M.Tech (Computational Design) [AKSHAY ARORA] 2018

VIBRATIONAL ANALYSIS OF ALUMINIUM 6061 MATRIX COMPOSITE

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

COMPUTATIONAL DESIGN

Submitted by:

AKSHAY ARORA

(2K16/CDN/01)

Under the supervision of

Prof. VIKAS RASTOGI

DEPARTMENT OF MECHANICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

JULY, 2018

DELHI TECHNOLOGICAL

UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, (AKSHAY ARORA), Roll No. 2K16/CDN/01 student of M.Tech (Computational Design), hereby declare that the project Dissertation titled "**Vibrational analysis of aluminium 6061 matrix composite**" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not been previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi **(AKSHAY ARORA)**

Date:

DEPARTMENT OF MECHANICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the project Dissertation titled "**Vibrational analysis of aluminium 6061 matrix composite**" which is submitted by Akshay Arora, Roll No. 2K16/CDN/01 [Department of Mechanical Engineering], Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **(Prof. VIKAS RASTOGI)**

Date: **SUPERVISOR**

ACKNOWLEDGEMENT

I am obligated to the **Dept. of Mechanical Engineering, DTU** for providing the opportunity to carry out the thesis work, which is an integral part of the curriculum in M. Tech program at the Delhi Technological University, Delhi. I take this opportunity to express my deep gratitude and respects to my guide **Prof. Vikas Rastogi** for introducing the topic with their keen interest, valuable guidance, strong motivation and constant encouragement during the course of work. I would like to pay my deep sense of thankfulness **to Prof. Vipin HOD, Department of Mechanical Engineering, DTU.**

I express my sincere thanks to **Mr. Anuj Sharma (Ph.D. Scholar)** for his guidance and support without which I could not have completed my thesis.

I thank my classmates who were never too busy when I needed the moral support throughout the work and helped me out in every possible situation. Lastly, I would like to thank my Parents and my Sister for always being there when I may have needed the most and for keeping my spirit at heights.

AKSHAY ARORA

M. Tech (Computational Design)

2k16/CDN/01

ABSTRACT

The present study deals with the fabrication of aluminium 6061–alumina 8% vol. composite shaft by optimized stir casting manufacturing process. The properties of the composite being formed is computationally calculated by the Digimat-MF software. Shafts demand variable loading conditions in the applications and thus its vibrational study becomes vital. In this study, analysis of static and dynamic vibrational characteristics and its comparison of the conventional Al 6061 alloy with the $\mathrm{Al}\ 6061 - \mathrm{Al_2O_3}$ composite shaft have been carried out. Damping property is the basic form, which shows the vibrational characteristics of a component and its ability to overcome the vibrational problem , thus statically, the damping ratio is calculated and at a given excitation frequency, the critical speed of shaft obtained is compared with the experimentally obtained transverse frequency.

Finite element modal analysis of shafts is done with the help of Ansys with the prescribed condition of bearing and damped conditions. Campbell diagram is plotted in respect to observe different mode shapes and its comparison is done for both the shafts.

Composites are generally used in making drive shafts of the automobiles as better mechanical properties with reduced weight and high specific modulus is obtained. The results showed that the Aluminium 6061 composite rotor is depicts better vibrational characteristics as enhanced natural frequency is achieved along with its damping factor.

Keywords: Vibration Analysis, Stir casting, Aluminium composite, Modal Analysis, Campbell diagram, Driveshaft

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF NOMENCLATURE

E = Young's Modulus in GPa

ρ = Density of the material in kg/m^3

ξ= Damping ratio/ factor of the material

A= Area of shaft in m^2

I= Moment of inertia of shaft. m^4

L = Length of the shaft in meters

l= Length of shaft between the bearing

f = Frequency in Hz

T = Time period of oscillation in seconds

x = Displacement vector

A_{max}= Maximum Amplitude

F_{max}= Frequency of shaft at maximum amplitude

X = Excitation of the shaft in rpm

N_c= Natural frequency of shaft

ω_{cage}= Rotation of cage of the bearing

V_p= Volume of reinforcement particles

V_m= Volume of matrix

V_c= volume of composite

LIST OF ABBREVIATIONS

MMC = Metal Matrix Composite

FFT = Fast Fourier Transformation

SEM= Scanning electron microscope

FEM = Finite element method

AMC= Aluminium Matrix Composite

PM = Powder metallurgy

RVE = Representative volume element

MFH = Mean Field Homogenization

FRF = Frequency response function

VC= Varying compliance

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

Rotary machines are the most vital components of the modern industrial sector. Catastrophic failure of such elements has a colossal effect on the system. Several efforts had been made to reduce the probability of these kinds of failures. Many rotor faults can lead to catastrophic failure if undetected properly and in time therefore study and investigation of dynamics of rotor are a matter of concern since last four decades. Additionally, improving fuel economy, reducing vehicle emissions, increasing styling options, enhancing performance, and maintaining safety, quality, and profitability are just a few of the challenges addressed daily by the industry. This has led to the introduction of new type of materials for rotor namely composite rotor. Of the new metallic materials, metal matrix composites (MMCs) are anticipated to have a significant niche in the industry. Their high specific modulus and fatigue strength, wear resistance, and tailorable properties such as thermal expansion are a few of the important attributes (Amalina, 2008)

Dynamic analysis of composite rotor is an emerging area of research due to its practical importance and several issues are associated with this analysis due to its complexity and increasing demand of reliable defect detection techniques. The vibration problems of composite rotor generally pose nonlinearity. Metal matrix composites (MMCs) are often overshadowed by carbon fiber composites when it comes to light weighting parts and structures. But MMCs do have a number of unique and interesting advantages over other lightweight materials that have been used by industries such as aircraft, defense, space, oil and gas, nuclear fusion, renewable energy, automotive, marine and rail.

Aluminium is the most abundant metal in the Earth's crust, and the third most abundant element, after oxygen and silicon. It makes up about 8% by weight of the Earth's solid surface. Due to easy availability, high strength to weight ratio, easy machinability, durable, ductile and malleability aluminium has been amongst the most useful metals.

To meet various requirements, aluminium is alloyed with copper, magnesium, zinc and other alloying elements. The designation of wrought Aluminium alloy is shown in the Table 1.1

Table 1.1 Designation of wrought aluminium alloy

Alloy Designation	Details
1XXX	99% Pure aluminium.
2XXX	Cu containing alloy.
3XXX	Mn containing alloy.
4XXX	Si containing alloy.
5XXX	Mg containing alloy.
6XXX	Mg and Si containing alloy.
7XXX	Zn containing alloy.
8XXX	Other alloys.

A composite is a material formed by the combination of two or more distinct materials macroscopically in such a manner that the properties obtained of the composite is enhanced and better as compared to the individual combined material. A composite consist of two phase a matrix phase and a reinforcement.

(i) Matrix phase: It is the major phase used in making of a composite, which helps in binding of reinforcements and is used in distribution of stresses across the composite material.

(ii) Reinforcement: It is the material reinforced (inclusions) into the matrix in form of particulates, fibers etc. Its role is to increase the mechanical properties (such as stiffness, strength) of the composite being formed.

(iii) Metal matrix Composite: It is a composite, where atleast one of the constituent in the composite should be a metal and the other can be a metal or non-metallic material.

Various reinforcements that can be reinforced into the Aluminium or other nonferrous metal matrix are shown in the Table 1.2.

Table 1.2: Reinforcements in the matrix

Reinforcement	**Matrices**
Boron, fiber (including coated)	Aluminium, titanium
Graphite fiber	Aluminium, magnesium, copper
Alumina fiber	Aluminium, magnesium
Silicon carbide fiber	Aluminium, titanium
Alumina-silica fiber	Aluminium
Silicon carbide whisker	Aluminium, magnesium
Silicon carbide particulate	Aluminium, magnesium
Boron carbide particulate	Aluminium, magnesium

For the development of MMCs, commonly used base metals are titanium, magnesium, copper, nickel and aluminium. But the most widely used metal is aluminium due to its inherent features such as light weight, strength, excellent thermal and electrical properties, good reflective properties, and impermeability and cost effectiveness. (Madhukar, 2016). Aluminium metal matrix composites are widely used in aerospace, automobiles, defense, structural and thermal management areas, which ultimately results into drastic changes in the product design and development with reduced weight and volume, thus offering economically execuTable alternatives (Muryama, 1999). By using suitable kind of reinforcement with aluminium matrix, the properties of aluminium metal matrix composite can be tailored according to the demand of any application.

For high temperature application MMCs are very much effective as compared to carbon fiber composites. Drive shafts in trucks and large passenger cars offer a particularly attractive application of DRA. Although the majority of automotive drive shafts are constructed from steel, aluminium driveshaft which has been in use in selected applications for a number of years. Their primary appeal has been the significantly lower weight of the aluminium driveshaft, coupled with the ease with which it can be balanced. Current drive shafts, whether steel or aluminium, are constrained by the speed at which the shaft becomes dynamically unstable. (Koczak, 2007)

The critical driveshaft speed, N_c, is given by

$$Nc = \frac{60 * \pi^2}{2\pi * L^2}\sqrt{\left[\frac{E}{\rho}\right] * \frac{I}{A}} \quad - (1.1)$$

The important aspect of this formula is that the critical speed of the shaft depends upon the properties of material i.e. $\frac{E}{\rho}$ (specific modulus) ratio. Thus by increasing this ratio can lead to better dynamic characteristics of shaft whose performance could even be better than the alloys of the respective metals. Thus composite gives a wide range of application in the aspects of automobile industry due to its improvement in combined properties. (Eliasson, 1995)

1.2 ADVANTAGES OF ALUMINIUM MATRIX COMPOSITES

Following advantages are achieved with aluminium matrix composites.

- Increase in Elastic constant 'E'.
- Increased yield and tensile strength.
- Increase in wear resistance.
- Decreased coefficient of thermal expansion.
- Increase in damping characteristics of composite as compared to parent metal.
- Weight is reduced hence fuel economy could be achieved.
- Longer fatigue life than aluminium shaft.

1.3 PROBLEM DESCRIPTION

Metal matrix composites are gaining popularity in automobile and aerospace industry. Aluminium being a very light weighted metal is widely used in such applications. One such common application is the Aluminium composite driveshaft which is used to transfer torque to the wheels. Thus it's important to analyze its vibration static as well as its dynamic characteristics and to compare its performance with the conventional material. In this thesis Aluminium 6061 alloy and Al 6061- Al_2O_3(Alumina) critical speed and damping properties are compared. Study of fabrication of aluminium composites is done and a 8% vol. aluminium-alumina composite shaft is being produced using the stir casting process, further the damping ratio (ε) and dynamic vibration analysis is calculated experimentally by impact hammer test and running the set up at a speed respectively, using the OROS data analyzer. FFT's of the response are recorded to get the results. Computational ANSYS FEM (modal analysis) is done on the two shafts Al 6061 and Al 6061-Al_2O_3 composite to find the mode shapes and form a campbell diagram and to compare it's results with the experimentally obtained data.

1.4. Processing of Aluminium matrix Composites

Aluminium based MMCs can be manufactured by the following methods:

1.4.1 Liquid-state processing

a. **Stir casting:**

This process involves mixing of ceramic particles into the liquid aluminium matrix to form a MMC. The major property of stir casting is the wettability of inclusion particulates with the molten aluminium is improved by using the stir casting process to manufacture the composite. It is the simplest and the most economical method to process an AMCs. Uniform distribution of particulates is achieved by stirring the mixture with a stirrer and the optimum conditions to get proper distribution in the metal matrix. Generally up to 30% particulates of size varying from 5-100μm can be casted out with the aluminium liquid. Porosity is one the casting defect, which can occur during the process thus a vacuum environment, is required to eliminate any such possibility

With some optimized condition with speed of stirrer, number of blades, angle of blades of the stirrer and preheating the reinforcements before pouring it into the molten liquid, which ensures good wettability and proper uniform distribution, is achieved. There is advancement of mechanical properties such as strength, elastic modules, specific strength and specific modulus all is increased but ductility is decreased as ceramic reinforced are brittle in nature. Stir casting process is shown in the Fig. 1.1 the process includes an inert gas environment in order to reduce the dissolvent of atmospheric air to reduce porosity.

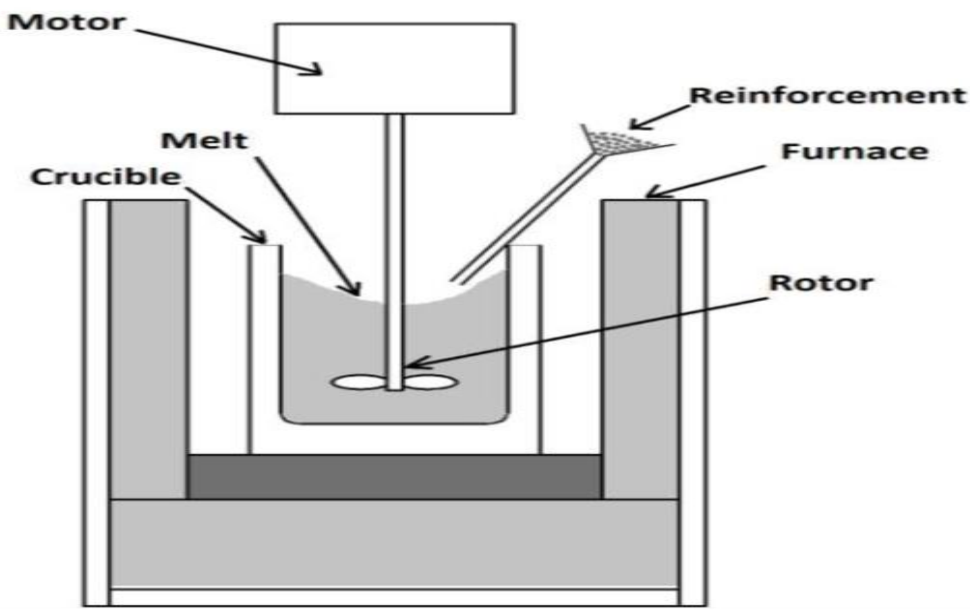

Fig. 1.1 Stir casting process

b. Infiltration process:

Liquid aluminium alloy is injected/infiltrated into the crevices of the porous preforms of continuous fibre/short fibre or whisker or particle to create AMCs. Depending on the nature of reinforcement and its volume fraction perform can be infiltrated, with or without the application of pressure or vacuum. AMCs having reinforcement volume fraction ranging from 10 to 70% can be produced using a variety of infiltration techniques. In order to retain its integrity and shape, it is often necessary to use silica and alumina based mixtures as binder. Some level of porosity and local variations in the volume fractions of the reinforcement are often noticed in the AMCs processed by infiltration technique. The process is widely used to produce aluminium matrix composites having particle/whisker/short fibre/continuous fibre as reinforcement.

