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CARBON NANOTUBE REINFORCED ALUMINIUM ALLOY COMPOSITES - A REVIEW

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ABSTRACT

Carbon nanotubes (CNTs) reinforced metal matrix composites (MMCs) are developed for its high elastic modulus, specific strength and aspect ratio, over the past two decades. This review summarizes the research work carried out for the development of carbon nanotubes (CNTs) reinforced aluminium alloy metal matrix composites (AMCs). CNT reinforced polymers and ceramics have attracted the attention of large number of researchers since their discovery in 1991. However, CNT reinforced AMCs have received the least attention. The present review focuses on processing techniques, CNT dispersion, strengthening mechanisms and mechanical properties of AMCs. Various processing techniques used for synthesis of nanocomposites have been reviewed. Homogenous dispersion of the reinforcement into the aluminium metal matrix has been reviewed. Further, the factors involving in strengthening mechanism have been reviewed. Enhancements of mechanical properties by the addition CNT in aluminium alloy are also summarized.

Keywords*: Carbon nanotubes; Metal Matrix Composites; Uniform Dispersion and Strengthening.*

1. Introduction

Carbon nanotubes (CNTs) are one of the most exciting nanostructural materials due to their superior mechanical, thermal, and electrical properties [1–3]. Carbon nanotubes (CNTs) discovered by Iijima in 1991, have high specific strength of 55.55 GPa / (mg/m3) and high specific modulus of 555.55 GPa / (mg/m3), which makes them ideal reinforcements in composites. Theoretical and experimental investigations on CNTs have reported their Young's modulus and tensile strength to be of the order of 1 TPa and 100 GPa respectively [4–9]. Their excellent mechanical properties and low density of 2.0 g/cm3 makes them as a viable reinforcing phase in a variety of polymer, ceramic, and metallic matrices to design high-performance composite materials [10].

Carbon nanotubes can be visualized as a graphene sheet that has been rolled into a tube with hemispherical caps at both ends. Diamond cubic crystal structure is formed with each carbon atom having four nearest neighbours arranged in a tetrahedron while graphite is formed with each carbon atoms arranged in a hexagonal array. For CNT, each carbon atom is linked to three nearest neighbours. Rolling the sheets of graphite into cylinders form carbon nanotubes [11]. The properties of nanotubes depend on atomic arrangement, the diameter and length of the tubes [12].Nanotubes exist as either single-walled or multi-walled structures. Multi-walled nanotubes (MWNTs) are simply composed of concentric single-walled nanotubes (SWNTs) [12]. The structures of SWNTs and MWNTs were shown in Figures 1(a) & 1(b).

Primary synthesis methods to prepare single walled and multi walled nanotubes include methods of arc discharge, laser ablation and chemical vapour deposition [12]. A multiwalled carbon nanotube (MWCNT) is made up of many single walled carbon nanotubes (SWCNT) arranged in a concentric manner. The attractive mechanical properties of single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) are of great interest in the scientific community as a new kind of reinforcement material for the production of novel MMCs [13]. Fig.2 shows the number of journal articles published on CNT reinforced Aluminium alloy nanocomposites in the last eight years. It is clearly observed that there has been increase in the number of studies on that topic since 2005.These articles address various aspects, such as processing, microstructure, dispersion, mechanical properties and the chemical interaction of CNTs with aluminium metals.

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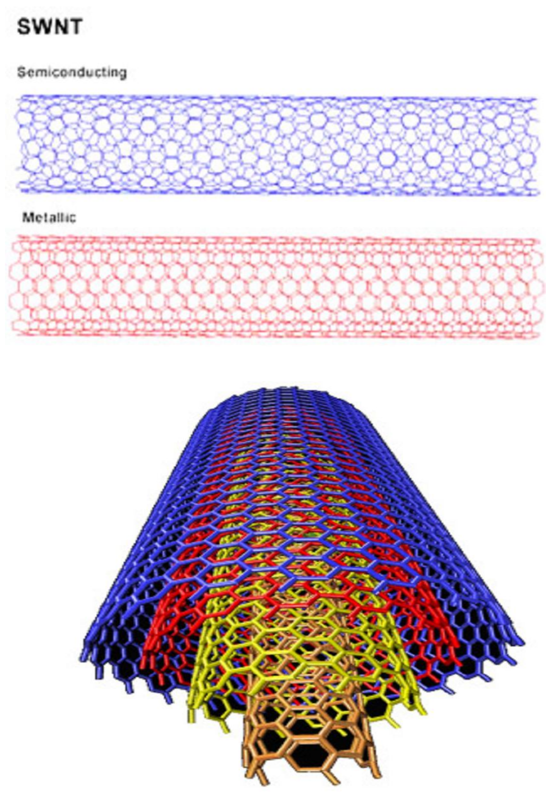

