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Machining characteristics of nanocomposites

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ABSTRACT

Nanocomposites were prepared with Al/Al-Si alloys (LM 6 and LM 25) as matrix and multi wall carbon nanotube (MWNT) of 0.25, 0.5, 0.75, 1.0 and 1.5 wt. % as reinforcement through powder metallurgy (PM) followed by sintering and hot extrusion techniques. Fabricated nanocomposites were machined on a Panther 1530/1650 lathe by using tungsten carbide tool. Recurrence quantification analysis (RQA) was used to study the machining characteristics by using cutting force signal stability. Highest value of determinism (DET-one of the RQA parameter) was observed for 0.5 wt.% MWNT reinforced Al and Al-Si nanocomposites. This attributes better machining characteristic due uniformity of the signals. Also it is observed better mechanical properties at 0.5 wt.% reinforced nanocomposite and further reinforcement deteriorate the machinability and mechanical properties. Copyright © 2011 VBRI press.

Keywords: Aluminum; carbon nanotube; machining; recurrence plot; RQA.

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Introduction

In the recent technological era the carbon nanotubes reinforcement in polymer and metal matrix developing an entirely new class of nanocomposite materials. By literature review most of the research works on CNT based nanonanocomposites available on polymer [**1-2**] and ceramics matrix nanocomposites [**3-4**]. Researchers have also been made an attempt to produce metal matrix nanocomposites with CNT as reinforcement and metals such as Aluminium, Magnesium, Copper and Zinc as matrix materials [**5-8**] and reported.

Materials having higher Stiffness associated with damping property are sought for dynamic mechanical systems such as in space-crafts, semiconductor equipment and robotics [**9**]. Carbon Nanotubes (CNT) usage as reinforcements in Al and Al-Si nanocomposites has proved suitable material for critical dynamic system applications. These materials are highly expensive. To reduce wastage during secondary operation and to obtain required accurate geometrical parts, it is necessary to study the basic manufacturing and machinability of the material at the time of design of material and selection. From literature it is found that cutting force amplitude as a character for machinability study and its values were used for surface roughness measurement and it depends on microstructure of commercial engineering materials [**10**]. It was also described a technique involving the use of three mutually perpendicular components of the cutting forces (static and dynamic) and vibration signature measurements for machinability study. In other side it is necessary to optimize machinability from the point of economy. In this view many researchers tried various conventional techniques for machining optimization include geometric programming, geometric plus linear programming, goal programming, sequential unconstrained minimization technique, dynamic programming etc. also the latest techniques for optimization include fuzzy logic, scatter search technique, genetic algorithm, Taguchi technique and response surface methodology were tried. As per the authors knowledge no literature is available on machinability study of this new material (CNT based Al and Al-Si nanocomposites) by any of the methods. Present work deals the fabrication and study of machining characteristics of CNT reinforced Al/Al-Si nanocomposites by using Recurrence Quantification Analysis (RQA). Highlight on the importance of properties [**11**] and also the requirement of very small % as reinforcement, CNT is taken as reinforcement. As the cost of single wall carbon nanotubes are costlier compared to the Multiwall Carbon Nanotubes (MWNT), MWNTs are selected for the fabration of nanocomposite.

Experimental

Materials

Particulate reinforced Al and Al-Si nanocomposites were manufactured using MWNTs (size 10-15 nm outer and 2-6 nm inner diameter with length of 0.1-10 micro meter and 90% purity synthesized using Chemical Vapour Deposition (CVD) method) as reinforcement and Al, LM6 and LM25 (powders of 200 mesh size) as a matrix separately. Al, LM6 and LM25 were supplied by M/s metal powder. Co, Chennai and MWNT supplied by M/s sigma Aldrich, Bangalore.