1.4.2 SOLID STATE PROCESSING:

a. Powder metallurgy:

Mixing of aluminium alloy powder with ceramic fiber/whisker particle is a handy technique for the making of AMCs. Mixing can be conceded out either dry or in liquid suspension. Mixing of the mixture is often followed by the process compaction, and high temperature sintering in order to obtain the required product. PM manufactured AMCs, enclose oxide particles in the form of plate like particles of a small number of tens of microns or nm thick and in volume fractions ranging from 0.05 to 0.5 depending on powder's past and processing conditions.

b. Diffusion bonding Process:

Mono filament-reinforced AMCs are mostly manufactured by the diffusion bonding or by the evaporation of comparatively thick layers of aluminium on the surface of the fibre. Aluminium 6061 with boron fibre composites have been usually manufactured by diffusion bonding. However, the process is further generally used to produce Ti based fibre reinforced composites. The process is bulky and obtaining high fibre volume fraction and homogeneous fibre distribution is tough. The process is not fit to produce complex shapes and components.

c. Physical vapour deposition:

The process comprises uninterrupted passage of fibre through a section of high partial pressure of the metal to be deposited, where condensation takes place so as to create a relatively thick coating on the fibre. The vapour is produced by guiding a high power electron beam onto the end of a solid bar feed stock. Usual deposition rates are 5–10 μm per minute. Composite production is typically accomplished by assembling the coated fibers into a pack and fusing in a hot press or HIP operation. Composites with even distribution of fiber and volume fraction as high as 80% can be made by this technique.

In this work stir casting technique used to manufacture aluminium-alumina composite shaft although technique is the best suited technique in order to manufacture composites but it is one of the most costly process in order to manufacture it. Therefore in this project stir casting technique with some optimum conditions (speed, blade angle etc) is used in order to manufacture the aluminium composites.

1.5 VIBRATION OF ROTATING SHAFTS

When a body goes to and fro motion with respect to its equilibrium position, it is said to be vibrating. Vibration is an important phenomenon in engineering and should be checked in order to regain stability. Vibration can be classified as:

- Free Vibration
- Forced Vibration
- Damped Vibration

When a body is vibrated in to and fro motion without any external aid then its called a free vibration motion. For example a spring-mass system after giving an initial force is vibrating on its own. When an external agent is applying the force or torque to the system in order to vibrate it continuously, then such a system is known as forced vibration. And if, a dashpot damper is used with the spring-mass system in order to damped out the vibrations generated in the form if friction, then this system is called a damped out vibration system.

In the design of high speed rotating machinery, shafts are of fundamental importance. Even though the vibration of rotating shafts has attracted a great deal of attention in the past, as indicated by the rapid growth in the literature, difficulty is still encountered when shafts are required to run smoothly at high speeds. It is well known that severe vibration may occur at certain "critical" speeds and cause damage. In general, the motion of the shaft is quite complex. Thus an adequate understanding of the dynamic behavior of high speed rotating shafts is essential to the designer.

Critical speed: Unbalance exist in all the rotating machines irrespective of how much correction is done on the system as some manufacture defect is always present and thus an eccentricity is always obtained. When a shaft or rotor is rotated a certain speed is obtained at which shaft tends to bow out reaching high amplitude deflection causing it to failure of shafts thus this speed at which it behaves such is known as critical speed of shaft. Critical speed equals the natural frequency in the transverse direction.

Whirl is caused due to the following factors:

- Mass unbalance
- Gyroscopic effect

- Fluid friction across the bearing.

Thus, it becomes crucial to study about the dynamic behaviour of shaft to check and analyze the critical speed and stability of shaft at different speeds and loads correspondingly.

1.5.1 TIME DOMAIN V/S FREQUENCY DOMAIN (FFT)

Vibration's amplitude is plotted against two types of system the earlier being used as time domain and the later is in frequency domain.

In the time domain analysis the horizontal axis represents the time period of oscillation, and in frequency domain the horizontal axis is replaced by the frequency i.e. $f = \frac{1}{T}$.

In Figs. 1.2 & 1.3, it can be seen that the sin wave signal is represented as a peak in frequency domain making it easier to understand the graph interpretation.

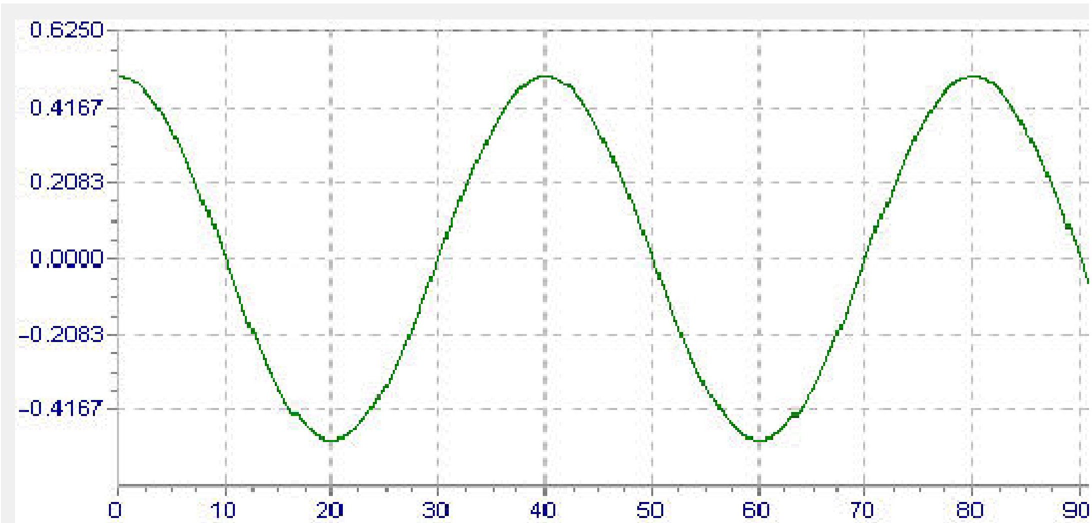

Fig.1.2 Time domain analysis [39]

Time domain is not used in condition monitoring of vibrational analysis as it includes various signals whereas FFT uses fast fourier mathematics which is a speeding process. And speeds up the plotting of the graph, in simple words FFT picks the important key points of the signal which needs focus while time domain analysis needs the whole spectrum to be checked.

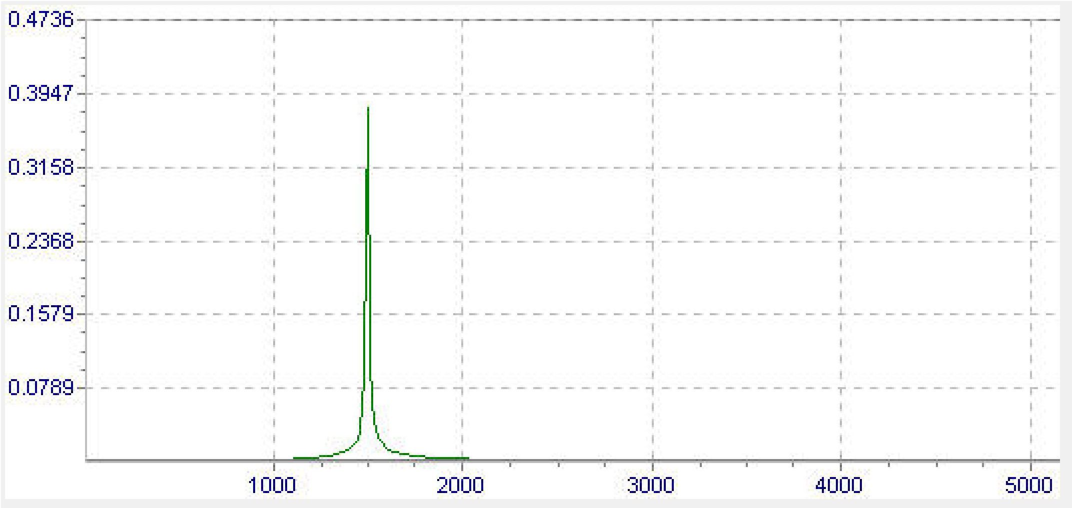

Fig.1.3 FFT analysis [39]

The main advantage of using FFT overt time spectrum is the fact that in real world certain disturbances in form of noises can also overlap in time domain hence the vibration signal of machine when measured won't give correct reading, therefore it is necessary to use frequency spectrum as it will minimize the effects of noises to a smaller amplitude as compared to the required vibration signal which will corresponds to the higher form of signal.

1.6 Organization of Thesis

The chapters of the thesis are arranged in the following manner. Chapter 1 is the introduction part and shows the basic information regarding the project description and its related terms. Chapter 2 deals with the literature review of the fabrication and vibration works of researchers in this field. Chapter 3 shows the mathematical modeling of the vibrational part and the mean field homogenization basic introduction. Chapter 4 shows the experimental set up used for vibrational analysis of the shafts. Chapter 5 discuss about the results obtained experimentally and computationally and significant error is measured in the critical frequency and damping ratio obtained. Chapter 6 provides the Conclusion of the results and the future scope of the present work.

CHAPTER 2
LITERATURE REVIEW

Rotors are an essential part of various applications and it's vibration characteristics is an important aspect which needs attention of researchers. Occasionally alloys are used to make drive shafts but recently composites are a replacement for the conventional material because of its enhanced mechanical properties, hence it is important to study about the composites fabrication and its vibrational aspects to improvise it and increase its applications. Significant amount of research has been conducted in the areas of fabrication and measurement of vibrational properties experimentally.

(Koczak et.al, 1993)[2] have discussed about the various applications & uses of metal matrix composite in industries, household & commercial sectors. Aluminium-Alumina composites are used in transmission housing & in aerospace applications due to its high specific strength (strength to density ratio) and also in making automobile driveshaft as the composite are having high specific modulus compared to its alloys. They provide a formulation too which shows with specific modulus critical speed of shaft is increased

(Elomari et. al., 1995)[3] have investigated the effect of prestraining on the elastic modulus, E, and damping capacity, tan Φ of 10 and 20 vol. % Al_2O_3 particle-reinforced composites as function of temperature using dynamic mechanical analysis. Both elastic modulus and damping capacity were found to increase with volume fraction. At 10 vol % the modulus and damping both had no effects. However, at 20 vol % it was observed that the modulus decreased with increasing prestrain but corresponding to it damping increased significantly. These results are discussed in terms of fraction of broken particles, particle size, and differential in thermal expansion between the matrix and Al_2O_3 particulate. The 20vo1% composite which showed the greatest particle damage with prestrain also had the highest damping capacity, tan Φ ~ 0.42 at 10 % prestrain. Therefore, the damping capacity measured with the DMA can be used as a sensitive indicator of microstructural damage in MMCs.

(Hashim et.al, 1999)[5] have studied about processing of metal matrix composites through stir casting technique. Various parameters such as pouring temperature, stirrer speed, size of impeller and it's position (angle) are very important parameters to reduce the defects produced during casting process & to optimize the process effectively as these can change the mechanical properties of composite. By controlling the reinforcements & using optimize condition a better composite can be obtained in a cheaper way. He even explained about how wettability is influenced by reinforcement's parameters.

(Park et. al., 2001)[7] have studied that the mechanical properties of metal matrix composites (MMCs) are critical to their potential application as structural materials. A systematic examination of the effect of particulate volume fraction on the mechanical properties of an Al_2O_3-Al MMC has been undertaken. The material used was a powder metallurgy processed Al 6061 matrix alloy reinforced with MICRAL-20TM, a polycrystalline microsphere reinforcement consisting of a mixture of alumina and mullite. The volume fraction of the reinforcement was varied systematically from 5 to 30% in 5% intervals. The 20 powder metallurgy composites were extruded then heat treated to the T6 condition. Extruded liquid metallurgy processed Al Alloy 6061 was used to establish the properties of the unreinforced material. The main purpose for producing metal matrix composites (MMCs) is to achieve light materials with high specific strength and stiffness. Of special interest in this regard are particulate reinforced metal matrix composites (PRMMCs), which possess several additional advantages. The composites had higher elastic module than the unreinforced alloy. The elastic modulus increased as particle volume fraction was increased but at a progressively decreasing rate. The decrease in the rate of stiffening with increasing particle volume fraction is attributed to an increase in the number of fractured particles present in the composites. The composites had better tensile and yield strengths than the unreinforced alloy. However, there was no significant change in strength as the particle volume fraction changed.

(Betta, 2001)[8] has used a DSP machine to compare unfaulty and faulty shaft models vibration behaviour where he find that maximum amplitude is obtained at rotating frequency itself, while he compared it with different conditions where unbalancing of shaft , misalignment between the shafts show the behaviour of vibration & amplitude with healthy conditions. Also the bearing looseness & how it produces harmonics in the FFT (Fast Fourier Transformation) graphs.

