International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Dynamical Performance Analysis of Moving Part Material Replacement from Cast Iron to EFB Fiber Filled Epoxy of CNC Woodworking Machinery

Farkhan[a], Yohanes Aris Purwanto[b*], Wawan Hermawan[c], Erliza Hambali[d]

[a,b,c]Department of Mechanical and Biosystem Engineering, Bogor Agricultural University, Kampus IPB Dramaga, Bogor,16680, Indonesia

[d]Department of Agroindustrial Technology, Bogor Agricultural University, Kampus IPB Dramaga, Bogor,16680 Indonesia

[a]Email: farkhan@cncindonesia.com

[b]Email: arispurwanto@ipb.ac.id

[c]Email: w_hermawan@ipb.ac.id

[d]Email: erliza.h@gmail.com

Abstract

CNC machinery is widely used at various kind of industrial sector to manufacture of art products up to satellite products. Instead of its massive utilization in automotive and electronic industry which mostly use metallic component, wood working industry has been using it to produce furniture’s, merchandises, and other house ware product which apply light non-metallic low density material. High removal rate in wood machining process needs high speed application due to its low density material; however most of wood working CNC machine is built on heavy steel structure for both its supporting structure and moving structure. In fact, the raw material is much lighter than the carrier itself. Its wasteful movement causes vibrations that effect on machining accuracy, productivity and live of cutting tool.

----

* Corresponding author.

This research applied new light weight composite material base on renewable resource of Palm Oil Empty Fruit Bunch (EFB) natural fiber as filler material combine with thermosetting polymer epoxy as it's matrix to be constructed as moving mechanical structure of high speed 3D CNC wood working router machine to improve its dynamic performance. Comparative analysis shown that it has better dynamic performance on high speed machining process compare with traditional cast iron material.

Keywords: Dynamical Performance; EFB Filled Epoxy; Composite Material; CNC Woodworking Machinery.

1. Introduction

CNC (Computerized Numerical Control) machine tool is an element of a closed-loop system in which it interact with the cutting process, and represented by their respective transfer function. Each element acquires dynamic force whereas the input is a time-variable quantity [11]. Static stiffness and damping capacity of machine tools structural material respectively play important role which influence on its performance in every applied load and force condition. Static stiffness responsible in CNC machine tool geometry and makes sure it runs on its center of cutting tool edge at any ambient condition, on the other hand, damping capacity of structural material is a variable of machine tools capability in running more efficiently and producing in higher quality product, especially in high speed machining application.

Most of CNC machine tool material, including in woodworking application using metallic material such as low carbon steel or cast iron for both structural part and moving part. Only a few of them using Aluminum for certain low duty application, however it causes high cost and also low mechanical strength issue. Steel has better static stiffness compare with cast iron; on the other hand cast iron has better damping capacity and vice versa. Some machine tool manufacturer uses combination of it, or hybrid structure. Cincinnati Milacron produced their CNC Machining Center by combination of welded steel on its structural body and cast iron on its moving parts to get better static stiffness and also damping capacity respectively [7]. Furthermore, research on hybrid structure of machine tool has been done by several researcher to acquire better static and dynamic stiffness and also damping capacity which involve some advance material such as granite, synthetic granite, polymer concrete, ferro cement, epoxy resin concrete, polyester resin, steel-fiber polymer concrete, etc [10].

Comparative study of hybrid construction has been done by several researchers to investigate its dynamic performance. Reference [1] replaced the vertical and horizontal slides of a large CNC machine with bonding high-modulus carbon-fiber epoxy composite sandwiches to welded steel structures using adhesives for high speed milling application, however it remain using heavy welded steel construction for material strength issue in relatively high cutting force application in common metallic component machining. In order to develop light weight material for moving structure of CNC machine tool for common application, it is necessary to impose a research step by step which starting with relatively low cutting force application such as woodworking machining. However, wood which has density 0.6 – 0.8 g/cm^3 is much lighter raw material compare with some ferrous material which has 7 – 8 g/cm^3 definitely needs high speed application in its cutting process, and of course involves highly dynamic motion performance of its machine.

1.1. Dynamic Performance of CNC High Speed Machining Process

Dynamic behavior of machine tool is influenced by the movement of cutting tool or workpiece and cutting force applied in it in certain coordinate direction that is causing displacements in three coordinate directions, which is then cause vibration [5]. However, in high speed machining application, the prime mover provides much energy for desired operation, and CNC machine tool has provision for executing relative motion of cutting tool and workpiece that are essential for the particular operation [6]. It may then thus seen that any cutting operation must inevitably be accompanied by certain process in feed axis motor or spindle motor and the friction processes specially when running in high speed operation. Dynamic analysis of machine tool can be locked upon as an elastic system, which are the cutting process, load of motor, and friction that generates heat and metal deformation are then known as working process [11]. The working process processes and machine tool elastic system (ES) constitute a closed loop system as shown in Figure 1.

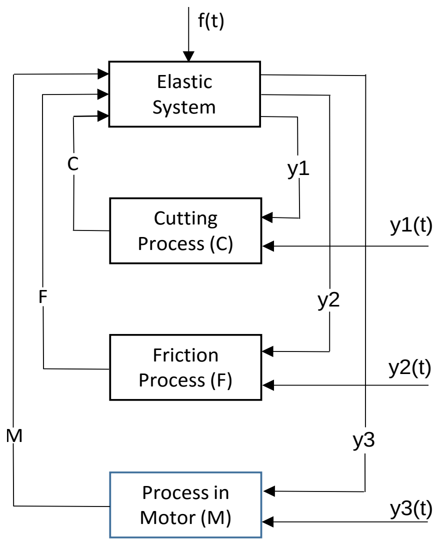


Figure 1: block diagram of closed-loop machining system

Considering above multiple loop system is difficult to analyze, thus this research analyze the dynamic behavior by simplifying it become single loop system [11], which finally has 3 process systems such as cutting process (CP), friction process (FP), and process in motor (MP). Those of systems considering as an equivalent elastic system (EES). For instance, if EES considered as an element, the units of its transfer function (W_{EES}) will be mm/kgf. Similarly, the units of the transfer function of cutting process (W_{CP}), friction process (W_{FP}), and process in motor (W_{MP}) will be kgf/mm. Let say when perturbance on *y(t)* is acting on cutting process and f(t) = 0 as seen on Figure 2.