Establishment of compaction load

In this study a die and punch set of 25.4 mm diameter was used to obtain specimen as per ASTM B-925. Zinc stearate was applied to die and punch to minimize friction during the compaction process. In order to achieve the good density trial compaction was carried out by applying load of 60KN to 180KN through a hydraulic press of 40-Ton capacity at the rate of 2 Ton/min. 35 grams of powder was taken for compaction. Density was determined in each trial. From the density versus load, it was observed that maximum density obtained at optimum load of 120KN, 160 KN and 140 KN for Al, LM6 and LM25 respectively as shown in **Fig. 1**.

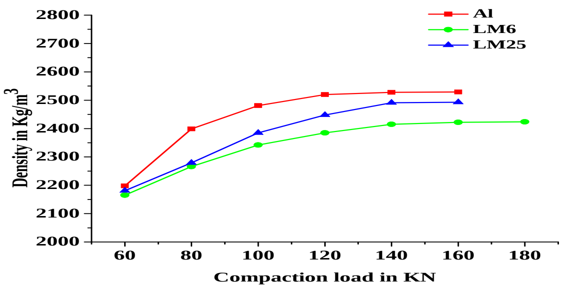


Fig. 1. Density versus load of Al, LM6 and LM25 compacts.

Nanocomposite preparation

The MWNT was rinsed in concentrated Nitric acid, then filtered, washed with de-ionized water and dried at 120^{o}C to remove the surface impurities [**12**]. Predetermined quantity of MWNT was mixed with matrix in ethanol solution by using ultrasonic shaker for 30 min. Then, the matrix and reinforcement blend was dried at 120°C in vacuum (less 10^{-2} Pa) and broken up by using Retsch PM100 high speed planetary ball mill for duration of 10 min at 200 rpm. Specimens of size 25.4 mm diameter was produced by above said compaction technique. After compaction the green specimen was subjected to extrusion at around 350 ^{o} C fallowed by sintering in nitrogen atmosphere for 1 hour at suitable temperature (560^{o}C-Al, 515^{o}C-LM25 and 490^{o}C-LM6).

Recurrence plots and recurrence quantification analysis for machinability study

Recurrence Plots (RP) were first described in 1987 [**13**]. RP is a technique by which one can qualitatively assess a time series signal embedded in phase space. In general, deterministic and regular signals tend to form diagonal line structures whereas random signals form scattered points distributed throughout the RP. Laminar systems (states are changing slowly with time or they are stationary) show vertical line structures in their corresponding RPs.

It is always difficult to predict precisely the status of a system just by observing the corresponding RP. Some means of quantification of RPs would make understanding the behavior of the system more correctly. Charles L. Webber et al. have developed a technique called Recurrence Quantification Analysis (RQA) in 1992, which was based on quantifying the diagonal line structures present in RPs. In 2002, Norbert Marwan et al. successfully added the quantifications based on vertical line structures. Some of the important variables in RQA are recurrence rate (RR), determinism (DET), entropy (ENTR), laminarity (LAM) [**14-18**]. Visual Recurrence Analysis (VRA), CRP Toolbox for Mat lab, Dataplore, TISEAN and Bios Analyzer are few of the codes and software available for Recurrence Plots and Recurrence Quantification Analysis. In this work VRA developed by Eugene Kononov was used.

Results and discussion

Density

Density of the neat matrix and MWNT reinforced nanocomposite specimens were computed and plotted as shown in **Fig. 2(a)**. From this it is observed that, density before and after sintering decreases with increase in wt. % of MWNT in the nanocomposites. It was also observed that, the density was decreased remarkably in case of nanocomposite having more than 1 weight percent of reinforcement. This was due to agglomeration of MWNT in the matrix this result was supported by the TEM images as shown in **Fig. 3**.

Hardness

Hardness of neat matrix Al, LM6 and LM25 and MWNT reinforced nanocomposite specimens were determined using Rockwell Hardness Testing apparatus as per ASTM B-925 and plotted as shown in **Fig. 2(b)**. It was observed from the graph that, the hardness value increases as the reinforcement increases up to 0.5 wt. % and further decreasing as reinforcement increases. This is due to clustering of MWNT in the matrix at higher concentration.