(Saiza et. al., 2003)[10] have demonstrated that the wetting behaviour and strength at aluminium/alumina interfaces is an active subject of research. Al/alumina applications include ceramic-metal composites and several applications for electronic industries. They found that in a solid-state joining, the strength of the joint increases with increasing joining temperature, whereas, in a liquid-state joining, the strength of the joint gradually decreases with increasing temperature due to the formation of unbounded areas. The highest strength reached 400 MPa when the interface was formed around the melting temperature of aluminium. An aluminium layer close to the interface became a single crystal when it was bonded to a sapphire. The combination of alumina and aluminium is well known and has many applications. For instance, a-alumina has been used in the electronic industry for many years as a ceramic insulator, whereas aluminium is one of the best electrodes, having good electric conductivity, second only to copper.

(Harsha, 2006)[11] have studied about the response of a balanced rigid rotor supported by rolling element bearings. The appearance of regions of periodic, sub harmonic and chaotic behaviour is seen to be strongly dependent on the radial internal clearance and rotor speed Poincar"e maps and frequency spectra are used to elucidate and to illustrate the diversity of the system behaviour.

(Kok, 2007)[12] have studied about the wear tested the Al 2024 –Al2O3 composite and found that wear resitance of the composite formed was much higher than the usual Al 2024 alloy which was due to Al2O3 particle properties, thus he showed that as increasing Al2O3 (10% to 30%) hardness is increased and less wear loss is observed. Some 16 microns size particle were used in the later stage the size was changed to 32 microns which had better wear resistance.

(Durai et. al., 2007)[13] have revealed that nanocrystalline materials have high potential for use in structural applications in which enhanced mechanical characteristics are required. Al–Zn/ Al_2O_3 and Al–Zn–Cu/ Al_2O_3 have been prepared via reaction sintering of partially reacted oxide mixtures derived from a high-energy ball milling process. The sintered samples had been characterized by XRD. Pin on disc type apparatus has been used for determining the wear rate. It is proposed in this study that the wear resistance of the milled composites was better than that of the unmilled composites, since Al_2O_3 particle size plays the main role in bearing the external load, and there is a good interfacial cohesion between Al_2O_3 particles and the matrix. On the basis of microscopic observations and analysis of the wear surface a change in mode of wear from mild to severe has been proposed at different loads. Mechanical milling process causes a uniform distribution of the dispersed second phase in the matrix and lowers the inter-particle distance. Milled and then sintered composites have better hardness and wear resistance than the conventional (unmilled but sintered) composites. The wear rate decreases with the sliding distance and attains a sTable value after some time for both the composites, and this is presumably owing to the subsurface hardening.

(Razavi et. al., 2007)[14] have demonstrated that densification response of aluminium powder reinforced with 5 vol.% nanometric alumina particles (35 nm) during uni axial compaction in a rigid die. The composite powder was prepared by blending and mechanical milling procedures. To determine the effect of the reinforcement nano particles on the compressibility of aluminium powder, monolithic Al powder, i.e. without the addition of alumina, was also examined. It was shown that at the early stage of compaction when the rearrangement of particles was the dominant mechanism of the densification, disintegration of the nano particle clusters and agglomerates under the applied load contributes in the densification of the composite powder prepared by blending method. As the compaction pressure increases, however, the load partitioning effect of the nano particles decreases the densification rate of the powder mixture, resulting in a lower density compared to the monolithic aluminium. It was also shown that reinforced aluminium powders. Morphological changes of the particles upon milling increase the contribution of particle rearrangement in densification whilst the plastic deformation mechanism is significantly retarded due to the work hardening effect of the milling process. Meanwhile, the distribution of alumina nano particles was improved by mechanical milling, which in fact, affects the compressibility of the composite powder.

(Zhang et. al., 2008)[15] have measured the wear resistances of alumina, alumina/silicon carbide composite and alumina/mullite composite by abrasive wear. And they studied the influence of fracture mode and worn surface pullout on wear resistance. The results are as follows: the main wear mechanisms of alumina and alumina/silicon carbide were fracture wear and plastic wear respectively, and for alumina/mullite composite, fracture wear and plastic wear mechanisms worked together. The wear resistance of the alumina/SIC composite and the alumina/mullite composite was better by a factor of 1-3 than that of the monolithic alumina. There were two main reasons for the better wear resistance which is the improved mechanical properties and the more smooth worn surfaces. However, the primary reason was the reduction of area fraction of pull out on the worn surfaces induced by fracture mode transition.

(Boukhalfa et.al, 2008)[16] have developed a p-version, hierarchical finite element was employed to define the model. A theoretical study allows the establishment of the kinetic energy and the strain energy of the shaft, necessary to the result of the equations of motion. In this model the transverse shear deformation, rotary inertia and gyroscopic effects, as well as the coupling effect due to the lamination of composite layers have been incorporated. A hierarchical beam finite element with six degrees of freedom per node was developed and used to find the natural frequencies of a rotating composite shaft.

(Sino et.al, 2017)[17] have studied the dynamic instability of an internally damped rotating composite shaft. A homogenized finite element beam model, which takes into account internal damping, is introduced and then used to evaluate natural frequencies and instability thresholds. The influence of laminate parameters: stacking sequences, fiber orientation, transversal shear effect on natural frequencies and instability thresholds of the shaft are studied. The results are compared to those obtained by using equivalent modulus beam theory (EMBT), modified EMBT and layerwise beam theory (LBT), which were used in the literature. This parametric study shows that shaft instability thresholds can be very sensitive to laminate parameters. The analysis shows that although transversal shear has a minor influence on the first frequencies, its effect was much more significant for the following ones, thereby directly influencing instability thresholds.

(Dana et.al, 2010)[19] have presented a comparison approach, from theoretical and experimental perspectives, of the CTE and the influencing factors on the thermal behaviour (e.g. manufacturing conditions, material morphology, material structure, environmental conditioning, etc.) for classes of two and multiphase polymeric composites. The samples were manufactured using self-developed technologies and were made up as a particle reinforced, fibre reinforced or particle-fibres and particle-particle combinations reinforced polymeric composites. The fillers used were different materials (metallic, ceramics) with different particle sizes and were embedded in different volume fraction, solely or in combinations into polymeric matrices. Mori-Tanaka modal is used to compare and calculate the properties in the digimat software.

(Sarina et. al., 2012)[21] have declared that the wettability of Aluminium on inclusions with particles is believed to be an important factor affecting the filtration of aluminium. To describe the wetting behaviour of the Al with ceramic at lower temperatures used in filtration and casting the metal, a semi-empirical calculation was used. It indicated that aluminium does not wet alumina around the casting temperature, but wets SiC at this temperature, so a priming height is needed for metal to infiltrate alumina. Increasing temperature also improve the wettability of Al on ceramic. Improved wetting of aluminium on ceramics with temperature is an advantage in getting molten metal to infiltrate alumina. In priming filters, it is necessary to have a metal height above the filter or to increase the temperature. However, filtration may proceed at lower temperature once the metal has entered the filter.

(Bai et.al, 2012)[22] have studied about the parts of hydro-turbine and its stability as it is often damaged and affected by the vibration and this often results in great loss. The reason of vibration is various. Based on a real machine in laboratory, ANSYS finite element software were used to model the main shaft system in the hydro-turbine generating unit. On this basis, it takes the modal analysis and calculates the critical speed of rotation. The results can provide a reference for dynamic analysis and a foundation for the design or improvement. As the order number increases, the frequency also becomes larger. From the modal map it can be seen that the sixth order's vibration is very fierce and complex. The first and the fifth order's vibrations appear to be lateral vibrations. The others left shows they includes torsional vibration. Some of the modes don't appear well, maybe it's the reason that thrust bearing is not taking into consideration. As the working speed of rotation increases, due to the gyroscopic effect, the natural frequency of the positive whirl will increase while the negative whirl decrease. When the speed of the rotation equals the angular frequency, it is the critical speed of rotation, which clearly shows on the campell diagram. From the whole solving process, gyroscopic effect should be considered when you set the options for this analysis, because it does affect the dynamic characteristic a lot. Actually, you can’t get a campbell diagram if you don’t choose the coriolis option on.

(Kanga et. al., 2013)[23] have depicted that the hardness and tensile behaviors of aluminium matrix composites reinforced with nanometric Al_2O_3 particulate have increased with the volume fraction of the reinforcement. Above 4 vol. % of Al_2O_3, however, the strengthening effect leveled off because of the clustering of Al_2O_3. The main strengthening mechanism was Orowan strengthening of effective nano-Al_2O_3 particles evenly distributed in the matrix.

(Sonawane et.al, 2013)[24] have processed Al 6061-Alumina composite using stir casting technique. He processed the composite by optimizing the conditions for uniform distribution of particles by keeping the blade at 45 degree & using four blades. For good wettability the temperature at which Aluminium should be pour is kept at 630 celsius and by preheating the mould the porosity problem is reduced somwhow and a composite with better mechanical properties is obtained.

(Gubran et. al., 2014)[28] have developed six automotive propeller shafts made of different materials. Finite element modeling based on shell element is used in the eigenvalue analysis. Shaft weights, buckling torque and dynamic performance for different design alternatives, were studied. Simulated Annealing (SA) Algorithm is used for optimization. Results showed the possibility of designing a single-piece propeller hybrid shaft made of fibre-reinfoced composite and aluminium tube having less weight compared to that of steel shaft and having its critical speed was above the shaft operating speed

(Ramnath et.al, 2014)[29] have studied the fabrication and properties of Aluminium composite with Boron Carbide particles reinforced into it. Stir Casting was used and 95% aluminium alloy was used as metal matrix wth 3% alumina & 2% Boron Carbide was used. Various test were performed on that sample which includes (tensile test, Brinell hardness test, Flexural test & impact test) to calculate the property of material which showed an improved version over the custom metal alloys.

(Babar et.al. 2014)[30] have analysed the misalignment vibrations across the shaft. Experimental studies have performed on a rotor bearing system to predict the vibration spectrum for shaft misalignment. Here accelerometer is used along with a device called as Fast Fourier Transform (F.F.T.) Analyser. Initially case of perfect aligned shaft is considered for measurement of vibration and then case of misaligned shaft is considered. The misaligned shaft vibrates and then the vibratory motion in the shaft is sensed by accelerometer at the ball bearing housing. The accelerometer sends the sensed vibration data to F.F.T. Analyser which can change the sensed data by accelerometer to meaningful data shown in the PC, such as; frequency, Amplitude, displacement and so on. The obtained experimental predictions are in agreement with the ANSYS results. Both the measured and ANSYS results spectra shows that degrees of shaft misalignment.

(Sha et. al., 2015)[31] have calculated the Macro-mechanics properties parameters of the material aiming at the question of predicting mechanics properties of long fiber reinforced metal matrix composites (MMC) shafts, two periodical arrangement of fiber. Six representative volume element models (RVE) were presented. The results are compared with that of three frequently Micro-mechanics models. On the basis, taking a low pressure turbine as study object, then the results were calculated of specified RVE model will be used in modal analysis of shafts with MMC, the numerical simulation method is used to calculate natural frequency, analyzing the influence of layers angles, thicknesses and sequences on modal and natural frequency.

(Jain et.al, 2016)[33] have investigated the nonlinear dynamic behaviour of multi cracked rotor system, which was analyzed experimentally and analytically with the considerations of the effects of the crack depth, crack location and the shaft's rotational speed. A new extension of Lagrangian method was used for analyzing the dynamic behaviour of a multi-cracked rotor system through Umbra Lagrangian formalism. The effects of crack depth on the shaft's stiffness and natural frequencies were analyzed experimentally. Natural frequencies have been obtained through vibration analyzer using impact hammer test under static conditions. It has been noticed that the stress concentration on the first crack had increased due to the presence of the second crack. Another interesting phenomenon is the influence of one crack over the other crack for mode shapes and for threshold speed limits.

(Sathishkumar et.al, 2016)[34] have investigated a study with the shaft is taken from the head stock of the lathe machine. In this analysis the shaft was connected with bearing and gear. This was the major important component to be taken into account while designing. The objective was to build a model and assemble the part files and to analyze the various stress and deformation. The part files and assembly were did by using CREO software and the analyzing was done by using a ANSYS software. The static analysis was used to analyze the stress and deformation of the shaft when it is subjected to a particular load and the modal analyze was executed to govern the vibration features (mode shapes and natural frequencies) of shaft. The results obtained by the stress analysis were found to be good agreement and modal analysis i.e., vibration characteristic like frequency and mode shapes were presented were within the limit.

(Zhang et.al, 2017)[36] have investigated the longitudinal vibration characteristics of composite drive shaft were investigated An analytical method for longitudinal vibration natural frequency was developed, and then a finite element analysis is performed to explore the longitudinal vibration behaviour of drive shaft, mainly including natural frequencies, mode shapes, and longitudinal vibration reduction. Effects of thrust bearing stiffness, fibre orientation and length-diameter ratios of composite drive shaft on its longitudinal vibration behaviour were also examined. The result shows that the first order natural frequency of composite drive shaft increases with the thrust bearing stiffness while the vibration response decreases. Increasing the fibre orientation and decreasing the length-diameter ratio can both reduce the first order frequency and the vibration response.

(Nadel et.al, 2017)[37], have studied about the driveshaft vibration and analyzed it’s vibrational characteristics along with design aspects. Conventional steel driveshaft was replaced with e-glass/ epoxy, carbon/ epoxy and hybrid composite driveshaft. In the study, shaft was designed successfully for both steel and composite driveshaft. Shaft was analyzed using FEA software ANSYS and applied to minimize the weight of shaft which was subjected to constraints such as torque transmission, buckling torque, critical speed and fundamental natural frequency. Results were compared with theoretically obtained results.

(Mula et. al, 2018)[38], have investigate on the structure of an ultrasonically cast nanocomposite of Al with 2 wt.% nano-sized Al2O3 (average size ~10 nm) dispersoids showed that the nano-composite was consisting of nearly continuous nano-alumina dispersed zones (NDZs) in the vicinity of the grain boundaries encapsulating Al2O3 depleted zones (ADZs). And they also revealed that nearly 92% increase in the hardness and ~57% increase in the tensile yield strength were obtained in the present nanocomposite, as compared to those of the commercially pure Al, cast by the non-contact ultrasonic casting method. These improvements in the hardness and tensile strength were due to the reinforcement by only 1.4 vol. % nano-sized Al_2O_3 dispersoids in the Al matrix.

