Chapter

Damping Study on MWCNT-Reinforced Al Composites

Paul Suresh Samuel Ratna Kumar and Savariar John Alexis

Abstract

In this chapter, damping study on Aluminium-MWCNT based nanocomposites materials are discussed to increase the damping property for applications like engine head, pistons and cylinder blocks and other aerospace components. The Al-MWCNT composites were developed using Ball-milling, cold-isostatic, extrusion and compo-casting process. Corresponding, surface morphology and micro-structure study were discussed. The improved damping property of Al-MWCNT materials were discussed. The hysteresis damping of the composite material was understood by Tan delta and storage modulus (or) dynamic young's modulus. Tan delta and storage modulus of Al-MWCNT composites were performed using dynamic mechanical analyser, by varying the temperature range from room temperature to 500°C (heating phases and cooling phases), at different frequencies. The Al-MWCNT shows some good damping property with increased temperature and decrease in storage modulus. The mechanisms behind the damping property were discussed.

Keywords: aluminium (Al), multi-wall carbon nanotube (MWCNT), damping property, storage modulus, temperature, frequency

1. Introduction

In various structural applications like aerospace, aeronautical, marine and automotive cause vibrations occur during their regular operation after a period of usage which affects the human comfort due to their unwanted noise [1]. To overcome the vibration problems, researchers have proposed newly developed materials with high damping capacity [2, 3]. These vibrations are also prone to increase with temperature.

In recent years, advanced materials like nanocomposites, have been developed to play a vital role in component design with good damping, stiffness and low density. Metal matrix nanocomposites (MMCs) are one of the advanced composite materials which combines nano-based reinforcements in a metal-based matrix. They have excellent properties for application-based design [3].

Many industries use aluminium and its alloys due to their low density/weight and high mechanical properties. However, the damping property of the aluminium and its alloys is poor. Further to develop the damping of the material aluminium based nanocomposites were developed based on the requirements. Many nano-based reinforcements were used to improve the strength and stiffness properties, still they suffer from limitations like poor damping and plasticity. For the above reasons carbon nanotubes (CNT) were used as reinforcements in proper composition to transfer the physical and mechanical properties into the bulk aluminium material [4].

Nanotubes have high thermal and electrical conductivity, strength and modulus, and also it shows its potential in damping applications due to their low density and high specific surface area. Very few studies have been carried out on aluminium reinforced CNT composites for improving the damping property. Many researchers used CNT in polymer matrix composites to improve the damping property [5, 6]. Based on the above studies, CNT with proper composition/dispersion can improve the mechanical strength and damping property. The positive result is due to friction and slippage that occurs in the inner and outer walls of carbon nanotubes and polymer matrix [7, 8]. The mechanism behind the improved damping property is due to interfacial slip on CNT reinforced composites. CNT reinforced composites have good damping property which is influenced by weight (or) volume fraction, dispersion pattern of nanotubes, temperature and frequency [4–6, 8].

Only very few research works have been carried out to find the hysteresis in damping, in CNT reinforced polymer matrix and this is due to shear slip mechanism [9]. The energy dissipation in the CNT-polymer matrix nanocomposites occurs due to mismatch in elastic, dispersion of reinforcement and composition, interfacial shear-strength between CNT-polymer matrix. No research work was reported to find out the hysteresis in damping for aluminium based CNT reinforced nanocomposite material. Hence, this work aims to study the hysteresis damping behaviour of CNT reinforced aluminium and its alloys from various composition in weight (or) volume fraction, manufacturing techniques, dispersion pattern and temperature influence.

2. Materials design

The manufacturing methods used for developing Aluminium alloys-MWCNT and its microstructure observations are elaborated in this topic.

2.1 Fabrication of nanocomposites

AA 2024 (aluminium alloy) was used as a matrix material in a powder form of ~50 μm and reinforced with multi-walled carbon nanotubes (MWCNT) of 1 wt% with a purity of 95%. MWCNT used here were developed using catalysis of hydrocarbon. To obtain high purity and uniform dispersion of MWCNT, raw MWCNT with 95% purity undergone reflux with concentrated nitric acid at a temperature of 120°C for 10 h. After the process, by using distilled water MWCNT was continuously washed until the acidity gets dissolved. Then ethanol was added to influence the homogeneous dispersion. AA 2024 in powder form was mixed into MWCNT (ethanol solution) and the powders (AA 2024-CNT) distributed uniformly with ultrasonic shaker (mechanical stirring machine) for about 28 min. After the mechanical stirring process, mixed AA 2024 and MWCNT powders were kept in vacuum ~10^{-2} Pa at 120°C to remove the water content. The dried AA 2024 and MWCNT powders were smashed with ball milling process [10]. After fabricating AA 2024-MWCNT composite, to have a uniform dispersion cold isostatic pressing (CIP) along with extrusion process was used, proper structure of gas-atomized powders and to restrict the AA 2024-MWCNT formation [11]. Compared to other mechanical processes, CIP process shows a wide uniform distribution of density throughout the developed composite material, due to the distribution of pressure at isostatic state. The AA 2024-MWCNT (mixed powders) were packed in an Al bundle of 62 mm diameter into a rubberized bag and degasification process were done using vacuum pump mechanically operated at 0.01 Pa for about 20 min before

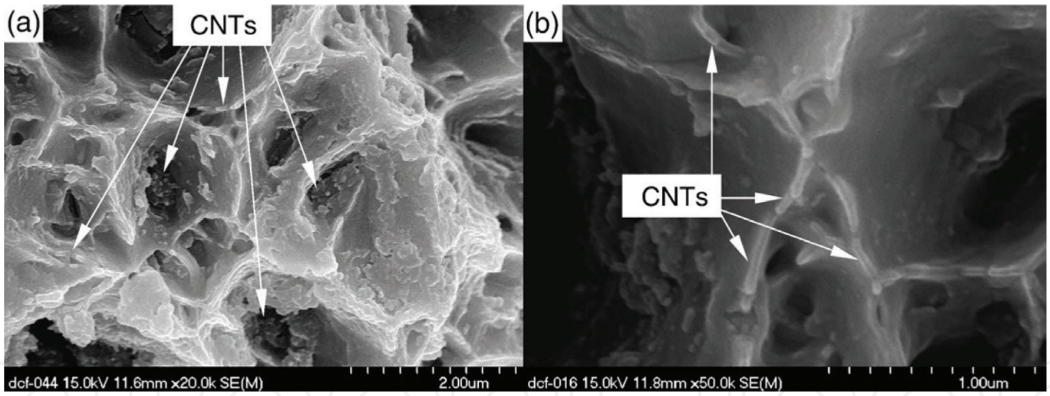

Figure 1.
Scanning electron microscope (SEM) image of (a) MWCNT reinforced in AA 2024 matrix and (b) magnified view of (a) [11, 12].

