Effect of Cutting Parameters on the Surface Roughness of MWCNT Reinforced Epoxy Composite Using CNC End-Milling Process

G. Harii Krishna Rao[1], M. N. M Ansari[2], Shahida Begum[3]

[1, 2, 3] Centre for Advance Materials, College of Engineering,
Universiti Tenaga Nasional, Malaysia, Kajang, 43000, Selangor Malaysia

Abstract: ***This research reports the study on effect of cutting parameters using CNC Milling to obtain quality surface finish that is specified by customer for machined parts. In this research, an attempt has been made to study the effects of cutting parameter that influence the surface roughness quality. The depth of cut is the most dominant factor of this study. The medium significant factor is feed rate and followed by spindle speed. The most important interactions, that effect surface roughness of machined surfaces, were between the feed rate and depth of cut for this particular type of MWCNT Epoxy composite. This research becomes part of major contribution for the manufacturing industry especially machining of MWCNT/epoxy composite materials using CNC milling process. Interestingly, this project can be regarded as an exclusive work because the information's and solutions achieved at the end of this research was significant and can be implemented in future demanding CNC industries especially in carbon nanotube/epoxy composites applications and alsoas a reference to future researchers.***

Keywords: MWCNT, Epoxy Composite, Nanotechnology, CNC milling, Manufacturing

1. Introduction

Surface finish is a quality that is specified by customer for machined parts [1]-[3]. In recent years, many advances have been made in the field of polymer matrix composites [4]-[7]. It has not yet been proven to industry that these advances have significantly affected the cost of machining this class of composites. Machining a composite is a most difficult process when compared to machining a monolithic material [8]. A cost effective machining of MWCNT/Epoxy composites has not been proven so far. Capable machining practices established in the past decade have not been optimized for machining MWCNT/Epoxy composites. This may cause loss of materials and time. Optimized process parameter can cause effective machining and better surface finish [9]-[10]. Hence, an optimized technique is proposed in this study to overcome this problem. There are many parameters that have effect on surface roughness, but most are difficult to quantify adequately [11]-[14]. In milling operation, there are many parameters such as cutting speed, depth of cut and feed rate that have great impact on the surface finish. In order to maximize the gains from milling operation, an accurate model of process must be constructed. In this research, an attempt has been made to study the effects of cutting parameter that influence the surface roughness quality.

1.1 Milling process

A milling machine is a machine tool used to machine solid materials. Milling machines are often classed in two basic forms, horizontal and vertical, which refers to the orientation of the main spindle. Figure 1.0 shows sample milling process. Both types range in size from small, bench-mounted devices to room-sized machines. Unlike a drill press, which holds the work piece stationary as the drill moves axially to penetrate the material, milling machines also move the work piece radially against the rotating milling cutter, which cuts on its sides as well as its tip. Work piece and cutter movement are precisely controlled to less than 0.001 in (0.025 mm), usually by means of precision ground slides and lead screws or analogous technology [14].

1.2 Epoxy Composites

Epoxy is a co-polymer, that is formed from two different chemicals. These are referred to as the "resin" and the "hardener". The resin consists of monomers or short chain polymers with an epoxide group at either end. Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A. The hardener consists of polyamine monomers, for example Triethylenetetramine (TETA). When these compounds are mixed together, the amine groups react with the epoxide groups in order to form a covalent bond. Each NH group can react with an epoxide group, so the resulting polymer is heavily cross linked, rigid and strong [14].

1.3 MWCNT Reinforcing Filler

Carbon nanotube (CNTs) describe a family of nanomaterials made up entirely of carbon. In this family, multi-walled carbon nanotube (MWCNTs) are of special interest for the industry and will be the subject of this research. Structurally MWCNTs consist of multiple layers of graphite superimposed and rolled in on themselves to form a tubular shape. Such cylindrical graphite polymeric structures have novel or improved properties that make them potentially useful in a wide variety of applications in electronics, optics and other fields of materials science.