make The differential operator *d/dt* is replaced by algebraic operator *p* in the dynamic characteristic, hence [11]:

$$y = P.\ W_{EES}(p) = [y(t) - y]W_{CP}(p)W_{EES}(p)$$

$$y\left[1 + W_{CP}(p).\ W_{EES}(p)\right] = ytW_{CP}(p)W_{EES}(p) \qquad (1)$$

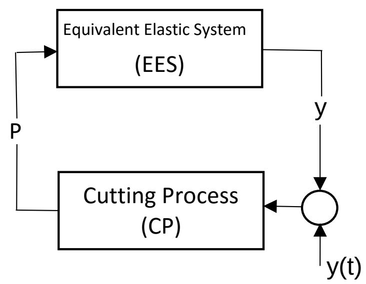


Figure 2: Block diagram of EES-CP System

Above equation approximately determine that forced vibrations are caused by perturbances acting on EES and the cutting process. These vibrations affect the machining accuracy, productivity, and life of cutting tool. The effect on productivity is dictated by the interaction of forced vibration with chatter on machining surface result [18]. Normally, the amplitude of the velocity of vibration and vibration spectrum will be higher at dominant excitation frequency and its harmonic, moreover much higher when occurring with natural frequencies of the elements of EES.

1.2. Woodworking Machining Process

As commonly known in metal machining process, the cutting force of woodworking machining is also depends upon the cutting speed, feed, depth of cut, rake and clearance angle. Under steady-state cutting conditions, these parameters are constant, and therefore, the cutting force also remains constant. However, when there is relative motion between the cutting edge and workpiece due to vibration, the values of the above parameter are affected. The issue that confounds machining research is the extreme anisotropy and heterogeneity of wood. Consequently, tool wear, cutting forces, power consumption and surface quality will change with the cutting direction (*CD*)[3]. These machining properties are also influenced by moisture content. Figure 3 illustrates three main cutting directions in wood machining, however in most of material data book it is simplified become two cutting directions, which are transversal and longitudinal *CD*.

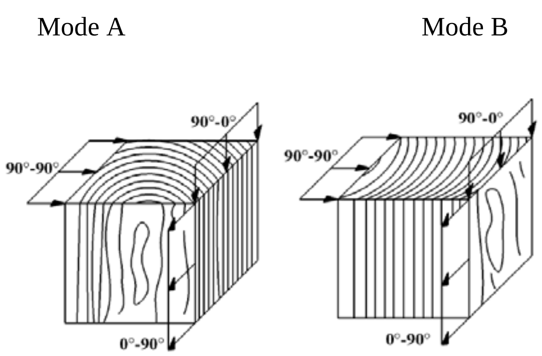


Figure 3: Wood machining cutting direction (*CD*)

According to Figure 4a, cutting tool will remove the wood material near the surface of workpiece by shearing it to form of the chip. Material with thickness *t* will is sheared and travels as a chip of thickness *tc* along the rake face of the tool. The chip thickness ratio (cutting ratio) is determined by:

$$r = \frac{t}{tc} \qquad (2)$$

Refer to kinematic relationship of cutting speed, there are three velocities ie: cutting speed (v) which is velocity of the tool relative to workpiece, chip velocity (v_c) which is the velocity of the chip relative to the tool face, and shear velocity (v_s) which is the velocity of the chip relative to the work. From continuity of mass, vt = $v_{c.}t_{c,}$ then cutting ratio can be determined:

$$r = \frac{t}{tc} + \frac{Vc}{v} \qquad (3)$$

From kinematic relationship, the vector sum of cutting velocity and the chip velocity is equal to the shear velocity vector, which is shown:

$$v_2 = \frac{v\cos\alpha}{\cos(\phi - \alpha)} \qquad (4)$$

Bigger cutting ratio needs higher cutting force, however we need to know the shear angle *Ø* in order to calculate the shear stress in cutting from force measurement. Practically, the shear plane angle *Ø* is varied depending on the nature of each material (mechanical and chemical properties) to be machined. Base on the upper bound model of shear zone, a criterion for predicting *Ø* has been developed. The predicted shear plane angle $Ø_0$ is given by:

$$\cos(\phi_o - \alpha)\sin\phi_o = \frac{k_o}{k_1}\left[\cos\left(45 - \frac{\alpha}{2}\right)\sin\left(45 + \frac{\alpha}{2}\right)\right] \qquad (5)$$

Where;

α = rake angle

k_0 = $\sigma_0 / \sqrt{3}$ and σ_0 is the yield strength of material

k_1 = $\sigma u / \sqrt{3}$ and σu is the tensile strength of material

A) B)

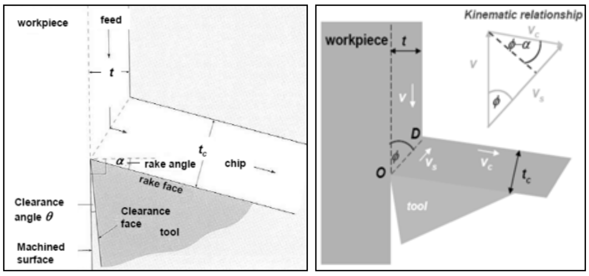


Figure 4: Mechanism of cutting (A) and velocity relationship (B) in orthogonal machining

Above equations show that mechanical material properties determine cutting force, and cutting force influences dynamical characteristic of EES system. However, in wood machining which has relatively low yield and tensile strength compare with metal machining does not mean has low vibration force also.

Due to its low density properties, it needs higher feed rate and higher spindle speed in the same time, which is meant needs higher speed of feed axis motor and spindle motor.

Fig 1 shows that motor process will impact to dynamic characteristic of CNC machine tool.

Table 1: Relationship between density, strength, and hardness for cutting speed of various material

Type of Material	Density ρ (g/cm$^{3)}$	Strength σ_y (MPa)	Brinell hardness	Cutting Speed
Carbon Steel	7.8 - 7.9	250 - 1155	125 - 160	90 - 110
Cast Iron	7.05 - 7.35	215 - 790	120 - 300	30 - 125
Aluminum Alloys	2.5 – 2.9	30 - 500	30 - 150	450 - 1000
Wood, typical	0.6 – 0.8	30 - 70	2.2 – 7.7	800 - 2000

2. Fabricating and machining of EFB filled epoxy composite

Oil palm empty fruit bunches (EFB) which is 21% -24% share part of the total fresh fruit bunches (FFB) has not been utilized optimally. Palm oil mill generally returns EFB into plantations to be used as fertilizer. However, because of the large numbers, and transportation costs are expensive, and not comparable with the needs of the fertilizer itself, then finally palm oil mill granted to accumulate this EFB in open fields, and this deposit potentially produces methane gas released into open air causing damage to the ozone layer.