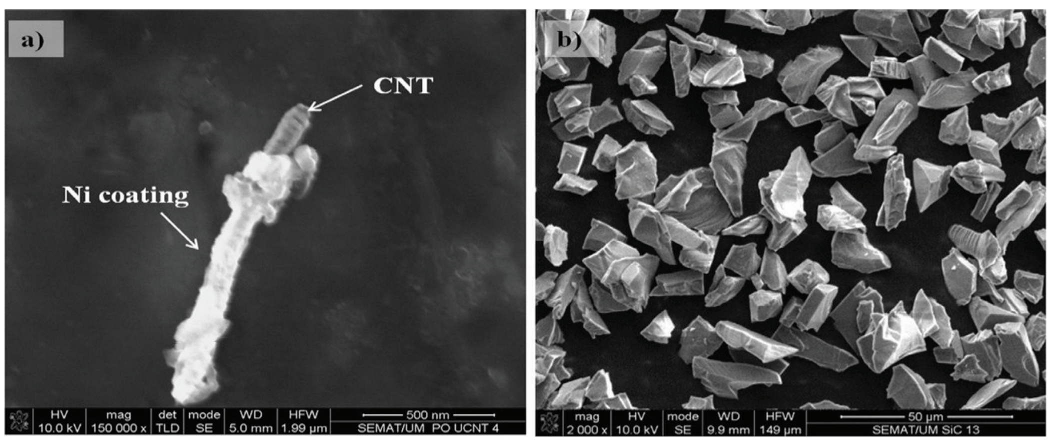

Figure 2.
(a) Nickel-coated MWCNT with an outer diameter 50 nm. (b) Silicon carbide (SiC) with a particle size of ~13 μm [13, 14].

the rubber gas gets wrapped. By using CIP process the mixed AA 2024-MWCNT powders were densified for 10 min at 300 MPa pressure [12]. After the CIP, using extrusion process composite billets were made at an extrusion ratio of 25:1 around 460°C of extrusion temperature. The SEM image of AA 2024-MWCNT composite shows the uniform dispersion of MWCNT reinforcement into the matrix material (**Figure 1**).

Aluminium silicon (AlSi) alloy powder-MWCNT composites [13] and AlSi-MWCNT-SiC are the hybrid composites developed to understand the damping behaviour of the material [14]. AlSi alloy powder with particle size of 325 mesh is used a matrix material.

Ni (Nickel) coated MWCNT (Cheaptubes, USA) was used as reinforcement with a purity of 95% (before coating), an outer diameter of 50 nm, length of 0.5–1.95 μm and Silicon Carbide (SiC) particles with a size approximately 13 μm [14]. To eliminate (or) restrict (or) control the formation of Al_4C_3 (brittle intermetallic) during the AlSi-MWCNT mixing, Ni coated MWCNT were used in this composite. The brittle intermetallic will reduce the damping property of the developed composites. The scanning electron microscope (SEM) images shows the Ni coated MWCNT and SiC particles [14] (**Figure 2**).

AlSi alloy powder and the corresponding reinforcements were mixed mechanically in a closed jar (stainless steel) with a milling balls of 10 mm diameter made of steel. The powder to ball ratio is of 10:1. The jar rotated at uniform speed around 40 rpm for 6 days in low energy ball milling [10, 13, 14].

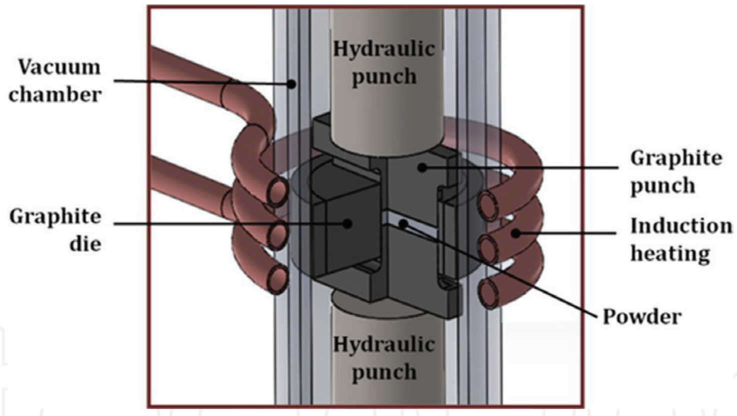

Figure 3.
Graphical representation of sintering process with hydraulic punch [14].

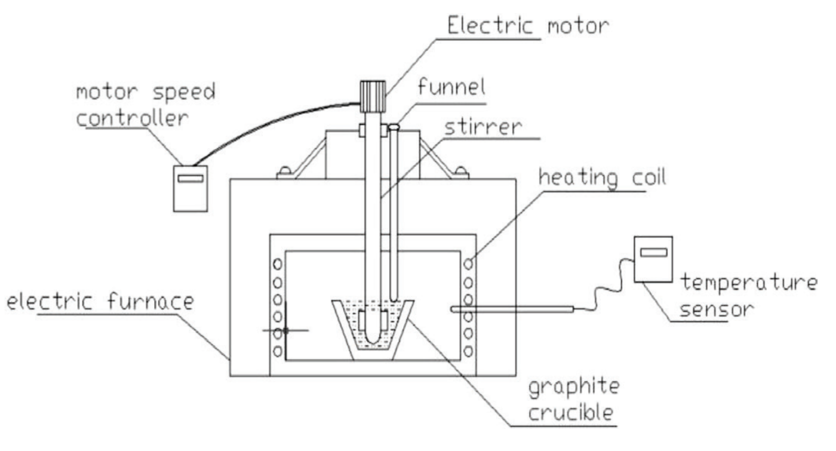

Figure 4.
Graphical representation of compo-casting process.

