into polymers at very low weight fractions can improve mechanical properties of the resulting nanocomposites. In the present paper, multi-walled carbon nanotubes (MWCNTs) at different weight ratios (0.05, 0.1, and 0.5 wt.%) were added to polyester.

Mechanical stirring, ball milling and sonication technique were used to achieve good dispersion state of MWCNTs in the polymeric matrix. The results of mechanical tests (tensile and flexural) exhibit improvements of tensile and flexural strengths by 6% and 20%, respectively, at only 0.05 wt.% MWCNT. Improvements in Young's modulus and flexural modulus were also observed. Scanning electron microscopy was employed to determine the dispersion state of nanotubes in the matrix as well as the fracture surface properties. The Fig. 3.4 shows the used MWCNT powder and SEM image (×500).

Fig. 3.4. Used MWCNT powder and SEM image (x500)

From choosing the above materials for the experimentation process, the materials have been studied and the various physical and mechanical properties are obtained. The Table 3.1 shows the various properties of the materials selected.

Table 3.1. Material Properties



MATERIAL S	Hardness (MPa)	Thermal conductivity (W/mk)	Thermal expansion (K)	Density (g/cm²)	Compressive strength (MPa)
Aluminium	107	205	23.5 x 10^{-6}	2.70	530
Nickel	638	85	8.5 x 10^{-6}	8.902	200
Cobalt	1043	100	12 x 10^{-6}	8.86	295
MWCNT	55	103	5 x 10^{-6}	1.32	416

3.2 CALCULATION

In this chapter, the pure form composition and the various composition of the Aluminium metal matrix composite with different metals in terms of grams used for the manufacture of samples and testing are calculated and found. The formulae with density and weight percentage of materials relationship has been. The calculation of the required materials in terms of weight are given below

Pure form Composition
86Al+10Ni+4Co
Density of Materials
Al = 2.53 kg/m^3 Ni = 8.908 kg/m^3 Co= 8.86 kg/m^3
MWCNT = 2.6 kg/m^3
Density = (Weight % of Al) × (Density of Al) + (Weight % of Ni) × (Density of Ni) + (Weight % of Co) × (Density of Co)
= 0.86×2.53+0.10×8.908+8.86×0.04
= 2.1758+0.908+8.9
Density = 11.9838 kg/m^3
Mass = Density × Volume
= 11.9838 × π × 0.05 × 0.10
Mass = 0.1881g
Amount of materials
Al = 0.1881 × 0.86 Al = 4.6221g
Ni = 0.1881 × 0.10 Ni = 0.5374g
Co = 0.1881 × 0.04 Co = 0.2149g
0.5% of MWCNT
85.5Al + 10Ni + 4Co + 0.5MWCNT

Density of materials
Al = 2.53 kg/m^3 Ni = 8.908 kg/m^3 Co = 8.86 kg/m^3
MWCNT = 2.6 kg/m^3
Density = (Weight % of Al) × (Density of Al) + (Weight % of Ni) × (Density of Ni) + (Weight % of Co) × (Density of Co)
+ (Weight % of MWCNT) × (Density of MWCNT)
= 0.855×2.53+0.10×8.908+8.86×0.04+0.05×2.6
= 2.16315+0.908+8.9+0.13
Density = 12.1011g
Mass = Density × Volume
= 12.1011 × π × 0.05 × 0.10
Mass = 0.1899g
Amount of materials
Al = 0.1899 × 0.86 Al = 4.5957 g
Ni = 0.1899 × 0.10 Ni = 0.5375g
Co = 0.1889 × 0.04 Co = 0.2150g
MWCNT = 0.1889 × 0.005 MWCNT = 0.0171g
0.75% of MWCNT
85.25Al + 10Ni + 4Co + 0.75MWCNT
Density of materials
Al = 2.53 kg/m^3 Ni = 8.908 kg/m^3 Co = 8.86 kg/m^3
MWCNT = 2.6 kg/m^3
Density = (Weight % of Al) × (Density of Al) + (Weight of Ni) × (Density of Ni) + (Weight % of Co) × (Density of Co)
+ (Weight % of MWCNT) × (Density of MWCNT)
= 0.8525×2.53+0.10×8.908+8.86×0.04+0.075×2.6
= 2.1568+0.908+8.9+0.195
Density = 12.1598 kg/m^3
Mass = Density × Volume
= 12.1598 × π × 0.05 × 0.10
Mass = 0.1909g

