Dynamic Characteristics of a Hybrid Composite Drive Shaft for Automotive Application

by

Mohd Madzhir b Ibrahim

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(Ir. Idris bin Ibrahim)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2011

CERTIFICATION OF ORIGINALITY

This is to verify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or person.

Mohd Madzhir b Ibrahim

ABSTRACT

Composite material is a breakthrough in engineering especially in automotive application. Automotive parts which being produced by this material always performs better compare to conventional material. D.G. Lee et al. (2004) states that, drive shaft being produced by composite material offers up to 75% of weight reduction which will contribute to fuel efficiency, 160% increase in torque capability, and higher natural frequency which is about 9390 rpm for wider safety margin. The main constraint for using composite is the higher price of material especially the fiber. The main idea for this study is to replace the carbon fiber with much cheaper material, palm oil fiber. This new composite will later on being put into test using machine fault simulator at four different speeds and its dynamic characteristic will be recorded. The data obtained will be analyzed using skewness, kurtosis, peak to peak, crest factor and root mean square (RMS). From experimental results, we can see that lower RMS value is obtained for composite drive shaft compare to steel drive shaft with same diameter. Thus, it shows that the composite material is a suitable candidate to substitute the usage of steel as material for drive shaft for automotive application in term of vibration study.

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TABLE OF CONTENT

ABSTRACT iii
ACKNOWLEDGEMENT iv
TABLE OF CONTENTS v
LIST OF FIGURES vi
LIST OF TABLES vi

CHAPTER 1: INTRODUCTION

1.1 Background of Study 1
1.2 Problem Statement 2
1.3 Objective 2
1.4 Scope of Study 2

CHAPTER 2: LITERATURE REVIEW

2.1 Drive shaft 3
2.2 Composite material 4
2.3 Palm oil Fiber 6
2.4 Fiber treatment process 8
2.5 Adhesion 11
2.6 Vibration study 14

CHAPTER 3: METHODOLOGY

3.1 Research Methodology 15
3.2 Project Scheduling 17
3.3 Tools and Materials 20

CHAPTER 4: RESULT AND DISCUSSION

4.1 Vibration study 24
4.2 Vibration study along the drive shaft 31
4.3 Mass reduction. 33

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion 33
5.2 Recommendation 33

REFERENCES 35
APPENDICES 37

LIST OF TABLES

Table 2.1: Percentage of fiber length 8
Table 3.1: Tabulation of work and dateline proposed in FYP 1 17
Table 3.2: Tabulation of work and dateline proposed in FYP 2 18
Table 4.1: Mass of Drive shaft 33

LIST OF FIGURES

Figure 1.1: Mazda RX8 and Ford Econoline 1
Figure 2.1: Schematic diagram of conventional two piece drive shaft 3
Figure 2.2: Conventional drive shaft and composite drive shaft. 5
Figure 2.3: Filament wetted winding 5
Figure 2.4: Future outlook for natural fiber after 1997 7
Figure 2.5: Constitution of a natural fiber cell 9
Figure2.6: Effect of UTS on soaking period 10
Figure2.7: Effect on volume fraction to tensile strength 12
Figure 2.8: Effect on volume fraction on Young modulus 12
Figure 2.9: SEM showing the fiber pull-out from matrix 13
Figure 2.10: SEM showing a small gap between fiber and matrix 13
Figure 2.11: Normal distribution. 14
Figure 3.1: Project flow 19
Figure 3.2: Machine fault simulator 20
Figure 3.3: mixer 20
Figure 3.4: Granulator 21
Figure 3.5: Oven 21
Figure 3.6: Empty fruit bunch after treated with NaOH 22

Figure 3.7: Epoxy and Hardener 22

Figure 3.8: Sodium Hydroxide 23

Figure 3.9: Aluminum rod 23

Figure 4.1: Composite drive shaft fitted at machine fault simulator 24

Figure 4.2: Example of raw data obtained using VibraQuest pro 25

Figure 4.3: RMS versus speed of shaft 25

Figure 4.4: Peak to peak versus speed 26

Figure 4.5: Graphical explanation of skewness 27

Figure 4.6: Skewness versus speed 28

Figure 4.7: Kurtosis 29

Figure 4.8: Kurtosis versus speed 29

Figure 4.9: Crest factor versus speed. 30

Figure 4.10: Location of accelerometer at machine fault simulator 31

Figure 4.11: RMS versus speed at accelerometer 1 31

Figure 4.12: RMS versus speed at accelerometer 2 32

Figure 4.13: RMS versus speed at accelerometer 4 32

CHAPTER 1

INTRODUCTION

1.1 Background of Study

A drive shaft as mention in Wikipedia (28 June 2011) is a mechanical component for transmitting torque and rotation, usually used to connect other components of a drive train that cannot be connected directly because of distance or the need to allow for relative movement between them.

Common material in manufacturing the drive shaft is steel. Steel was chosen because of low in cost and the ability to withstand the stress when subjected to torsion and shear stress. But, steel has low specific stiffness which causes the bending natural frequency to be low. As a result, drive shaft needs to be produced in two pieces when the length exceeds 1.5 m to avoid the whirling vibration at high speed, D.G. Lee et al. (2004). These will not only causing the increase in part complexity but also increased in weight which cause the drop of fuel efficiency.

Automotive industry has evolved and the focus now is the new material which can provide better performance with reasonable cost. The first composite drive shaft was developed by the spicer U-joint Division of Dana Corporation for the Ford Econoline models in 1985. Lee mention in his paper that general motor pickup truck which adopted the Spicer product enjoyed a demand three times that of projected sales in its first year (1988). High performance vehicle such as Mazda RX 8 used composite drive shaft to reduce the rotational mass (Wikipedia, 28 June 2011).

Figure 1.1: Mazda RX8 and Ford Econoline (Wikipedia)

Most popular composite drive shaft in research and development nowadays is aluminium as matrix together with carbon and glass fiber as reinforcement. This composite if manufactured correctly with right stacking sequence and orientation will produced, as mention by Lee, mass reduction, increase in torque capacity, higher natural frequency and better fatigue properties.

1.2 Problem Statement

Most of the drive shaft produced nowadays used steel as material. According to F. Schmelz, et al (1992) when a length of a steel drive shaft is around 1.5m, it is usually manufactured in two pieces to increase the fundamental bending natural frequency. This will lead to part complexity and decrease the fuel efficiency due to increase in weight. Other than that, Schmelz also mentioned that due to low specific stiffness of steel (E/ρ), the natural bending frequencies will be lower than 5700 rpm (for one piece drive shaft). Specific stiffness of glass fiber is 1.5 times higher than the steel made it possible to manufacture the one piece drive shaft with higher natural bending frequency (more than 5700 rpm). As a result, drive shaft not only can rotate at higher speed without whirling vibration but most importantly reduce in weight which leads to fuel efficiency.

1.3 Objectives

1. Fabricate a hybrid composite material drive shaft for automotive application.

2. Test, analyze and compare the dynamic characteristic of composite drive shaft using spectrum analyzer.

1.4 Scope of the study

This study includes the study of vibration, composite materials, drive shafts and fiber. It also involve in manufacturing and testing the dynamic characteristic of the drive shaft.

CHAPTER 2

LITERATURE REVIEW

2.1 Drive shaft

An automotive drive shaft, or sometimes known as propeller shaft is used to transmits power from the engine to the differential gears of the wheel-drive vehicle. Two main requirement for design a drive shaft is the torque transmission capability (for passenger cars, van and small truck it should be larger than 3500 Nm) and natural bending frequency (need to be higher than 6500 rpm) to avoid whirling vibration. The whirling vibration is actually resonance due to the rotational speed of drive shaft to be equal to the fundamental natural bending frequency. The natural bending frequency is inversely proportional to the square of the shaft length and proportional to the square root of specific stiffness (D.H.Cho et al, 1997).

Common drive shaft is made of steel and the fundamental bending frequency of steel drive shaft is not more than 6500 rpm, thus, making one peace drive shaft which is longer than 1.0m is impossible without changing the material. Such a complex and heavy structure will produce noise and vibrations that are transmitted to the vehicle through a center bearing. Figure 2.1 shows the component two piece drive shaft in a vehicle.

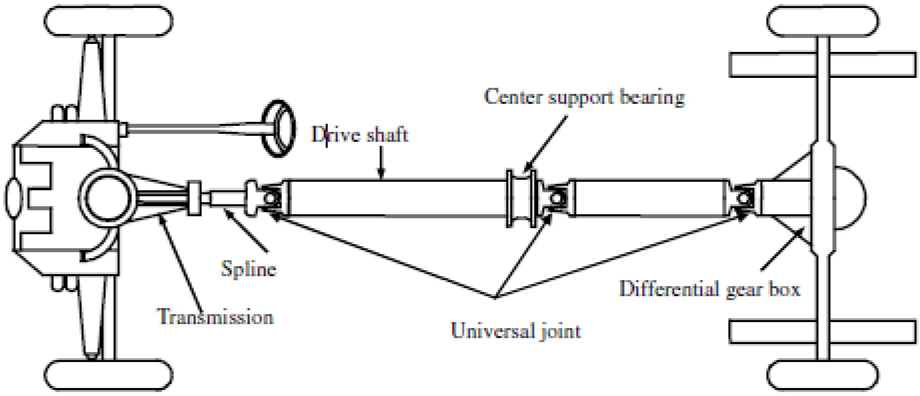


Figure 2.1: Schematic diagram of the conventional two-piece steel drive shaft for a rear wheel driving vehicle.