The mixed composite powder is divided and placed into the moulds made of graphite. AlSi alloy composites were developed using hot-pressing at a vacuum pressure of 10^{-6} Pa and heated using an induction furnace (high frequency). The developed composite mould then placed in the chamber, where the composite specimens will get compressed at 1 MPa and simultaneously heated to 500°C at a heating rate of 25°C/min. After the temperature reaches 500°C, pressure on the composite specimens is increased to 35 MPa without changing the heating rate. For the pressure of 35 MPa the temperature was steadily maintained for 550°C around 10 min [14]. Then the composite specimens are cooled until it reaches the room temperature (**Figure 3**).

AA 5083 material reinforced with MWCNT and developed into a composite by varying MWCNT composition of 1, 1.25, 1.5 and 1.75 in wt fraction using compo-casting (semi-solid state) method shown in **Figure 4** to improve damping and corrosion resistance property [15, 16]. To avoid the intermetallic bond between Al and MWCNT, compo-casting method was selected. A chemical bonding between Al and MWCNT will occur at 600°C [17]. The semi-solid-state temperature of Al was measured using thermocouple during casting process. Correspondingly, the MWCNT reinforcement was added into the matrix material and stirred for 2 min at a speed of 300 rpm. Then, molten melt was poured into the mould and desired composite material was developed [15, 16].

2.2 Microstructure observations of nanocomposites

The structure before and after milling of nanocomposites powder is presented which was obtained using scanning electron microscope (SEM) image, refer

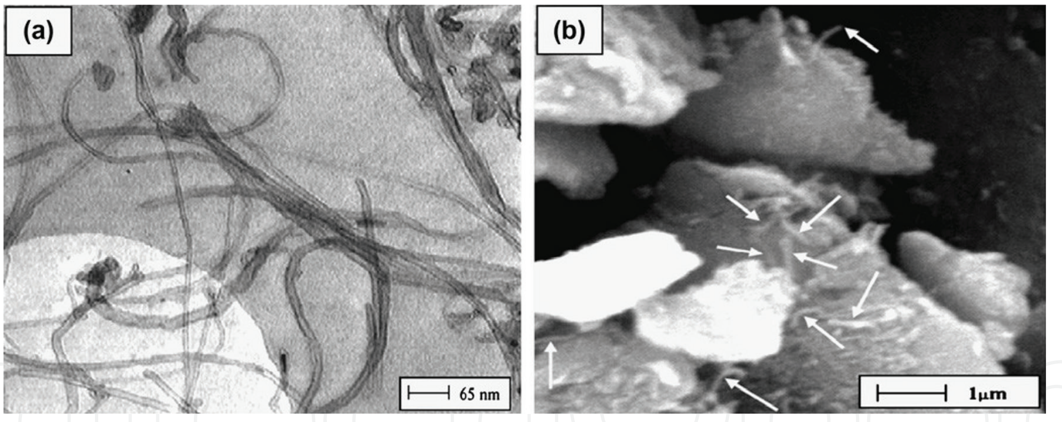

Figure 5.
(a) MWCNT view with high magnification and (b) dispersed MWCNT into the aluminium 2024 nanocomposite [11, 14, 18, 19].

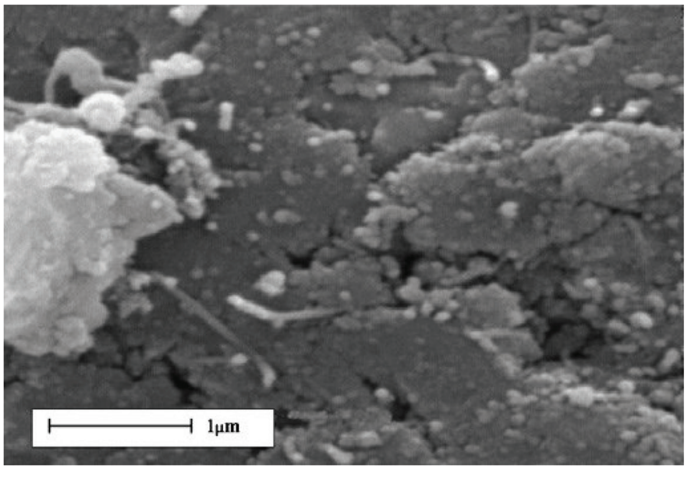

Figure 6.
SEM image of aluminium 2024 matrix nanocomposite with uniform dispersion of MWCNT into the matrix [11, 18, 19].

Figure 5(a) and **(b)**. It shows that the MWCNT length have been varied due to the milling process. A nanocomposite is consisting of AA 2024 as matrix material in an average grain size of 30 nm and the corresponding reinforcement MWCNT with change in outer diameter and its length respectively was developed [18–21]. The SEM image shows the uniform dispersion of MWCNT into the AA 2024 matrix material, due to ball milling along with extrusion process shown in **Figure 5**. The SEM image of all composites in **Figure 6** shows the dispersion of CNT with less porosity, due to to hot pressing techniques. This shows the effectiveness of developing AlSi-MWCNT and AlSi-MWCNT-SiC composites using hot pressing techniques [14].

In **Figure 7(A)** AlSi-MWCNT composite image, the white zones in MWCNT is due to the Ni coated on MWCNT and in **Figure 7(B)** and **(C)** shows a cluster formation of MWCNT in AlSi-MWCNT-SiC composites [14]. Transmission Electron Microscope (TEM) analysis, Energy dispersive X-ray spectroscopy (EDX) and X-ray diffraction (XRD) were carried out to check the chemical bonding (brittle intermetallic reaction) between MWCNT and AlSi. No reaction was occurred due to the Ni coated MWCNT [12–22].