Amount of materials
Al = 0.1909 × 0.86 Al = 4.5825g
Ni = 0.1909 × 0.10 Ni = 0.5375g
Co = 0.1909 × 0.04 Co = 0.2150g
MWCNT = 0.1909 × 0.075 MWCNT = 0.0403g
1% of MWCNT
85Al + 10Ni + 4Co + 1MWCNT
Density of materials
Al = 2.53 kg/m^3 Ni = 8.908 kg/m^3 Co = 8.86 kg/m^3
MWCNT = 2.6 kg/m^3
Density = (Weight % of Al) × (Density of Al) + (Weight % of Ni × (Density of Ni) + (Weight % of Co) × (Density of Co) + (Weight % of MWCNT) ×(Density of MWCNT)
= 0.85×2.53+0.10×8.908+8.86×0.04+0.1×2.6
= 2.1505+0.908+8.9+0.26
Density = 12.2185 kg/m^3

Mass = Density × Volume
= 12.2185 × π × 0.05 × 0.10
Mass = 0.1918g
Amount of materials
Al = 0.1918 × 0.85 Al = 4.5693 g
Ni = 0.1918 × 0.10 Ni = 0.5375g
Co = 0.1918 × 0.04 Co = 0.2150g
MWCNT = 0.1918 × 0.1 MWCNT = 0.0537g
Total amount of material
Al = 18.3696g Ni = 2.1499g Co = 0.8599g MWCNT = 0.111g

4.RESULT DISUCSSION

4.1 Microstructures of fabricated composites

4.1.1 Microstructure of specimen fabricated without reinforcement

The SEM image of the reinforcing material (MWCNT) is given in Figure 4.1, which shows the grain size and grain shape of the reinforcement particulates. The micrograph of Al-10Ni-4%Co composite material without reinforcement particulate is shown in Figure 4.2. Aluminum matrix is seen as grey backgrounds with white glossy particles are nickel and cobalt. Even distribution of nickel and cobalt is observed in the aluminum matrix. This sample is the powder metallurgical product of pure Aluminum and pure copper in 86:10:4 ratios, compacted at a pressure of 2 ton to 5 ton.

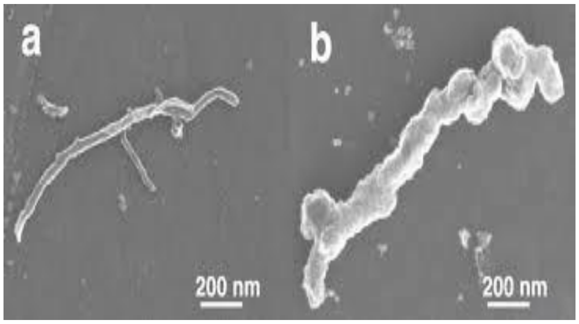


Fig. 4.1. SEM image of MWCNT

The SEM image shows the metal matrix composite with the unfused particles of nickel grains and partial dissolution of the copper in aluminum solid solution has taken place during the sintering, which may be due to low sintering temperature and the sizes of nickel powder has variations in the grain size resulting the higher sized grains made insoluble. The dissolution of the nickel and cobalt in aluminum depends on the temperature and the size of the grains.

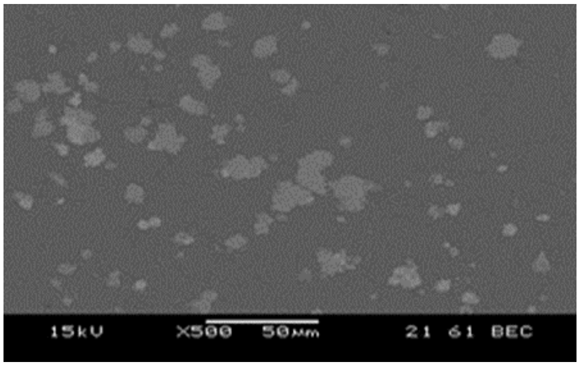


Fig. 4.2. SEM image of aluminium metal matrix without Reinforcement

The SEM image of Al-10%Ni-4%Co powder metallurgical product matrix are compacted at 5 tons in a closed die. The microstructure given in Figure 6.3 shows some unfused /undissolved free nickel and cobalt in the matrix. The percentage of free nickel is about 10% and cobalt is 4% in volume. The rest of the matrix shows fine fused aluminum solid solution.