2.2 Composite material.

Aluminum is a common material used in research regarding drive shaft to substitute the usage of steel in the fabrication of drive shaft. Aluminum is lighter, thus it is more fuel efficient. Specific stiffness, or sometimes called specific modulus (major effect of natural bending frequency other than length), is the value of young modulus divided by density. Young modulus is a measure of the resistance of a material to elastic (recoverable) deformation under load. Aluminum has the value of specific stiffness of 26 x 10^6 m^2s^{-2} and steel has the specific stiffness of 25 ± 0.5 x 10^6 m^2s^{-2}. The difference between these two values is too small. Thus, even though this new drive shaft is fabricate using the aluminum it cannot significant value of natural bending frequency. But the good thing is that by using aluminum, the weight of the drive shaft reduced tremendously. Some composite drive shaft design by researcher (Lee,2004) has mass reduction of 75 percent. This will lead to fuel efficiency, and lesser noise and vibration.

With its main function to transmit torque and rotation, M.A. Badie et al. (2006) suggest that “laminated composites, with their advantage of higher specific stiffness, gained sustainability in the field of torque carrying structure through many applications”. Badie et al (2006) said that “composite drive shafts offer the potential of lighter and longer life drive train with higher critical speed”. Because of many advantages offer by composite material, a lot of money was dedicated in research and development in order to come up with cheap, reliable, high performance and sustainable design of drive shaft.

The part complexity of drive shaft also being reduced if the shaft can be fabricated in one piece. Figure 2.2 shows the component that is crucial in a drive shaft in order for it to perform properly. It clearly shows that the composite drive shaft needs less component compare to steel shaft.

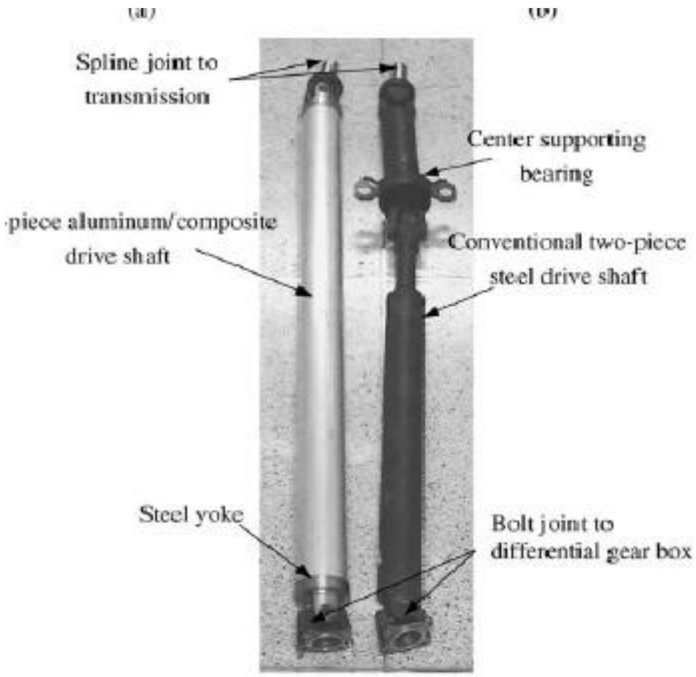
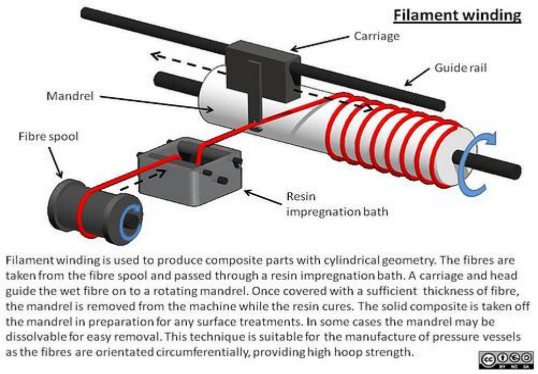


Figure 2.2: Conventional driveshaft and composite drive shaft.

Common fiber used to reinforce the aluminum drive shaft is glass and carbon fiber. These fibers will go through a process called filament wetted winding. Filament winding consists of winding continuous roving of fiber onto a rotation mandrel in predetermined patterns. There are two types of winding which are wet and dry. In wet winding method, the fiber picks up resin either by passing through a resin bath or from a metered application system. On the other hand, in dry winding method, the component is cured after several layers and removed from the mandrel. Figure 2.3 shows the graphical explanation of filament wetted winding process.



Filament winding is used to produce composite parts with cylindrical geometry. The fibres are taken from the fibre spool and passed through a resin impregnation bath. A carriage and head guide the wet fibre on to a rotating mandrel. Once covered with a sufficient thickness of fibre, the mandrel is removed from the machine while the resin cures. The solid composite is taken off the mandrel in preparation for any surface treatments. In some cases the mandrel may be dissolvable for easy removal. This technique is suitable for the manufacture of pressure vessels as the fibres are orientated circumferentially, providing high hoop strength.

Figure 2.3: Filament wetted winding.

The fundamental natural bending frequency of the carbon fiber composite drive shaft can be twice as high as that of steel or aluminum because the carbon fiber composite material has the value of 113 x 10^6 m^2s^{-2}(Wikipedia, 2011), which is more than 4 times the specific stiffness than steel or aluminum, which make it possible to manufacture the drive shaft of passenger car in 1 piece. The usage of glass fiber as reinforcement will not do much help in the natural bending frequency of the composite drive shaft because the specific stiffness of glass fiber is slightly higher than the aluminum and steel, which is 28±10 x 10^6 m^2s^{-2}.

Glass fiber on the other hand is use in some research paper to eliminate galvanic corrosion between the aluminum and carbon fiber (layer of glass fiber between carbon fiber and aluminum). High material cost and complicated manufacturing practice lead this research paper to explore new material which much cheaper cost, green characteristic and simple manufacturing methodology.

2.3 Palm oil Fiber

Oil palm or *Elais guineensis* is a major agricultural industry in Malaysia. It contributes about US$ 7.3 billion in export earning each year, mostly from the export of palm oil under many company such as FELDA, Genting plantation, IOI, Sime Darby and many more independent estate. Currently, there is more than 3 millions hectare of oil palm plantation in Malaysia. This creates, in total, about 90 million MT of renewable biomass (trunks, fronds, empty fruit bunches and palm press fiber) each year.

The empty fruit bunches (EFB) represent about 9% of this total. They are the residue left after the oil extraction process completed at the oil mill. The oil mills are usually located near or in the plantation itself. EFB is a suitable raw material for recycling because it is produced in large quantities in localized areas.

EFB is a valuable resource which can be converted into fiber for the use as:

i. Fuel for energy power generation.
ii. Filler in molded particle boards/MDF
iii. Fiber in bales for export.

iv. Mulching mats.
v. Pulp and paper.
vi. Biodegradable fiber reinforced concrete.
vii. Processed animal feed.

Empty fruit bunch fiber offers an alternative material to substitute the usage of glass or carbon fiber and inorganic fillers. This natural fiber having several advantages:

i. High specific strength.
ii. Low cost.
iii. Low density
iv. Renewable nature
v. Biodegradability
vi. Absence of associated health hazards
vii. Easy fiber surface modification and treatment.
viii. Wide availability

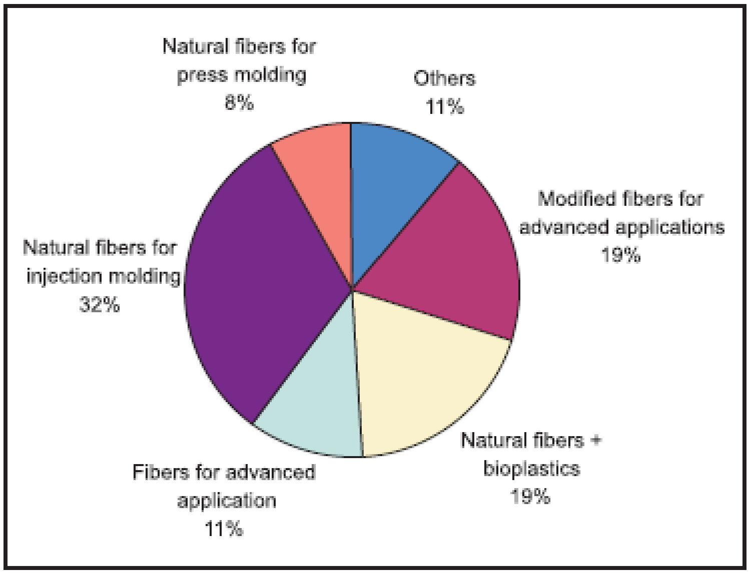


Figure 2.4: Future outlook for natural fiber after 1997 (natural fiber reinforced polymer composite, 2006)

The EFB has the highest fiber yield and is the only material commercially utilized for fiber extraction. The EFB fibers not only strong and stable but also could be processed easily into various dimensional grades to suit specific application in various conditions.