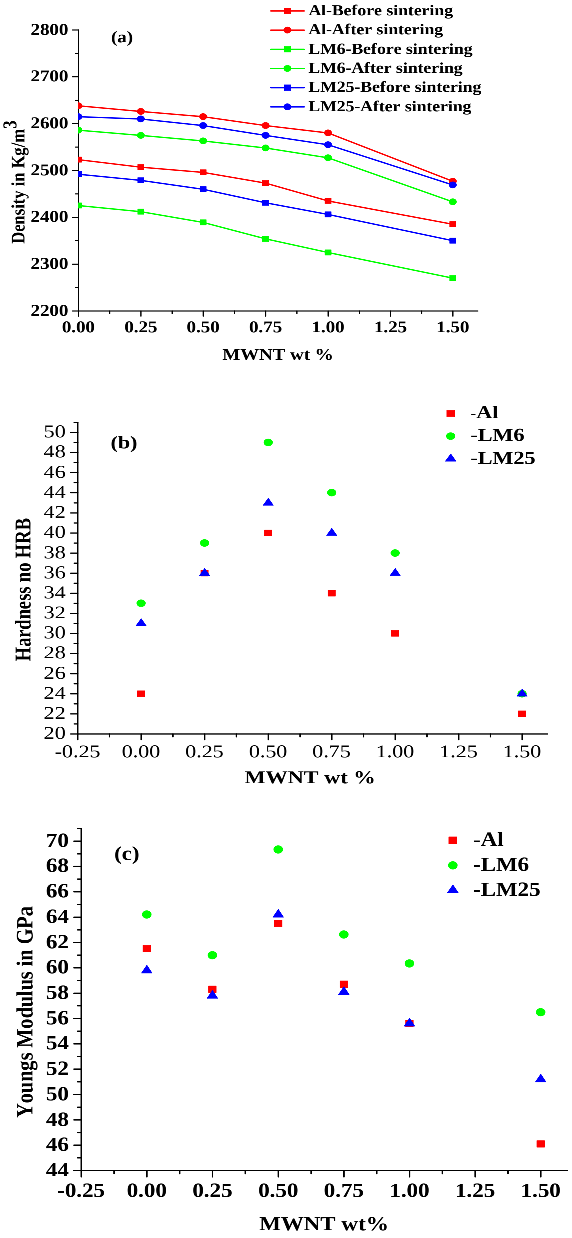


Fig. 2. (a) Density, (b) Hardness and (c) Young s modulus of nanocomposites.

Young's modulus

The young's modulus of neat matrix and MWNT reinforced nanocomposite specimens were examined as per ASTM standard B925-03 by using computer interfaced electronic load cell controlled Monsanto tensometer. It was observed that 0.5 wt % MWNT nanocomposites exhibits highest value (Al- 63.5 GPa, LM6- 69.33 GPa and LM25- 64.2 GPa). Further increase in MWNT in the nanocomposites was not beneficial. This reduction in young's modulus is also due to the agglomeration of MWNT in the matrix. At higher content agglomeration reduces interfacial bonding and weakens the material. Due to this the high concentration leads to stress concentration and reduces the fracture toughness. The young's modulus of nanocomposites mentioned as shown in **Fig. 2(c)**.