CHAPTER 3
MATHEMATICAL MODELING

The following mathematical modeling technique is employed in this work. The details are given in the next sections.

3.1 CONVENTIONAL COMPOSITION PROPERTIES EVALUATION TECHNIQUE

From the basic of microstructure the mechanics of material conventional method of calculation and formulation of composite is used.

Volume Fraction,

The fiber volume fraction is used to calculate the property of the composite formed by combining two of more constituents. It is being given as,

$$V_p + V_m = V_c \tag{3.1}$$

Volume fraction being given as,

$$\frac{V_p}{V_c} + \frac{V_m}{V_c} = 1 \tag{3.2}$$

From the rule of mixture, Elastic modulus of the composite can be calculated by:

$$\mathrm{E_c V_c = E_p V_p + E_m V_m} \tag{3.3}$$

3.2 HALF-POWER BANDWIDTH TECHNIQUE

Damping is the energy dissipation properties of a material or system under cyclic stress.

The magnitude or modulus of the response is the root sum squared of both of the real and imaginary terms. The half power methodology for calculating damping is based on finding the bandwidth for each mode. The bandwidth is the outcome $\Delta\omega$ across the resonant response at the amplitude of $0.707R_{max}$. The damping value obtained is also known as hysteretic damping or complex stiffness damping. (Olmos, 2010).

The method used here is the well-known half-power bandwidth, which although strictly applicable only to lightly damped single degree of freedom systems is frequently applied to well-separated modes of multi degree of freedom systems. In Fig. 4.1 the half-power bandwidth technique is shown.

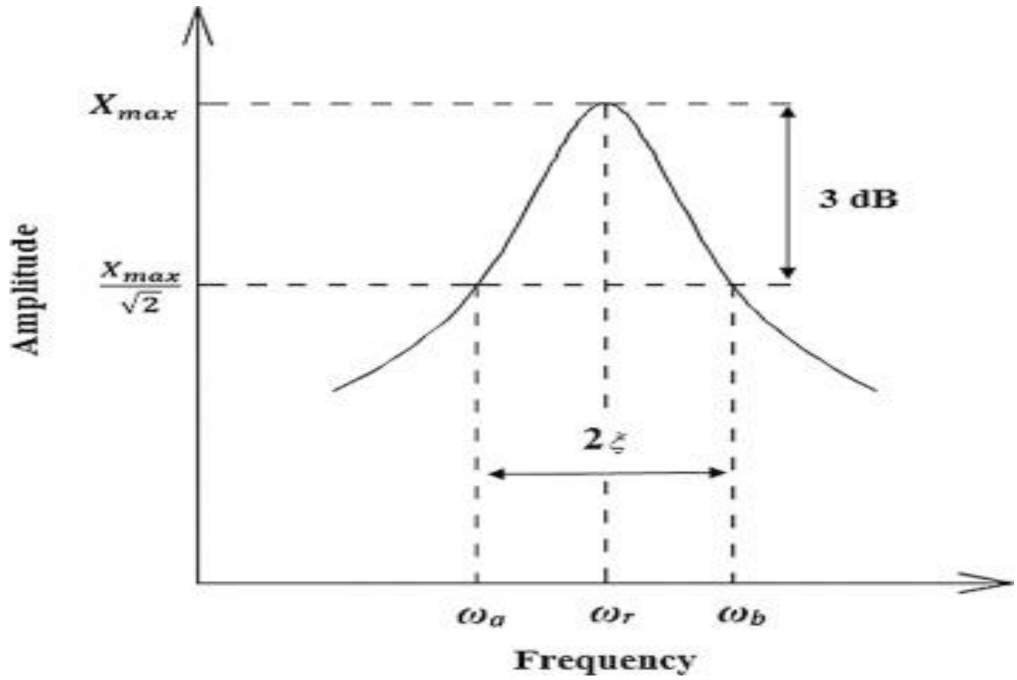

Fig. 4.1 Half-power bandwidth [40]

Damping factor can be calculated as:

Damping factor/ratio $(\xi) = \frac{\omega_b - w_a}{2 * \omega_r}$ (3.4)

It is one of the easier methods to estimate the structural damping of the material and gives accurate damping results, when the mode shape created is not so congested.

3.3 Modal Analysis

Modal testing is the utmost commonly used technique. Modal testing is an experimental procedure in which the natural frequencies of an assembly are calculated by vibrating the structure with a known excitation. While it vibrates, the structure will perform in such a way that some of the frequencies will not react at all or be highly attenuated, and some frequencies will be enlarged in such a way that the only limiting factor is the energy available to sustain the vibration. These frequencies, where the structure resonates, are the natural frequencies of the structure. Euler beam modeling is considered where shear deformation is not used.

By using Euler's Bernoulli beam theory,

$$\frac{\partial^2 \mathrm{w}}{\partial \mathrm{t}^2} + \frac{\mathrm{EI}}{\rho}\frac{\partial^4 \mathrm{w}}{\partial \mathrm{x}^4} = 0 \tag{3.5}$$

To find the solution of the equation use variable separation method,

$$(x,t) = (x)(t) \tag{3.6}$$

(x) is known as mode shape of the system (t) is time modulation

$$(x)\,\frac{\partial^2 q}{\partial t^2} + \frac{EI}{\rho}\frac{\partial^4 \varphi(\mathrm{x})}{\partial x^4}\,(t) \tag{3.7}$$

$$-\frac{EI}{\rho}\left(\frac{1}{\varphi(\mathrm{x})}\right)\left(\frac{\partial^4 \varphi(\mathrm{x})}{\partial x^4}\right) = \frac{1}{q}\left(\frac{\partial^2 q}{\partial t^2}\right) \tag{3.8}$$

$$\frac{EI}{\rho}\left(\frac{1}{\varphi(\mathrm{x})}\right)\left(\frac{\partial^4 \varphi(\mathrm{x})}{\partial x^4}\right) = \frac{1}{q}\left(\frac{\partial^2 q}{\partial t^2}\right) = -\omega^2 \tag{3.9}$$

hence

$$\frac{d^2 q}{dt^2} + \omega^2 q = 0 \tag{3.10}$$

$$\frac{\partial^4 \varphi(\mathrm{x})}{\partial x^4} - \frac{\rho\omega^2}{EI}\varphi(\mathrm{x}) = 0 \tag{3.11}$$

$$\beta^4 = \frac{\rho\omega^2}{EI} \tag{3.12}$$

$$\frac{\partial^4 \varphi(\mathrm{x})}{\partial x^4} - \beta^4 \varphi(\mathrm{x}) = 0 \tag{3.13}$$

The solution of the equation is given as ,

$$(t) = C_1 cos\omega t + C_2 sin\omega t \tag{3.14}$$

$$(x) = Asinh(\beta x) + Bcosh(\beta x) + Csin(\beta x) + Dsin(\beta x) \tag{3.15}$$

hence,

$w(x,t)= [Asinh(\beta x) + Bcosh(\beta x) + Csin(\beta x) + Dsin(\beta x)] * [C_1 cos\omega t + C_2 sin\omega t]$

Considering a simply supported beam with boundary conditions:

$w = \frac{\partial^2 w}{\partial x^2} = 0$ & $\frac{\partial^2 w}{\partial t^2}$=0 at x=0, L

Solving with the help of boundary condition we get,

$$\sinh(\beta l)\sin(\beta l) = 0 \quad (3.16)$$

Substituting this in the equation, we get

$$\frac{n\pi}{l} = \beta$$

Substituting the value to the original equation, we get

$$\omega^2 = \frac{n^2\pi^2}{l^2}\sqrt{\frac{EI}{\rho A}} \quad (3.17)$$

Thus the equation shows the analytical behaviour of natural frequency for different modes.

3.4 MEAN FIELD HOMOGENIZATION (MFH)

Homogenization techniques are often constructed on direct finite element analysis of RVE at micro scale using macroscopic values as the boundary conditions. Then computed results are returned to macro scale by averaging methods. This methodology is very accurate and gives detailed micro fields. However, exclusively for nonlinear problems, it is computationally very expensive. In addition, the creation of discrete model of RVE is also necessary. Preparation of discrete illustration of composite's microstructure can lead to added difficulties. Another method is mean field homogenization (MFH). MFH is based on analytical models and gives only approximations of the volume averages of stresses and strains, both at the macro level and in each micro phase. (Ogierman,2013).

3.4.1. MORI-TANAKA HOMOGENIZATION TECHNIQUE

Mori Tanaka Model is used to calculate the properties of composite, it assumes the average stress across the matrix with Eigenstrain values corresponding to it. (Benveniste, 1987) reformulated it so that it could be applied to composite materials. He considered anisotropic phases and ellipsoidal phases. From the uniform boundary conditions on the displacements and tractions he concluded that,

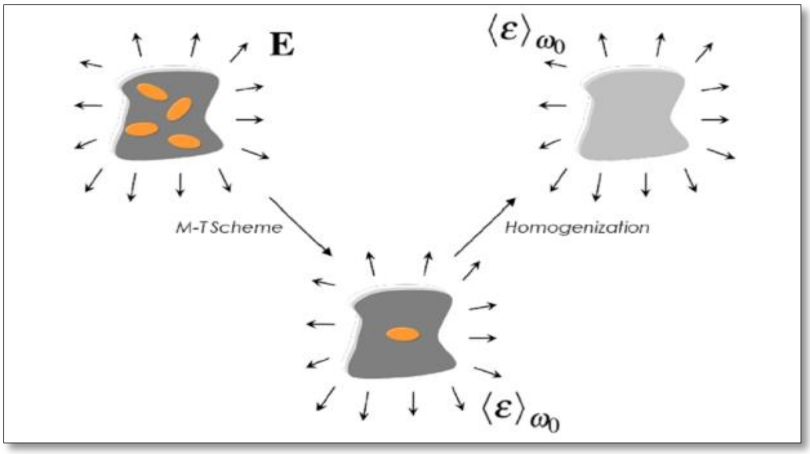

Fig. 4.2 Mori-tanaka model explanation

$q(s) = \varepsilon^0 x$ and $\sigma(s) = \sigma^0 n$

$q(s)$ *and* $\sigma(s)$ *denotes as displacements and traction vectors respectively.*

Thus now the net stiffness matrix is denoted by

$\bar{\sigma} = \bar{C} * \varepsilon$, where $\bar{C}$ is equivalent stiffness tensor.

Benvensite studied that each inclusion in the real RVE behaves as if it were isolated in the real matrix. The body is infinite and subjected to the average matrix strains in the real RVE as the far field (remote) strain. The M-T model is very successful in predicting the effective properties of two-phase composites. In theory, it is restricted to moderate volume fractions of inclusions (less than 25% say) but in practice it can give good predictions well beyond this range.

CHAPTER 4
EXPERIMENTAL SETUP

4.1 FABRICATION OF SHAFT

To conduct the vibration static and dynamic analysis two different composition shafts were prepared:

1) Aluminium 6061 alloy.
2) 8 % by volume Aluminium 6061-Alumina (ceramics) Composite.

These shafts were prepared by using the stir casting process and in order to improve the wettability of ceramic particles with molten aluminium 6061 certain optimum conditions are used which is provided by (Naher, 2003) in his computational model studied and verified these conditions for producing AMC's by stir casting are as follows:

- Preheating of ceramic particles up to 200 Celsius before reinforcing it into the liquid.
- A mechanical stirrer was used which was preheated before entering it into the mold, it was rotated at 200 rpm with its depth be at $\frac{2}{3}rd$ from the bottom of the mould.
- The stirrer consisted a 4 blade system all aligned at 45 degree to the axis.
- To reduce porosity an inert gas (argon gas) chamber was used to remove the air contact with the mixture.

Fabrication of composites through casting is a difficult process and can cause poor mechanical properties due to poor wettability and porosity which can indulged a component into a failure, yet stir casting is very economical as compared to other processes exist for manufacturing of composites.

Table 4.1 Al 6061 Composition

Element	Si	Fe	Cu	Mn	Ni	Pb	Zn	Ti	Sn	Mg	Cr	Al
Percentage	0.43	0.7	0.24	0.139	0.05	0.24	0.25	0.15	0.001	0.802	0.25	Rest

SEM images are taken for the 8% composition shaft in order to verify the particle distribution inside the Al 6061 matrix.