EFB is a fibrous material that is hard and tough and it shows morphological similarities with coconut coir [14]. SEM (scanning electron microscopic) image of EFB fiber shows the presence of lacuna like portion in the middle surrounded by a porous tubular structure [14]. The pores of fibre surface has 0.07 μm average diameter and this porous surface is useful to produce a better mechanical interlocking with the epoxy matrix material in the composite fabrication [14]. However the porous surface structure also facilitates the penetration of water into the fiber by capillary action, especially when it is exposed to water [13].

Figure 5: accumulated EFB that is waiting to be returned to the field (Source: PTPN 13)

Starch granules found in the interior of vascular bundles of EFB [9]. Silica bodies are also found in great number on fiber strand. They attach themselves to circular craters which are spread uniformly over the fiber surface. The silica bodies, through hard, can be dislodged mechanically, leaving behind perforated silica-crater, which would enhance penetration of matrix in composite fabrication [13]. High cellulose content [15] and high toughness value [4] of EFB make it suitable for composite applications. However presence of hydroxyl group makes the fibers hydrophilic, causing poor interfacial adhesion with hydrophobic polymer matrices during composite fabrication. This may lead to poor physical and mechanical properties of the composite [12]. EFB fiber also contain oil residue around 4.5% [2] that will significantly influence the fiber-matrix compatibility.

The ester components of which may affect coupling efficiency between fiber and polymer matrix as well as the interaction between fiber and coupling agents [12].The fiber properties can be improved substantially through surface modifications. Chemical treatments decrease hydrophilic property of the fibers and also significantly increase wettability with polymer matrix [7]. There are number of treatment methods on EFB to improve its properties and make it compatible with polymeric matrices. Reference [14] have studied EFB fiber and conclude that it is suitable for composite raw material. EFB containing cellulose in the range of 43% - 65% and Lignin of 13% - 25% make it compatible with several polymer raw materials such as natural rubber, polypropylene, polyninyl chloride, phenol formaldehyde, polyurethane, epoxy, and polyester.

Main parameter in micro mechanical modeling of composite material is the volume fraction of the fibers and the matrix. The volume fractions are Vf and V_m for the fibre and the matrix respectively. Vf and V_m are defined such that:

$$V_1+V_m = 1 \quad (6)$$

This relation is valid if the composite is solid, i.e. it does not contain any pores.

By assuming that the strain in a RVE is homogeneous, the stiffness of a composite can be approximated by [1]:

$$Dc = VfDf + VmDm \quad (7)$$

Where $\mathbf{D}_c$, $\mathbf{D}_f$ and $\mathbf{D}_m$ are the stiffness matrices of the composite, fiber and the matrix respectively. Vf is the volume fraction of the fibers and V_m the volume fraction of the matrix. Equation 7 is referred to as the Voigt approximation, the rule of mixture (ROM) or the parallel-coupling model. The approximation might be more familiar in its one- dimensional form:

$$Ec = VfEf + VmEm \quad (8)$$

where E_c, Ef and E_m are the E-modulus of the composite, the fibre and the matrix respectively.

If the stress field is assumed to be homogeneous, the compliance matrix can be approximated according to [1]:

$$Cc = VfCf + VmCm \quad (9)$$

and its one-dimensional form:

$$\frac{1}{Ec} = \frac{Vf}{Ef} + \frac{Vm}{Em} \quad (10)$$

which is referred to as the Reuss approximation or the series-coupling model.

The strength of composite materials in receiving mechanical loads can be improved by using fiber reinforcing material which has high mechanical strength and stiffness, and also improves wettability to increase interfacial bonding between resin-fiber by using a coupling agent. Therefore used EFB fiber raw materials must have as high strength and uniformity as possible, since the out coming strength of composite is significantly determined by it. In addition, the fiber treatment process is proposing to improve wettability, and not to weaken the strength of the fiber itself, accordingly it needs to be controlled to obtain optimal conditions.

Fabrication of EFB fiber filled epoxy has been developed with 10% fiber volume fraction and it contained epoxy with ratio 1:2 mixture between hardener and resin. 1% wt Silane coupling agent has been added to improve mechanical and chemical bonding between fiber and epoxy. It was fabricated using compressed molding method with vibrating and heat treatment to prevent porosity and increase its density. The machining process of EFB filled epoxy composite can be shown on Figure 6.

Figure 6: EFB fiber filled epoxy composite machining process

3. Fabricating and machining of EFB filled epoxy composite

This research selected table unit of CNC woodworking milling machine as a moving part to be studied. In mostly CNC woodworking machineries, this part obviously moves carrying wood raw material in one or two axis direction, depends on machine structural type. Cross saddle structure type moves table unit in two axis direction which are X and Y axis, meanwhile in double column structure type, it moves one axis direction which is X axis, which is then the movement velocity is acknowledged as cutting speed. According to Equation 2 and 3, the cutting speed is relative to workpiece and some other cutting condition parameters, and refer to table 1 comparison data which is provided by cutting tool maker, spindle speed (*n*) in RPM and feed axis rate (*Vf*) in mm/min is determined by equation 11.

$$v_c = \frac{D.\Pi.n}{1000}$$

$$n = \frac{v_c.1000}{\Pi.D} \qquad (11)$$

$$Vf = fz.n.Zc \qquad (12)$$

Where *D* is cutting tool diameter which is determined according to workpiece dimension and profile. V_c (cutting speed) and *Zc* (feed per tooth) is provided by cutting tool maker which is referred by cutting tool material type and geometry. Faster cutting speed and feed per tooth recommendation will impact to metal removal rate of machining process, and relative also to higher feed axis rate which causes high dynamic force and generates vibration. This factor will be used as a research methodology to compare the dynamical performance of each material to simulate high speed cutting process.

The sample of composite material result can be shown on Figure 8. Finished dimension composite table unit moving part mass weight is about 7 times lighter than its traditional ASTM 40 grade cast iron material, and base on weighing measurement and volumetric analysis, the density is 1.02 g/cm^3 while the traditional cast iron material is 7.08 g/cm^3. In addition, the tensile strength test showed that it has much weaker strength compare with cast iron. However, even lesser strength, it is still promising material for particular application such as CNC woodworking moving part since it has nearly similar specific strength which was 31.1 kN.m/kg, while gray cast iron has 38.9 kN.m/kg. Overall comparison illustrated on Figure 7, and base on this result, it was decided to carry on the research to further observe its dynamical performance when it is implemented on CNC moving part.

