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INVESTIGATION INTO FATIGUE, DAMPING AND TENSILE PROPERTIES OF MULTI-WALLED CARBON NANO TUBE AL6061 METAL MATRIX COMPOSITES USING STIR CASTING TECHNIQUE

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ABSTRACT

Al6061 alloy as matrix and Multiwall Carbon Nanotube (MWNT) as reinforcement (0, 0.5, 1, 2,3,4 & 5 weight percentage) have been successfully fabricated by Stir Casting Technique. Fatigue is a mechanical property of the material, which occurs when a material is repeatedly subjected to an average stress which is lower than the materials yield stress. Hot rolling is used mainly to produce sheet metal or simple cross sections, such as rail tracks. Damping specimens were prepared according to ASTM E 756-05 standard and the specimens were subjected to free vibration test to investigate the damping ratio and natural frequency. It is observed from the free vibration test data improvement in damping ratio, natural frequency and modulus when reinforced with 2 weight percentage of MWNT. Increase in weight percentage of MWNT beyond 2 wt% leads to deterioration in damping ratio, natural frequency and Young's modulus. This is due to agglomeration of reinforcement phase. Also the mechanical properties of the developed composites have been studied.

Keywords: *Multiwall Carbon Nanotube (MWCNT), Al6061, fatigue, Damping ratio, Natural frequency and Stir casting technique.*

1. Introduction

In aerospace, automobile and other structural applications, the demand for materials possess superior properties like higher strength to weight ratio, high modulus and high temperature stability along with good damping ability is continuously increases. However, it is difficult to achieve all these properties in a single material. Components used at higher operating temperatures, metal matrix composite materials with a good reinforcement are preferred. Mr.Hui Lu, Xianping et.al.[1] have summarized the development of the design concept of high damping composite materials and the investigation of their fabrication and properties, including mechanical and damping properties and suggested a new design concept of high damping composite materials. Wan Di-qing et.al.[2] have investigated the low frequency damping properties of as-cast hypoeutectic Mg-Ni alloys. The results show that the as-cast hypoeutectic Mg-Ni alloys exhibit high damping capacities. N. Srikanth et.al.[3] studied that elemental magnesium was reinforced with nano-size alumina particulates. The results revealed that an increase in the alumina content up to 0.4% volume percentage lead to an increase in the damping capacity up to 34%. J. Zhang et.al[4].studied that High-damping materials allow undesirable mechanical vibration and wave propagation to be passively suppressed. This proves valuable in the control of noise and the enhancement of vehicle and instrument stability. K. S. Umashankar et.al.[5[have investigated that Nano particulate composites with Al-Si alloys (LM6 and LM25) as matrix and Multiwall Carbon Nanotube (MWNT) as reinforcement (0.25, 0.5, 0.75, 1.0 and 1.5 weight percentage) have been fabricated by powder metallurgy process, the specimens were subjected to free vibration test to investigate the damping ratio and natural frequency. It is observed from the free vibration test data; both alloys (LM6 and LM25) have shown significant improvement in damping ratio, natural frequency and modulus when reinforced with 0.5 weight percentage of MWNT. Gabriel A. Lo´ pez et.al.[6] have investigated absorption of vibration energy by mechanical damping has attracted much attention in several fields such as vibration reduction in aircraft and automotive industries, nanoscale vibration isolations in high-precision electronics, building protection in civil engineering, etc. Typically, the most used high damping materials are based on polymers due to their viscoelastic behavior. Chia-Yen Peng et.al.[7] describes a unique experimental facility designed to measure damping of materials at cryogenic temperatures for the Terrestrial

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Planet Finder (TPF) mission at the Jet Propulsion Laboratory.. Wan Di-qing et.al.[8]have investigated (DMA) was applied to systematically investigate the low frequency damping properties of as-cast hypoeutectic Mg-Ni alloys. The results show that the as-cast hypoeutectic Mg-Ni alloys exhibit high damping capacities. C.F. Deng et.al.[9] have fabricated a multi-walled carbon nanotube (MWNTs) reinforced 2024Al composite by mixing 2024Al powders and CNTs, cold isostatic press and hot extrusion. The damping behaviors of the composite were investigated with frequency of 0.5, 1.0,5.0, 10, 30 Hz, at a temperature of 25–400 °C. The frequency significantly affects the damping capacity of the composite when the temperature is above 230 °C, CNTs are a promising reinforcement for metal matrix composites to obtain high damping capabilities at an elevated temperature without sacrificing the mechanical strength and stiffness of a metal matrix. Rodney S.Ruoff et.al.[10] investigated the tensile and bending stiffness constants of ideal multi-walled and single-walled carbon nanotubes are derived in terms of the known elastic properties of graphite. Tensile strengths are estimated by scaling the 20 GPa tensile strength of Bacon's graphite whiskers. The natural resonance (fundamental vibrationalfrequency) of a cantilevered single-wall nanotube of length 1 micron is shown to be about 12 MHz. G. Overney et.al.[11] have investigated that the low frequency vibrational modes and the structural rigidity of long graphitic carbon tubules consist of 100, 200, and 400 atoms.