Fig. 1(a) Single walled CNT and 1(b) Multi walled CNT [12]

1.1 Aluminium based MMCs

Aluminum alloys are widely used in aerospace, automotive industries as they possess low density, capable of being strengthened by precipitation hardening, have good corrosion resistance, high thermal and electrical conductivity [14]. Most CNT applications in composites focus on polymer matrices because of the flexibility in the composite fabrication techniques. Only limited studies, however, have been reported for metal matrix composites (MMCs). Recently, the interest to increase aluminum strength for applications in the aerospace and aeronautic industries has motivated the study of aluminum matrix composites (AMCs), which can exhibit better mechanical properties at medium and room temperatures. Most of the aluminium alloys possesses the density of 2698 kg/m^3 which is near that of pure aluminium. The melting point of pure aluminium is 660°C which is relatively low melting temperature compared to other potential matrix metals. These characteristics facilitate on processing of Al-based MMCs by solid state routes, such as powder metallurgy, and casting methods [15]. Around 20% of aircraft components are being manufactured by Al-based MMCs [16].

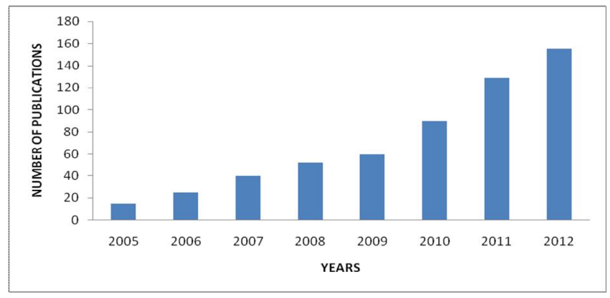

Fig. 2 Number of Publications on CNT Reinforced Aluminium Alloy Nanocomposites during the years from 2005

Aim of the present review is to theoretically understand the various processing route for making Al-CNT nanocomposites. The section on strengthening mechanisms discusses different mechanisms, factors affecting strengthening, models and hypotheses. The section on dispersion of CNT into Al matrix reviews disperses behavior of CNTs in the Aluminium. The section on enhancement of mechanical properties summarises increases in tensile, compression strength and hardness of CNT reinforced aluminium composites and also its wear and corrosion studies. Finally, the section on plasticity discusses various micromechanical models and its plastic and elastic properties.

2. Processing Technique

There are variety of processing techniques are available for preparing Carbon nanotube reinforced Aluminium metal matrix (AMC-CNT) composites. Fig.3 shows the various processes for synthesis of CNT-reinforced Aluminium MMCs. Processing Techniques can be divided into three main categories i.e. solid state processing, liquid state processing and vapor state processing. Powder metallurgy is one of the most popular and widely applied solid state processing technique for preparing AMC-CNT composites. Electro deposition and electroless deposition are the other most important techniques in the category of vapor state processing. Following subsections will present all of these processing techniques [17].

2.1 Powder metallurgy

Powder Metallurgy (PM) is one of the common and versatile processes used in the fabrication of Aluminium metal matrix composites by mixing the metallic matrix powder and reinforcements followed by compaction and high temperature consolidation. The blending of powder is carried out in liquid suspension or dry condition. The compaction is carried out by cold isostatic pressing (CIP) followed by degassing and consolidation by hot isostatic pressing (HIP) or extrusion. Various studies have been carried out in the synthesis of MMC by PM technique [18-20]. The use of lower temperature compared to liquid state processes minimizes the undesirable interfacial reactions and enhances the mechanical properties. Most of the studies on Al-CNT composites have been carried out using the powder metallurgy method. The primary processes consists of mixing CNTs with metal powder by grinding or mechanical alloying, followed by consolidation by compaction and sintering, cold isostatic pressing, hot isostatic pressing, or spark plasma sintering. Then secondary processes are rolling, equal channel angular processing, extrusion, etc. Different variations of powder metallurgy techniques are discussed briefly in the following sub-sections.

