Modeling And Analysis Of Automotive Engine Crankshaft Made Of Composite And Functionally Graded Materials

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ABSTRACT

With the consistent advancement and technical improvisation in the automobile industry, the researchers are working on the material optimization techniques to select and utilize the materials effective in power transmission. It is well known that power transmission systems in the mechanical industries and, namely, in automotive machineries, require a durable material with proper properties to ensure the optimum operational conditions during power transmission. The material utilized in the driving shaft must have a proper endurance and considerable yielding limit that means they have that ability to sustain the fatigue in the power transmission elements. The method of study is that engine shafts are a major part of the automobiles and the production of these shafts is an important requirement for the resistance against bending and torsion. The torsion and bending resisting moments are important before selecting the material. As a result, selecting the optimal material and surface treatment procedure to offer the highest performance for the shaft is crucial. Wear resistance and corrosion resistance are the two most important factors to consider when selecting a material for a surface. This paper is able to show the effect of materials of the crankshaft on those two elements. The research discusses the shafts of three different types of materials: homogeneous, composite, and functionally graded materials (FGM). For the optimum performance of the vehicle engine shaft, FGM is the ideal material to consider. It has been shown that the performance of crankshaft was improved in case of FGM. Based on the results of the modal and harmonic analysis, it is concluded that FGM crankshaft would offer the best durability and show optimum performance when compared with the other two material crankshafts investigated in this study.

1.INTRODUCTION

The automobile industry requires proper selection of materials for the power transmission. The main aim of selecting the suitable materials is to increase the effectiveness of the bending and torsion resistance. Functionally graded materials (FGM) provide varying quality grades with the dimensions. Functionally graded materials (FGMs) have turned into the object of public consideration for different application fields. FGMs have the properties of the two unrefined substances, which are combined as one, and the part dispersion is evaluated consistently. For instance, one of the FGMs delivered utilizing the properties of metallic perseverance with an appreciable advantage of endurance limit. It can utilize functionally graded materials (FGM) as a material to endure the stresses. The creators have proposed another creation technique utilizing a strategy bringing about a mechanical partition of solids and fluids and they have prevailed about delivering thick squares of FGMs utilizing this technique. Moderate cover of the limit layers through persistent degree utilizing filtration refined useful degree of FGMs. This research article focuses on choosing the optimum material for an engine shaft and the surface treatment method. Shafts are always designed in a circular shape, which is due to the distribution of stress in the shaft towards the radius which can make them to be in a solid or hollow shape. When rust poses a severe danger to the shaft's longevity, stainless steel is the material that is most likely to hold up the longest. 440C stainless steel and 316 stainless steels are the two most prevalent stainless-steel grades used to make linear shafts. The parameters for choosing a material for an engine shaft are entirely dependent on the application. There are several predefined factors to consider when choosing a shaft's material, such as the strength factor, shaft stiffness, and the shaft's capacity to go through several heat treatment methods.

Although there are some common features that must be present in the material from which the shaft is manufactured, they are as follows:

(i)High strength

(ii)Simplicity to manufacture so that the production process is as painless as possible.

(iii)It must have strong heat treatment qualities so that the shaft can resist harsh operating conditions.

Steel is one of the materials of choice for the manufacturing of shafts in normal operation. It has a considerable amount of strength and can handle most operating circumstances. Because it is inexpensive, it is favored over a variety of more expensive materials. A functional graded material (FGM) is a sort of amalgamated form created by combining two or more different types of materials. A compositional gradient is projected onto the mixture of specifications of FGM. As a result, it exhibits diverse qualities depending on the situation. The production technique for functionally graded materials has been mentioned in Figure 1.1

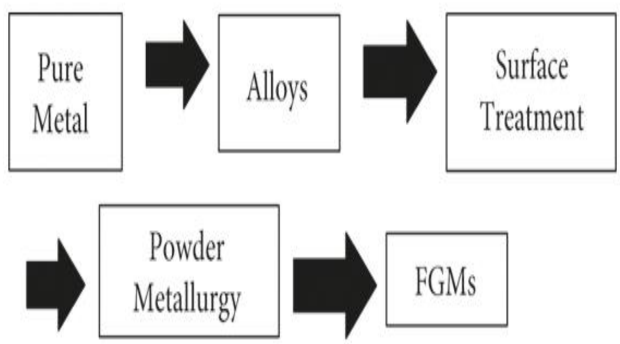


Figure1: FGM Production Process

A large portion of FGMs is molecule supported FGMs and their arrangements rely upon position. The particle reinforced FGMs, which contain particles (ceramics) in the framework (metal), the grid, will be exposed to plastic deformation; particles will have a loose bond that will eventually break. The heat resistance of the functionally graded materials is appreciable in the major conduct of utility for the power transmission purposes. In the past many investigations of FGMs, a perceptible mixture of metals has taken on to ensure the desirable material properties.