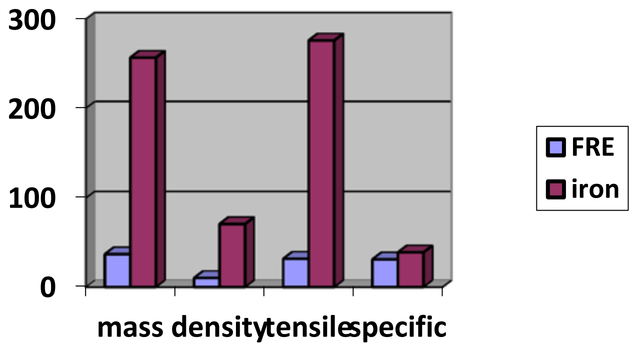


Figure 7: comparison between EFB fiber filled epoxy (FRE) composite material and traditional cast iron material

Raw EFB filled epoxy material is machined under the same method and condition with traditional cast iron material. Machining process was using CNC milling with the same NC program with a little tuning in cutting parameter to suit EFB filled epoxy material condition. In case of low density material properties, dry machining is applied to prevent coolant or oil penetration to EFB filled epoxy, and cause higher moisture content. However, need further research to prove it.

Top view Bottom view

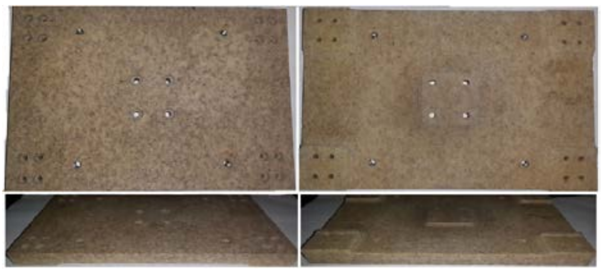


Figure 8: Sample of CNC milling moving part (table unit) made by using EFB fiber filled epoxy composite material

3.1. Experiment equipment

This research will use a miniature size double column type milling machine. Testing machine technical specification data is presented on Table 2. The machine is categorized as semi high speed machine since it uses linear guide way motion system with medium speed servo motor which is coupled with high speed and high precision ballscrew driving system. Semi high speed CNC equipment was equipped on this machine, however it's already use network servo controller for communication between CNC and servo driver to accommodate high speed machining process. High resolution feedback device with 1280000 pulse/revolution is equipped on this machine to ensure smooth motor operation and enhance the accuracy of positioning. Online monitoring software with analytic graphical function is provided by CNC equipment maker, and being used for this research to acquire motor load data through current and percentage load data, friction and vibration through positioning feedback error.

Table 2: Specification of testing CNC machine

Technical Specification	Description/ Dimension	Unit
Machine Type	Vertical Milling	
Structural Type	Double Column Gantry	
Structural Material	Cast Iron	ASTM 40
CNC Controller	DSP 32 bit CPU	Delta NC-300
Travelling Axis (X/Y/Z)	200 x 130 x 70	mm
Travelling Feed Axis Rate (X/Y/Z)	15000	mm/min
Max Spindle Speed	5000	RPM
Max Feed Axis Motor Speed	3000	RPM

Two types of table unit moving part material was prepared for testing. Original CNC table unit moving part made by cast iron material was first removed from testing machine (Figure 9A) and having dimensional measurement to ensure that it has identical dimension with another table unit moving part made by EFB fiber filled epoxy material. Those two specimens dimension has been verified by dimensional and geometrical checking using proper and standard metrological equipment such as dial caliper (0.002 mm grade), micro meter, and dial height gauge. Dimension checking also ensured that there was no significant adjustment when replacing both types of CNC moving part. Overall dimension of table unit is illustrated on Figure10 which shows its geometry, dimension, and tolerance.

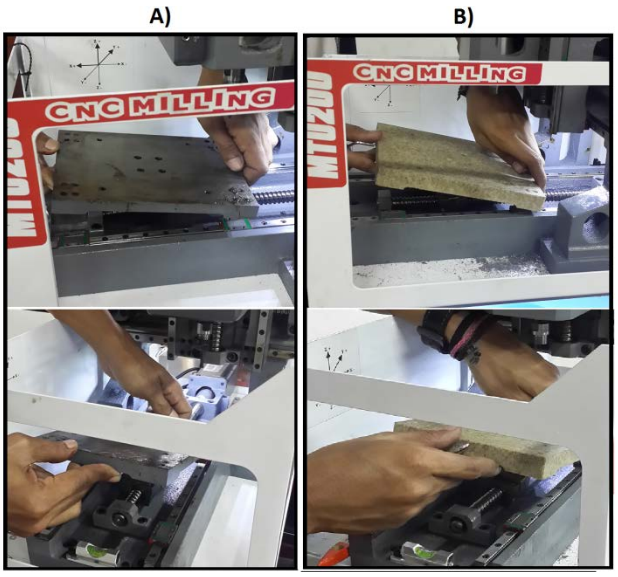


Figure 9: Removal and installation of CNC milling moving part (table unit) A) cast iron ASTM 40 material. B) EFB fiber filled epoxy material.

Mass weight measurement has also been done to compare actual mass weight of both specimens. Measurement data collection is presented on Table III as moving part technical specification. Density value on Table III was acquired from ratio between actual mass weights with theoretical volume of moving which was got from simulation of 3D design software. In addition, the specific tensile strength value was also acquired from ratio between theoretical tensile strength values with density value. These data had positive value and indicated that new CNC table unit moving part composite material has predominance in its dynamic characteristic according to theory, and it was feasible to proceed next step research to prove it. However, there are many factor that may effect on dynamical performance of machine tool. This research try to validate predominance value of all new material on dynamical performance of woodworking CNC machine.

This research measured kinematic vibration of moving part by using 3 axis accelerometer which is equipped on National Instrument myRIO-1900 electronic development module that is shown on Figure 11A. The monitoring and control software was using LabVIEW system design software. Herewith the technical specification of accelerometer:

- Number of axis : 3

- Range : ±8 g
- Resolution : 12 bits
- Sample rate : 800 S/s
- Noise : 3.9 mg rms typical at 25 °C