2.1.1 Mechanical alloying

Mechanical alloying (MA) is a solid state powder processing that allows production of homogeneous materials starting from blended elemental powder mixtures.

As far as the manufacturing of MMCs concerned for powder metallurgy components, the improvement of particle distribution throughout the matrix can be accomplished through high-energy ball milling. This method was first developed by Benjamin (1970) to produce oxide dispersion strengthened (ODS) nickel base super alloys for applications in aerospace. The high-energy ball milling process generally involves repeated cold-welding, fracturing and re-welding of powder mixtures in a planetary ball mill [21]. This is now known as mechanical alloying or mechanical milling. The process in which mixtures of powders are milled together is denominated mechanical alloying (MA); it involves material transfer to obtain a homogeneous alloy by repeated deformation /welding /fracture mechanisms. On the other hand, milling of powders of uniform composition, in which material transfer is not required for homogenization, is termed mechanical milling [22]. Mechanical alloying appears to be an ideal method to synthesize nanocomposites in a variety of systems. The most obvious advantage of the MA technique is that a uniform dispersion can be achieved by optimizing the processing conditions [19, 20, 23-27]. Additionally, a high volume fraction of the reinforcement with nanometer dimensions can be incorporated into a number of metallic matrices [28]. During high-energy milling the powder particles are repeatedly flattened, cold welded, fractured and rewelded [22].

2.1.2 Mixing/Mechanical alloying and hot pressing

Some of researchers have used this route for making Al-CNT nanocomposites. Xu et al [29] successfully fabricated by the hot-pressing process of Aluminium-carbon nanotube composites and found aluminium-carbide phases with composition AlC and AlC2 in the microstructure. SWCNT reinforced nanocrystalline Al composite fabricated by Zhong et al [30] using hot pressing method and observed SWNTs were not broken and were not dissolved in the aluminium matrix at the high consolidation temperature. Kashyap et al [31] carried out MWCNT reinforced aluminium by PM technique followed by hot extrusion and applied the shear log model for the MWCNT Young's modulus calculation. The modulus estimated was 897 GPa which is close to the theoretical value of 1 TPa.

2.1.3 Spark Plasma Sintering

Spark plasma sintering (SPS) is a pressure assisted rapid sintering technique which generates high temperature spark plasma between the gaps of compacted powder via electrical DC pulse discharge. SPS has emerged as a non-conventional powder consolidation method in sintering a number of novel materials which are either difficult or impossible to sinter by conventional hot-pressing [32]. This method is, generally, suitable for consolidation of nanopowders, without allowing sufficient time for grain growth. Kwon et al [32] carried out combination of spark plasma sintering followed by hot-extrusion processes which leads to well-aligned CNTs in the extrusion direction. Effective stress transfer takes place between the Al matrix and the CNTs due to the formation of aluminum carbide.SPS is a rapid solidification technique where high quality and uniform compacts can be sintered rapidly at comparatively lower temperatures when compared to conventional sintering methods.

2.1.4 Semi solid powder processing

Semi-solid powder processing (SPP) is a promising technology that combines the benefits of semi-solid forming and powder metallurgy. It enables mixing of various particle or fiber elements for improved composite properties and eliminates post-processing steps required in powder metallurgy routes [33]. Wu et al [34] carried out synthesizing of Al6061-CNT composite by SPP. Four steps required for SPP namely powder preparation, pre-compaction, heating and semi-solid forming.