2. Materials and Methodology

2.1 Materials

The epoxy resin consists of two components that are clear Epoxy resin 331 where its viscosity is 11,000 - 14,000 cps. Epichlorohydrin hardener consists of polyamine monomers, for example Triethylenetetramine (TETA) where its viscosity is 350 - 450 cps. Both chemicals are obtained from authorized chemical supplier located in Puchong, Selangor. Multi-walled carbon nanotubes (MWCNT) supplied by School of Chemical Engineering, USM with specific surface area of 100 m^2/g and density of 2.6 g/cm^3. The MWCNT has purity percentage of 93%. The diameter of the carbon nanotubes are 10-20nm and the average length of the nanotube was 50 µm.

2.2 Mould Fabrication

Three (3) aluminium moulds were prepared using CNC Milling. For this mould preparation, the settings of the machining parameters are: cutting speed of 2000 rpm, feed rate at 200 mm/min and depth of cut of 3 mm each level with total three steps.

2.3 Preparation of MWCNT epoxy composites

Epoxy resin 331 and hardener Epichlorohydrin in stoichiometric ratio of 100 : 50, with 0.3 wt% amount of the MWCNT require to prepare MWCNT reinforced composite block. Table 1 shows the mixing ratio for the composite casting.

Table 1: Composition of epoxy resin, hardener and MWCNT

EPOXY				MWCNT	
Resin		Hardener			
wt %	g*	wt %	g*	wt %	g*
62.46	53.14	37.24	26.66	0.3	0.2
ARMWCNT 0.3					

g * - grams

2.4 Experimental Set Up of Machining Process

The work piece of MWCNT epoxy composite was clamped tightly against the solid jaws of fixtures at four position level by measuring the height level of four edge point of square sample in order to reduce vibration and withstand the cutting force. Then the programming code is uploaded with use of floppy drive and written using CNC simulator software. After completing the end-milling operation, the sample was cleaned softly using wet cloth to remove the excessive accumulated chips around the surface line. For this particular machining, coolant is in off state due to the material being machined is soft and flexible which can absorb the coolant liquid and cause changes in mechanical properties. The solid jaws and solid collects are opened to remove work piece sample and end mill tool respectively. The Scanning Electron Microscopy (SEM) and optical microscope is used to observe the tool and surface roughness feature of work piece. The surface roughness measured using perthometer roughness profilometer and average measurement were taken from 5 different locations in each machined line and recorded in MINITAB statistical software. Measurement values collected and saved for further analysis and discussion.

2.5 Surface Roughness Evaluation

The average roughness (R_a) is the point of area between the roughness profile and its mean line, or the integral of absolute value of the roughness profile height over the evaluation length. The R_a is specified by the following equation:

$$R_a = \frac{1}{L}\int_0^L |Y(x)|\, dx \ (\mu m) \quad (1)$$

Where, R_a is the roughness,

x – Distance along measurement
L – Evaluation length
Y– Height

2.6 Machining Parameter

To improve the quality of surface roughness of MWCNT epoxy composite and process with minimum cost and time constraints, the Taguchi parameter design techniques [16] are applied in design of experiment (DOE). Minimum surface roughness average (R_a) was carried out since the value represents better or improved surface roughness. The controllable parameters are selected because of their most potential effecting factor on surface roughness quality in end milling operation. The parameters are the depth of cut denoted as (A), the spindle speed denoted as (B) and the feed rate denoted as (C). Table 2 shows the input factors and the levels.

Table 2: Input factors and Levels

Factors	*Levels*		
	Level 1	*Level 2*	*Level 3*
Depth of cut, (A)	0.4	0.6	0.8
Spindle speed, (B)	1000	1250	1500
Feed rate, (C)	10	20	30
DOE based on interactions of factors (AB,AC,BC)			

As designed previously, the machining done for the composite material by CNC machine with g-code programming with auto parameter change in program line. Figure 1 shows the machined sample MWCNT composite material. Later, each line was studied with microscopy and surface roughness using perthometer [15].