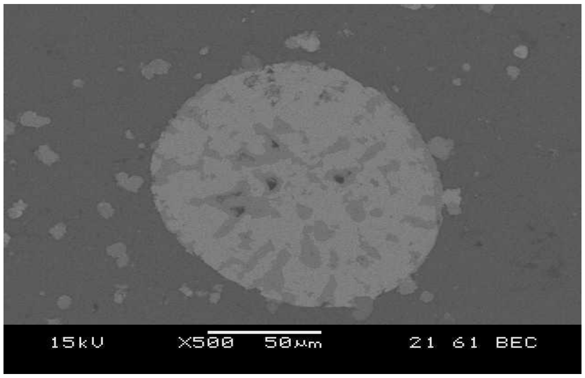


Fig. 4.3. SEM image of aluminium metal matrix with unfused nickel

4.1.1 Microstructure of specimen fabricated without 0.5% Reinforcement

The SEM image of Al-10%Ni-4%Co with 0.5% reinforcement particle (MWCNT) powder metallurgical product microstructure given in Figure 6.4 shows some reinforcement particle distributed among the matrix. The specimen is created at a controlled compacting pressure of 2 ton to 5 ton maintained at a temperature of 480^0C, holding for 10 seconds. The percentage of nickel and cobalt are same for all the samples and the reinforcement particle is about 0.5% in volume. The rest of the matrix shows fine fused aluminum solid solution The particles of MWCNT are uniformly present distributed in the matrix. The MWCNT particles are shown as whitish tube like structured particles in Al-Ni-Co matrix.

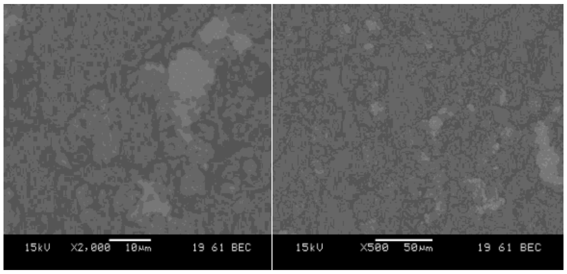


Fig. 4.4. SEM image of aluminium metal matrix with 0.5% reinforcement

4.1.2 Microstructure of specimen fabricated without 0.75% Reinforcement

The micrograph of Al-10%Ni-4%Co with 0.75% reinforcement particle (MWCNT) powder metallurgical product microstructure given in Figure 6.5 shows

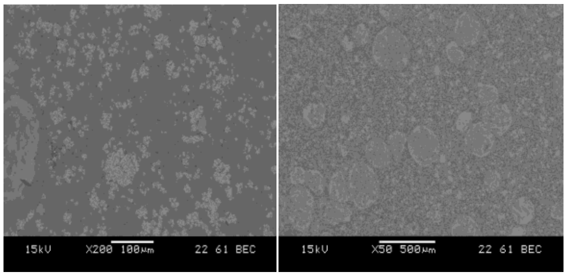


Fig. 4.5. SEM image of aluminium metal matrix with 0.75% reinforcement the evenly distributed MWCNT with 0.75% by volume fraction. Rest of the matrix shows fine fused aluminum solid solution.

Distribution of MWCNT particles are uniform and are seen as whitish tube or strands distributed among the aluminium matrix. Comparing to the previous 0.5% sample the presence of MWCNT particles are more in the matrix. The microstructure of Al-10%Ni-4%Co with 0.75% MWCNT presented in Figure 7.5 powder metallurgy composite shows fine fused aluminum metal matrix composite in a solid solution. Uniform distribution of MWCNT particles is observed in the matrix. As the percentage of MWCNT is more the particles of MWCNT are more in given field of view.