K T Kashyap et.al.[12] were fabricated the CNT/Al nanocomposites by powder metallurgy technique after extrusion of the nanocomposites bright field transmission electron microscopic (TEM) studied, From the TEM images, a novel method of ascertaining the Young's modulus of multi-walled carbon nanotubes is worked out in the present paper which turns out to be 0·9 TPa which is consistent with the experimental results. Dong Qian et.al.[13] have studied carbon nanotubes mechanical properties including high strength, high stiffness,low density and structural applications. Young's modulus, bending stiffness, buckling criteria, and tensile and compressive strengths. nanoropes, filled nanotubes, nanoelectromechanical systems, nanosensors and nanotube-reinforced polymers. B B Verma et.al.[14] investigated the Fatigue properties of a thermomechanically treated 7475 aluminium alloy have been studied in the present investigation. The alloy exhibited superior fatigue life compared to conventional structural aluminium alloys and comparable stage II crack growth rate. X. Xia et.al.[15] contributions of the reinforcement volume fraction and annealing temperatures to crack opening force and propagation energy are systematically studied by three point bending tests and by SEM investigations. The bending test data show that for the same reinforcement volume fraction, 2618 and 7075 Al composites require much higher force to open the cracks than 6061matrixg.Studies reveal that the energy absorption level of the materials during crack propagation depends on both matrix strength and ductility which relates to the reinforcement volume fraction, composition and heat treatment conditions. P. J. Haagensen et.al.[16] summariz fatigue test on high strength steel specimens in the as-welded condition and specimens treated by ultrasonic impact treatment, TIG dressing and a combination of TIG dressing and ultrasonic impact treatment. In the present work MWNT reinforced Al6061alloy -MWCNT composites are produced by stir casting process and their fatigue, damping and tensile properties have been investigated.

2. Materials and Methods

2.1 Matrix and Reinforcement material

Al6061 powder (200 mesh) and multiwalled carbon nano tubes (MWCNT) were procured whose properties are as in tables.1 and 2.

Table 1: Chemical Composition of Al6061 alloy

Component	Amount (Wt. %)
Aluminium	Balance
Magnesium	0.8-1.2
Silicon	0.4 – 0.8
Iron	Max. 0.7
Copper	0.15-0.40
Zinc	Max. 0.25
Titanium	Max. 0.15
Manganese	Max. 0.15
Chromium	0.04-0.35
Others	0.05

Table 2: Properties of Mutiwalled Carbon Nano Tube(MWCNT)

Properties	Values
Purity	Carbon > 95% (trace metal basis)
OD × ID × L	10-30 nm × 2-6 nm × 15-30 µm
Total Impurities	Amorphous carbon<3% (TEM))
Melting Point	3652-3697 °C
Density	1~2 g/cm^3

2.2 Method and preparation of composite

Development of Al6061-MWCNT metal matrix composites using stir casting method. The procured Al6061 Alloy was taken in a graphite crucible and melted in electric furnace. The temperature was slowly raised to 800-8500C.The melt was degassed at 8000C using a solid dry hexachloro ethane degasser. The molten metal was stirred to create a vortex and the particulate (MWCNT) were introduced. The preheated multi-walled carbon nanotubes were slowly added in to the melt. The percentage of MWCNT added was 0, 0.5, 1, 2, 3, 4 & 5 weight percentage. The stirred dispersed molten metal was poured in to preheated iron moulds 22 mm diameter and 120 mm height and cooled to room temperature. The materials were tested using Brinell hardness tester. The microstructure of the MMC's was observed under a optical microscope and scanning electron microscope at various locations across the specimen to examine the distribution of carbon nano tubes in the matrix. Samples were subjected to fatigue, damping and tensile behavior of the specimens.