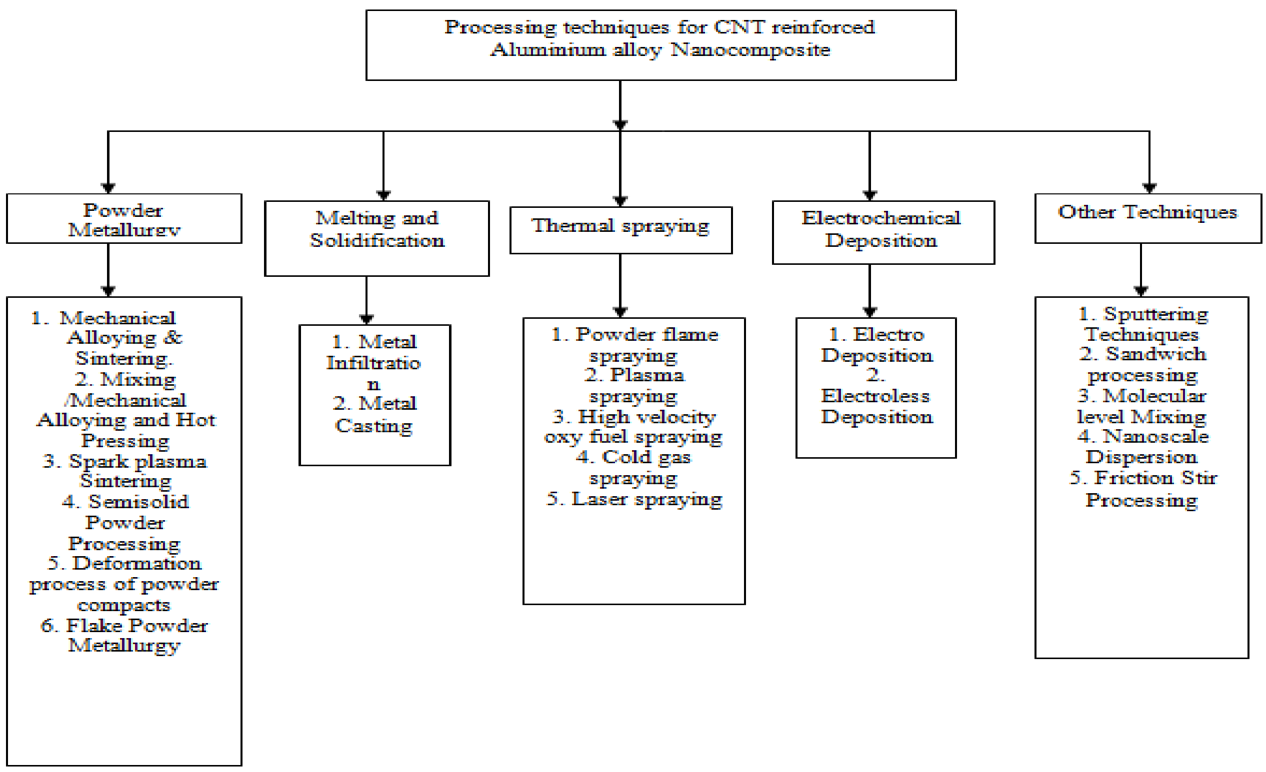

Fig. 3 Various Processes for Synthesis of CNT-Reinforced Aluminium Metal Matrix Composites [17]

2.1.5 Deformation processing of powder compacts

The addition of CNT reinforcements into powder metallic matrix via mixing in planetary mills or by high energy ball milling and compacted by different severe plastic deformation (SPD) processes can improve mechanical properties compared to conventional engineering materials [35]. There are different methods developed for compaction of powders via SPD techniques. The main methods are conventional extrusion [36], equal channel angular pressing (ECAP) with back-pressure [37], high-pressure torsion (HPT) [38], reciprocating extrusion [39] etc.

2.1.6 Flake powder metallurgy

Flake powder metallurgy (flake PM) was used by Jian et al [40] to achieve a uniform distribution of CNTs in CNT/Al composites.

Spherical Al particles were first processed by ball milling into two dimension nanoflakes to make their geometries more compatible with the one dimension nature of CNTs, and then surface modified with a polyvinyl alcohol (PVA) hydrosol to make their surface properties more compatible with the carboxyl functionalized CNTs. A homogeneous and individual distribution of CNTs in Al powders was achieved simply by direct slurry blending.

2.2 Melting and solidification route

Melting and solidification are liquid state processing techniques for synthesizing CNT-reinforced metal matrix composites. Using this route, we can achieve high relative density. However, this process may cause damage to CNTs. This method is adoptable for matrix having low melting point. Another limitation is that CNTs tend to form clusters due to surface tension forces [17].