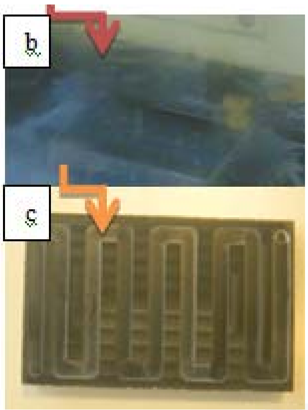


Figure 1: (a) CNC milling (b) Milling process (c) Machined MWCNT/epoxy composite

2.7 Analysis Method

2.7.1 Taguchi Analysis

The mean response for each run in the orthogonal array is analyzed and the signal-to-noise ratio (SNR) is deployed to analyze the most dominant effect of parameters towards the surface roughness quality. The signal-to-noise ratio is determined from the equation 5. The smaller the better concept of Taguchi's method [16] is adopted to obtain the optimal performance as given below:

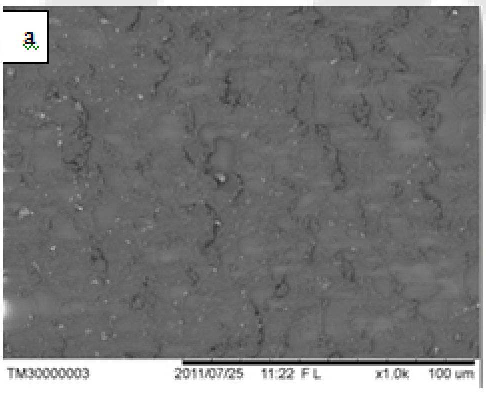
$$SNR = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (2)$$

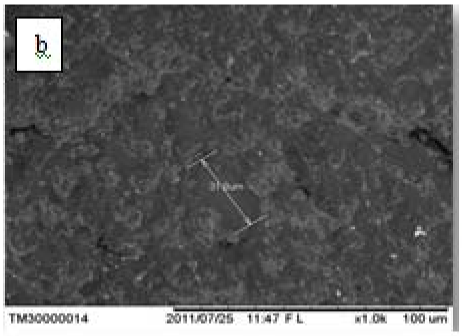
The signal-to-noise ratio SNR_L will be utilized to target the largest response. However, in this study the smallest response is desired and the SNR_S will be selected and equation 5 will be used in Minitab software in order to obtain SNR output and linear model of means.

3. Results and Discussion

3.1 Machined surface morphology

In this study, some samples were studied under Scanning Electron Microscopy (SEM) to look more detailed surface roughness variation. Figure 2 shows the detailed SEM images obtained from table top SEM. Figure 2 explains that, the surface structure are clearly smooth and very minimal level of bright patches. These shows at this cutting parameter level, the surface roughness can be achieved at minimum level.





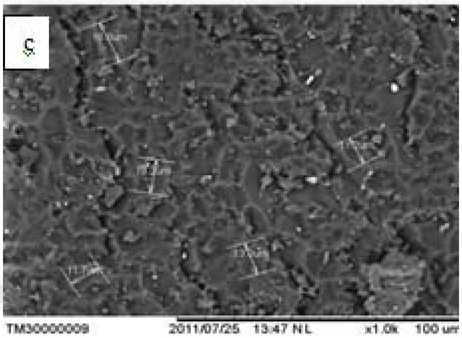


Figure 2: Sample SEM images
(a) F10,S1000,D0.8 (b)F30,S1000,D0.8 (c)F30,S1500,D0.8

3.2 Surface Roughness Analysis

The main effect of cutting parameters are shown in plots given in Figure 3 which points out that each cutting parameter factors had different pattern of plots. From this result, it can be judged that the roughness value improves in increasing and decreasing of parameter values. The highest roughness obtained at 0.6 mm of depth of cut. While in spindle speed of 1500 rpm and feed rate of 10 mm/min shows the similar average roughness value.

Also the interaction plot describes the same manner as the main effect plots. From figure 4 the significant interaction only can be seen between depth of cut and feed rate. So, the optimum cutting conditions for surface roughness with high evidence should be set to lowest level of depth of cut which was dominant factor for the surface roughness, and lowest level of cutting speed and highest level of feed rate. Same interactions were found significant from Figure 3 which means that the signal to noise ratio follow significantly the response factor that were surface roughness. From Figure 4, the main significant interaction had pair of order for the plot. The red line in row 1 column 3 explains that as feed rate increases, the roughness decreases, while the other two line seems be same pattern and not significant changes while feed rate increasing. Same goes to row 3 and column 1 shows the black and red line increase and decreases as depth of cut increases, while green line not showing significant changes when depth of cut increases. Other interactions all are in same pattern which most of the lines are parallel to each other which is showing not significant effect for surface roughness quality.