3. Results & discussions

3.1 Fatigue test

Fatigue is a mechanical property of the material, which occurs when a material is repeatedly subject to an average stress which is lower than the materials yield stress. The fatigue specimens were heat treated T6 and turned as per ASTM- standard. The fatigue test was conducted by Rotating Beam Fatigue Testing Machine as shown in figure. 1(a) and figure.1(b)

Fig. 1(a) Fatigue test specimen

Fig. 1(b) Rotating Beam Fatigue Testing Machine

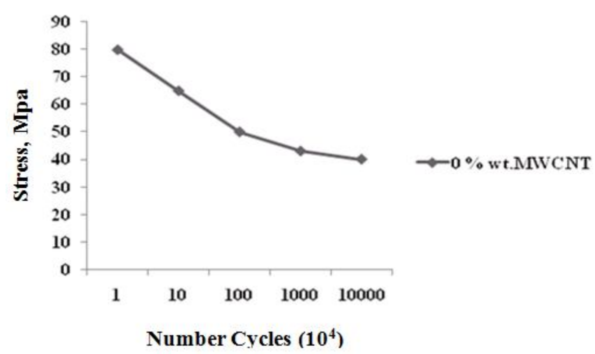

Fig. 2 Stress v/s No.of Cycles (Al6061-0 wt.%MWCNT)

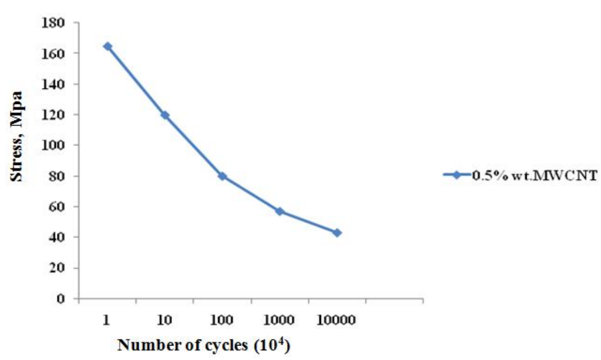

Fig. 3 Stress v/s No. of Cycles (Al6061-0.5 wt.%MWCNT)

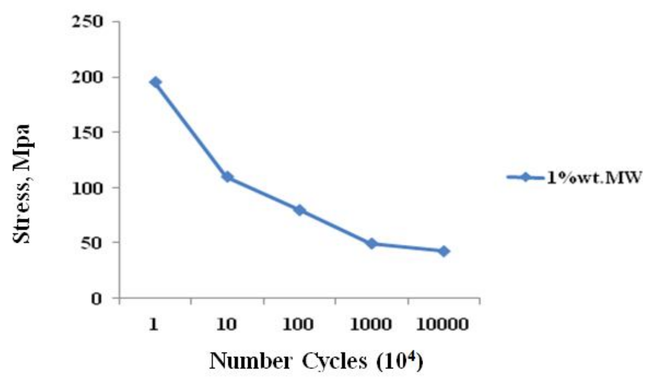

Fig. 4 Stress v/s No. of Cycles (Al6061-1wt. %MWCNT)

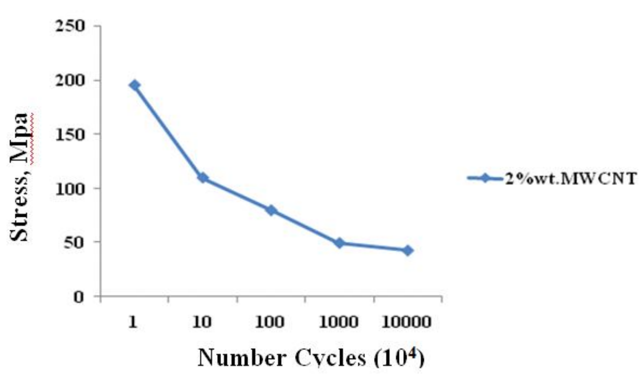

Fig. 5 Stress v/s No. of Cycles (Al6061-2 wt.%MWCNT)