2.3 Thermal spray

Thermal spraying can be defined as the spraying of molten or semi-molten particles on to a substrate to form a coating/deposit by way of impact and solidification. Thermal spraying methods offer the advantage of large cooling rates as high as 10^8 K s^{-1} during solidification which often results in the formation/retention of nanocrystalline structure in the coatings [41-42].High velocity oxy fuel (HVOF) spraying is based on high pressure combustion process has been widely used in the automotive and aerospace industry to deposit coatings of metals and ceramics. Kang et al [43] analyzed the interfacial reaction between MWCNTs and Al matrix by using HVOF spraying. They found formation of aluminum carbide (Al_4C_3) at the defect sites on the MWCNT surface. These result in the deterioration of the reinforcement in the composite. Bakshi et al [44] using cold gas kinetic spraying for MWCNT reinforced AA6061 nanocomposite coatings preparation. 500 µm thick coatings were successfully achieved on to AA6061 substrate.

2.4 Electrochemical route

Electro deposition as a technique which is versatile in making coatings, bulk products in micro to nano dimensions. This technique has also been used for coating CNTs with metals to produce one-dimensional composites. Many research efforts have dealt with CNT/polymer composites, which exhibit a tremendous strengthening effect for the composites. However, the results in metals are not as encouraging as those in polymer. This is mainly due to the difficulties in achieving homogeneous dispersion of CNTs in metal matrix and good interfacial bonding between CNTs and metal matrix. So far, nearly all the efforts were made through powder metallurgy route, which involved mixing of CNTs with metal powders by ball milling or chemical process.

Both electro deposition and electroless deposition have been used for Al-CNT fabrication. Electro deposition requires the traditional electrochemical cells in which composite film is deposited by current flow between anode and cathode. The second technique, known as electroless plating, does not require any external energy source. This is basically a chemical process, in which thermo chemical decomposition of metallic salts takes place in the bath to release metallic ions that forms composite with CNTs. Electro deposition techniques already used for making MWCNT-Ni and MWCNT-Cu composites and electro less deposition techniques already used for making MWCNT-Ni alloys and MWCNT-Mo alloys.

2.5 Other Techniques

2.5.1 Sputtering Techniques

Al-CNT composite films were fabricated by sputtering pure Al on the surface of aligned multi-walled CNT arrays and the result of aluminum carbide (Al4C3) was formed at the interface between the Al and CNT layers [45]. The carbide formed on the surface as well as on the tips of the CNTs improves the interfacial interaction between the CNTs and the Al layers [45]. This fine precipitate could strengthen aluminum alloys by the precipitation hardening mechanism [46-47].

2.5.2 Sandwich Processing

Sandwich processing could become popular technique because of its ease of processing [17]. Salas et al [48] have explored shock wave consolidation of 150 µm aluminum powder and 2 wt. % and 5 wt. % MWCNT aggregates. They found large agglomeration at grain boundaries. The tendency of agglomeration increases with CNT content. This has resulted in deterioration of the mechanical properties of the composite.

2.5.3. Molecular Level Mixing

Molecular level mixing is one of the promising route to obtain homogeneous dispersion of CNTs. Cha et al [49] fabricated CNT reinforced alumina nanocomposite by a molecular level mixing process and an in situ spark plasma sintering process [SPS]. They reported enhanced hardness due to a load transfer mechanism of the CNTs. Also they found increased fracture toughness arising from the bridging mechanism of CNTs during crack propagation.

2.5.4 Nanoscale Dispersion (NSD)

Noguchi et al [50-51] developed a mixing method called nanoscale dispersion (NSD), which disperses the CNTs with a metal powder using natural rubber as a mixing medium he fabricated of MWCNT/Al composites, precursors of MWCNT/Al composites were prepared in the first step. A required amount of MWCNT powder were gradually added and mixed in succession into 100 g of natural rubber following fabrication procedure of MWCNT/elastomer composites except that the precursors were not cured. Al powder was mixed in order to cause capillary actions in the next step. Kwon et al [52] fabricated Al-CNT composites using NSD with combination of SPS and hot extrusion.