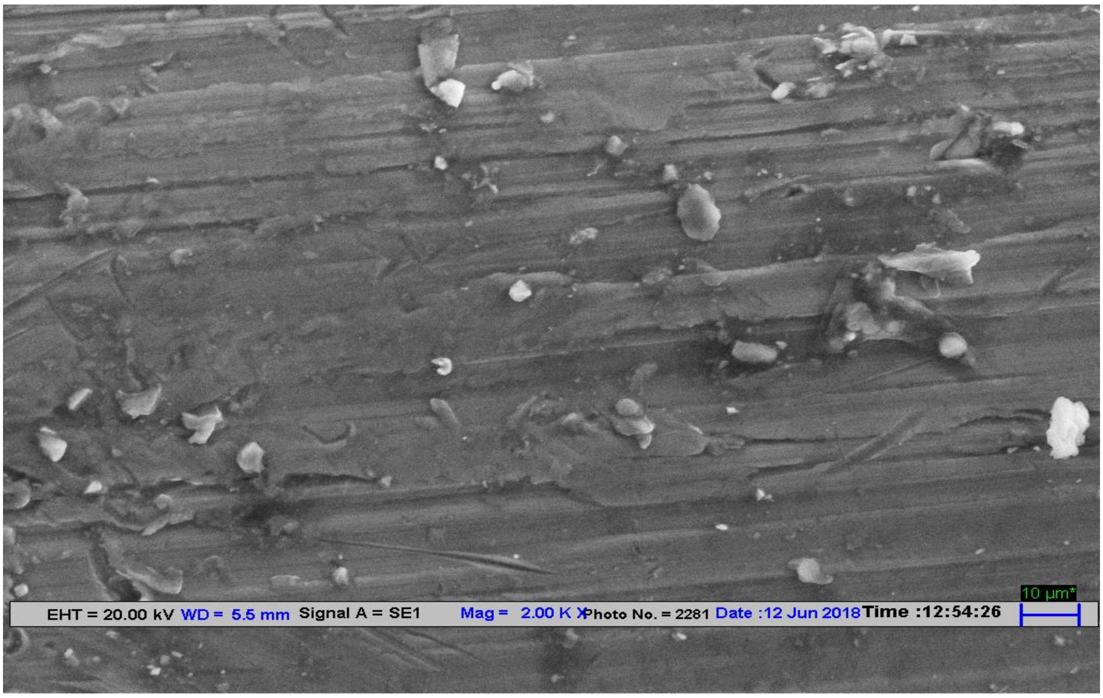

Fig. 4.1 SEM image of 8 % Al 6061 composite

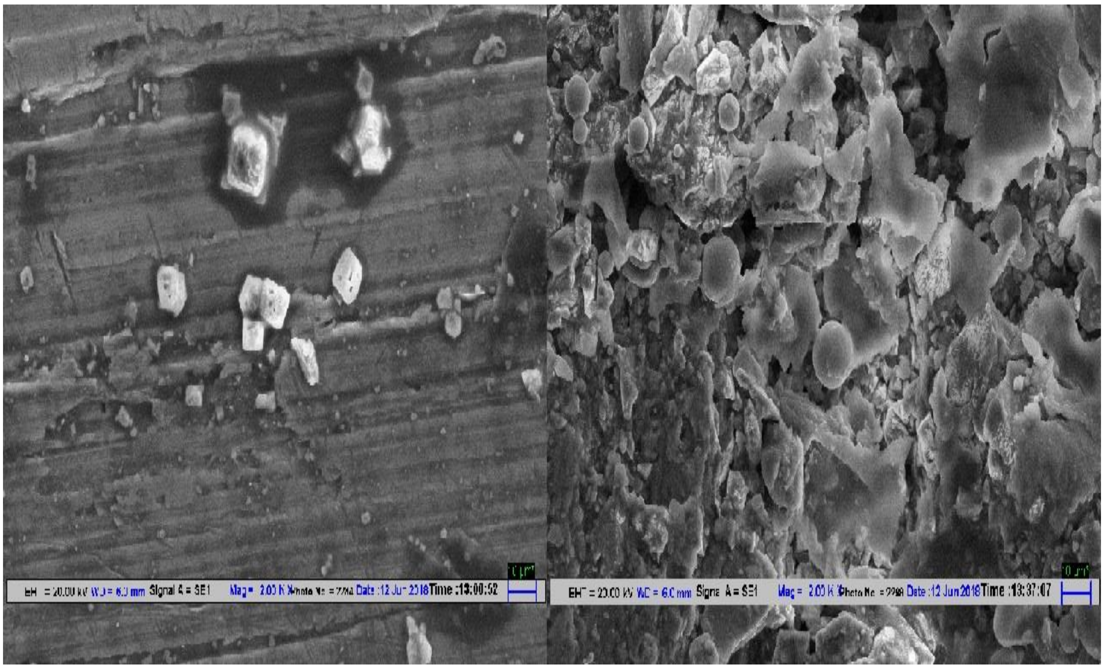

Fig. 4.2 (a) showing agglomeration of Alumina particles and (b) showing voids/porosity in between the particles

The average size of particles obtained from the SEM images is about 50µm in Fig. 4.1 and it showed some amount of agglomeration of particles at some spots, which can disturb the uniform properties of the composite formed. But due to errors in casting process some agglomeration and voids are created in the shafts as shown in the Fig. 4.2 of (a) and (b).

4.2 PREDICTION OF MECHANICAL PROPERTIES

Properties of the composite formed were tested computationally using Digimat-MF software. Digimat-MF is the Mean-Field homogenization module of Digimat which offers the capability to define the local material behavior as a function of:

1. The matrix and inclusion phases
2. The composite microstructure morphology (inclusions weight, shape and size).

The purpose of mean-field homogenization (MFH) is to compute approximate but accurate estimates of the volume averages of the stress and strain fields, both at the RVE level (macro stresses and strains) and in each phase. It is important to emphasize that MFH does not solve the RVE problem in detail, and therefore does not compute the detailed micro stress and strain fields in each phase.

There are different MFH models, each based on some specific assumptions. The simplest models are due to Voigt and Reuss. Voigt model assumes that the strain field is uniform inside the RVE. Consequently, the macro stiffness is found to be the volume average of the micro stiffness's. In the Reuss model, the stress field is assumed to be uniform in the RVE. Therefore, the macro compliance (the inverse of the stiffness) is found to be the volume average of the micro compliances. Voigt and Reuss models generalize the simple 1D model of bars in parallel, and in series, respectively. Both models are too simplistic. Indeed, assuming that strains or stresses are uniform within a composite is not realistic. Moreover, if each phase is isotropic, both models predict an isotropic composite, regardless of the shape and orientation of the inclusions, which is physically false.

4.3 STATIC AND DYNAMIC VIBRATION ANALYSIS EXPERIMENTAL SET UP

For measuring the vibration of the shaft in static and dynamic condition a data analyzer is required to be equipped with all the necessary sensors and NV Gate software which will pick up the sensors signal and to convert it into the computer language so that a FFT graph is obtained. For the study of signals OROS (vibration data analyzer) is used.

4.3.1 DATA ACQUISITION SYSTEM

For the capturing of data OROS OR36 (4-16 channels) modulator multi analyzer/recorder as shown in Fig. 4.3 is used. This is a dedicated and advanced version of data acquisition technique available for practical purposes in R&D and testing. Data can be stored in the PC or the hard drive memory of OROS. Speed of the motor is measured using a tachometer.

Fig. 4.3 OROS 36 Vibration analyzer

4.3.2 PROXIMITY SENSORS

Non-contact proximity sensors/ displacement sensors are used to measure the distance of the object across a gap. It is used for static impact testing for measuring the vibration amplitudes across the shaft. LJ12A3-4-Z /BY model was used with a maximum distance of 4mm that can be measured. In the static analysis proximity sensors are used to measure the displacement form. Sensors are kept at the middle of the shaft as the maximum displacement occurs at the middle between the bearing length. It is cheaper in cost and with its sensitivity it can measure small variations too with a good accuracy.

Fig. 4.4 LJ12A3-4-Z /BY proximity sensor

4.3.3 ACCELEROMETER SENSOR

This transducer is used to measure the amplitude of vibration signal of shaft. It is placed on the z direction of the bearing housing.PCB-78534 accelerometer is used in the experiment whose sensitivity is 0.01 v/g. In the dynamic analysis accelerometer is used over the bearings to measure the acceleration signals of dynamics over a specified speed.

Fig. 4.5 PCB-78534 Accelerometer

4.3.4 IMPACT HAMMER

Impact hammer shown in the Fig. 4.6 is used to apply a sudden load on the shaft to displace its position. It is basically used in static analysis where the calculation of damping ratio using different solution technique.

Rubber made tip is used which helps to soften the impact onto the shaft.

Fig. 4.6 Impact hammer

These all sensors are used in the experiment set up which are connected in the input channel section of OROS analyzer and then the OROS is connected to the PC where NV Gate software investigates the signals received from the analyzer. FFT graph is used over time domain as it separates the noise or harmonics signals against the true required vibration signals making it easier to study the analysis. Static analysis is carried out to find the static vibration characteristics such as damping ratio of the shafts by the half power bandwidth method which is an approximate method by applying a constant force in transverse direction for both the shafts and then measuring the FFT through proximity sensors, whereas dynamic characteristics of the shafts, it is rotated at certain speed to compare the parent metal and the composite shaft's acceleration.

Thus the vibrational analysis is carried out in such a way and comparison is made statically and dynamically for both the shafts.

Table 4.2 Parameters of specimen used

Parameter	Value
Length of shaft	1000 mm
Length of shaft between bearings	660 mm
Diameter of shaft	22 mm
Internal damping coefficient of shaft	0.0003 N s m^{-1}
Speed of shaft	500 rpm
SKF 1204 ET N9 Bearings	2

Two SKF 1204 ET N9 bearings are used to support the shaft rotation and their specification is mentioned in Table no. 4.3.

Table 4.3 Specification of SKF 1204 ETN9 bearing

Parameter	Value
Outer diameter of bearing (R_o)	47 mm
Inner diameter of bearing (R_i)	20 mm
Width of the bearing	14 mm
Number of balls	12

Bearing vibrations are also considered in the experiment which produces harmonics across the range of frequency. It is known as varying compliance frequency which adds in the frequency of shaft. Lubrication of bearing and tight coupling between the DC motor and the shaft is made using the spider coupling.

At first static test was conducted at 52.4 Kb/samples rate and then dynamic analysis was conducted by rotating the shaft at 500 rpm and after it is stabilized at dynamic condition the measurement of FRF was taken by the accelerometer sensor The test is performed several times in order to reach the accuracy as for impact test a constant similar force was required to make a comparison between the static conditions of both the shaft. The shaft is prepared according to the ASTM conditions.

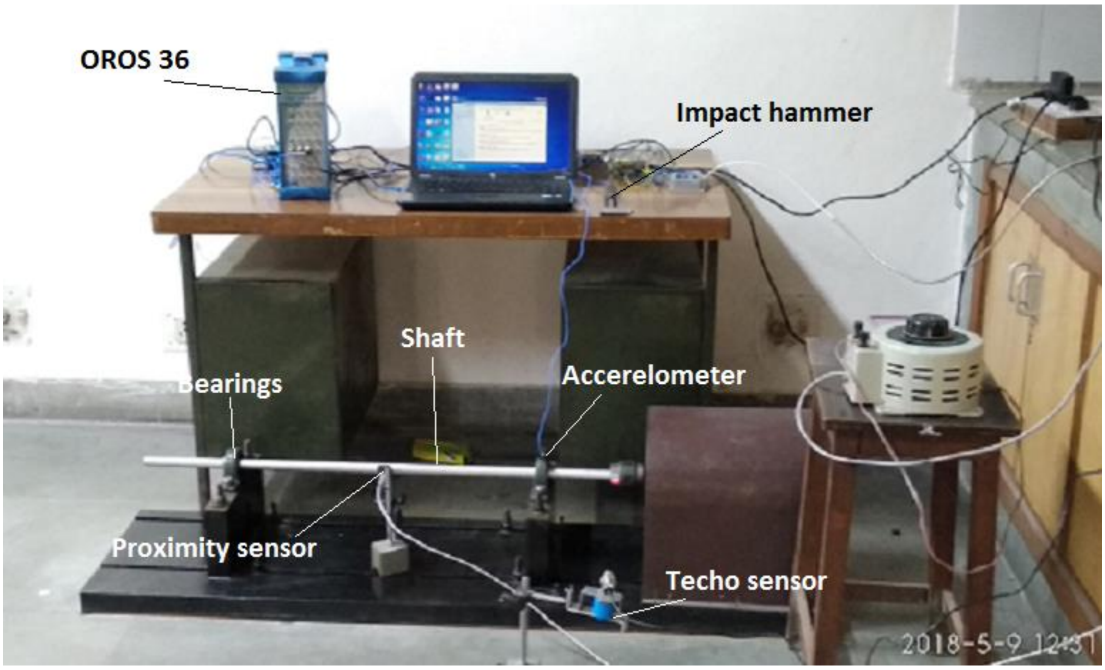

Fig. 4.7 Experimental Test Set Up

In the Fig 4.7 the experimental set up consisting of motor, a flexible coupling with sensors to measure the signal is presented. FRF response is captured by the analyzer and the results are generated using the Fast Fourier transformations, further the results are computationally compared with Ansys software output where modal analysis using the finite element method with fine meshing is done on the two different shafts to draw out a comparison between the two.

Static and dynamic Analysis is carried out on the system and response of the shaft is measured along with the sensors output, Vibration can be measured in Time-domain wavelet form or in Fast Fourier transform form, here FFT is used as it distinguishes with the harmonics with the actual peak of the response in observed. A comparison is captured for the two shafts and characteristics for vibrations are calculated.

The next chapter will present results and discussions.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 MECHANICAL PROPERTIES OF AL-AL2O3 COMPOSITE USING DIGIMAT-MF

Digimat MF software is used to calculate the properties of the 8% composite computationally. The properties obtained are being used to calculate the critical speed of the shaft for both Al 6061 and Al 6061 composite.

Table 5.1 Comparison of specific modulus of both the shafts

Material	E	ρ	E/ρ (10^6)
Al 6061	70 GPa	2700 Kg/m^3	25.9259
8 % Al 6061-Al_2O_3	77.66 GPa	2796 Kg/m^3	27.77539

Percentage increase in specific modulus = $\frac{27.77539-25.9259}{25.9259}$*100 = 7.133%

Thus we can see that the Al 6061 composite tends to have higher specific modulus ($\frac{E}{\rho}$) ratio which will increase its vibrational and stiffness capacity and will make it better than the Aluminium based alloys.

5.2 VIBRATIONAL CHARACTERISTICS OF THE SHAFTS

5.2.1 STATIC VIBRATION ANALYSIS

Impact hammer test is conducted to calculate the damping characteristics of the shafts. An FRF response is plotted showing (displacement v/s frequency) graph where peak amplitude is obtained. Using the half-power bandwidth technique to approximately calculate the damping ratio of the shafts. Figs. 5.1 & 5.2 shows the FRF of Al 6061 and 8% Al 6061-Alumina composite.