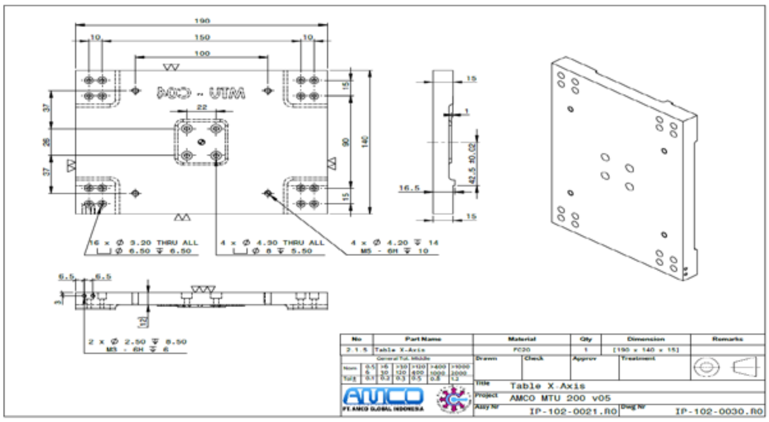
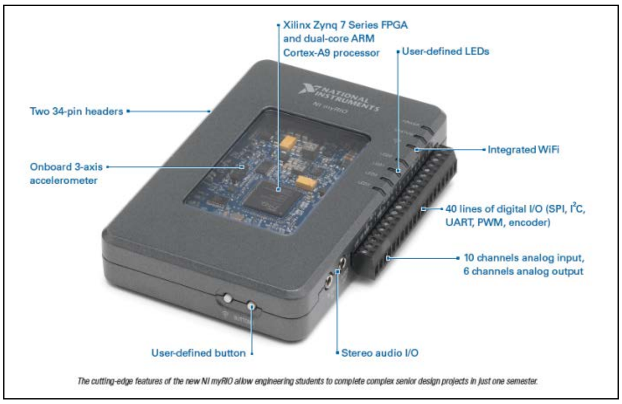


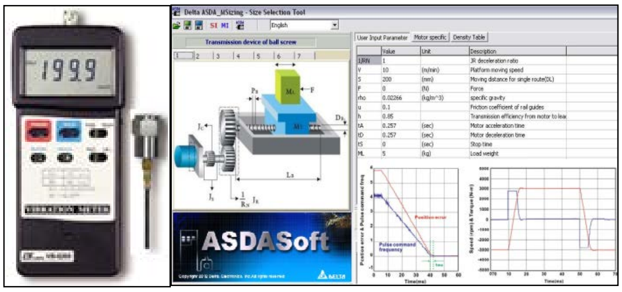
Figure 10: Technical drawing of testing CNC milling moving part (table unit)

Table 3: Specification of moving part specimen

Technical Specification	Gray Cast Iron ASTM-40 Material	EFB Fiber Filled Epoxy Material
Dimension (mm)	190 x 140 x 16.5	190 x 140 x 16.5
Machining Process	Milling/Drilling/ Tapping/Grinding	Milling/Drilling/ Tapping/Grinding
Volume	362.34 m^3	362.34 m^3
Weight	2567 g	355 g
Density	7.08 g/cm^3	1.02 g/cm^3
Tensile Strength	276 N/mm^2	31.72 N/mm^2
Specific Tensile Strength	38 kN.m/kg	31.1 kN.m/kg



A



B C

Figure11: A).National Instrument myRIO-1900; B). Lutron VB-8200 Vibration Meter; C). Delta ASDA-Soft V5.03.03

As for vibration parameter value such as velocity and acceleration was measured by Lutron VB-8200 Vibration Meter which has ISO, CE, IEC 1010 standard as shown on Figure 11B. The specifications of equipment will be as follow:

- Frequency range : 10 Hz – 1kHz (meet ISO 2954)
- Velocity range : 0.5 – 199.9 m/s
- Acceleration range : 0.5 – 199.9 m/s^2
- RMS and Peak Measurement

Online monitoring software with analytic graphical function for real time detection of motor load data through current and percentage load data, friction and vibration through positioning feedback error is using ASDA-Soft V5.03.03 which was provided by Delta Electronic, Inc. The measurement configuration is illustrated on Figure12 which measured X axis motor dynamic performance on testing machine when using two types of moving part material, i.e.: cast iron, and EFB fiber filled epoxy.

3.2. Testing Condition

According to Figure 1 of closed loop machining system, the cutting process (CP), friction process (FP), and Process in Motor (MP) are perturbances acting that effect much on dynamical behavior of machine tool.

Dynamic performance, before and after moving part (table unit) replacement were measured on X axis only since the testing machine table unit is moving on X axis motion direction.

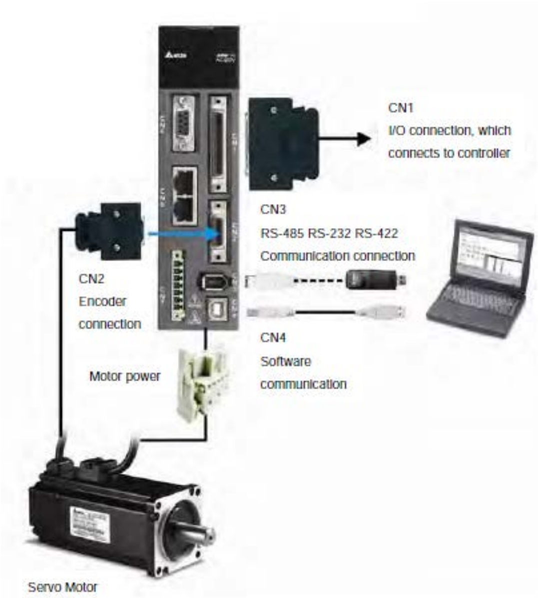


Figure12: Servo motor dynamical performance measurement

It involved X axis servo motor, ballscrew, and linear guide way on its motion. It was measured under following conditions:

- Cutting Condition

To represent cutting process (CP) perturbance, this research applied cutting test to acquire the real data of moving part vibration and effect on its damping capacity. Therefore, National Instrument myRIO-1900 and Lutron VB-8200 accelerometers were placed on spindle and X axis table unit (moving part) when cutting process test (Figure 13D, E, F). LabVIEW vibration analysis software were used for vibration data acquisition.

Cutting tool was using Ball Endmill Diameter 6 mm. Depth of cut was 0.5 mm, spindle speed was 5000 RPM. The table unit feed rate (f) parameter is a variable to identify some dynamic characteristic in certain condition. Feed rates are applied were 250, 500, 750, and 1000 mm/min which represented medium speed machining process. SS400 (low carbon steel) raw material were used to represent peak cutting force condition of wood cutting, since wood material has so wide range mechanical properties.

- Dry Run Condition

To represent friction process (FP) and motor process (MP) perturbance, this research applied dry run test (no cutting condition) to acquire the real data of moving part friction on its slide guide way, ballscrew and nut, servo motor mechanism, and all of bearing and effect on its vibration, using the value of acceleration ($m/s^{2)}$ and velocity (m/s). Therefore, National Instrument myRIO-1900 and Lutron VB-8200 accelerometers were placed exactly on tested moving part (X axis table unit) as illustrated on Figure 13B. As for servo dynamical performance analysis was provided by Delta ASDA-soft servo analyzer software which is measured the real time data of positioning error, current, and percentage load as illustrated on Figure 13A.