Fabrication procedure for Al-CNT composites was shown in fig.4. The SPS could fabricate Al–CNT with a relatively high density and degree of orientation for the CNTs. The CNTs were already well dispersed prior to this step because the NSD was used to produce a homogeneously mixed powder. Furthermore, grain growth in the matrix was obtained. Damage to CNTs did not occur during the SPS, because of the pinning effect by the CNTs and oxides, and the rapid heating.

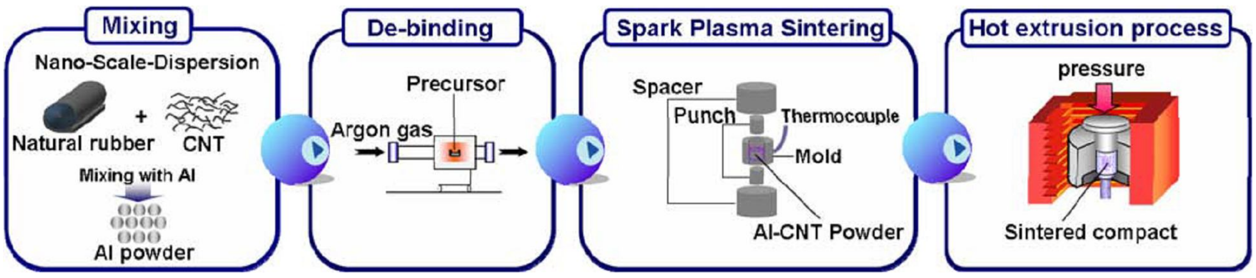

Fig. 4 Fabrication Procedure for Al–CNT Composites [51]

2.5.5. Friction Stir Processing (FSP)

Friction stir processing (FSP), a development based on the basic principles of friction stir welding (FSW) [53], is a relatively new metal-working technique. The basic concept of FSP is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into a work piece and traversed along the desired path to cover the region of interest. The tool heats the work piece via the friction between the tool and work piece and by the plastic deformation of the material, and drives the softened material around the pin to flow. The combination of tool rotation and translation results in the movement of material from the front to the back of the pin. Recently, Liu et al [54] fabricated CNT/aluminum composites by a combination of powder metallurgy and subsequent FSP. They achieved good dispersion along the grain boundaries and found less damage to CNTs during FSP was not severe. Izadi et al [55] fabricated more than 50 vol. % MWCNT-Al composites by multi-pass FSP. The micro hardness of the produced composites was two times higher than the original aluminum alloy.

3. Strengthening Mechanisms

George et al [19] explained three major mechanisms namely thermal mismatch, Orowan looping and shear lag models along with experimental procedure for making CNT/Al composites.

3.1 Thermal mismatch

This mechanism obtained by mismatch of coefficient of thermal expansion between Al and CNT. CNTs have a low coefficient of thermal expansion (1 X 10-6 K-1). Aluminium have greater coefficient of thermal expansion (23.6 X 10-6 K-1). These lead to prismatic punching of dislocations at the interface and work hardening of the matrix [19].

3.2 Orowan looping

In this mechanism the motion of the dislocations is inhibited by nanometer sized carbon nanotubes, leading to bending of these dislocations between the carbon nanotubes. This produces a back stress, which will prevent further dislocation movement and result in an increase in yield stress. [19].

3.3 Shear log

This model involves the transfer of load from the matrix to the reinforcement by interfacial shear stress. Thus the stiffness of the carbon nanotubes is directly utilized. High aspect ratio CNTs are favored with this model [19].