Figure 8 shows the TEM image of AlSI-MWCNT interfacial bonding established during hot pressing techniques. EDX analysis results shown in **Figure 9** is obtained from three areas such as AlSi, MWCNT and AlSI-MWCNT interference zone. The

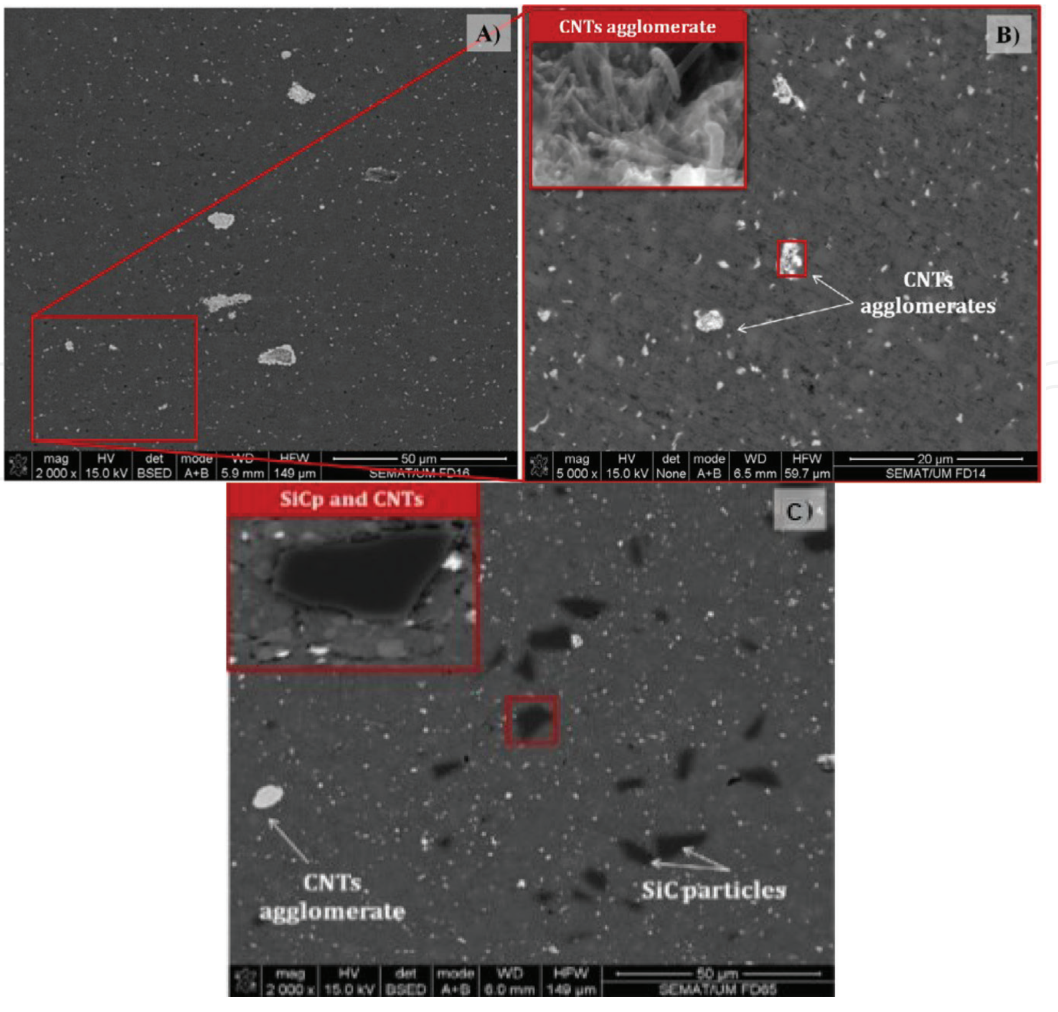

Figure 7.
The surface morphology image of (A) agglomeration of MWCNT, (B) MWCNT agglomeration with magnified view and (C) dispersion pattern of MWCNT and SiC into the AlSi matrix [13, 14].

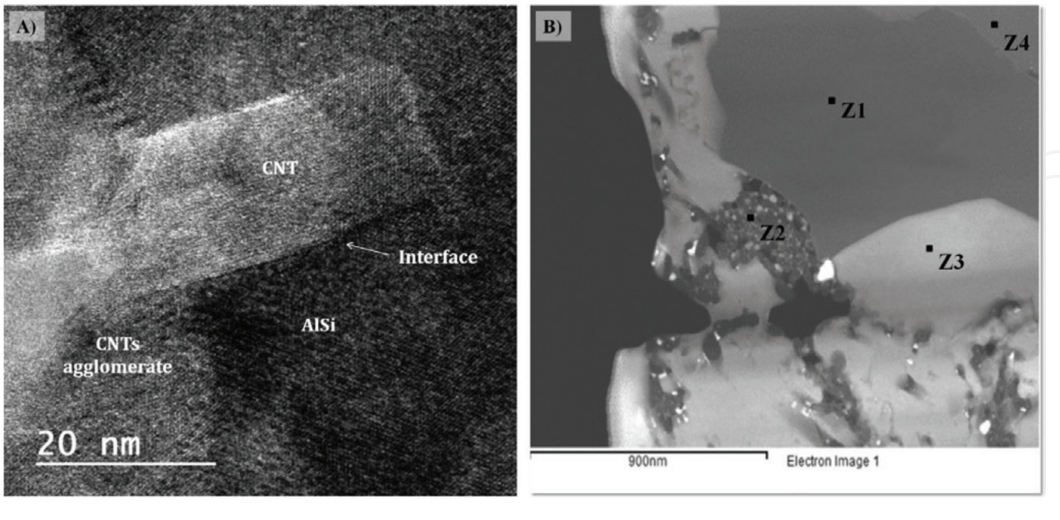

Figure 8.
Transmission electron microscope (TEM) image of (A) interface between Aluminium alloy–MWCNT (B) MWCNT agglomeration view with EDX [14, 23].

Z2 shows the presence of Ni and C (carbon), Z3 shows the presence of Al and Ni which indicate the intermetallic reaction compound between AlSi matrix material and MWCNT coated Ni reinforcement [14].