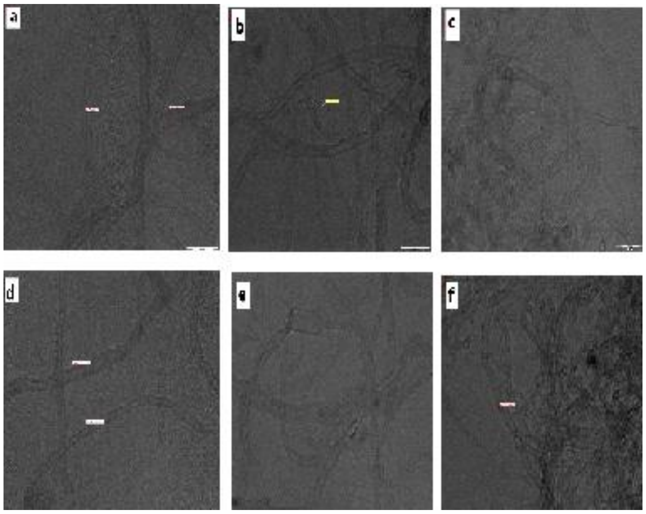
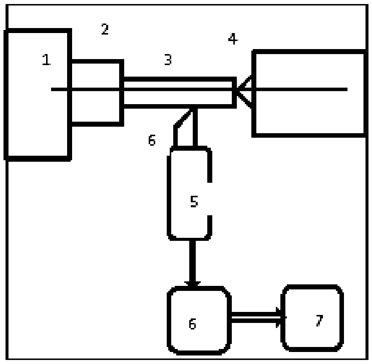


Fig. 3. TEM image of (a) Al - 0.5 wt.% MWNT, (b) Al -1.0wt.% MWNT, (c) Al -1.5 wt.% MWNT, (d) LM6 - 0.5 wt.% MWNT, (e) LM6 -1.0 wt.% MWNT, (f) LM6 -1.5 wt.% MWNT.

Experimental study of machinability and results

Fig. 4 shows the schematic diagram of experimental setup to study the machinability of nanocomposites on a Panther 1530/1650 lathe. The experiment carried out for a specimen size of 8 mm diameter and span length of 80 mm with the spindle speed of 1250 rpm using Kennametal DNMG 150608 tool insert with standard tool holder PCLNR 2020 K12. In this study 0.0375 mm/rev, 0.5 mm and 1250 rpm as feed, depth of cut and spindle speed respectively were selected as machining parameters to achieve better surface finish. Cutting forces were sensed using a Kistler 9257 B dynamometer and Kisteler 9257 B charge amplifier. The force signals in three directions were acquired by National Instruments PCI-4472 eight channel data acquisition card at a sampling rate of 1000 samples per second using LabVIEW 8.6 interface. Cutting force signals in the direction of depth of cut (z direction) were taken as the inputs for analysis with VRA.

From the recurrence quantification analysis the deteminisim was calculated and used to assess the machining characteristics of the materials in view of randomness and the expected value of the variable. The time domain signal and the corresponding RP for Al and its variants were given in Figure. 5. In the plot, recurrence rate (RR) was kept at 10 %, so that more recurrence points will be visible in the RPs and hence the line structures are clearly visible. Referring to **Fig. 5(b)** and **5(d)**, the number of diagonal structures were more in case of 0.5 wt. % MWCNT reinforced Al nanocomposite compared to Al base alloy. It indicates that the force signal was more deterministic in case of 0.5 wt. % MWCNT reinforced Al nanocomposite. RP were also obtained for other materials and the recurrence quantification Analysis were carried out by considering the suitable time delay and embedding dimensions with help of VRA software. **Table 1** represents the different parameters of RQA for Al, LM6 and LM25 materials respectively with rising temperature.



1. Headstock
2. Chuck
3. Work piece
4. Dead centre
5. Cutting tool
6. Tool post
7. Data acquisition system

Fig. 4. Schematic diagram of experimental setup.

Table 1. RQA Parameters

RQA Parameters	Al	LM6	LM25
DET (%)	3.04	17.51	4.98
L	2.72	2.25	2.63
ENTR	1.17	0.62	1.08
LAM (%)	1.99	9.56	1.46
TT	2.34	2.47	2.33

The DET, L and ENTR are RP diagonal line structure based variables. LAM and TT are RP vertical line structure based variables. As the value of determinism increases it was the indication that more number of signals repeating. This will increase the number of diagonal lines. This was also an indication that system behaving more stable. It was observed that when machining gives good surface finish which exerts uniform force. When the machining process gives irregular force components, it is the indication that there exists non-uniformity in the surface. In the other words, a system produces uniform signal, the RQA will give higher value of determinism. The **Table 2** represents the determinism values for Al, LM6 and LM25 and its nanocomposites respectively.