4. Dispersion of CNT into Al Matrix

CNT dispersion within the matrix is important to achieve efficient and effective load transfer to the nanotubes. This helps to ensure uniform stress distributions and minimizes the effect of stress concentration. The dispersion is a bigger challenge at higher CNT concentration where the probability of CNT cluster formation is high. Kuzumaki et al [18] have used stirring in ethanol at 300 rpm for 30 min to disperse 5 and 10 vol. % CNTs in Al. Choi et al [23] have used a control agent of 1 wt. % stearic acid (CH_3 (CH_2)16COOH) was added to prevent agglomeration of the powder and also have used aluminium with 4.5 vol. % CNT and the weight ratio of ball-to-powder was 15:1. Milling variables affect the dispersion, dimension and interface structure of MWCNTs. With an insufficient milling intensity, MWCNTs are mostly located on the surface of powder, exposed to severe impact, and readily damaged. As the milling intensity increases, MWCNTs are embedded inside the powder and then dispersed through plastic deformation of the powder [23]. Singhal et al [56] have fabricated Al-matrix composites reinforced with amino-functionalized multiwalled carbon nanotubes (1.5 wt. % fCNTs) using the powder metallurgy process. A good dispersion of fCNTs in Al matrix was achieved and they do not agglomerate with each other. Esawi et al [57] have used MWCNTs of two different morphologies one is stiff and straight (large diameter) and other is bent and entangled (3.5 times smaller diameter). They used ball milling subsequently hot consolidated by hot extrusion. They found that the smaller diameter bent and entangled CNTs were more difficult to disperse with increase in CNT content compared to another one. Furthermore, they found the smaller diameter CNTs having a larger effective interfacial contact area with the aluminium matrix compared to the larger one. Yang et al [58] have developed uniformly dispersed CNT reinforcement in Al powder by impregnation route with a low Ni content (0.5 wt. %) and in situ synthesis of CNTs in Al powder by chemical vapor deposition. High dispersion was achieved by using this route.

Liao et al [59] carried out three mechanical mixing methods through high energy and low energy ball millings, and compared them to a novel polyester binder-assisted (PBA) mixing method. Experimental results showed that the high energy and low energy ball-milled CNTs disintegrated and there were residual stresses, unlike the PBA-CNTs. They reported mechanical property enhancements of the Al-0.5 CNT composites from PBA and high energy ball milling were superior to that mixed by low energy ball milling. They found good dispersion effect in PBA and high energy ball milling technique. Javadi et al [60] used mechanical alloying to disperse 2 wt. % MWCNTs in an aluminum (Al) matrix. MWCNT powders were sonicated before mechanical alloying; it was possible to prevent the agglomeration of mixture powders during the mechanical alloying. The CNTs were homogeneously dispersed in the composites, and their structures were kept unchanged by the mechanical alloying.

5. Enhancement of Mechanical Properties

Carbon nanotubes (CNTs) exhibit relatively low density ranging from 1.2 g/cm3 for single walled CNT to 1.8 g/cm3 for multi walled CNTs, and subsequently have high specific strength of 55.5 GPa/(mg/m3). These unique mechanical properties of CNTs make them promising reinforcements for synthesizing light weight, high strength metal matrix structural composites. Sarkar et al [61] fabricated multi walled carbon nanotube (MWCNT)/alumina (Al2O3) nanocomposites having different CNT contents by wet-mixing and pressure less sintering. They found the highest improvement of 15–34% in hardness and 34% increase in fracture toughness was achieved in 0.3 vol. % MWCNT/Al2O3 nanocomposite than pure Al2O3. Nanostructured Al 2024–MWCNTs composites were produced using optimized mechanical milling and hot pressing methods by Jafari et al [26]. Nanostructured Al 2024 powder was first prepared through 30 h mechanical milling of the alloy powder and MWCNTs up to 3 vol. % were added to the milled Al 2024 powder and milled for different times. DTA analysis was applied on 4 h-milled nanocomposite powder containing 3 vol. % MWCNT. DTA pattern (Fig.5) reveals an endothermic peak at 6320C due to Al2024 melting. Moreover, an exothermic peak is observed at 645-6580C indicating the reaction between Al and MWCNT and consequently the formation of aluminum carbide (Al4C3) phase [26]. Relative density of nanocomposite remained at the constant level of 98% with MWCNT loadings up to 2 vol.%, but decreased to 95% when 3 vol.% MWCNT is added.