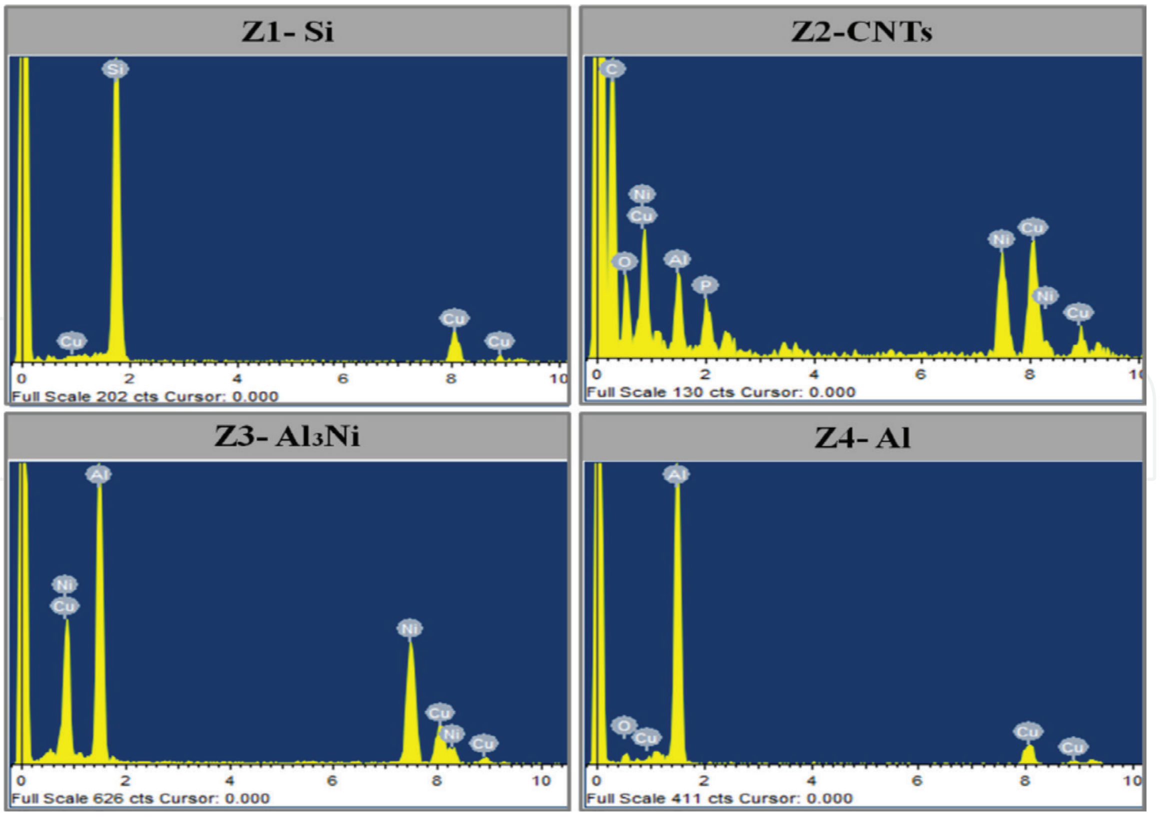

Figure 9.
EDX image of AlSi-reinforced MWCNT with interface and cluster formation [14].

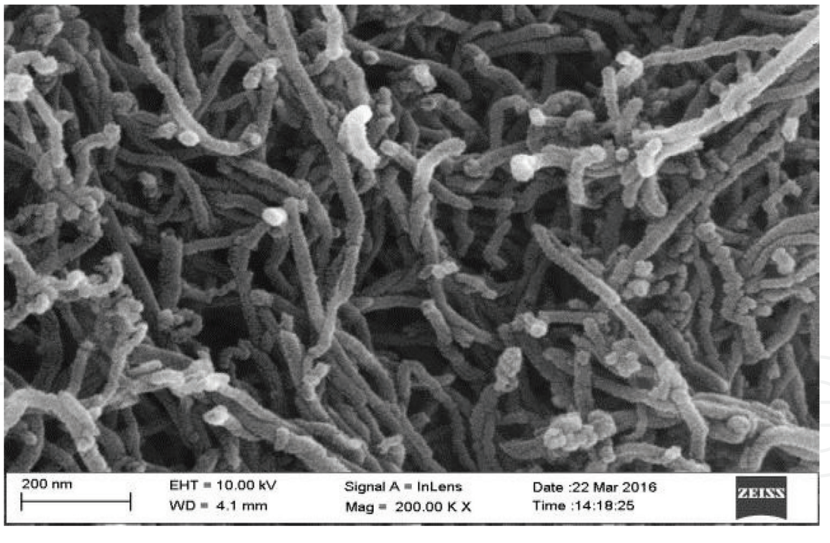

Figure 10.
Field emission scanning electron microscope (FESEM) image of closely bonded MWCNT [15, 16].

A uniform dispersion of AA 5083-MWCNT composites were attained using compo-casting method with minimum cluster formation. In **Figure 10**, field-emission scanning electron microscope (FESEM) image shows the structure MWCNT. **Figure 11** shows back-scattered electron (BSE) FESEM image of MWCNT reinforced into the matrix material. The addition of MWCNT into the matrix material is less than 2 wt fraction. Hence, the presence of nanotubes cannot be viewed in the XRD pattern. By using compo-casting method the brittle inter-metallic bonding can be neglected and improved damping property is achieved [16].