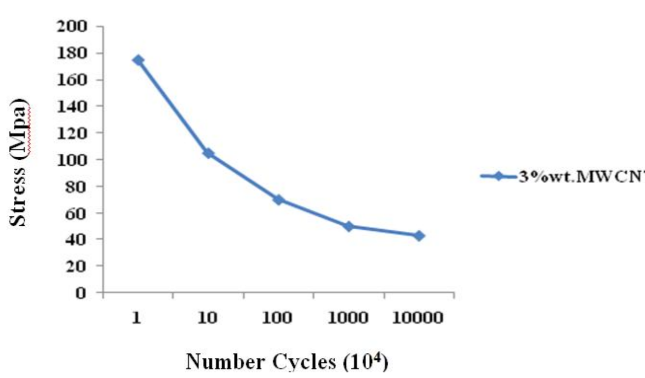

Fig. 6 Stress v/s No. of Cycles (Al6061-3 wt.%MWCNT)

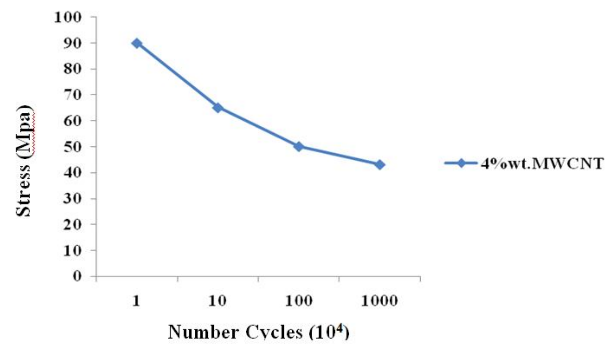

Fig. 7 Stress v/s No. of Cycles (Al6061-4 wt.% MWCNT)

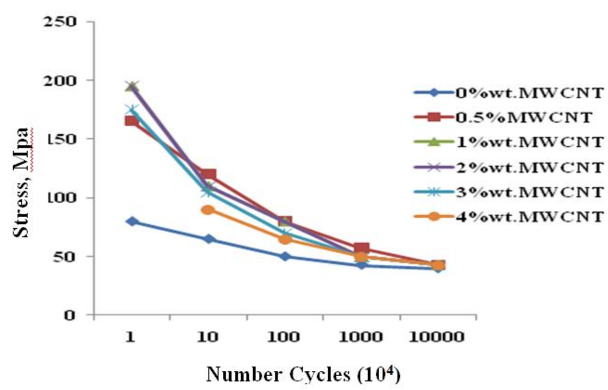

Fig. 8 Stress v/s No. of Cycles (Al6061- wt.% MWCNT)

The figure.2 to 7 show Stress v/s No. of cycles for failure of various specimens for different percentage weights of MWCNT.

The figure.8 shows combined graph of Stress versus No. of cycles for failure of various specimens for different percentage weights of MWCNT. It is concluded that 1 wt% of MWCNT and 2wt% have maximum fatigue stress value. The maximum endurance strength was attained between 1%wt. and 2% wt. MWCNT. As increase in wt % of MWCNT increases the fatigue strength of the material. Hence, between 1-2 % weights composition is the best suitable composition for Fatigue life cycle.

3.2. Damping

The hot rolled specimens were prepared for damping test. The size of 65 mm X 8 mm X 1 mm were prepared from Al6061- MWCNT composites. The specimen was subjected to free vibration according the standard test methods for measuring Vibration-Damping properties of materials as per ASTM E 756-05. The specimens were treated as self supporting materials with cantilever beam configuration. The experimental setup consists of an accelerometer A&D 3101 with sensitivity 9.8mV/g which is used to measure the beam response. Data acquisition is through National Instruments eight channel industrial platform sound and vibration measurement module having 24 bit resolution and acquisition rate capability of 1024 kS/s. Signal conditioning and analysis are done through National Instruments . Three sample specimens were subjected to testing in each composite and average value was taken to compute damping ratio and the natural frequency. The damping ratio is calculated and tabulated in Table. 3.

The following fig.9 to fig.11 exibit amplitude v/s time.

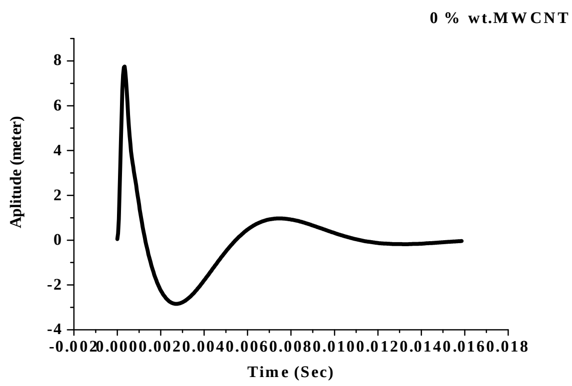

Fig. 9 Ampitude v/s Time (Al6061- 0% wt.MWCNT)