To represent high velocity on high speed machining process, highest feed rate (*f*) was applied, however it was gradually from 5000, 10000, 15000, and 20000 mm/m for analyzation purpose. Under feed rate 20000 mm/m, X axis servo motor runs 3000 RPM on its maximum speed allowed in normal operation. However, this motor may run up to 5000 RPM but not for normal running.

Above testing condition generates several data that will be used for analyzation of overall dynamical performance of testing machine which applied two types of moving parts (X axis table unit) and the comparison data will be presented for decision process analysis and conclusion. LabVIEW vibration analysis software which were used for vibration data acquisition provided amplitude data in g unit (m/s^2) versus time. FFT spectrum was also provided automatically by the software for spectral analysis purpose. In addition, ASDA-soft dynamic servo analysis software also provided FFT data, but it didn't reflect on actual spectrum frequency data, but more for statistically data collection. However, amplitude level on this software shows values versus time that can be analyzed at the same time, and shows the tendency of some errors or perturbances.

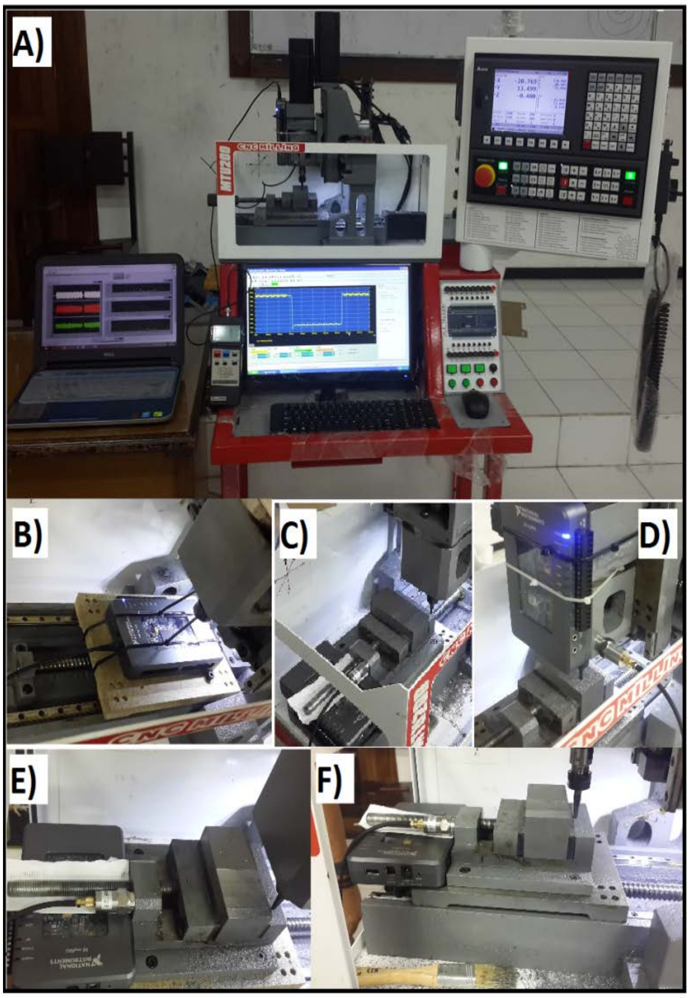


Figure 13: Testing condition

4. Fabricating and machining of EFB filled epoxy composite

This research has 3 major results that were incorporated each other in dynamical performance of CNC wood working refer to closed loop machining system. Since woodworking machinery applies high speed machining process, some high speed parameter were applied also, which meant high feed axis rate and also high rapid axis rate. During cutting, feed axis rate will be limited by spindle speed and cutting tool material and performance, however on dry cutting, the rapid axis displacement which was represented by table movement to X+ and X- direction will be limited by the servo motor rated torque. Research result is presented mostly by graphical presentation. Numerical data from Lab VIEW was processed on Microsoft Excel and presented as time domain versus amplitude. Frequency domain will not be presented here due to research limitation that replaced only on X axis (table unit) of CNC woodworking milling moving part. Considering most of machine system are remain using traditional cast iron material, the frequency response when cutting process perturbances will not significantly change, especially when accelerometer was placed on the spindle. Moreover, dynamic performance will be emphasized on performance comparison under replacement of traditional cast iron material to new light weight EFB FRE (fiber filled/reinforced epoxy) material. Through multiple testing techniques, dynamic performance of CNC woodworking machine moving structures using EFB FRE composite were tested. The same test was also conducted with the use of original material, ASTM type 40 gray cast iron casting (cast iron). Dynamic performance testing was basically to get the frequency response of the material to some perturbance parameters, namely CP, FP and MP, and subsequently served on the graphs in Figure13 ~ 18 below.

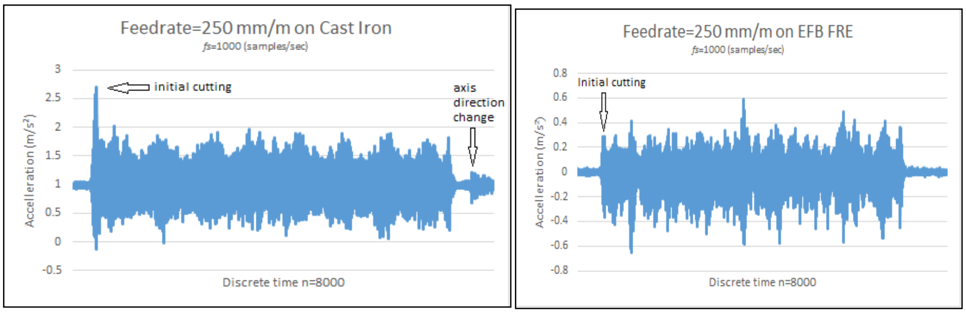


Figure 13: Vibration amplitude comparison graphs when cutting process (CP) with a ball endmill cutter Ø: 3 mm; S = 3000 RPM; d: 0.5 mm; feedrate: 250 mm/m between the use of moving structures made from FRE and cast iron