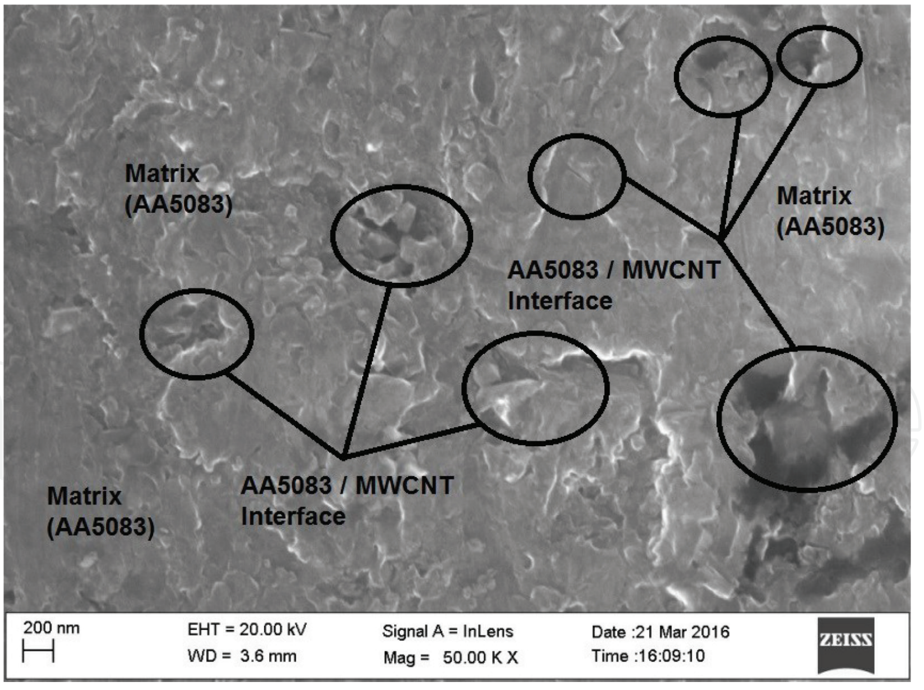

Figure 11.
Back-scattered electron (BSE) image of MWCNT interface and dispersion pattern [15].

3. Hysteresis damping study

3.1 Damping behaviour of AA 2024-MWCNT nanocomposites

The damping property of the developed AA 2024-MWCNT composites were experimentally tested using Dynamic Mechanical Analyser (DMA) [12–14]. Fixed as cantilever, and by varying the frequency to 0.5, 1, 5, 10 and 30 Hz at different temperatures (25–400°C). The damping properties are constant till the temperature is 199°C as shown in Tan delta curves of **Figure 12**, when the temperature is increased to 200°C

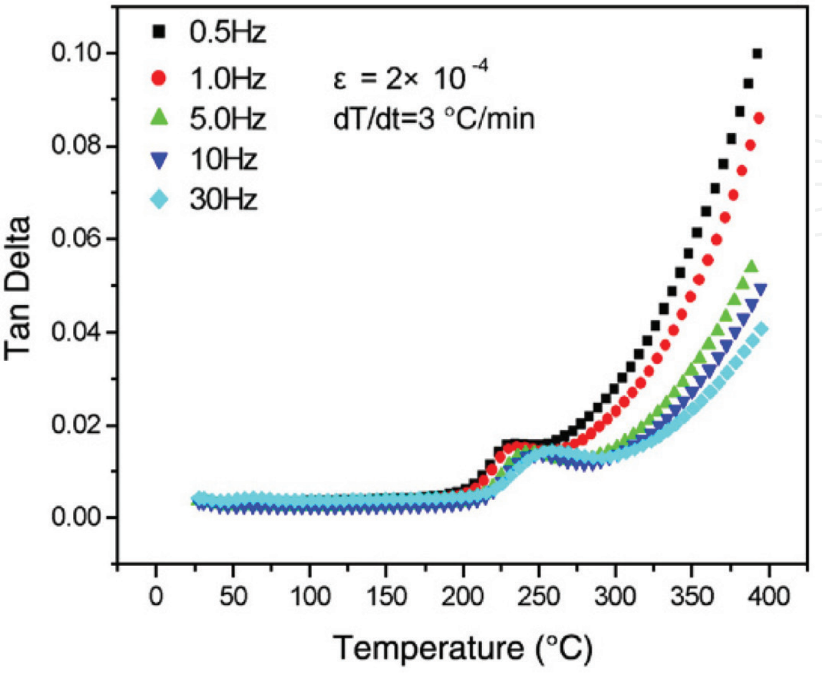

Figure 12.
Dynamic mechanical analyser (DMA) Tan delta vs. temperature curves of AA 2024-MWCNT composites for varying frequencies [12].

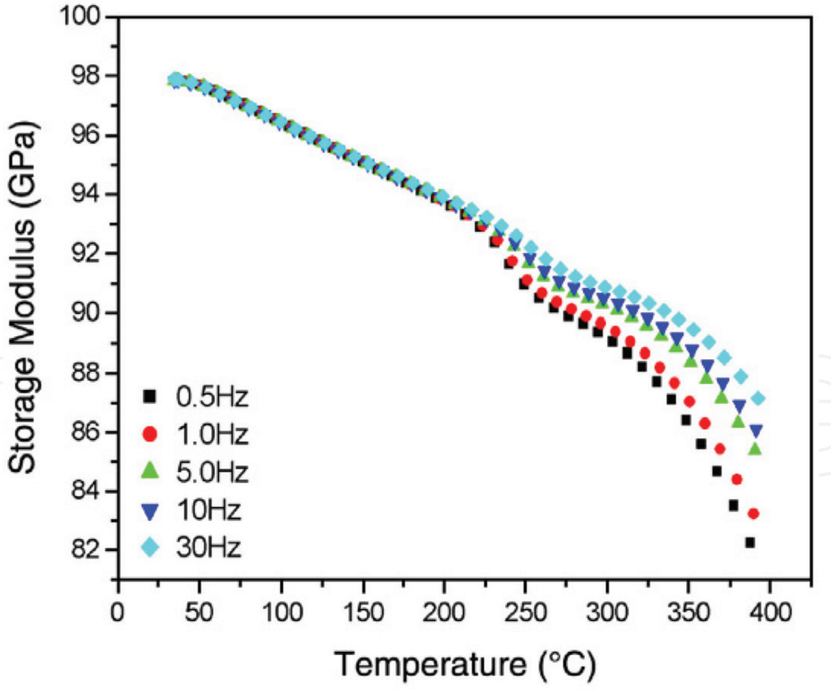

Figure 13.
Dynamic mechanical analyser (DMA) storage modulus vs. temperature curves of AA 2024-MWCNT composites for varying frequencies [12].

and above the changes in the damping property is intensely increasing at the lower frequency range [12]. Moreover, at 250°C there is a peak appears for 0.5, 1, 5, 10 and 30 Hz frequencies [24, 25]. Accordingly, increase in temperature shows increasing in the frequency [25]. At the temperature of 230°C, the damping property is more 10×10^{-3} for every single increase of frequency. At 0.5 Hz frequency and temperature of 400°C the damping property is 975×10^{-3}, which shows AA 2024 matrix reinforced MWCNT have a very high damping property at a maximum temperature [12, 24, 26, 27].