Oil palm Fiber is a natural fiber extracted from palm oil empty fruit bunch (EFB). During the extraction process, the Oil Palm fiber are shredded using granulator, separated, treated and oven dried. The extraction process involves chemical treatment using Sodium Hydroxide (NaOH) and hot water before it is oven dried at 70°C using oven

The length of fiber used in drive shaft is estimated by using weight basis by the following table:

Table 2.1: Percentage of fiber length.

Fiber length (mm)	% proportion (oven dry weight basis)
>10	30
5-10	50
<5	20

2.4 Fiber treatment process.

The effect of treating the Empty fruit bunches(EFB) with a fairly concentrated aqueous solution of a strong base, in order to produce great swelling with resultant change in the fine structure, dimension, morphology and mechanical properties (Bledzki,1999)

The main component of vegetable natural fiber is cellulose, but the non-cellulosic component such as lignin and hemicellulose also play a significant part in the characteristic properties of the fiber. hemicelluloses, which is believe to consist principally of xylan, polyuronide and hexosan, prove to be sensitive to the action of caustic soda, which exerts only little effect on lignin or a-cellulose. Figure 2.5 shows the structure of natural fiber cell.

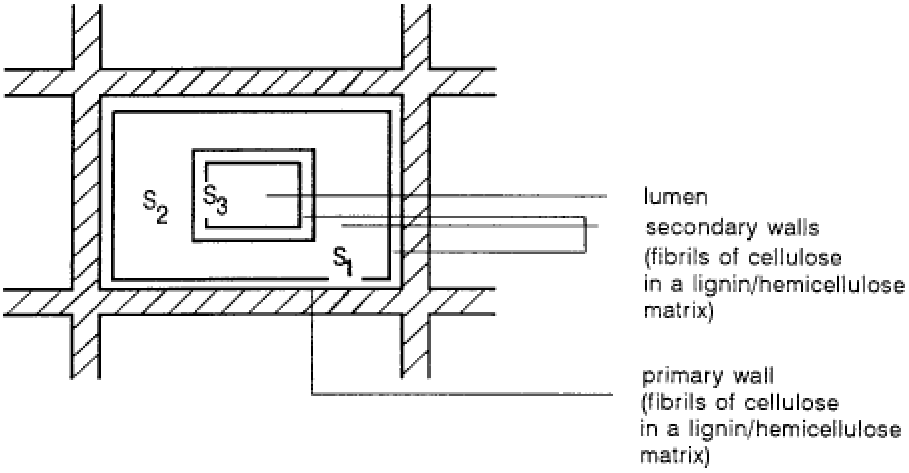


Figure 2.5: Constitution of a natural fiber cell (diagrammatic representation)

Studies show that the alkali treatment for natural fiber has significant effect of the tensile characteristic of the fiber due to removal of lignin and hemicelluloses. Reason behind this phenomenon is, as the hemicelluloses is removed, the interfibrillar region is likely to be less dense and less rigid making it more flexible to rearranging themselves along the direction of tensile deformation (bledzki, 1999).

When natural fibers are stretched, such arrangements amongst the fibrils would result in better load sharing by them resulting in higher stress development in the fiber. In contrast, softening of the inter-fibrillar matrix adversely affect the stress transfer between the fibril, thereby, the overall stress development in the fiber under tensile deformation. Due to removal of lignin gradually, the middle lamella joining the ultimate cells is expected to be more plastic as well as homogeneous due to the gradual elimination of microvoids, while the ultimate cells themselves are affected slightly. Further, some author reported about changes in the crystallinity trough alkaline treatment on coir and flax fibers. The increase in the percentage crystallinity index of alkali treated fibers occurs due to removal of cementing materials, which later on leads to a better packing of cellulose chains. On top of that, treatment with Sodium Hydroxide leads to a decrease in the spiral angle; make it close to the fiber.

Soaking period of natural fiber will have effect to its mechanical properties, such as ultimate tensile strength (UTS). The following diagram shows the effect on soaking period versus the ultimate strength.

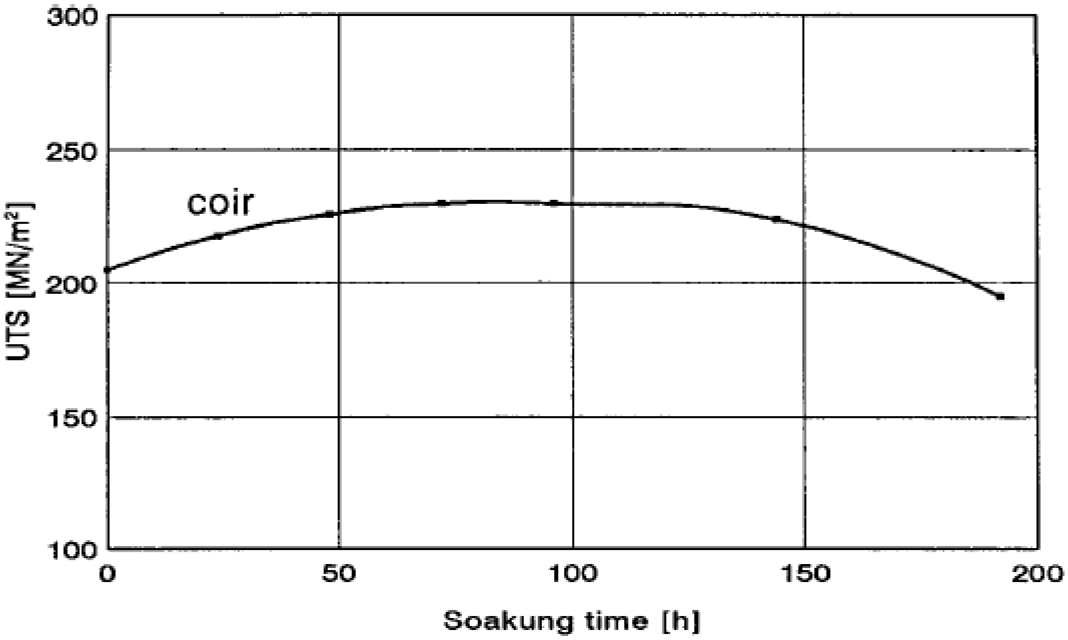


Figure 2.6: Effect of UTS on soaking period.

2.4.1 Concentration of NaOH

Different concentration of NaOH will resulted in different mechanical properties. (ultravilot thingy) reported that the EFB fibers treated with NaOH in his paper mentioning that Kappa number of the EFB decreased as the NaOH concentration was increased. In his experiment, the EFB was treated with 22% and 28% NaOH solutions. The flexural, tensile and impact strength of the composite made from 22% NaOH treated EFB showed and increasing trend as the % of EFB was increased. However, those with 28% NaOH treated EFB decreased as the % of EFB as increased. He concluded in his paper that, fiber treated with 22% NaOH displayed higher flexural, tensile and impact strength. However, no significant difference was observed for both type of composite with respect to flexural modulus. All of this effect was influence by two factors, which are:

i. The decrease of the light absorptivity (as a result of the removal of lignin)
ii. The degradation of fiber strength as a result of higher concentration of NaOH treatment.

2.4.2 Treatment with hot water.

Treatment of hot water is important to remove most of the grease and impurities at the palm oil husk. Palm oil fiber was soaked at approximately 90^{o}C for 1 hour.

2.5 Adhesion.

Selecting a proper type of epoxy and hardener is not the only challenge to impregnate both materials. Proper ratio of epoxy and hardener need to be determined. Other than that, epoxy-hardener solution with fiber ratio must be carefully selected too. Selecting right amount of ratio of epoxy and hardener will ensure the fiber is perfectly bond. Ratio of epoxy-hardener mixture with EFB will have effect on mechanical properties, tensile modulus and young modulus in particular. Study shown by (M.Z.M. Yusoff et al, 2010) the maximum young modulus can be obtained with 5% of fiber in weight basis (figure 2.8) and maximum tensile strength is when the EFB is at 0%,pure epoxy-hardener (figure 2.7).

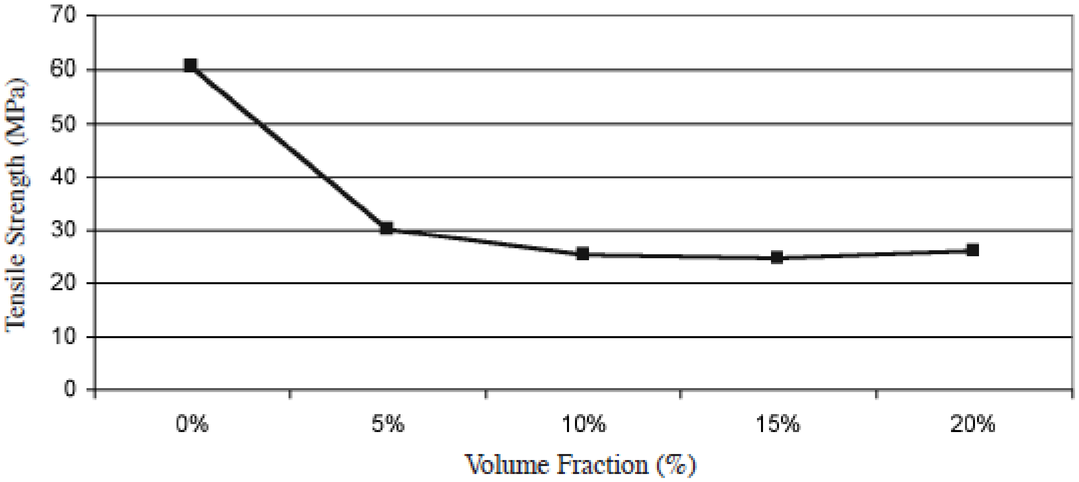


Figure 2.7: Effect on volume fraction to tensile strength.