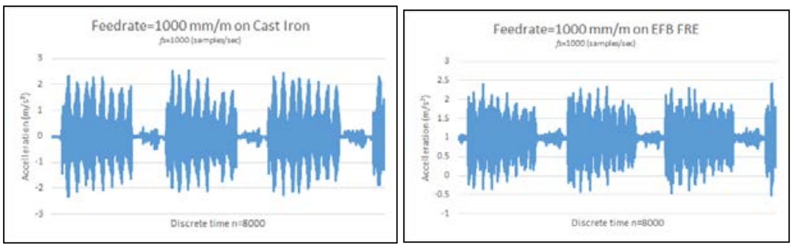


Figure 14: Vibration amplitude comparison graphs when cutting process (CP) with a ball endmill cutter Ø: 3 mm; S = 3000 RPM; d: 0.5 mm; feedrate: 1000 mm/m between the use of moving structures made from FRE and cast iron

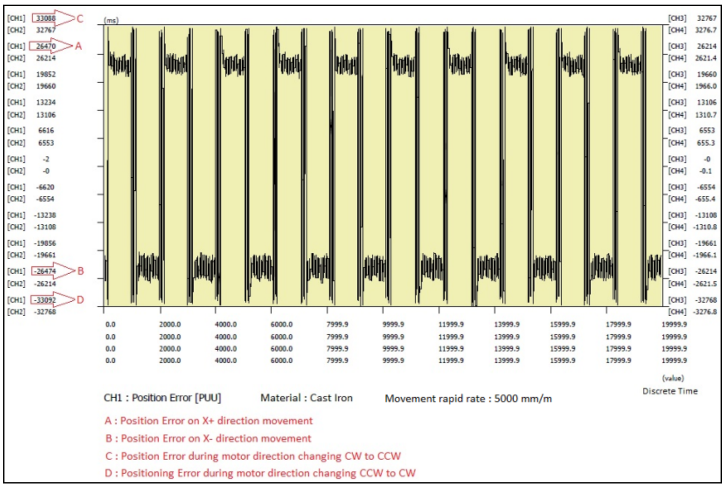


Figure 15: Position error graph in the size of pulses to represent the amount of friction (FP) during the process of 5000 mm/m rapid movements without cutting on the use of cast iron material

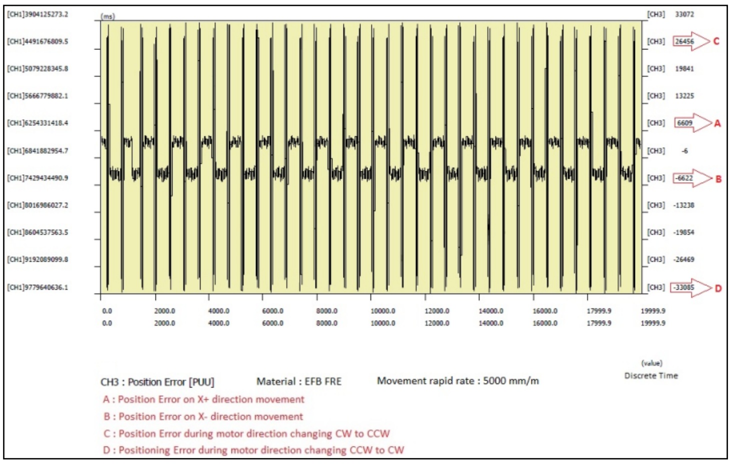


Figure 16: Position error graph in the size of pulses to represent the amount of friction (FP) during the process of 5000 mm/m rapid movements without cutting on the use of FRE material

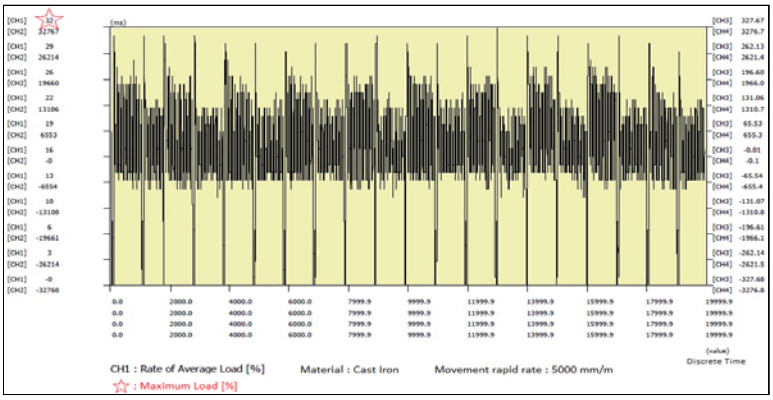


Figure 17: Average motor load at range of 0 ~ 100% to represent the process in the motor (MP) when rapid movement without cutting at 5000 mm/mn rapid rate on the use of cast iron

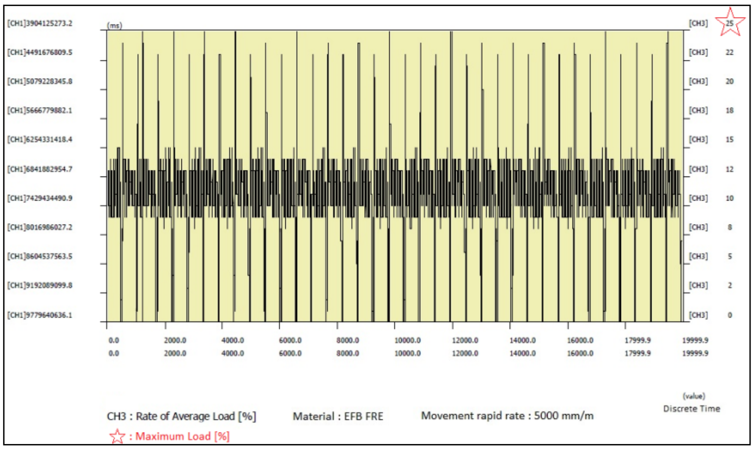


Figure 18: Average motor load at range of 0 ~ 100% to represent the process in the motor (MP) when rapid movement without cutting at 5000 mm/mn rapid rate on the use of FRE

Table 4: The dynamic test result which compilation of physical quantities such as velocity (m/s) and acceleration (m/s^2), as well as the amount of electricities in the form of an electric current (A) in rapid rate variances

Movement	Cast Iron Material			EFB FRE Material		
Rapid Rate (mm/m)	Acc (m/s^2)	Vel (m/s)	Curr (A)	Acc (m/s^2)	Vel (m/s)	Curr (A)
5000	2	6.3	0.56	3.4	10.2	0.43
10000	4	17.3	0.74	7.7	25.8	0.55
15000	5.2	26.3	0.98	10	47.9	0.66
20000	error	error	>1.55	11.4	65.4	0.69

Error : machine fault encountered when accelerating

Vibration test result (Figure 13 and 14) in the cutting process (CP) with 250 mm/m and 1000 mm/m feedrate indicates that the use of FRE contributed positively to reduced amplitude of the vibrations that occurred during the cutting process, in the range of -0.5 ~ 3 m/s^2 on cast iron materials, and ranges of -0.8 ~ 0.8 m/s^2 on FRE materials at 250 mm/m feedrate, and in the range of -3 ~ 3 m/s^2 on cast iron materials, and ranges; -1 ~ 3 m/s^2

on FRE material at 1000 mm/m feedrate. This shown that in this study, FRE material application reduced vibration better compare with cast iron material. The same result was also acquired by [16] that was using carbon reinforced epoxy material, which was structured sandwiched with iron.