It was observed that, the diagonal structures were more in case of all the three matrix materials when produced by powder metallurgy route compared to that produced by casting route. The diagonal structures further improve with reinforcement of 0.5 wt.% MWNT. This was a good indication to understand that machining characteristics of powder metallurgy material are better than the cast material. This may be attributed to controlled particle size and uniform distribution of particles which are helped in chip breaking mechanism. In addition to this the porosity factor in case of powder metallurgy materils may also aid in breaking up of the chips. The addition of CNT to Al, LM6 and LM25 intended primarily to improve its dynamic properties, there was also further improvement in the deterministic nature of the cutting signal. The CNTs also contribute in improving the deterministic nature of the signal by way of increasing the anti-friction property at the tool-material interface. The maximum value of young's modulus was achived in case of 0.5 wt% reinforcement indicate that the distribution and contribution of MWNT was in the optimum level. This indicates the increase in the stiffness of the material and increase in the vibration absorption properties also contributed for getting the stability in the machining process.

Table 2. Determinism (DET) values for Al and its variants

Material	MWNT reinforced nanocomposites				
	0.0 wt.%	0.5 wt.%	0.75 wt.%	1.0 wt. %	1.5 wt. %
Al based nanocomposites	3.04	3.36	3.17	2.44	2.01
LM6 based nanocomposites	17,51	18.01	15.92	5.92	4.52
LM25based Nanocomposites	4.98	5.42	3.66	3.5	3.12

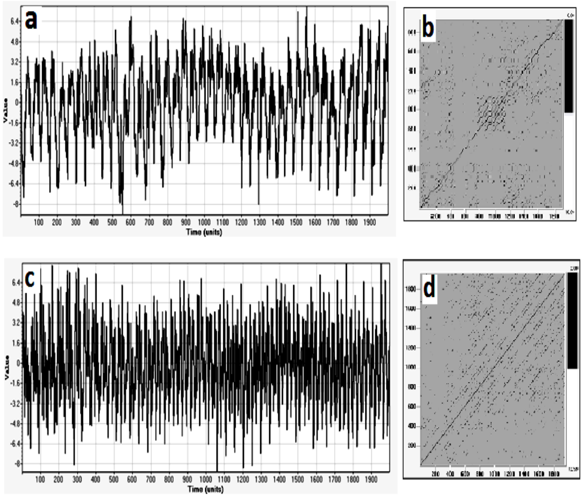


Fig. 5. (a,b & c,d) Time domain cutting force signal and corresponding RP for (a and b)without reinforced Al and (c and d) 0.5 wt % MWCNT reinforced Al nanocomposite samples

Conclusion

Al, LM6 and LM25 base material and with varying weight percentage of MWNT reinforced nanocomposites were fabricated by powder metallurgy method. Mechanical characterization and machining experiments were conducted on fabricated nanocomposites.The following conclusions were drawn from the experimental results.

Machining operation observed to be chaotic in nature, the RQA technique can be used to assess the machining characteristics by determining the regular or random nature of the cutting force signal.

- Al, LM6 and LM25 based 0.5 wt. % MWCNT reinforced nanocomposites produced by powder metallurgy shows the better machining characteristics
- LM6 having good mechanical properties in terms of hardness leads to stability during machining and it was enhanced by reinforcing it with 0.5 Wt. % MWCNT further improved the stability in the cutting force.
- The 0.5 Wt. % reinforced LM6 material proved to be a better material having scope in manufacturing of components for aeronautical, automotive and structural applications.

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