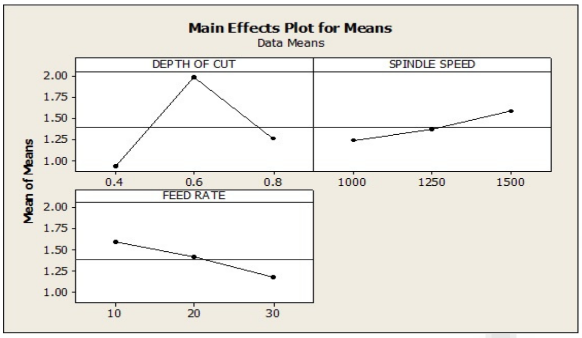


Figure 3: Main effect plots for Means

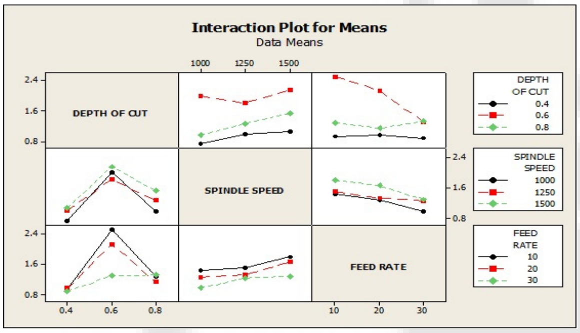


Figure 4: Interaction plot for means

From the both plots, it can be concluded that the significant effects of cutting parameters and also the interaction of parameters shows major contribution for roughness performance.

3.3 Analysis of Average Mean Responses

From Table 3, it clearly explains that the depth of cut contributes the highest effect (Delta = 1.0511) on the surface roughness followed by feed rate (Delta = 0.4094) and spindle speed (Delta = 0.3511) respectively. So, from here it can be concluded the overall hypothesis that depth of cut is far the most dominant factor affecting the surface roughness quality. Feed rate comes under rank 2 and spindle speed at rank 3. This result is not same as previous research on different non-composite materials on machining. Since this is the first attempt was made to study the effect of 3 major cutting parameters on surface roughness quality, it was finalized that depth of cut is dominant affecting factor for MWCNT Epoxy composite in CNC milling machining. Table 4 shows optimized parameter values.

Table 3: Response table of Average Surface Roughness

Level	Depth of cut	Spindle Speed	Feed Rate
1	0.9383	1.2356	1.5878
2	1.9894	1.3667	1.4228
3	1.2611	1.5867	1.1783
Delta	1.0511	0.3511	0.4094
Rank	1	3	2

Table 4: Optimized cutting parameters

Factors	*Before Optimization*	*After Optimization*
Depth of Cut, mm	0.5	0.4
Spindle Speed, rpm	1250	1000
Feed Rate, mm/min	20	30
Roughness, $R_{a(\mu m)}$	1.375	*0.6524(Predicted value)*

From the above obtained results, it is a breakthrough for machining a nanofilled epoxy composite material after getting the optimized values since no researchers was proven on machining this type of composite materials.

3.4 Effect of MWCNT on Surface roughness of MWCNT/Epoxy composites

An approach was made to study the differences in pure epoxy composites and with MWCNT filled epoxy composite. A breakthrough was identified where with adding MWCNT; actually it improves surface roughness from 0.76 to 0.66µm. The clear epoxy composites produces 0.76µm roughness while with the nanofilled epoxy composites produces only 0.66 µm. Figure 5 shows the differences between two different composites in bar chart form.