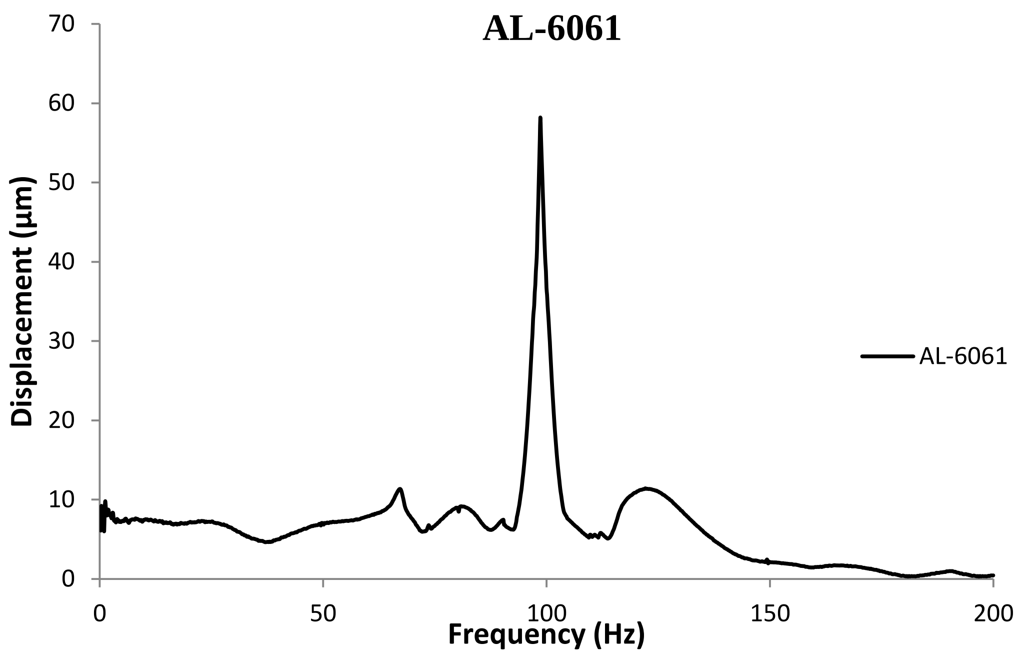

Fig. 5.1 Al 6061 FRF response

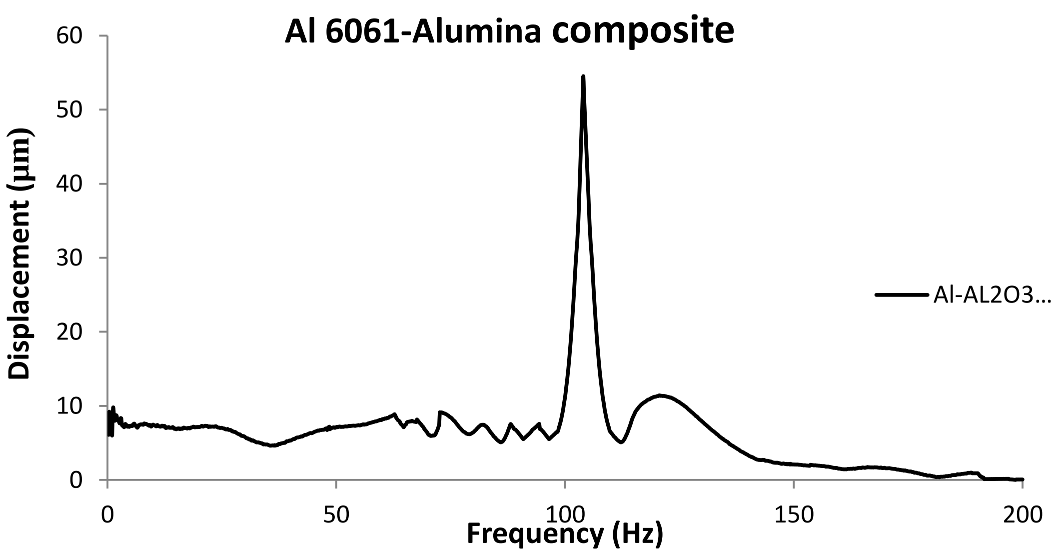

Fig. 5.2 Al 6061-Alumina composite FRF response

For a constant force, hammer is struck in between the bearings of the shaft transversely to develop vibration across the shaft. The displacement sensors placed in the middle of the shaft to sense the displacement produced due to vibration.

5.2.2 CALCULATION OF DAMPING PROPERTY USING HALF POWER BANDWIDTH

To calculate damping ratio characteristic of the shafts the formula of half power bandwidth which approximates the solution is used. The FRF response plot obtained from the experiment is calculated by knowing the maximum amplitude obtained and then dividing the corresponding amplitude by $\sqrt{2}$ to obtain the corresponding two frequencies, thus the formula calculated as:

$$\text{Damping factor/ratio } (\xi) = \frac{F_2 - F_1}{2 * F_{max}} \quad (5.1)$$

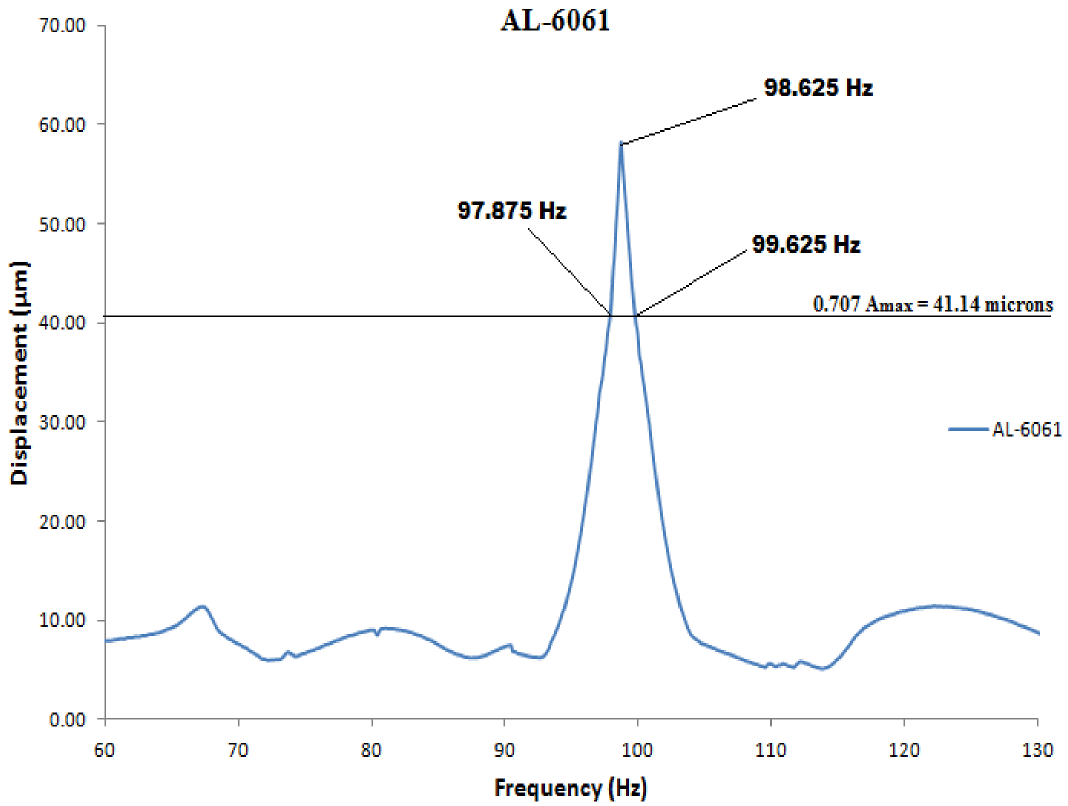

Fig. 5.3 Half power bandwidth explanation on Al 6061

Fig. 5.3 shows the half power bandwidth theorem for Al 6061 impact hammer test at a given force to calculate damping ratio. Similarly for the composite shaft we can calculate the damping ratio by calculating the following and using the equation 5.1

F_{max} = Frequency at maximimum amplitude

F_2, F_1 = Frequency at $0.707A_{max}$

Table 5.2 Half power bandwidth formulation

Material	A_{max}	$A_{max}/\sqrt{2}$	F_1	F_2	F_{max}	ξ
Al-6061	58.2µm	41.14µm	97.875Hz	99.625Hz	98.625Hz	0.008871
8%Al-6061-Al_2O_3	54.51µm	38.51µm	103.125Hz	105.125Hz	104Hz	0.009615

% increase in the damping characteristics = $\frac{0.0096153 - 0.008871}{0.008871}$*100 = 8.39%

Thus experimentally, the composite's static characteristics show 8.39% increment in damping ratio over the conventional aluminium alloy Al 6061.

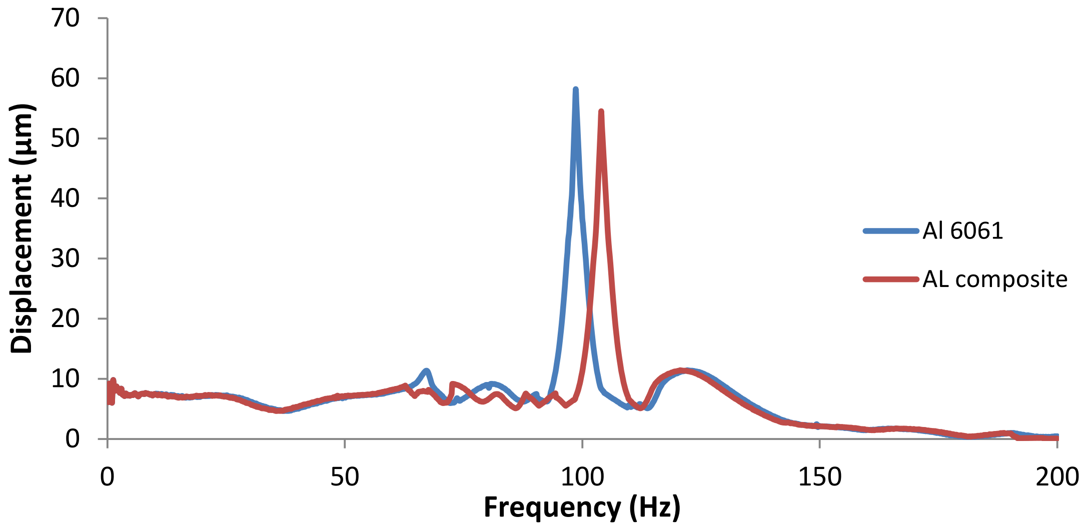

Fig. 5.4 shows the comparison of natural frequency of Al 6061 and Al 6061 composite

5.3.3 Dynamic Analysis of Shafts

With the set up consisting accelerometer, techo sensor and motor. The two shafts are rotated at 500 rpm and the readings are taken for the FRF response of both the shafts after stability of the system is achieved. A comparison is made between the two rotors to study about the fact that dynamically the 8% composite shaft is much stiffer as compared to the Al 6061 alloy shaft as it is showing less amplitude for the same rotational speed X.(Betta, 2002)

Fig. 5.5 shows the acceleration v/s frequency FRF response of shafts many harmonics and sub harmonics can be seen like a slight harmonic peak at 3VC value of bearing. These harmonics are developed due to random errors which cannot be eliminated easily as there are form errors in bearing parts which develop a bearing frequency which cannot be eliminated from the response results.

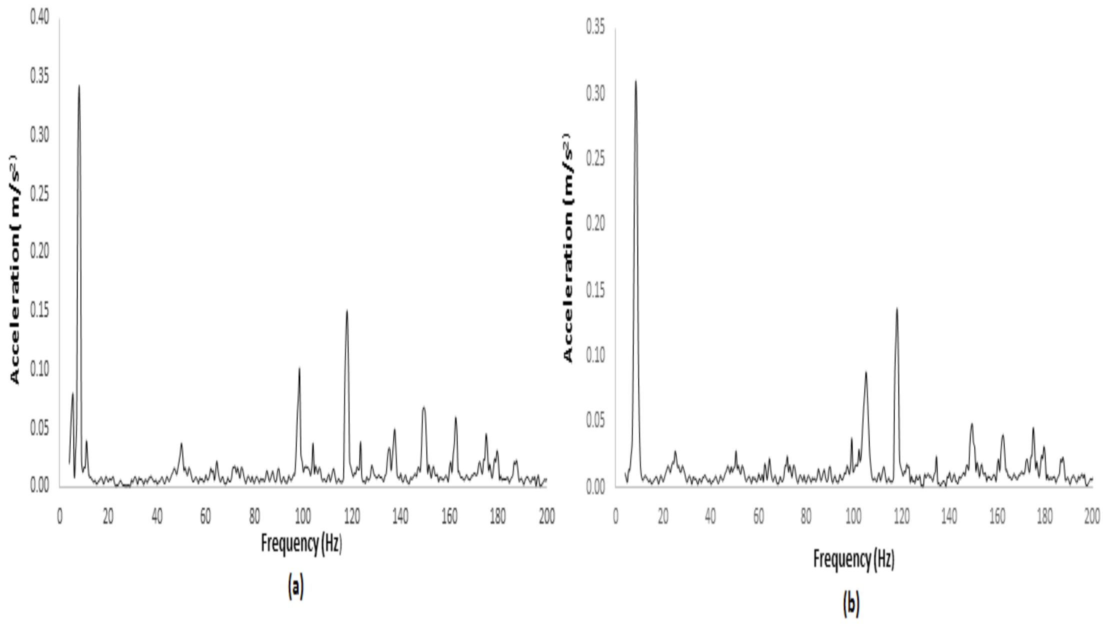

Fig. 5.5 Dynamic analysis of shaft showing (a) Al 6061 (b) Al 6061 composite

5.2.4 VARYING COMPLIANCE FREQUENCY OF BEARINGS

When the rolling elements are rotated in the cage which is in contact with the shaft an exciting frequency is generated across the bearing due to looseness of joining, deformation etc. in the bearing which travels through the outer race of bearing and is sensed by the sensors. These harmonics do include in the FRF of dynamic measurement of shafts and is included in the response of the shafts.

The characteristics frequencies are termed as varying compliance frequency (VC) are produced due to looseness in the outer race or with the inner race for shaft. The formulation of bearing depends on the rotating speed of shaft and the outer and inner radius of the bearing used. Thus VC produces harmonics in the result which is difficult to eliminate completely but can be reduced.