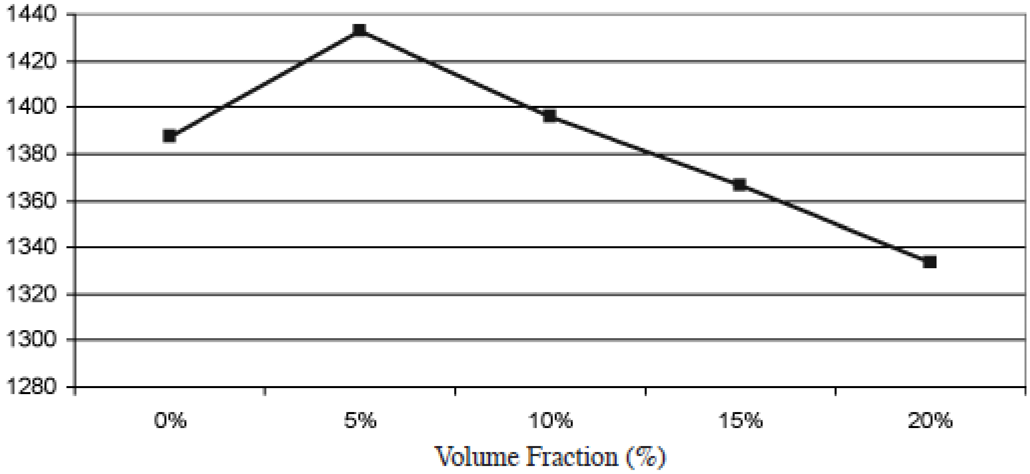


Figure 2.8: Effect on volume fraction on young modulus.

Figure 11 show that there was a small gap between fiber and matrix which means a poor adhesion or interfacial bonding for fiber and epoxy-hardener mixture. The void and small gap formed was probably caused by incomplete wettability or bonding between matrix resin and fiber during fabrication of composites. This was also reported by Arib et al. (2006) and Lee et al. (2005) as mention in research paper by Yusoff. This condition can be improvised by providing a good surface treatment for the fiber and proper mixing of epoxy-hardener and fiber.

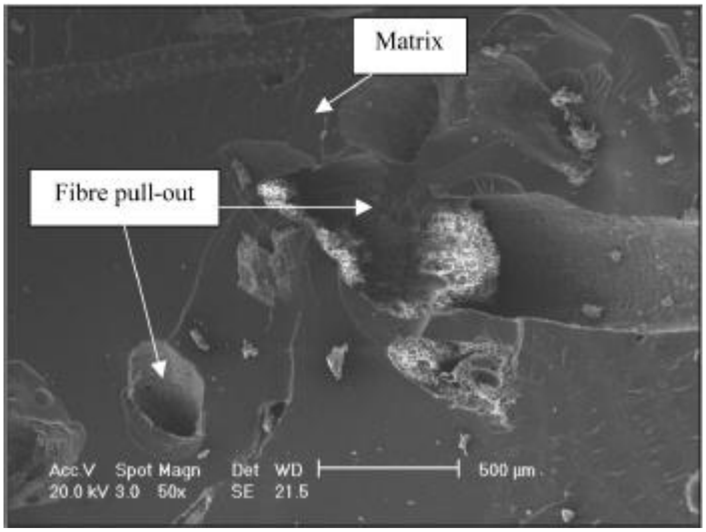


Figure 2.9: SEM showing the fiber pull-out from matrix.

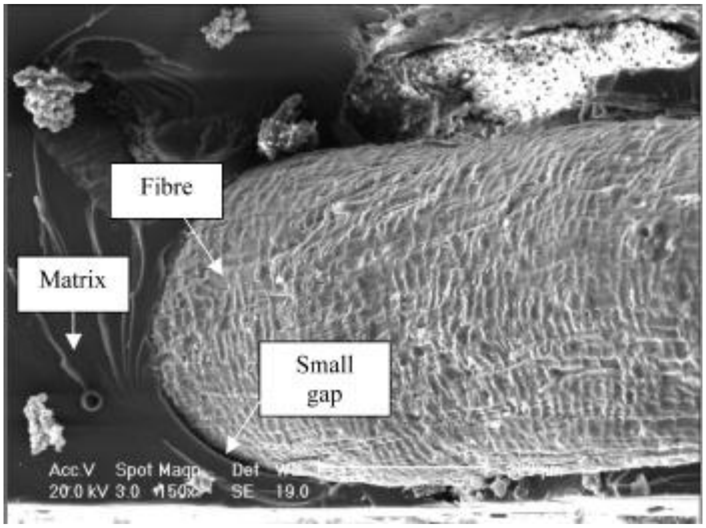


Figure 2.10: SEM showing a small gap between fiber and matrix.

2.5 Vibration study.

In this study, 5 methods were use to analyze the dynamic characteristic of composite drive shaft. The 5 methods are kurtosis, skewness, peak to peak, RMS and crest factor. For a good vibration, it should follow a normal distribution as shown in figure 2.11. For kurtosis, it will tell us the peak's shape of distribution, whether it is too flat or to sharp. On the other hand, the skewness will tell us whether the data is skewed to the right or left. This will tells us the density of amplitude, which will indicate the magnitude of data is heavy on the high or low side.

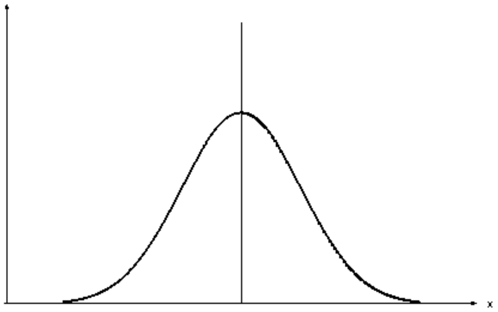


Figure 2.11: Normal distribution.

RMS or root mean square is the quadratic mean of the data. The data obtained is ranging from negative to positive with different value. So rms is chose as indicator to tell the mean value of vibration to ease the analysis and comparison process. Peak to peak value on the other hand is the measure of highest point and the lowest point of vibration magnitude obtain in the experiment. Higher peak to peak value shows high vibration impact of drive shaft. Crest factor give us the quality of the result obtained.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology.

For the completion of project, the work done will generally distributed into three phases which are:

i) Research and understanding of drive shaft and composite material.
ii) Material preparation and fabrication of composite drive shaft.
iii) Testing and analysis

3.1.1 Research and understanding of drive shaft and composite material.

Early stage of project started with the research and analysis of composite material and drive shaft. Various journal and research paper related with this subject was read and analyzed. Weekly meeting with final year project (FYP) supervisor, Ir. Idris bin Ibrahim was conducted to gain new idea and ensure the project is on schedule. Engagement session with fiber expert, Mr Azuan b Maoinser, post graduate student, Miss Raja Fauziah and Mr. Tamiru was conducted to obtain opinion and latest information regarding fiber and vibration analysis.

3.1.2 Material preparation and fabrication of composite drive shaft.

Fabrication process started with material preparation. Aluminium cylinder was purchased at TSA industries Sdn. Bhd at Chandan Raya industrial area, Kledang. The aluminum has the diameter of 5/8” and length of 22”. The reason of this size to ensure the drive shaft can fit into spectrum analyzer for analyzing purposes.

The fabrication process followed by the fiber preparation process. Empty fruit bunch was obtained from IOI palm oil plantation near Segamat, Johor. The empty fruit bunch is later on being shred using granulator at block 17, UTP. Fiber obtained from granulation process, being treated with hot water (approximately 90^{o}C) for 1 hour. The reason for this process is to remove grease and impurities for better bonding of the fiber. After it cool down to room temperature, fiber is treated with NaOH solution for 24 hours. This is to improve the mechanical characteristic of fiber and to ensure better interfacial bonding of fiber. After it is treated with NaOH solution, it rinse with tap water. Sample being subjected to oven dry at 70^{o}C for 24 hours.

In order to impregnate palm oil fiber with aluminum shaft, epoxy-hardener mixture was made. Epoxy hardener with ratio to 1:2 was chose and mix using mixer until the color of the mixture is equal. Fiber was added in the mixer to ensure the fiber is completely wetted.

A wrapper made of green net was prepared to fold the aluminum with fiber. The main purpose of using wrapper is to ensure palm oil fiber maintain its position around the aluminum shaft when the epoxy-hardener is still wet. The wrapper is taken off after 48 hours to help the composite drive shaft dry faster.

3.1.3 Testing.

Composite drive shaft later on being tested using spectrum analyzer. It is subjected to a different speed. The dynamic characteristic of the composite drive shaft is recorded and compared with steel drive shaft having the same and smaller diameter.

3.2 Project Scheduling.

The following Gantt chart is the list of activities for FYP 1 and FYP 2.

Table 3.1 : Tabulation of work and dateline proposed in FYP1 semester.

Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Research on drive shaft		🟦	🟦	🟦	🟦									
Research on composite material		🟦	🟦	🟦	🟦									
Extended Proposal submission						🟦								
Proposal Defence								🟦						
Research continues							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Fiber preparation							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Interim Report submission													🟦	

Table 3.2 : Tabulation of work and dateline proposed in FYP2 semester.

Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Lab booking	🟦	🟦												
Fabrication			🟦	🟦	🟦	🟦	🟦							
Progress Report submission								🟦						
Pre-EDX											🟦			
Dissertation writing									🟦	🟦	🟦			
Draft Report Submission												🟦		
Dissertation Submission (Soft bound)													🟦	
Technical Paper Submission													🟦	
Oral Presentation														🟦
Dissertation Submission														🟦

Fabrication process of drive shaft in this study is a little different from other paper. Most of research paper use filament winding process to reinforce the aluminum shaft, but, in this paper different approach was used. Much cheaper material with simple fabrication procedure was introduced.

3.2.1 Project flow

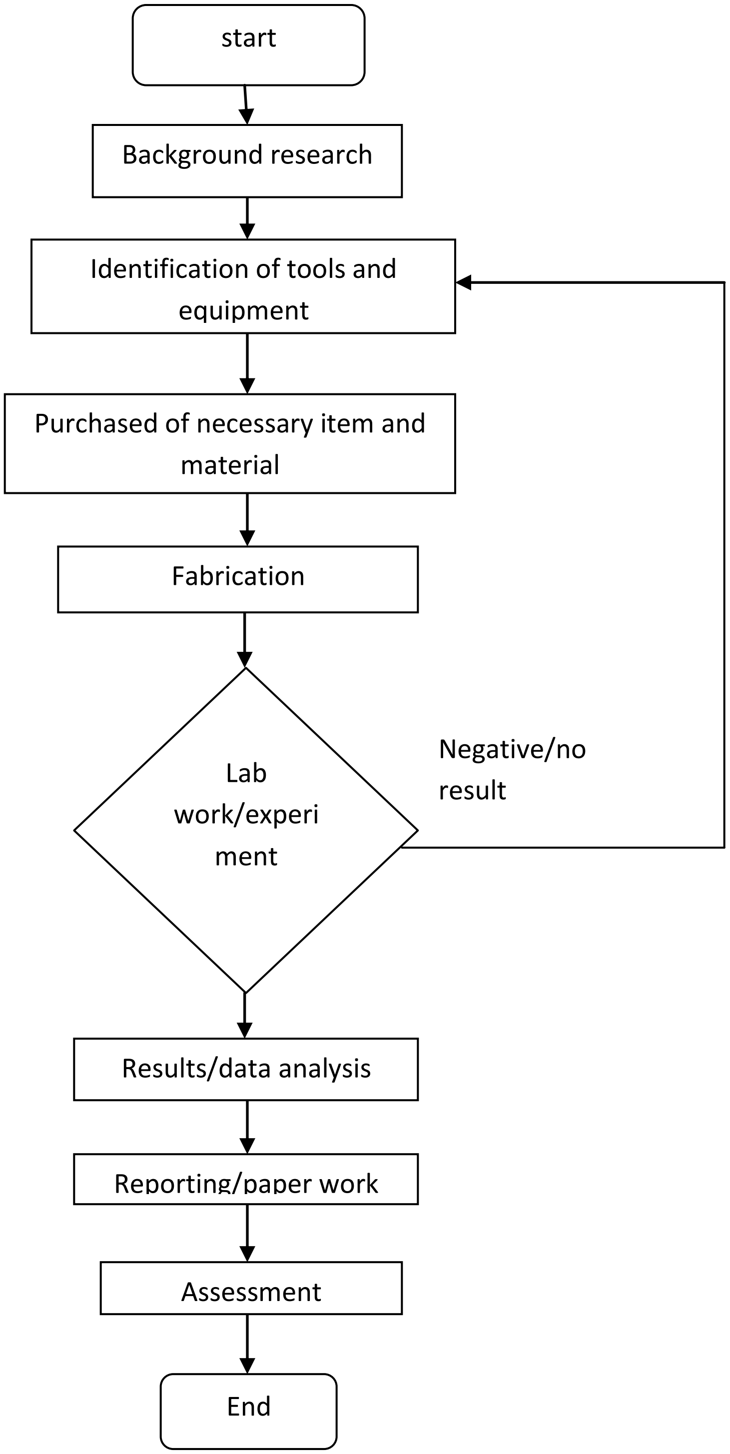


Figure 3.1: Project flow

3.3 Tools and material.

3.3.1 Machine fault simulator

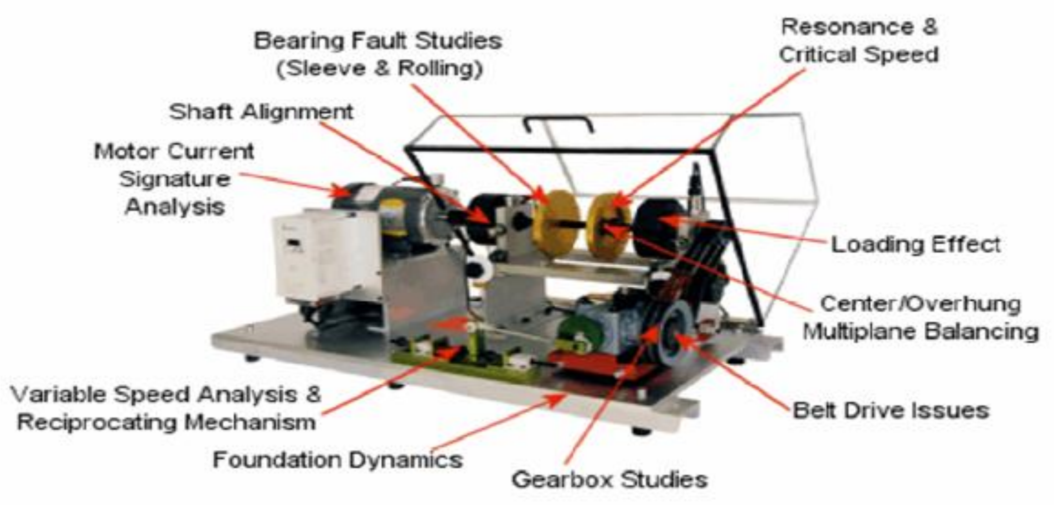


Figure 3.2: Machine fault simulator

To record and analyze the dynamic characteristic of drive shaft when subjected at different speeds. The maximum speed of machine fault simulator can be up to 3600 RPM. Can analyze the vibration of shaft with specific diameter of 3/8", 5/8" and 1". Equipped with software, VibraQuest pro that enabled the data to be converted into excel for further analysis.

3.3.2 Mixer

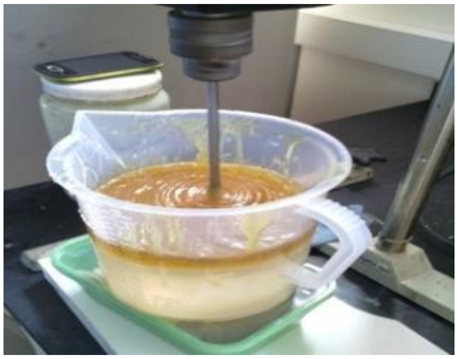


Figure 3.3: Mixer

To Properly mix the epoxy and hardener for better bonding between natural fiber and aluminum shaft.

3.3.3 Granulator.

Figure 3.4: Granulator

Granulator is a machine to grinding or shedding material into small pieces. In this study, granulator was used to shred the empty fruit bunches into small pieces ranging from 5mm to 20 mm. Empty fruit bunches need to be grind to ease the treatment process and most importantly to make it possible to wrap it around aluminum shaft.

3.3.4 Oven

Figure 3.5: Oven

Oven is a machine to remove moisture from any sorts of material. The temperature of this oven can be ranging up to 500^oC and can operate for weeks or month, depends on the requirement and specifications. Oven is important to speed up the moisture removal process. It can also reach the dryness of material that cannot be achieved with normal drying process. Removal of moisture content is important in order to have pure natural fiber and better mechanical characteristic.

3.4 Material

3.4.1 Empty fruit bunch

Figure 3.6: Empty fruit bunch after treated with NaOH

Empty fruit bunches is first granulated using granulator before treated with hot water to remove impurities. It is then treated with sodium hydroxide to improve the mechanical characteristic and separate it with one another.

3.4.2 Epoxy and hardener

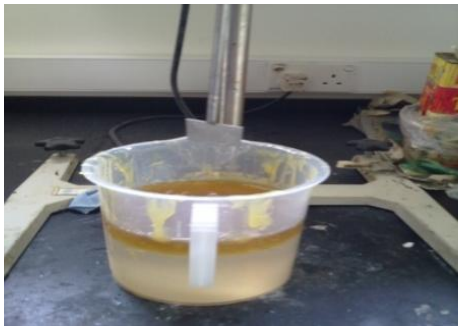


Figure3.7: Epoxy and hardener

Epoxy and hardener with specific ratio was obtained and stirred using mixer. The mixture is stirred for approximately 30 minutes to ensure that it is well blend.

3.4.3. Sodium Hydroxide (NaOH)

Figure 3.8: Sodium Hydroxide

Sodium hydroxide in the crystal form like in figure 3.7 will be transformed into aqueous form to treat the natural fiber for better mechanical characteristic.