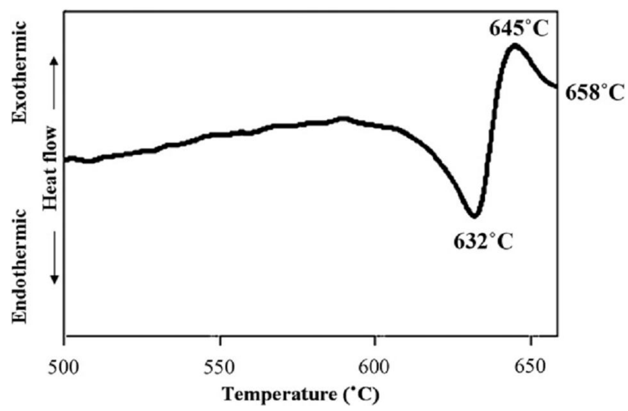

Fig. 5 DTA Pattern of 4 h-Milled Al2024–3 vol. % MWCNT Composite Powders [26]

Compressive strength of nanocomposites found a maximum value of 810 MPa at 2 vol.% MWCNTs addition which were 78%, 34% and 12% higher than that for Al2024–O (annealed condition),Al2024–T6 (artificially aged condition) and nanostructured Al2024. Addition of 3 vol. % MWCNT resulted in the nanocomposite to be highly brittle so that the maximum strain sustained was below 1% [26]. So et al [62] achieved disintegration of CNTs into C atoms and dissolution into Al nanoparticles by mechanically grinding two materials together. This low-temperature solid-state dissolution process involves several steps: (i) Mixing CNTs with Aluminium particles; (ii) Al nanoparticle formation; (iii) Disintegration of CNTs into C atoms; and (iv) Embedding of C atoms into Al nanoparticles. They achieved hardness by more than 50%. Laha et al [63] conducted uniaxial tensile tests on plasma spray formed (PSF) Al–Si alloy reinforced with MWCNTs. The addition of CNTs leads to 78% increase in the elastic modulus of the composite. Bustamante et al [20] produced novel Al-based nanocomposites reinforced with multi-walled carbon nanotubes by mechanical milling. Next, pressure-less sintering at 823K under vacuum and hot extrusion at 773K were carried out. The values of yield strength (σ_y), maximum strength (σ_{max}) and micro hardness of the composites were evaluated and reported as a function of carbon nanotubes content. This was shown in fig.6. Sridhar et al [10] fabricated Al-MWCNT composites by using mixing, cold uniaxial compaction followed by sintering and cold extrusion. They found the tensile yield and ultimate strength of Al-MWCNTs increased to 90% with 2 wt% addition of MWCNTs. Bakshi et al [64] compared the macro and nano scale mechanical and wear properties of CNT reinforced Al-Si composite coatings prepared by plasma spraying. They have conducted nano-indentation tests, macro scale compression test and nanoscratch tests. The differences in mechanical and wear properties at nano and macro scales were explained in terms of the bimodal CNT dispersion (well dispersed and clusters) in Al–Si matrix.

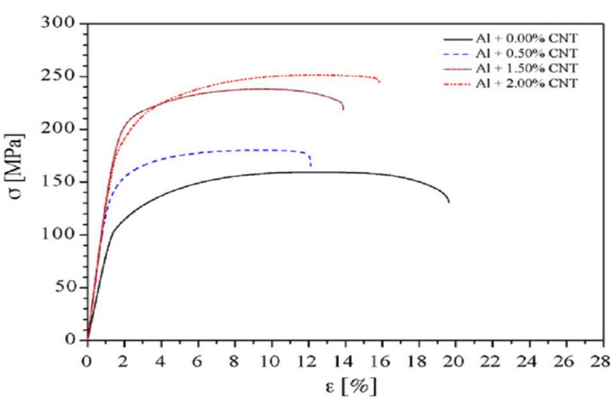

Fig. 6 σ_y Vs ε Graph showing the Enhancement of the Mechanical Properties Maintaining the Ductility of Representatives Al–CNT Composites after Hot Extrusion [20]

6. Summary

Carbon nanotube reinforced aluminium alloy composites are being developed for different applications, such as structural applications in aerospace industry and fabrication of microelectromechanical system (MEMS). We have reviewed that various processing routes for making CNT-Al alloy such as powder metallurgy, mechanical alloying and sintering, SPS, SPP, hot extrusion, ECAP, FPM, NSD, FSP, elctro and electroless deposition. We have also reviewed strengthening mechanisms and homogeneous dispersion of CNT reinforced aluminium alloy. Finally, we have analyzed enhancement of mechanical properties such as tensile strength, compressive strength, micro hardness, relative density and tribological behaviors like corrosion and wear study about CNT reinforced aluminium alloy.

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