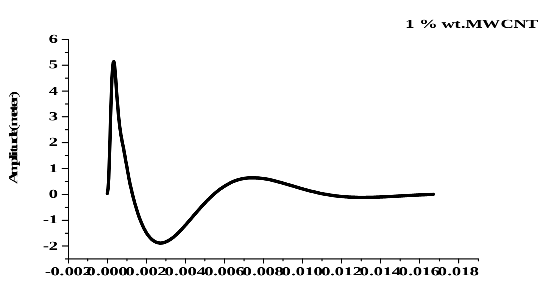

Fig. 10 Ampitude v/s Time (Al6061- 1 % wt.MWCNT)

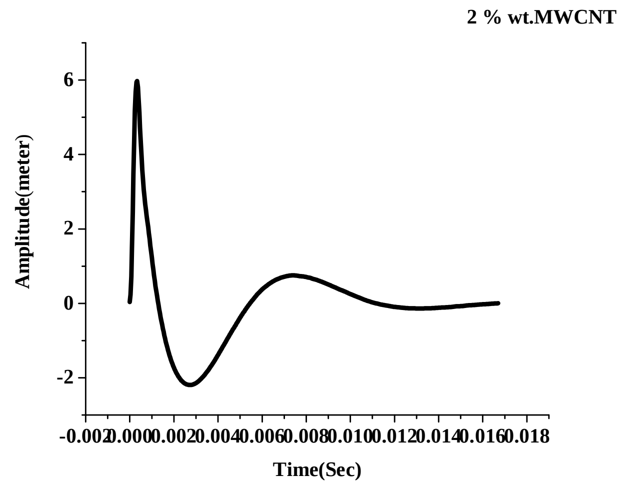

Fig. 11 Ampitude v/s Time (Al6061- 0% wt.MWCNT)

Table 3: The Damping Results

Specimen No.		Spring Stiffness k=3 EI/l^3 in N/m	Undamped Natural Frequency ω_n in Hz	Damping Ratio $\xi=1/[\sqrt{1+(2\pi/\delta)^2}]$		Logarithmic Decrement $\delta=\ln(x_o/x_1)$	Damping Factor in Ns/m	Critical Damping Cc=2 $\sqrt{km}$ in N m
0 %	1	509.81	499	0.301	Avg. 0.303	2.05	17.63	56.76
	2	509.81	499	0.304		2.39	20.23	56.76
	3	509.81	499	0.305		2.17	18.59	56.76
1 %	1	505.05	347.5	0.304	Avg. 0.309	2.005	18.16	59.47
	2	505.05	499	0.319		2.120	19.23	60.30
	3	505.05	498.5	0.304		2.005	18.05	59.37
2 %	1	500.83	499	0.387	Avg. 0.359	2.63	20.92	54.08
	2	500.83	499	0.395		2.708	21.58	54.63
	3	500.83	498.5	0.297		1.90	16.34	54.54
3 %	1	496.61	496	0.316	Avg. 0.309	2.00	17.53	55.48
	2	496.61	496.5	0.306		2.024	16.96	55.45
	3	496.61	496.5	0.307		2.031	17.28	56.28

Table.3.the damping results, it is evident that 2 weight % MWCNT reinforced Al6061 alloy exhibit excellent damping and natural frequencies in comparison with other weight percentages.2 weight percent MWCNT-6061Al composite exhibit high natural frequency (499Hz). This is due to composites possessing high stiffness on account of high modulus of MWCNT and its uniform distribution. The improvements in damping ratio for Al6061 with 2 weight percent MWCNT is 0.359. At lower weight percentage of MWCNT in the composites, the improvement in the damping ratio and natural frequency is very marginal. Higher weight percent of MWCNT in the composites leads to decrease in damping ratio and natural frequency. Clustering of multi walled CNT at higher weight percentage causes the decrease in natural frequency and damping ratio. At 2 weight percentage, the MWCNT is uniformly distributed. This results in good bonding between the reinforcement and the matrix. This provides large interfacial area between matrix and Reinforcement. This increases the modulus value as well as energy dissipation at interface.