3.4.4. Aluminum rod

Figure 3.9: Aluminum rod

Aluminum rod was chosen as the shaft due to light weight. The diameter of aluminum shaft is 5/8” and it is 22” long. This drive shaft will later being reinforce by natural fiber to transform it to composite material with better mechanical characteristic.

CHAPTER 4
RESULT & DISCUSSION

4.1 Vibration study

One of the keys component in this reseach is the vibration study. A fabricated drive shaft with the aluminum diameter of 5/8” was tested using machine fault simulator. The function of machine fault simulator is to record the vibration characteristic of the material. Drive shaft was subjected at 4 different speeds (500 rpm, 1000 rpm, 1500 rpm and 2000 rpm). Result of vibration characteristic then compared with steel drive shaft with same diamter, 5/8”, and smaller diamter, 3/8”. A few methods was used to compare and analysis the results, namely, RMS (root mean square), peak to peak, Kurtosis, skewness and crest factor.

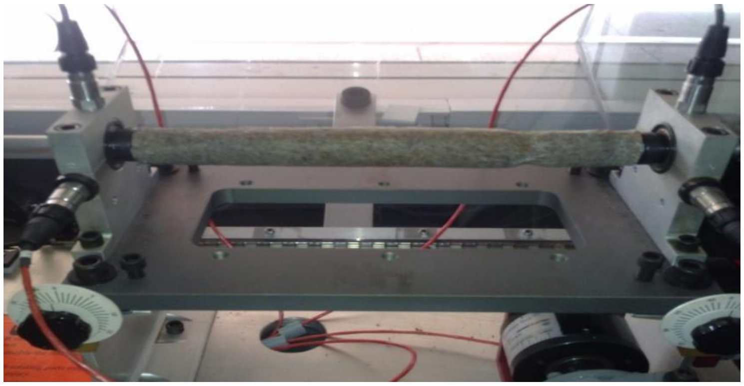


Figure 4.1: Composite drive shaft fitted at machine fault simulator.

The results obtained from the experiment is in form of time wave form. The graph obtained is amplitude versus time. In order for the result to be analyzed, it is exported in excel form (from graphical to numerical data). After being analyzed using 5 methods mention above, it is then plotted using graph. The data analyzed is the one obtained from the accelerometer closest to the source of rotation, motor. Reason for it is because, it yield the most vibration across the drive shaft. Data obtained from different accelerometer across the drive shaft also being analyzed.

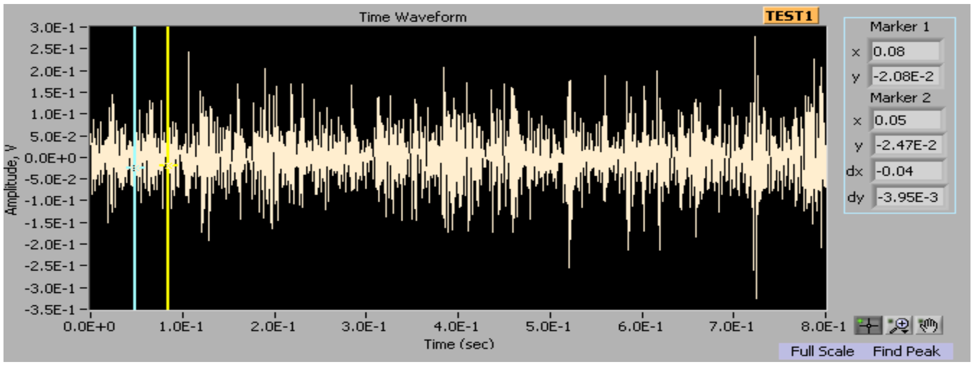


Figure 4.2: Example of raw data obtained using VibraQuest Pro.

4.1.1 RMS (Root mean square)

In mathematic, root mean square (abbreviated RMS or rms), also known as the quadratic mean, is a statiscal measure of the magnitude of a varying quantity. It is specially useful when variaties are positive and negative. It can be calculated for a series of discrete value or for a continuosly varying function. The name comes from the fact that it is the square root of the mean of the summation of square values. Formula for rms is stated below.

$$Xrms = \left(\left(\frac{1}{N}\right) \Sigma x_1^2\right)^{\frac{1}{2}}$$

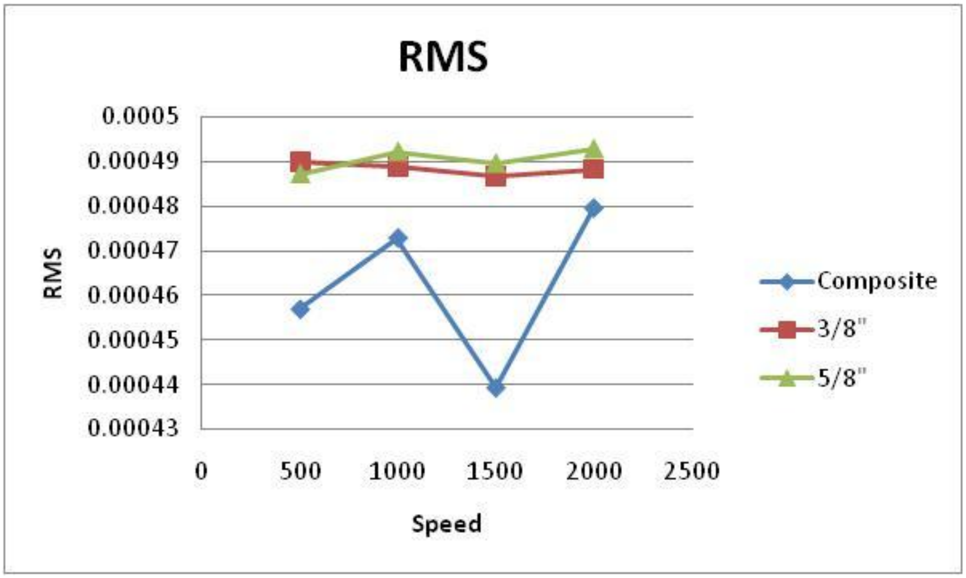


Figure 4.3: RMS versus speed

As we can see from the graph above, the magnitude of amplitude at accelerometer located nearest to the source of rotation is smaller at all speed compare with steel drive shaft with same and smaller diamter, 3/8” and 5/8”. This clearly shows that composite drive shaft yield least vibration compare to conventional drive shaft.

4.1.2 Peak to peak

Peak to peak analysis was used as an indication of the amount of lateral movement of the machine. It is also used to see whether unbalance in mass occured in the system. The advantage of this technique is that it only require information about one input and one output. Consequently, it represents the most widely applicable and least demanding of data in all mathematical methods for estimating capacity and capacity utilization (Kirkley and Squires 1999). Peak to peak analysis has been applied in many situation like fisheries by Ballard and Roberts (1977), Ballard and Blomo (1978), and Hsu (2003). Further information of the technique, including the mathematical specification of the approach, also provided in Kirley and Squires (1999). The formula for peak to peak analysis is given belom.

Formula : max X – min X

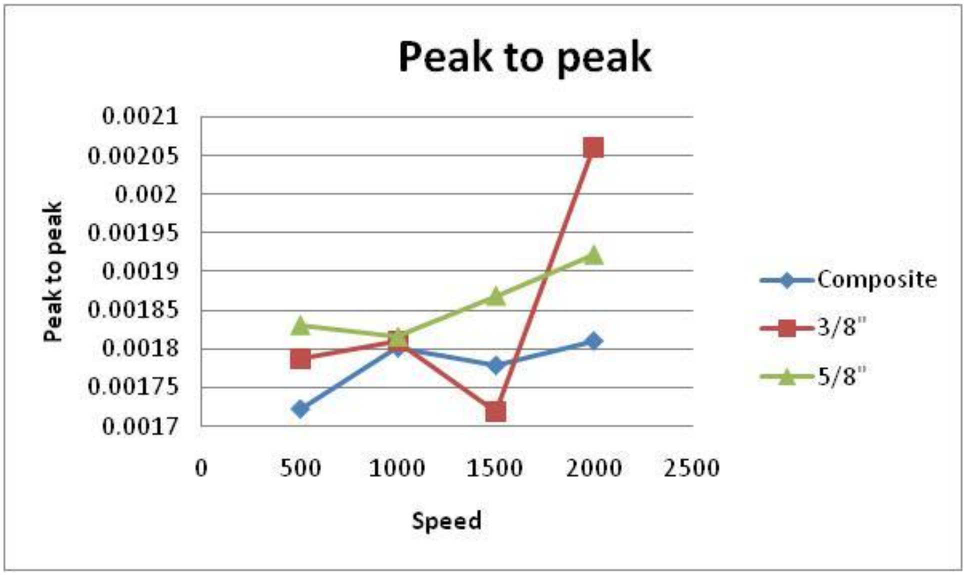


Figure 4.4: Peak to peak versus speed.

As we can see from figure 4.4, the amplitude for composite is lowest at almost all speed except at 1500 rpm. The significant difference can be seen at the 2000 RPM where composite has the amplitude difference at 0.00181, instead 5/8” and 3/8” drive shaft have the value of 0.00206 and 0.00192 repectively. This is 13.81 and 6.08 percent more compare to composite drive shaft.

4.1.3 skewness

Skewness is a measure of asymmetry of normal distribution statiscal method. For a very good condition of machine, the skewness is zero and any symmetric data should have skewness near zero. Negative values for the skewness indicate data that are skewed left and positive values for the skewness indicate data that are skewed right.