Positioning error testing obtained information how much friction that was emerged during rapid movement without cutting (FP), and was done with the varied of speed 5000, 1000, 15000, and 20000 mm/m that the results showed the contribution of the weight of the structure to move towards friction on sliding components. The testing results at a speed of 5000 mm/m (figure 15 and 16) shown that the use of FRE material produced lesser friction, which was in the range of -6622 error pulses at the motor rotation CCW (counter-clockwise) and the 6609 error pulses at the motor rotation CW (clockwise). This result was quite positive compared with the use of original material that produced greater friction that through an error indication of -26.474 pulses (CW) and 26.470 pulses (CCW), and similar trends results encountered at higher speed.

At last, to measure how much the contribution ratio between moving structure weight of CNC woodworking machine and workload of its driving motor, then the same parameters testing of friction (FP) which showed that the use of FRE material with significantly has lower weight compared with the original cast iron material reduced the dynamic workload of driving motor 25% to 32% at 5000 mm/m rapid rate (Figure 17 and 18). The percentage of load exponentially risen up when the speed increased gradually. Moreover, at 20000 mm/m feedrate under the used of its original material of cast iron, load testing was not able to generate percentage of load data, due to overloaded since CNC Controller protection system were activated, however this did not happen during the use of FRE material.

The same test also simultaneously measured to acquire the value of the vibration amplitude in the units of velocity (m/s) and acceleration (m/s^2) and the amount of RMS (root mean square) by using of vibration meter, and the value of electrical quantities such as current (I) in Amperage (A) to detected the motor load when quick movement through its diagnostic display (Table IV). A positive result was shown in the use of FRE material which the value of speed and acceleration were higher, but with the use of energy even lower.

5. Conclusion

Natural EFB fiber is potential to be composited with polymeric thermosetting material such as epoxy resin to acquire new light weight material for special purpose structural application such as moving part of CNC woodworking machine. Based on dynamic performance testing result, FRE (fiber reinforced/filled epoxy) able to replace a traditional cast iron material that was much heavier and stronger, and suitable for application as a moving structure of CNC woodworking machine that requires high dynamic performance.

6. Recommendation

Since this research has not yet resulted in strength reinforcement of epoxy-based composite material with EFB fruit stem fiber filled in macro size and random arrangement, it is suggested to other researcher to do some fiber preparation such as woofing to let the fiber bonded each other mechanically before composite fabrication.

References

[1] Aboudi, J., Mechanics of composite materials (Elsevier, Amsterdam, The Netherlands, 1991).

[2] AbuBakar, A., Hassan, A., Yusof, A.F.M., The effect of oil extraction of the oil palm empty fruit bunch on the processability, impact, and flexural properties of PVC-U composites. Int. J. Polym. Mater. 55, 627–641, 2006.

[3] Cristóvão, Luís, Machining properties of wood, Doctoral Thesis, Division of Wood Science and Technology, Department of Engineering Sciences and Mathematics, Luleå University of Technology, Skellefteå, Sweden, 2013.

[4] John, M.J., Francis, B., Varughese, K.T., Thomas, S., Effect of chemical modification on properties of hybrid fiber biocomposites. Composites Part A 39,352–363, 2008.

[5] J. P. Hung, Load effect on the vibration characteristics of a stage with rolling guides, Journal of Mechanical Science and Technology 23(1) pp. 92-102, 2009.

[6] J. Tlusty, Dynamics of high-speed milling, Trans. ASME, Journal of Engineering for Industry, 108 (2), pp. 59-67, 1986.

[7] Khalid, M., Ratnam, C.T., Chuah, T.G., Ali, S., Choong, T.S.Y., Comparative study of polypropylene composites reinforced with oil palm empty fruit bunch fiber and oil palm derived cellulose. Mater. Des. 29, 173–178, 2008.

[8] Khalil, H.P.S.A., Ismail, H. Effect of acetylation and coupling agent treatments upon biological degradation of plant fibre reinforced polyester composites. Polym. Test. 20, 65–75, 2001.

[9] Law, K.N., Daud, W.R.W., Ghazali, A., Morphological and chemical nature of fiber strands of oil palm empty-fruit bunch (OPEFB). BioResources 2 (3), 351–362, 2007.

[10] Mahendrakumar,N.,Syathabuthakeer, S.,Mohanram,P.V., Study of Alternative Structural Materials for Machine Tools, Proc. 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India, pp.645.1 – 645.6

[11] Mehta, N.K., Machine tool design and numerical control (Second Edition, Tata McGraw-Hill Publishing Company, 1996).

[12] Raju, G., Ratnam, C.T., Ibrahim, N.A., Rahman, M.Z.A., Yunus, W.M.Z.W., Enhancement of PVC/ENR blend properties by polymethyl acrylate grafted oil palm empty fruit bunch fiber. J. Appl. Polym. Sci. 110, 368–375, 2008.

[13] Shinoj, S., Visvanathan, R.,Panigrahi, S.,Kochubabu, M., Oil palm fibers (OPF) and it's Composite: A review. Journal of Industrial Crops and Product. 33, 7–22, 2011.

[14] Sreekala, M.S., Kumaran, M.G., Thomas, S., Oil palm fibers: morphology, chemical composition, surface modification, and mechanical properties. J. Appl. Polym.Sci. 66, 821–835, 1997.

[15] Sreekala, M.S., Thomas, S., Effect of fibre surface modification on watersorption characteristics of oil palm fibres. Compos. Sci. Technol. 63, 861–869, 2004.

[16] Suh, J.D., Lee, D.G., Design and manufacture of hybrid polymer concrete bed for high-speed CNC milling machine. J. Mechanical Material Design, volume 4, p. 113-121, 2008.

[17] Smith, Graham T. CNC machining technology (Volume I, Springer London, 1993).

[18] S. K. KIM and S. -Y. LEE , Chatter prediction of end-milling a vertical machining center, Journal of Sound and Vibration, Volume 241, Issue 4, 5 April 2001, pp. 567-586.