3.3. Tensile test

Tensile test were conducted at room temperature using a universal testing machine (UTM) in accordance with ASTM Standard E 8. Figure.12. shows tensile test specimen. The specimens were Rolled from the cast composites with the gauge length of the specimens parallel to the longitudinal axis of the castings. For each composite, four tensile test specimens were tested and the average values of the UTS and ductility (in terms of percentage elongation) were measured.

Fig. 12 Rolled specimen for Tensil test [Specification: 150 x 8 x 1mm]

Table 4: Tensile Test Values

Specimen (wt.%of MWCNT)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	% Elongation (Ductility)
0%	190.58	217.48	2.48
1%	192.11	218.24	2.52
2%	233.98	270.52	2.63
3%	248.55	278.67	2.68
4%	253.22	281.62	2.70
5%	262.5	290.0	2.72

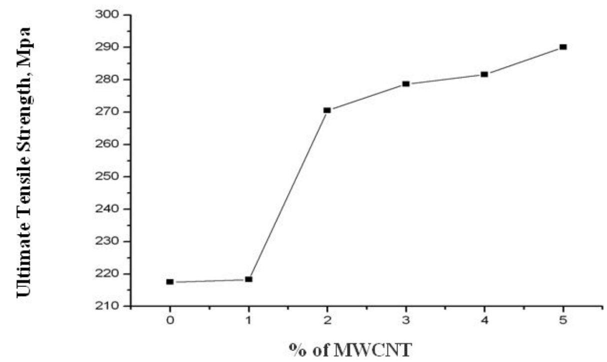

Fig. 13 Ultimate Tensile Strength v/s % of MWCNT

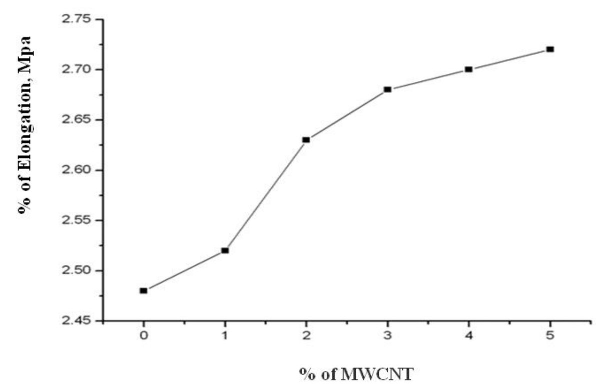

Fig. 14 % of Elongation v/s % of MWCNT

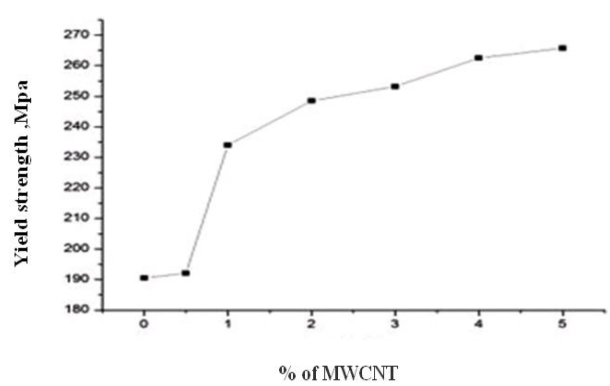

Fig. 15 Yield strength v/s % of MWCNT

From the above Table.4 and Figure.12,13 & 15, as the wt % of MWCNT increases, its Yield Strength, % Elongation and Ultimate Tensile Strength values also increasing gradually.

4. Conclusions

i. Aluminum6061 as matrix and MWCNT (0,0.5,1,2,3,4 & 5 weight percentage) as reinforced Metal Matrix Composite has been successfully developed by Stir Casting method. The obtained composites were heat treated as per Al6061 -T6 condition.

ii. It was found that fatigue has got its maximum stress value for 1% & 2% weight composition respectively. Hence, between 1 - 2% weight compositions are the best suitable composition for Fatigue life cycle.

iii. The Rolled specimens were subjected to free vibration test to evaluate the damping ability and natural frequency (stiffness).The Damping ratio decreases by increasing the reinforcement, after 2% wt. Hence 2% wt. reinforced 6061Al matrix is the best suitable composite for better damping ability and stiffness properties.

iv. The Rolled specimens Al6061-MWCNT were subjected to tensile test was found that increasing the MWCNT content within the 6061Aluminum matrix results in significant increases in the ductility, UTS and yield strength.

v. More than 2 wt % weight percentage of MWNT leads to clustering and thus the damping and stiffness properties are reduced remarkably.

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