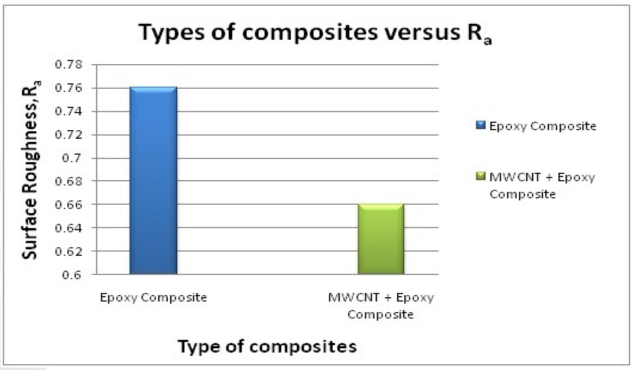


Figure 5: Comparison between two different composites

4. Conclusion

The effects of the depth of cut, spindle speed and feed rate on surface roughness were studied using MINITAB analysis software. Taguchi method was used to design the experiments and optimization. The ANOVA shows that all three factors and interactions have significant effects on the response. Moreover, the mean average roughness indicates that depth of cut contributes highest effect on the surface roughness, followed by feed rate and depth of cut. From this research, following conclusion could be reached with fair amount of confidence. Regardless of the category of the quality characteristic, the-smaller-the better for surface roughness, a good surface quality can be achieved at the highest feed rate (C = 30 mm/min), the lowest cutting speed (B = 1000 rpm) and lowest depth of cut (A = 0.4 mm) lead to optimal surface roughness value. Control parameters (A, B, and C) can be monitored using p-values from ANOVA analysis table which is fairly more accurate. Finally, the study shows that depth of cut is the most dominant factor of those studied. The medium significant factor is feed rate and followed by spindle speed. The most important interactions that effect surface roughness of machined surfaces were between the feed rate and depth of cut for this particular type of MWCNT/epoxy composite. This research becomes part of major contribution for the manufacturing industry especially machining of MWCNT/epoxy composite materials using CNC milling process and for future researchers.

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Author Profile

G. Harii Krishna Rao received Diploma in Mechatronics from polytechnic (PTSB) Kulim in 2007.Then he received Bachelor of Mechanical Engineering (hons) from University Tenaga Nasional in 2011. He is now pursuing Master of Mechanical Engineering at University Tenaga Nasional. His research interests are pre-dominantly in the manufacturing field of epoxy composites using Nano reinforces and also field of CNC machining. He is one of the Associate members of Institution of Mechanical Engineering (IMECHE) U.K. He also attended and presented posters in international conferences especially in San Jose, California (USA) 2012 and Intl. conference on APM 2014, CIPET Lucknow, India.

M. N. M. Ansari, is currently working as Senior Lecturer in Mechanical Engineering College of Engineering, Universiti Tenaga Nasional (UNITEN), Malaysia and a Visiting Research Scientist, RMIT University, Australia since August 2010. He received his Bachelor of Engineering degree in Mechanical Engineering from University of Madras, India in the year 1994. He received his P.G. Diploma in Plastics Engineering from CIPET, Ahmedabad (1995). He earned his Master's Degree in Computer Integrated Manufacturing from Anna University (2002). He joined the School of Materials, Polymers, and Mineral Resources Engineering at Universiti Sains Malaysia in August 2004 and completed his PhD degree in Polymer Engineering (2009). He has supervised more than 30 students Projects and published several technical articles in Journal and Conferences. He is also a Reviewer for UPM Journal, Malaysia, Nanotech 2012 & 2013 International Conference, USA, and International Journal of Automation Technology, Japan.

Shahida Begum, is currently working as Associate Professor in the Department of Mechanical Engineering at Universiti Tenaga Nasional (UNITEN), Malaysia. She had her BSc in Chemical Engineering from Bangladesh University of Engineering and Technology (BUET) in 1989 and PhD in Mechanical and Manufacturing Engineering from Dublin City University, Ireland in 1996. She is involved in teaching of different courses in undergraduate and post graduate level and actively involved with research and published many papers in reputed journals. She also worked as a post graduate research fellow at Harris Corporation, Semiconductor Division, Ireland. She is the Head for Centre of Advanced Materials in the university.