4.1.3 Microstructure of specimen fabricated without 1% Reinforcement

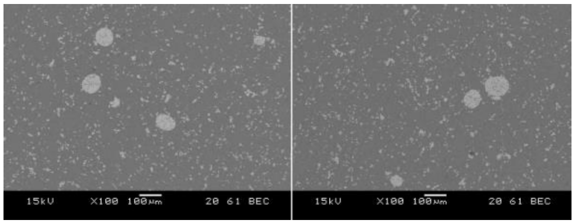


Fig. 4.6. SEM image of aluminium metal matrix with 1% reinforcement

The micrograph of Al-10%Ni-4%Co with 1% reinforcement particle (MWCNT) powder metallurgical product microstructure given in Figure 7.6 shows the evenly distributed MWCNT with 1% by volume fraction. Rest of the matrixshows fine fused aluminum solid solution. Distribution of MWCNT particles is uniform and are seen as whitish tube or strands distributed among the aluminium matrix. Comparing to the previous 0.75% sample the presence of MWCNT particles is more in the matrix. The microstructure of Al-10%Ni-4%Co with 1% MWCNT presented in Figure 7.5 powder metallurgy composite shows fine fused aluminum metal matrix composite in a solid solution. Uniform distribution of MWCNT particles is observed in the matrix. As the percentage of MWCNT is more than that of 0.75% reinforcement, the particles of MWCNT are more in given field of view.

4.2 Mechanical characterization

The hardness values of the prepared P/M specimens are determined using Vicker's hardness test are plotted as shown in Figure 6.7.

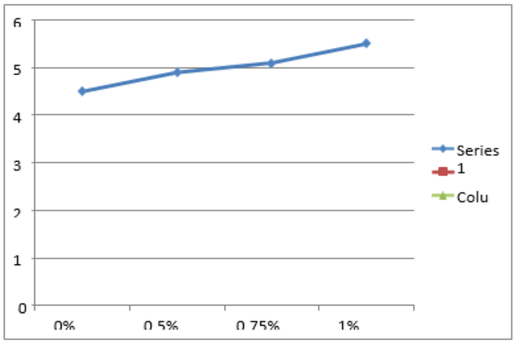


Fig. 4.7. Hardness value of matrix for different Composition of MWCNT

The hardness values obtained shows that, with increase in MWCNT reinforcement in the Aluminum-Nickel-Cobalt MMC, increase in hardness are observed. Initially with the addition of MWCNT particles (Rana et al. 2015), hardness values increases considerably but after a particular point, the increase in hardness is less. This is due to the addition of more amounts of MWCNT particles in the aluminum matrix, which has even distribution of MWCNT particles. Due to the mechanical property and presence of Nickel, the hardness of the metal is increased and the ductility of the composite decreases. It is found that the Hardness value of the matrix lies between 45 to 55 HV (Vicker's Hardness Number) based on the composition of Nickel and MWCNT. From the graph, it contains % composition of MWCNT on X-axis and Vicker's Hardness Number (HV) on Y- axis.

5. CONCLUSION

With an increased involvement of metal matrix composites in materials engineering and the addition of new proposed reinforcements, an opportunity has been provided in the research field, to get deeper into the exploration of metal matrix composites. The reinforcements have gained popularity in the past few years due to their capability to enhance material properties without deteriorating the mechanical and metallurgical aspects of the parent material. With these considerations, this study aims to analyze the hardness and microstructural analysis of Aluminium with different percentage (0.5%, 0.75% and 1%) inclusion of MWCNT reinforcement materials. The samples in the above-mentioned combinations were fabricated through powder metallurgy method. To analyse the characterization of the new materials obtained, the materials were subjected to SEM and optical microscopy analyses. To analyse the elemental composition and the phases of the new material was carried out. Experimental investigations were carried out on prepared samples to analyze their hardness and microstructure. Some key findings of the experiments carried out on Aluminium metal matrix composites.

The microstructure analysis showed a complete penetration of the reinforcements into the intergranular regions of the Aluminium.

The presence of Aluminium, Nickel, Cobalt and MWCNT as per their composition could be observed in the observation.

The microhardness of the composites was extremely good when compared with the unreinforced alloy. The microhardness of aluminium when reinforced with 0.75% MWCNT showed a peak increase

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