The varying compliance for a bearing is given as (Nguyen, 2015).

$$\text{VC} = \omega_{cage} * N_b \quad (5.2)$$

$$\omega_{cage} = \omega * \frac{R_i}{R_i + R_o} \quad (5.3)$$

From the Table 4.3 we can calculate the VC, and the following mode of VC is obtained as shown in Table 5.3.

Table 5.3 Rotational and varying compliance frequency at 500 rpm

Speed (RPM)	Frequency (Hz)	Varying Compliance (Hz)	3VC (Hz)
500	8.33	39.5791	118.7375

5.2.5 CRITICAL SPEED OF SHAFT

Critical speed or whirling speed of a rotating shaft depends on the property of material being used. When a certain speed is reached when the shaft starts to vibrate vigorously in the transverse direction, such a speed achieved is knows as critical speed of shaft where it becomes dynamically unstable.

$$N_c = \frac{60*\pi}{2\pi^2 * l^2} * \sqrt{\frac{EI}{\rho A}} \quad (5.4)$$

Table 5.4 comparison of Acceleration data of two shafts

Material	Acceleration (m/s^2) at X	Acceleration(m/s^2) at 3 VC
AL 6061	0.343	0.1503
AL 6061-Alumina	0.31	0.136

From the Table 5.4 it can be seen that the amplitude is decreased both for X and at 3VC which must be due to damping properties of composite and higher stiffness of the shaft and mass which will provide a higher reaction force on bearing making it less to deform and tightens the contact with the shaft.

5.3 FEM Modal Analysis of Shafts on Ansys

Experimental analysis of both the shafts has been done and static as well as dynamic property is analyzed and critical speed with damping ratios is calculated. It is seen that the Aluminium matrix composites have developed better mechanical properties as compared to the parent alloy.

Modal analysis is carried out on both the shafts to see the mode shapes and vibrational characteristic being obtained through computational method and compare it with analytically, experimentally and computationally all together. Different modal frequencies are obtained through Ansys. Damped analysis of shaft along with bearing is considered where stiffness and damping capacitance of SKF bearing considered.

5.3.1 Ansys modal analysis of Al-6061 and Al 6061 composite

Speed of rotation of shaft is provided on a end at 7000 rpm, bearing properties are given in the analysis part with fine sweep meshing of shaft mode shape and Campbell diagram is obtained to find the stability of the shaft.

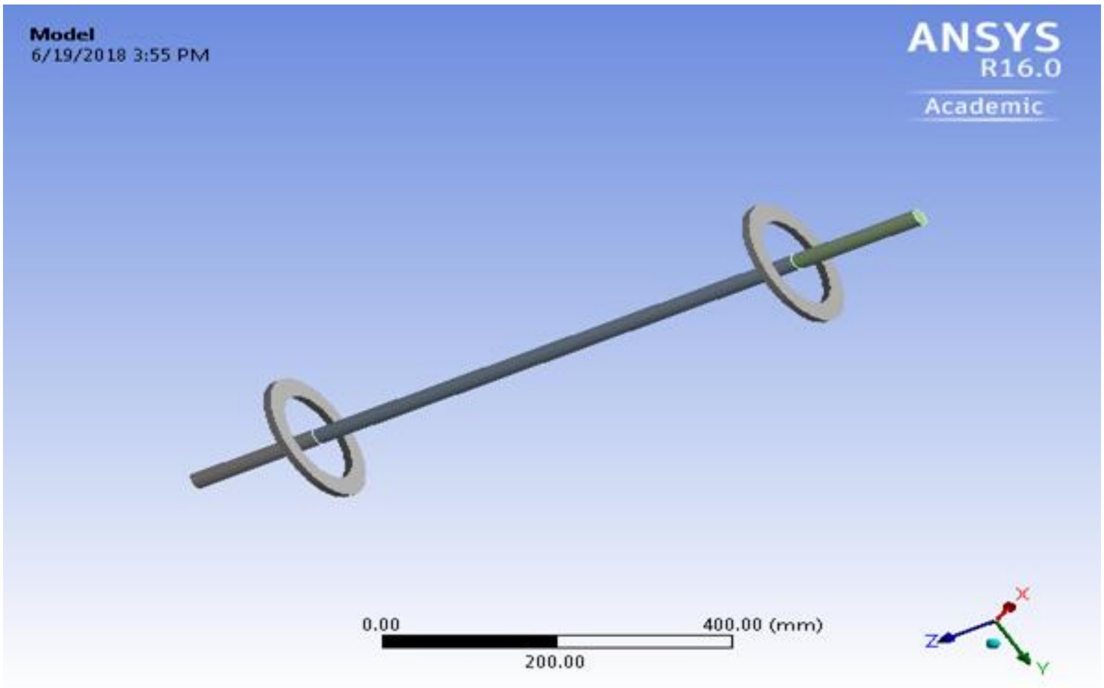

Fig. 5.6 Ansys modal Al 6061 shaft with bearings

The mode shape obtained for both the shafts are shown in Figs. 5.7 & 5.8 .At high speed (keeping the speed constant) it can be seen that the maximum amplitude is lower for the composite as compared to the conventional alloy, this is due to the high torsional stiffness being obtained by the alumina particle and better damping property of the shaft which improves the vibrational characteristics.

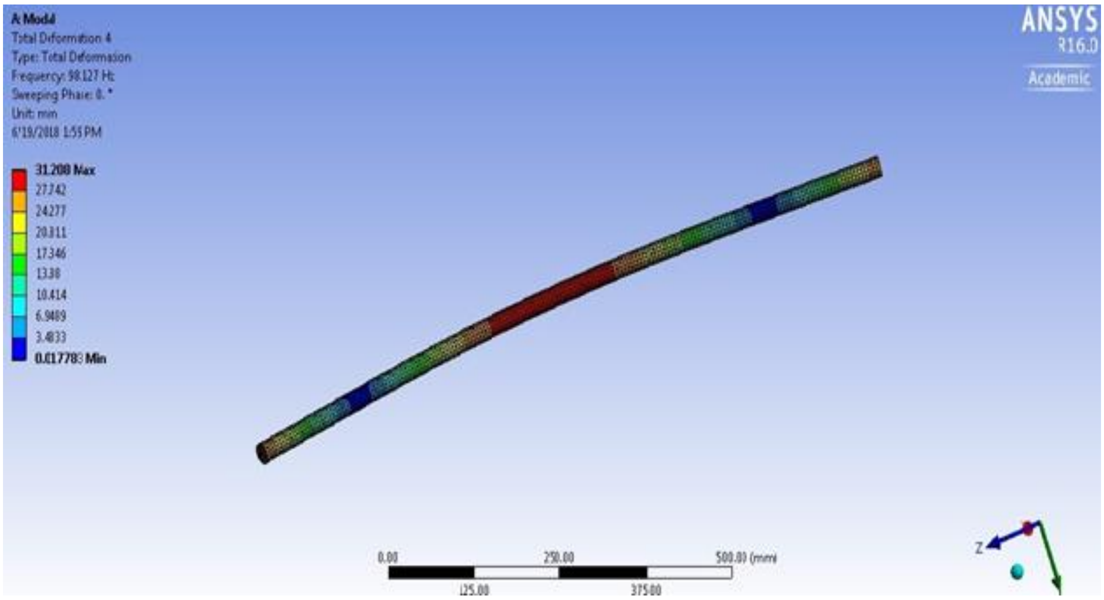

Fig. 5.7 Mode shape of Al 6061

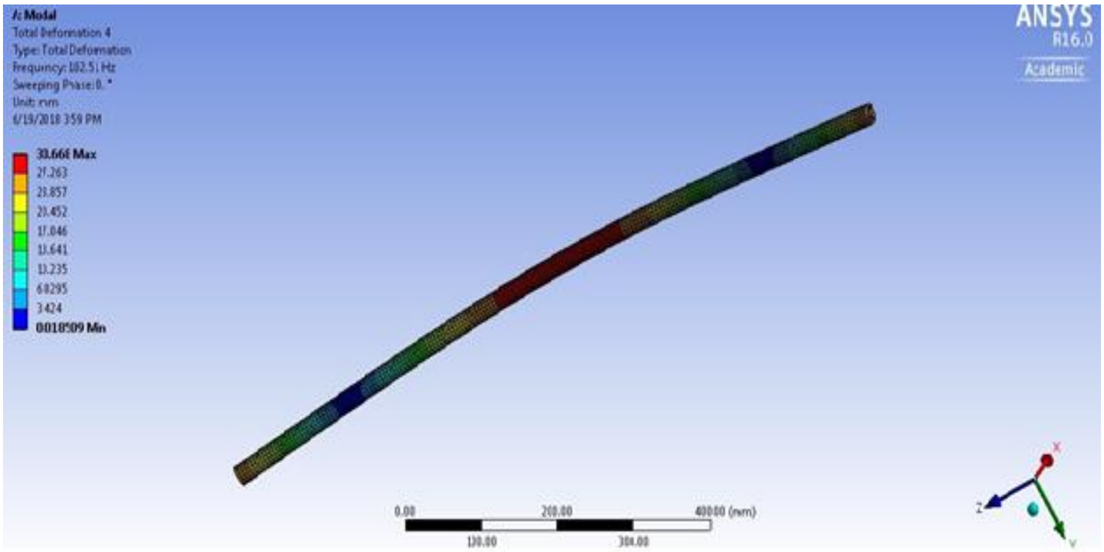

Fig. 5.8 Mode shape of Al 6061-Aumina composite

For a typical frequency the mode shape with amplitude shows that the composite being displaced slightly less than the parent alloy, which is due to the better damping property of the composite and the higher stiffness of the composite shaft.

Table 5.5 Comparison of Vibrational characteristics analytically, experimentally & computationally

Material	Analytical N_c (Hz)	Experimental N_c (Hz)	Computational N_c
Al 6061	100.94	98.625	98.702 Hz
Al 6061 composite	105.01	104	102.51 Hz

Error in experimental, computational and analytical model for natural frequency is shown in the Table 5.6 while error percentage for damping ratio in between the experimentally obtained value and computationally obtained is compared for both the shafts and shown is in the table no. 5.7.

Table 5.6 percentage error in natural frequency

Material	% error between experimental and analytical (N_c)	% error between experimental and computational (N_c)
AL 6061	2.2934	0.078
AL 6061 composite	0.96098	1.4326

Table 5.7 Experimental and computational damping factor

Material	Experimental Damping (ξ)	Ansys Damping (ξ)	Percentage Error (%)
AL 6061	0.008871	0.0091569	3.22
AL 6061 composite	0.0096153	0.009527	0.9183

5.3.2 Campbell diagram for Al 6061 & Al 6061 composite

When the body vibrates, it follows a particular pattern movement for a particular natural frequency and this pattern formed is called as mode shape. Mode shapes helps to determine and visualize the displacement of shaft at its natural frequencies.

Campbell diagram represents the critical frequency as a function of rotation of shaft. It shows the relationship between the system frequencies with the excitation frequency at which the shaft is rotated, the natural frequency is plotted on the y-axis and the excitation speed is plotted in the x-axis direction. It consists of different eigen modes of frequency with gyroscopic effect being included in the analysis. At 0 to 7000 rpm, the Campbell diagram is plotted for both the shafts as shown in the fig. 5.9 which shows the natural frequency with the speed of the shaft where a resonance condition is obtained to show the natural frequencies of the rotor. Different modes were obtained and bearing property with stiffness and damping are used in the process with damped analysis which shows that forward whirl increases with increase in the rotating speed while backward whirl is decreased with increase in speed.

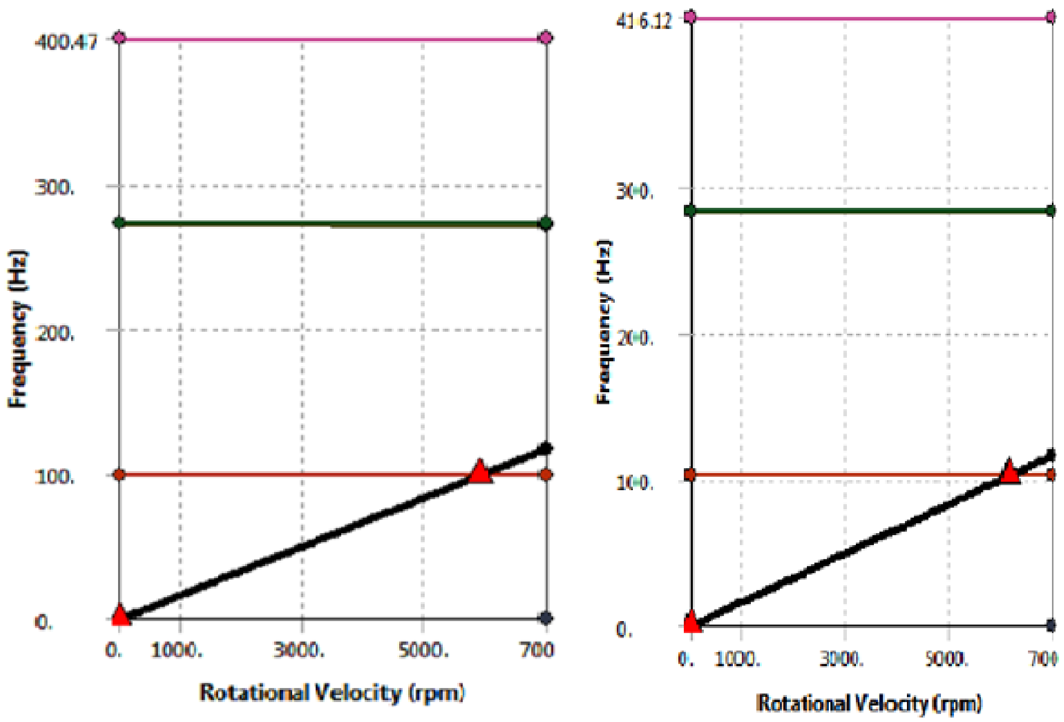

Fig. 5.9 shows the Campbell diagram of Frequency v/s Rotation speed for (a) Al 6061 & (b) Al 6061 composite

Certain eigenmodes are generated where all the members of the shaft give the same sinusoidal frequency known as eigen frequencies at which either the amplitude increases or decreases and thus the description of the amplitude of the various parts is known as mode shape.