From **Figure 13**, it shows the storage modulus of DMA of the developed composites. It is observed that storage modulus of the AA 2024-MWCNT composites expressively reducing due to increase of temperature; simultaneously, the storage modulus is greater during higher frequency, when the temperature goes beyond 230°C [13, 24]. When the temperature reaches the maximum of 400°C [25], AA 2024-MWCNT composites shows some higher storage modulus around 82.3 GPa, than the AA 2024 alloy material of 71 GPa at the room temperature [24, 25]. Also, AA 2024-MWCNT shows some high mechanical properties without affecting the damping property of the material.

3.2 Damping behaviour of hybrid nanocomposites

The damping property of the developed composites AlSi-MWCNT and AlSi-MWCNT-SiC were experimentally tested using DMA, using temperature as a function [12–14] (room temperature to 300°C). Also, by varying frequencies to 1, 50 and 100 Hz, damping property of the composite material was measured [27, 28]. The damping property of the developed composites that were influenced by frequency and temperature is shown in **Figure 14**. At the initial condition of frequency (1 Hz), a steady change in increased damping property with high temperature is shown in **Figure 14(A)**. During the second frequency condition (50 Hz) comparable changes found at 150–200°C temperature shown in **Figure 14(B)**. At the final frequency value of 100 Hz, AlSi-MWCNT, AlSi-MWCNT-SiC found to decrease in their damping property due to maximum temperature as shown in **Figure 14(C)** [13, 24, 27, 28]. The curves shown in **Figure 14** indicate that damping property increases and decreases in a particular frequency level [28, 29].

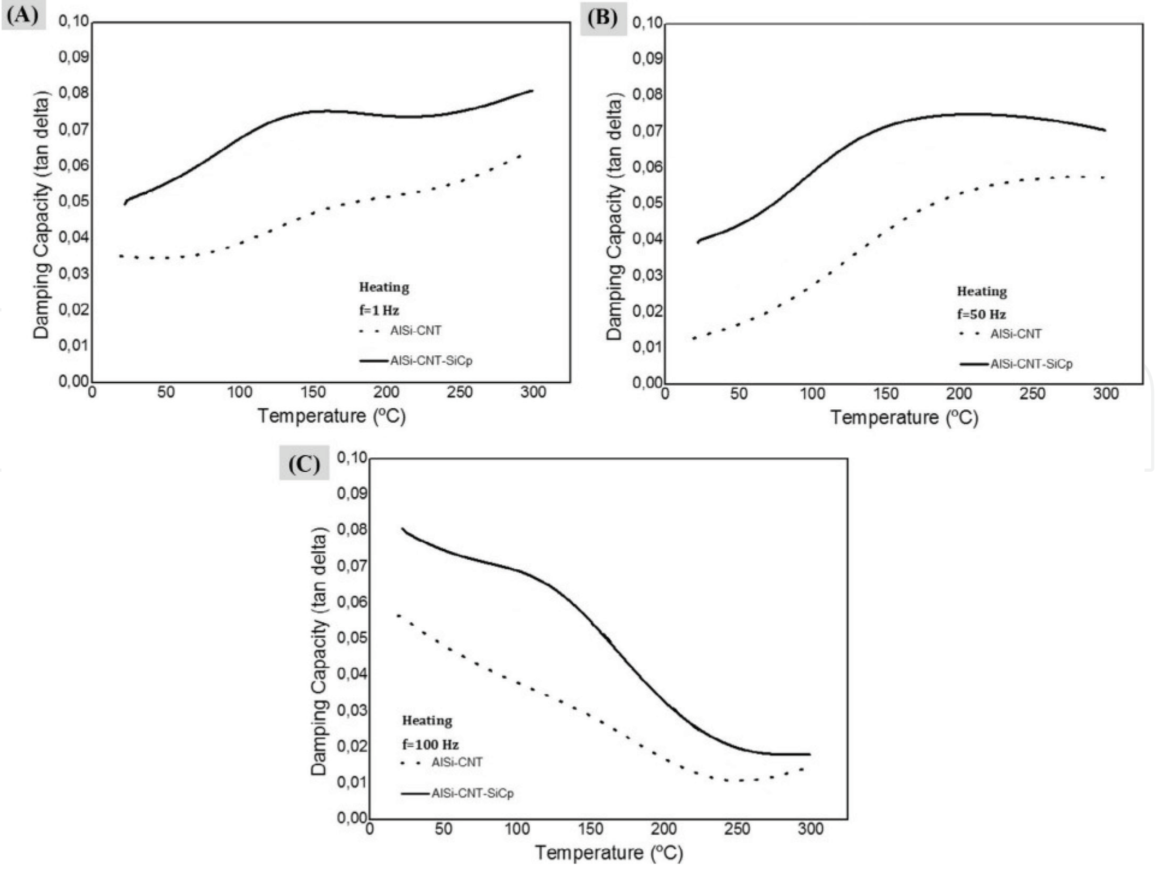

Figure 14.
Dynamic mechanical analyser (DMA) Tan delta vs. temperature curves of AlSi-MWCNT and AlSi-MWCNT-SiC composites for varying frequencies [13, 14].

Figure 14 shows Tan delta curves of AlSi-MWCNT, AlSi-MWCNT-SiC composites having maximum damping property value at the temperature of 150°C. At some point the damping property gets decreased due to MWCNT, SiC reinforcements experiencing low energy dissipation under maximum frequency condition [12–14, 29]. The cluster formation of MWCNT and SiC will affect the damping property of the material. Hence, the homogeneous dispersion of MWCNT into an AlSi matrix material increases the high interfacial-sliding and improves the damping property [29, 30].