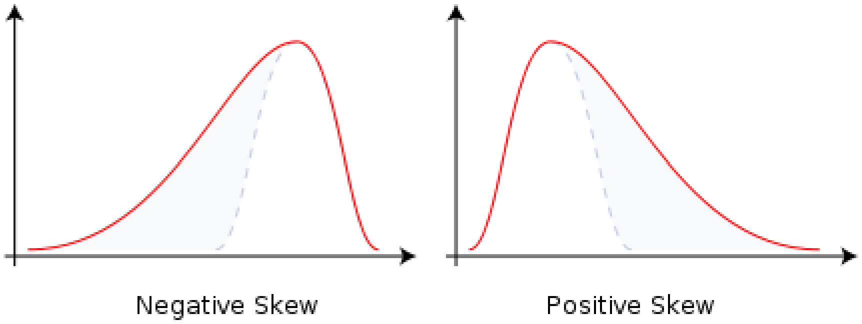


Figure 4.5: Graphical explanation of skewness.

Negative skew is the one where the tail is longer, which mean the mass of the distribution is concentrated on the right of the figure. It has relatively few low values. The distribution is said to be left skewed or skewed to the left.

Positive skew in the other hand, has longer right tail. In other word the mass of distribution is concentrated on the left of the figure. It has relatively few high values. The distribution is said to be right skewed or skewed to the right.

On the other hand, if the distribution is symmetric, which often is not the case due to many factors, the mean= median and the skewness will be zero. In this case, graph value which closer to zero will be consider have better distribution. Formula for skewness is given below:

$$g = E\frac{(s - \mu)^3}{\sigma^3}$$

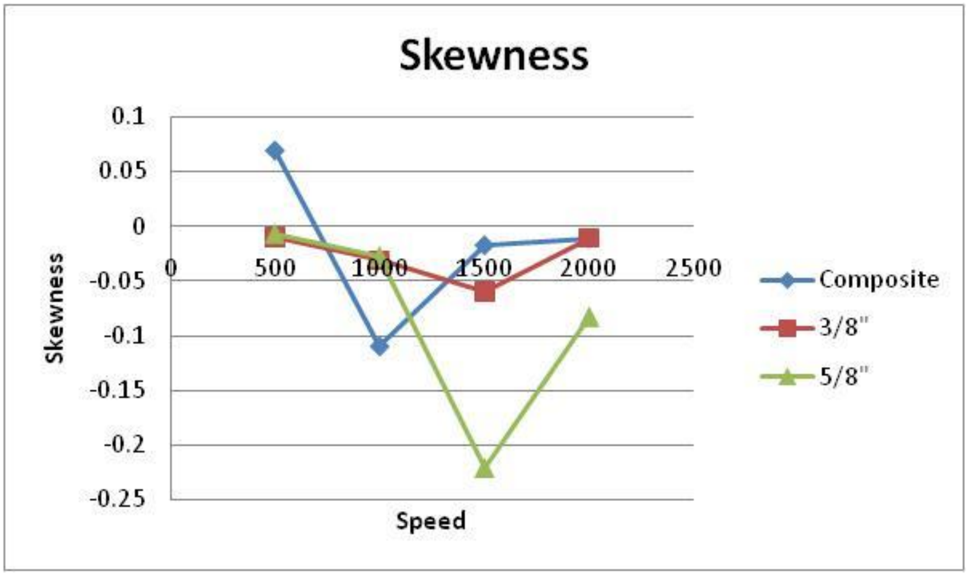


Figure 4.6: Skewness versus speed.

From the graph above, we can say that drive shaft with diameter 3/8" has better normal distribution followed by composite and 5/8" drive shaft. From above graph, we can say that, at low speed, all 3 drive shaft has positive value. This means that, it has few high values (peak) at low speed. As speed increased, the value of skewness dropped and become negative which shows that increased in number of high value frequency. At the maximum speed, composite drive shaft and 3/8" shaft has positive value compare to 5/8" which has negative value.

4.1.4 Kurtosis

Kurtosis is any measure of the "peakness" of the normal distrubution. In a similiar way to the concept of skewness, kurtosis is a descriptor of the shape of a probability distribution. It can be used to measure how the signal is distorted due to faults or machine deterioration.

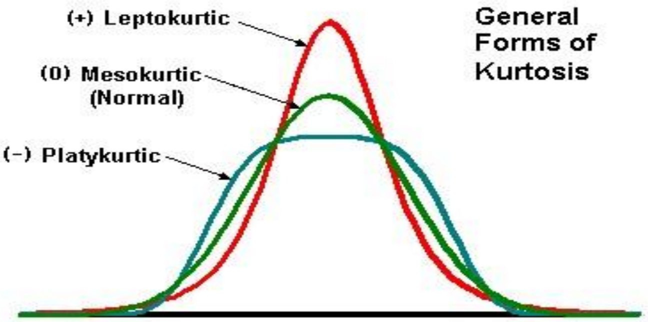


Figure 4.7: Kurtosis

Mesokurtic distribution is a terminology used when the distribution is normal. It can be achieved when the value of Kurtosis is zero. Positive excess kurtosis is called “leptokurtic” or mean slender. In term of shape, a leptokurtic distribution has a more acute peak around the mean and fatter tail. On the other hand, negative kurtosis is called platykurtic, which means broad. In term of shape, a platykurtic distribution has a lower, wider peak around the mean and has thinner tails. The formula for kurtosis is given below.

$$\text{Kurtosis} = \mathrm{E}\frac{(\,s - \mu\,)}{\sigma^2}$$

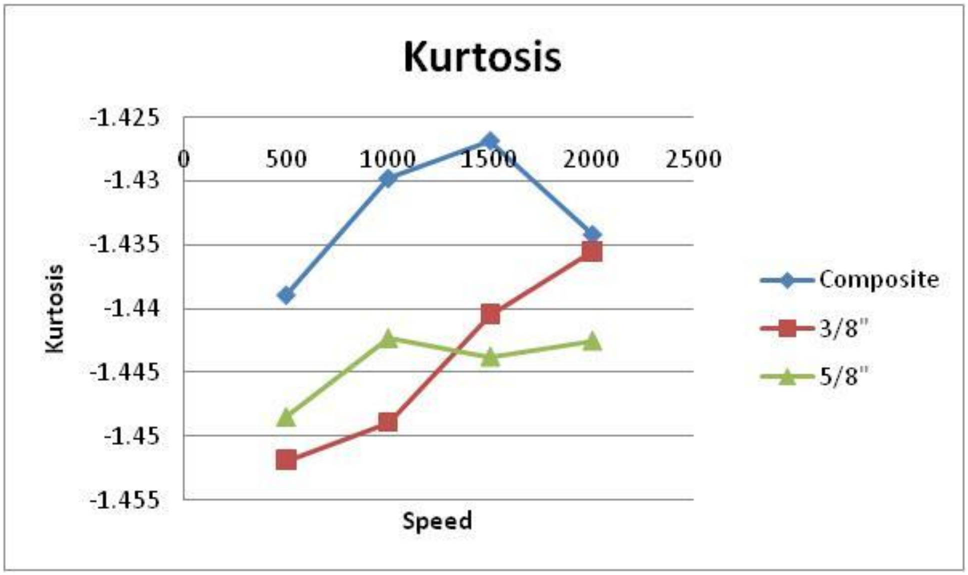


Figure 4.8: Kurtosis versus speed

From the graph above, we can see that all value obtained is negative for all shaft, including composite and steel. This mean, all the shaft follow the platykurtic distribution. But composite drive shaft has the value closer to zero at all 4 different speed compare to 3/8” and 5/8” steel drive shaft.

4.1.5 Crest factor

Crest factor or also known as peak-to-peak average ratio (PAR) is a measurement of a waveform, calculated from the peak amplitude of the waveform divided by the RMS value of the waveform. It is therefore a dimensionless quantity. The main function of this measurement is to get an idea of the quality of the signal. It is also to give an idea of how much impacting occurred in waveform. Signal with more peaks will have higher crest factor. The formula for crest factor is given below:

$$\text{Crest factor} = \frac{\max(|X|)}{Xrms}$$

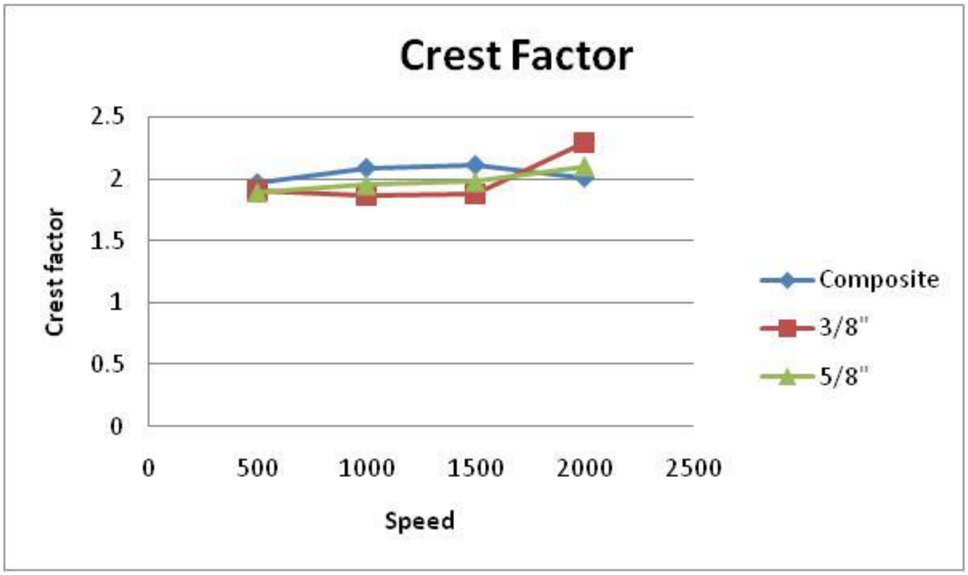


Figure 4.9: Crest factor versus speed

As we can from graph above, the crest factor is almost flat at all speed for all type of drive shaft. The value of crest factor for all drive shaft also is about the same. This shows that all the value obtained for all type of drive shaft is good.