In the Table 5.8, while computational method obtained different frequency modes, some of the modes and its corresponding critical speed is shown for both the shafts and it can be seen that the overall effect is increased in the composite shaft as compare to Al 6061 shaft making it firm that the vibration characteristics has been improved with increase in alumina percentage.

Table 5.8 Different Frequency modes obtained

Frequency Modes	**Al 6061**	**Al 6061-Alumina**
1	98.702 Hz	102.68 Hz
2	272.72 Hz	283.64 Hz
3	400.47 Hz	416.12 Hz

Thus the respective campbell diagram with different modes represents that the inclusion of alumina particles into the Alumiium 6061 alloy improves the dynamic vibrational property of the overall composite which makes it healthy to use against the conventional alloys in the driveshaft system.

CHAPTER 6
CONCLUSIONS AND FUTURE SCOPE

6.1 CONCLUSIONS

In the present work, a comparison is being made between two different rotors with one of the shaft being a composite. Shafts are generally used in various applications and it provides an opportunity to study about its behaviour and characteristics in order to avoid any catastrophic failures.

Different composition of shaft with different mechanical properties produce different FFT response for both the shafts, the composite shaft showed better vibrational properties in both static and dynamic condition.

- Fabrication of AMC by stir casting process is cost effective as compared to powder metallurgy and with using optimum conditions for reinforcements and stirrer a better quality product could be fabricated, yet the porosity issues remain a concern.
- There is an increase in the damping factor (ξ) for the $Al_{6061} - Al_2 0_3$ composite shaft by 8.39 % which is not only due to intrinsic damping of material but also improves due to friction of the bonded and non-bonded reinforcements around the aluminium matrix.
- Dynamic characteristic of both the shafts shows that at same exciting frequency the amplitude of composite is less than the $Al\ 6061\ alloy$ which is due to better damping property, higher stiffness and specific modulus of the composite shaft as an improved natural frequency is obtained, also for bearing varying compliance (3VC) the amplitude is decreased as stiffness of shaft is increased as well as load on the bearings is slightly increased as mass of shaft is increased. (Sunnersjot, 1978).
- Ansys modal analysis of the shafts with bearing effects shows the Campbell diagram for different mode shapes computationally verifies the experimental analysis of the shaft thus showing an improvement in critical speed of shaft in the composites.

6.2 FUTURE SCOPE

- A thorough research is available on Carbon/graphite epoxy polymer composite shaft but metal matrix composite rotors are the field yet to be explored.
- In metal matrix composites vibration analysis is done on plates but rotors behavior are still to be investigated. An exhaustive study is required to be done to observe the effect of reinforcements on the vibrational characteristics of these rotors.
- Vibration theories related to aluminium composites with SiC particle reinforcements are present but no work with alumina particles has been done.
- In future the aluminium-alumina composite shafts can be studied for its dynamic behaviour with load carrying applications such as rotors, gears etc. to replace the conventional shafts with composites with varying the volumetric percentage of reinforcements.

REFERENCES

[1]. Sunnersjot, “Varying compliance vibrations of rolling bearings”, Journal of sound and vibration, vol. 58, no.3, pp. 363-373, 1978.

[2]. C. S. Khatri, E. J. Allison, G. B. Michael, J. Koczak, “Metal-matrix composites for ground vehicle, aerospace, and industrial applications”, Fundamentals of metal matrix composites book, vol. 1, pp. 297-326, 1993.

[3]. J. Masounave, M.D. Skibo, R. Boukhili, S. Elomari, “Dynamic mechanical analysis of prestrained Al_2O_3/Al metal-matrix composite”, Journal of materials science, vol. 30, no. 12, pp. 3037-3034, June 1995.

[4]. J. Eliasson and R. Sandström, "Applications of Aluminium Matrix Composites", Key engineering materials, vol. 104-107, pp. 3-36, 1995.

[5]. J. Hashim, L. Looney, M.S.J. Hashmi, “Metal matrix composites: production by the stir casting method”, Journal of materials processing technology, vol. 92-93, pp. 1-7, August 1999

[6]. B. Muryama, “Progress and promise in aluminium composites metal Progress”, AMPTIAC News Lett., vol. 155, no. 6, pp. 47-50, 1999.

[7]. A.G. Crosky, A.K. Hellier, B.G. Park, “Material characterisation and mechanical properties of Al2O3-Al metal matrix composites”, Journal of materials science, vol. 36, no.1, pp. 2417-2426, April 2001.

[8]. A. Paolillo, A. Pietrosanto, C. Liguori, G. Betta, “A DSP-based FFT-analyzer for the fault diagnosis of rotating machine based on vibration analysis”, IEEE Transactions on instrumentation and measurement, vol. 1, pp.572-577,June 2001.

[9]. D. Brabazon, L. Looney, S. Naher, “Simulation of the stir casting process”, Journal of materials processing technology, vol. 143-144, pp. 567-581, 2003.

[10]. A. Tomsiaa, E. Saiza. K. Suganuma., “Wetting and strength issues at Al/α–alumina interfaces”, Journal of the european ceramic society, vol. 23, pp. 2787–2796, Aug. 2003.

[11]. S.P. Harsha , "The effect of speed of balanced rotor on nonlinear vibrations associated with ball bearings", Mechanism and machine theory, vol. 41, no. 6, pp. 688-706, June 2006.

[12]. K. Ozdin, M. Kok , "Wear resistance of aluminium alloy and its composites reinforced by Al_2O_3 particles", Journal of materials processing technology, vol. 183,no. 2-3, pp. 301-309, March 2007.

[13]. K. Das, S. Das, T. Durai., "Wear behaviour of nano structured Al (Zn)/Al_2O_3 and Al (Zn)–4Cu/Al_2O_3 composite materials synthesized by mechanical and thermal process", Materials science and engineering , vol. 4, pp. 88–94, 2007.

[14]. A. Simchi, H.R. Hafizpour, Z.R. Hesabi, "An investigation on the compressibility of aluminium/nano-alumina composite powder prepared by blending and mechanical milling", Materials science and engineering, vol. 454-455, pp. 89-98, April 2007.

[15]. F.C. Zhang, H.H. Luo, R.I. Tod , S.G. Roberts, T.S. Wang , "Influence factors on wear resistance of two alumina matrix composites", International journal on the science and technology of friction, lubrication and wear, vol. 265, no. 1, pp. 27-33, June 2008.

[16]. A. Hadjoui , Boukhalfa, S.M. Hamza Cherif, "Free Vibration analysis of a rotating composite shaft using the *p*-version of the finite element method", International journal of rotating machinery, vol. 2008, pp. 1-10, Nov 2008.

[17]. E. Chatelet, G. Jacquet , R. Sino, Thouraya Baranger, "Dynamic analysis of a rotating composite shaft", Composites science and technology, vol. 68, no.2, pp. 337-345,Feb. 2008.

[18]. E. Amalina, S. B. Ku, M. Nazrir, "Effect of weight percentage of Silicon carbide (SiC) reinforcement particles on mechanical behaviour of aluminium metal matrix composite". CA: University Malaysia Pahang, Nov. 2008.

[19]. C. Vasile, M.L. Dana, "Predicting, measuring and tailoring thermal properties of morphological and structural modified polymeric composite materials", Engineering the future, pp. 1-18, Nov. 2010.

[20]. A. Bertha, J.M. Roesset, Olmos, “Evaluation of the half-power bandwidth method to estimate damping in systems without real modes”, Earthquake engineering and structural dynamics, vol. 39, pp. 1671-1686, May 2010.

[21]. A. Kvithyld, B. Sarina, M. Tangstad, T. Engh, T. Kai, “Wetting of pure aluminium on graphite, SiC and Al2O3 in aluminium filtration”, Transactions of nonferrous metals society of china, vol. 2, no. 8, pp. 1930-1938, Aug. 2012.

[22]. B. Bai, C. Liu, L. Zhang, T. Guo, “Analysis of dynamic characteristics of the main shaft system in a hydro-turbine based on ANSYS”, Procedia engineering, vol. 31, pp. 654-658, June 2012.

[23]. S. Chan, Y. Kanga., “Tensile properties of nanometric Al_2O_3 particulate-reinforced aluminium matrix composites”, Materials chemistry and physics, vol. 85, no. 2–3, pp. 438–443,April 2013.

[24]. Bhandare, R. Gangaram, P.M. Sonawane, “Preparation of aluminium matrix composite by using stir casting method”, International journal of engineering and advanced technology, vol. 3, no. 2, pp. 1-5, Dec. 2013.

[25]. G. Kokot , W. Ogierman, “Mean field homogenization in multiscale modeling of composite materials”, Journals of achievements in materials and manufacturing engineering, vol. 61,no. 2, pp. 1-6, Dec. 2013.

[26]. C. Bag, H. Arik, V.S. Ekinci, “Effect of Al_2O_3 content and milling time on microstructure and mechanical properties of aluminium metal matrix composites”, Society for Experimental Mechanics, vol. 58, no.2, pp. 63-73, March 2014

[27]. V. Bharath , M. Nagaral, S. A. Kori, V. Auradi, “Preparation of 6061 al- al_2o_3 MMC’s by stir casting and evaluation of mechanical and wear properties”, in Proc. 3^{rd} Int. Con. on Materials processing and Characterization, pp. 1658-1667, Dec. 2014.

[28]. H.B.H. Gubran, K. Gupta, “Design optimization of automotive propeller shafts”, Journal of vibration engineering & technologies, vol. 2, No. 1, pp. 35-46, February 2014.

[29]. A. Siddique, A. Ghias , B.V. Ramnath, C. Elanchezhian, C. Parswajinan, M. Jaivignesh, S. Rajesh, “Evaluation of mechanical properties of aluminium alloy–

alumina–boron carbide metal matrix composites”, Materials and design, vol. 58, pp.332-338, Feb. 2014.

[30]. A.C. Babar, A.A. Utpat, “Vibration analysis of misaligned rotating shaft”, international Journal of mechanical engineering and information technology, vol. 2, no. 6, pp. 287-294,June 2014.

[31]. F. Zhao, L. Luo, Q. Jia, R. Zhao, X. Luan, Y. Sha,“Vibration modal analysis of continuous fiber reinforced metal matrix composites low pressure turbine shaft”, in Proc. Int. conf. on power, electronics and materials engineering, May 2015, pp. 2-7.

[32]. P. Hwang , V. Nguyen, “Dynamic analysis of rotor-ball bearing system of air conditioning motor of electric vehicle”, International journal of mechanical engineering and applications, vol. 3, pp. 22-28, Feb. 2015.

[33]. A.K. Jain, A.K. Agrawal, V. Rastogi, “Experimental investigation of vibration analysis of multi-crack rotor shaft”, in Proc. 12th International conference on vibration problem, July 2016, pp. 1451-1458.

[34]. K. Sathishkumar and N. Ugesh, “Finite element analysis of a shaft subjected to a load”, ARPN Journal of engineering and applied sciences, vol. 11, no. 9, pp. 1-5, May 2016.

[35]. C.S.P Rao, N. Selvaraj, P. Madukar, “Manufacturing of aluminium nano hybrid composites: a state of review”, in Proc. IOP Conf. Series: Materials Science and Engineering, Vol. 149. , pp. 1013-1024, July 2016.

[36]. T. Zhang, W. Wang, Y. Li, “The longitudinal vibration of composite drive shaft”, in Proc. 24th International congress on sound and vibration, July 2017, pp. 1-8.

[37]. A.R. Nadaf, V.A.Raika, “Design & analysis of composite shaft of passenger vehicle”, International research journal of engineering and technology, vol. 4, no.8, pp. 151-158, Aug 2017

[38]. S. Mula, S.C. Panigrahi, S.K. Pabi, S. Ghosh, P. Padhi, “On structure and mechanical properties of ultrasonically cast Al–2% Al2O3 nanocomposite”, Materials research bulletin, vol. 44,no. 5, pp. 1154-1160, October 2018.

[39].https://www.mathworks.com/matlabcentral/answers/uploaded_files/71667/17160838_1646141328735588_1887025192_n.png.

[40]. http://www.mfg.mtu.edu/cyberman/machtool/machtool/vibration/damping.html.

APPENDIX

1.1 CALCULATION OF AL 6061 AND Al_2O_3 MASS REQUIRED FOR MAKING THE SHAFTS

Property of AL 6061 and Alumina is given in the Table A 1.1

Table A 1.1 Property of Aluminium , Alumina and its composite

Material	Density (kg/m^3)	Elastic Modulus (GPa)
AL 6061	2700	70
Alumina	3900	370
8 % AL- Alumina composite	2796	77.66

A. Fabrication of Al 6061 shaft

As the required data for shaft specimen and properties are given in the Table no. 4.2 the volume of shaft is calculated.

Volume of shaft (V) = $\frac{\pi}{4} d^2 l = 3.801327 * 10^{-4} m^3$

Therefore, mass of Al 6061 required is $m_{Al6061} = \rho * V_{Al6061} = 1028.73 gms$

B. Fabrication of Al $6061 - Al_2O_3$ 8 % *by volume by stir casting*

From the required data mentioned in the Table no. 4.2, the volume of composite shaft

$$V_{Al6061} + V_{Al_2O_3} = 3.801327 * 10^{-4} m^3$$

Thus, for 8 % by volume we get,

$$V_{Al_2O_3} = \frac{8}{92} V_{Al6061} = 0.0869 V_{Al6061}$$

Therefore, the weights required for the casting of the shaft specimen is:

$$V_{Al6061} = 3.49722 * 10^{-4} m^3 \ \& \ V_{Al_2O_3} = 3.04 * 10^{-5} m^3$$

$$m_{Al6061} = 944.24 gms$$

$$m_{Al_2O_3} = 118.59 gms$$