AlSi-MWCNT, AlSI-MWCNT-SiC composites storage (or) dynamic modulus temperature function and its corresponding frequencies are shown in **Figure 15**. For all the frequency values, increase in temperature reduces the storage modulus and it can reduce the dynamic stiffness property [25, 31, 32]. Madeira et al. reported the same about the dynamic modulus in Al reinforced SiC particles [13].

In AlSi-MWCNT-SiC hybrid composites the storage modulus value is (~100 GPa) higher than AlSi-MWCNT composites (which is 73 GPa) in ambient (room) temperature shown in **Figure 15**. Based on the above results, adding MWCNT into the hybrid composites shows a very effective improvement in the modulus value [28, 31]. Therefore, Carbon nanotube provides a promising property which improves the damping property without compromising the mechanical properties. There are some of the major mechanisms involved in improving the damping properties are (i) interface sliding between MWCNT and AlSi matrix material (ii) a small amount of micro-voids due to ball milling method which dissipates energy are the two mechanisms which involves in improving the damping property of the developed material [24, 25, 32]. Based on the observations from Tan delta and storage modulus (or) dynamic young's modulus curves, it shows a hysteresis among the phases of heating and cooling [13, 25, 29].

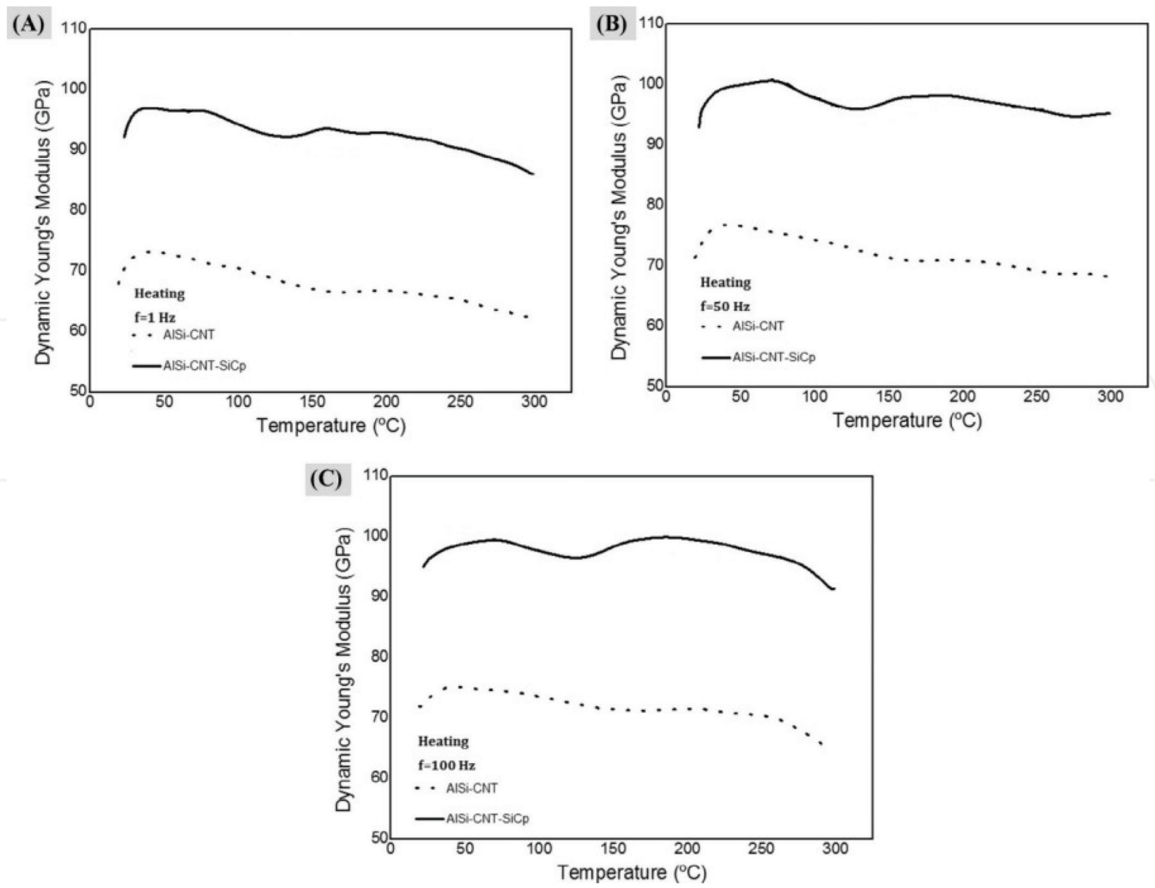

Figure 15.
Dynamic mechanical analyser (DMA) storage modulus vs. temperature curves of AlSi-MWCNT and AlSi-MWCNT-SiC composites for varying frequencies [13, 14].

4. Conclusions

From the above chapter, the following points are discussed:

1. The composites fabrication methods of Aluminium 2024 alloy, Aluminium Silicon alloy reinforced with MWCNT and SiC.

2. Dispersion pattern and interface between Aluminium alloys—MWCNT reinforcement into the matrix material observed with a minimum cluster formation is presented.

3. Ni coated MWCNT with varying composition into the matrix material are elaborated and Ni coated MWCNT resist the brittle intermetallic formation between matrix and the reinforcement.

4. Damping property was studied based on the dynamic mechanical analyser test.

5. Variation of frequencies and temperature shows the changes in damping property.

6. Hysteresis of damping for aluminium reinforced with MWCNT is explained.

7. Influence of MWCNT and damping mechanisms are briefed.

Notes/thanks/other declarations

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Acronyms and abbreviations

Al	aluminium
CNT	carbon nanotube
MWCNT	multi-wall carbon nanotube
AA	aluminium alloy
MMCs	metal matrix composites
AlSi	aluminium silicon alloy
SiC	silicon carbide
Al_4C_3	aluminium carbide
Ni	nickel
C	carbon
CIP	cold isostatic pressing
SEM	scanning electron microscope
FESEM	field-emission scanning electron microscope
TEM	transmission electron microscope
EDX	energy dispersive X-ray spectroscopy
X-RD	X-ray diffraction
BSE	back scattered electron
DMA	dynamic mechanical analyser

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