4.2 Vibration study along the drive shaft.

For above analysis, the value obtained is from the accelerometer located nearest to the source of rotation, motor. For this segment, the study for vibration value at both ends will be conducted. RMS has been chosen as a method to analyze the time wave form of drive shaft. RMS is found to be more accurate in order to find the quadratic mean of time waveform that has both negative and positive value.

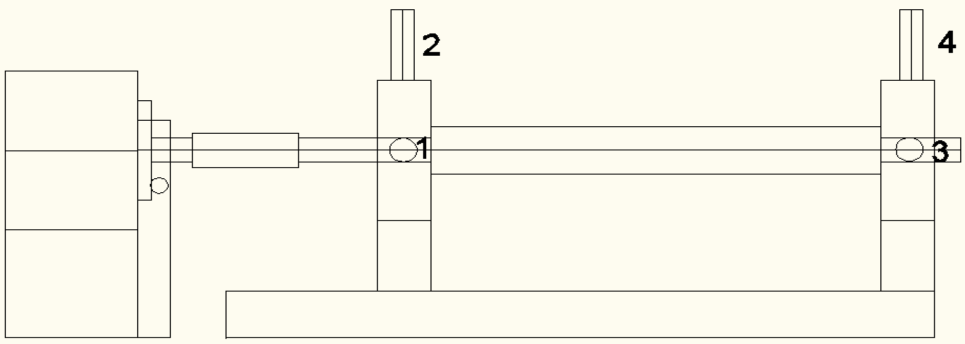


Figure 4.10: location of accelerometer at machine fault stimulator.

As we can see from figure 4.10, there are 4 accelerometers at machine fault stimulator. Two accelerometers at each end with one of it read the horizontal acceleration and the other one read vertical acceleration.

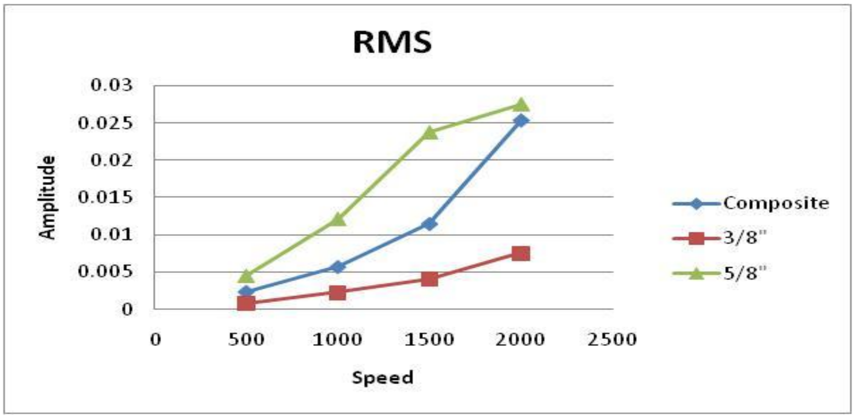


Figure 4.11: RMS value versus speed at accelerometer 1.

Figure 4.12: RMS versus speed at accelerometer 2.

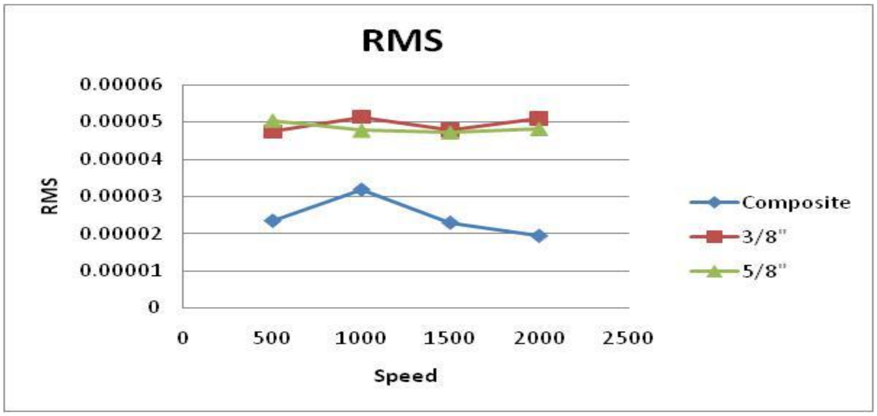


Figure 4.13: RMS versus speed at accelerometer 4.

From all 3 graphs above, we can concluded that, higher vibration occur at nearest source of rotation in horizontal direction. Both accelerometers at point 1 and 4 that reads the acceleration in horizontal direction has much lower value compare to accelerometer that reads the horizontal value. The acceleration for point 3 in other hand cannot be obtained due to system faulty.

From the graph above, we can also concluded that composite drive shaft has lower vibration compare to steel drive shaft except at point 1 where the RMS value for composite drive shaft is lower compare to steel shaft that have same diameter, 5/8”, but higher compare to drive shaft with smaller diameter, 3/8”.

4.3 Mass reduction.

One of the key points of fabricating composite drive shaft other than having higher natural bending frequency is significant mass reduction. For composite drive shaft, the mass of drive shaft is contributed by the mass of aluminum and fiber. Total mass of composite drive shaft is 0.525 kg. For conventional drive shaft made of steel with same diameter is weighing

Table 4.1: Mass of drive shaft

Item	Weight (kg)
Composite drive shaft	0.525
Steel drive shaft 5/8”	0.857
Steel drive shaft 3/8”	0.3086

Percentage of mass reduction of composite drive shaft with same diameter:

$$\frac{composite\ (kg) - steel\ (kg)}{steel\ (kg)} \times 100\ \%$$

$$\frac{0.525\ kg - 0.857\ kg}{0.857\ kg} \times 100\ \% = 38.74\ \%$$

As mentioned in literature review, weight has major effect on vibration and fuel efficiency. Heavier the material will caused bigger impact in vibration and reduced in fuel efficiency. By reducing almost half its original weight, the composite drive shaft will vibrate less and has higher fuel efficiency.

CHAPTER 5

Conclusion and Recommendation

5.1 Conclusion

Composite material is a solution for a better drive shaft. It has significant weight reduction, higher natural bending frequency and less part complexity. Exploring potential EFB as natural fiber to substitute the usage of carbon/glass fiber is a worth and highly potential study as the resource is abundant and much cheaper compare to glass/carbon fiber.

From the graph obtained from the experiment conducted using machine fault simulator, we can conclude that composite drive shaft, with lighter weight yield smaller vibration effect along the drive shaft compare to steel drive shaft having same diameter. At some speed and some point, composite drive shaft also yield smaller vibration effect compare to steel drive shaft with smaller diameter and lighter mass. This shows that composite drive shaft is a suitable substituted for better drive shaft with smaller vibration effect.

5.2 Recommendation.

1. Fiber length has much effect on the mechanical properties. Longer fiber length has better mechanical properties. In this study, granulator was used and the end product of fiber is relatively short. For better mechanical properties, modified version of granulator or special chopping machine can be used to obtain longer fiber length.
2. Fiber is strong at its direction. In order to produce a stronger reinforcement and better load distribution, the fiber should be arrange in desired angle and direction instead of random distribution.
3. Proper adhesive or adhesion method can be introduced in order to solve the “small gap” or “fiber pull out” problem.

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APPENDICES

Formula for Kurtosis:

$$g = E\frac{(s - \mu)}{\sigma^2}$$

Formula for skewness:

$$g = E\frac{(s - \mu)^3}{\sigma^3}$$

s = signal

μ = mean

E = expectation

σ = standard deviation

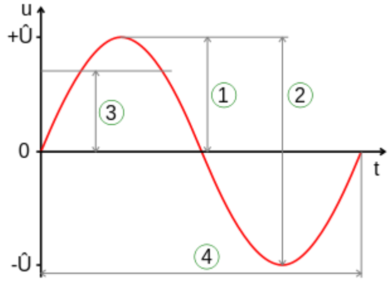
Formula for root mean square (rms)

$$Xrms = \left(\left(\frac{1}{N}\right)\Sigma x_1^2\right)^{\frac{1}{2}}$$

Where x= Amplitude, N= number of data

Formula for peak to peak

Peak to peak: max X – min X



Formula for crest factor:

$$C = \frac{\max(|X|)}{Xrms}$$

Formula for mass reduction:

$$\frac{composite\ (kg) - steel\ (kg)}{steel\ (kg)} \times 100\ \%$$