This paper is about the production of composite materials in the manufacturing aspect of functionally graded materials (FGM). The requirement for innovative materials with exact properties has brought about the slow adjustment of materials from their essential states (solid) to composites. Current advances in designing and the handling of materials have prompted another class of reviewed complex materials called practically evaluated materials (FGMs). This article takes a gander at the best handling innovations and uses of the high level, great items created in FGMs. It additionally features about the future exploration scope in FGMs.

In this paper, the evaluative methods on functionally graded materials (FGM) have been performed to study the effectiveness of using FGM in engine shafts. An outline has

been uncovered on the improvement of functionally graded materials (FGM), their ideas, their properties, and their primary assembling steps. This potential implies that the originator is not generally restricted to a scope of existing homogeneous materials, albeit many investigations have zeroed in on the examination of this material, engineers and different experts occupied with the plan cycle with functionally graded materials FGM. Utilization of the functionally graded materials FGM is by all accounts quite possibly the best materials in the acknowledgment of the maintainable advancement in the business.

The research entails finding the ideal material that will show optimum performance and would be able to avoid failure as much as possible. To plan, it is necessary to first understand the significant failures that occur over the life span of a crankshaft. When calculating the likelihood of a shaft failing, it is necessary to consider the types of loads that it is subjected to during its operation. One of the most encountered forms of load is rotational, which causes the shaft to twist and flex, potentially losing its stiffness and causing the system to collapse.

Other weights acting on the crankshaft could be as a result of location of loading. For example, in underwater systems, the shaft may corrode because of the presence and influence of water beneath it. As a result, going prepared for these unique situations is a must. Figure 1.2 depicts a cylinder and how various forces operate on it to induce deformation. Repetitive loading cycles induce fatigue failure. It is a startling truth, but the forces that generate plastic deformation are larger than the forces that cause fatigue failure. Corrosion-resistant characteristics and the ease with which it resists erosion are two significant factors to consider when evaluating for a part’s strength, as they indicate how much endurance and reliability it can rely on. Let us talk about fatigue planes and the process that causes our engine shaft to break due to fatigue failure. In the uncommon event of a fatigue failure, a thorough examination of the break planes is required to devise a preventative strategy. Torsion is something it can resist. The objective is to have a shaft with enough torsional strength to sustain the torque applied to it. The research entails finding the ideal material that will show optimum performance and would be able to avoid failure as much as possible. To plan, it is necessary to first understand the significant failures that occur over the life span of a crankshaft. When calculating the likelihood of a shaft failing, it is necessary to consider the types of loads that it is subjected to during its operation. One of the most encountered forms of load is rotational, which causes the shaft to twist and flex, potentially losing its stiffness and causing the system to collapse.

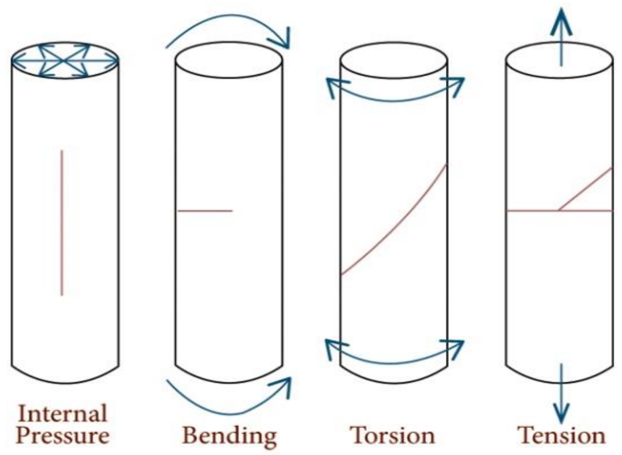


Figure 2: Fracture planes caused by general fatigue forces.

2.LITERATURE REVIEW

1. (Karthick et al., 2021) Finite Element Method is approached to analyzing the crankshaft, models were evaluated for static structural analysis. EN8 and Forged steel material compositions were given as input, and stress induced was calculated for specified boundary conditions. In the ANSYS workbench 17.2 software kit, the CAE technique of investigation is used. The values attained using the CAE method are like those achieved results experimentally, so the technique developed can be considered for material testing and assessment of crankshafts for structural analysis, and it is developed using the SolidWorks software program. The total deformation of EN8 and Forged steel two-wheeler crankshaft, it is observed that maximum deformation for EN8 and Forged steel is 0.017289 m and 0.01712 m, respectively. The Equivalent strain of the two- wheeler crankshaft for two materials is observed. Comparatively the maximum equivalent strain in EN8 (6.6602) material is higher than in Forged Steel (6.595) material. The equivalent stress analysis for the EN 8 and forged steel materials of crankshaft and, according to the static analysis it is found that both the materials have the same equivalent stress.

2. (Citti et al., 2018) The need to deepen the aspect of costs savings while designing and manufacturing mechanical components is becoming a feature of hard management by automotive manufacturers. They have compared the physical properties of quenched and tempered steel (QT steels), bainitic steels. To increase the fatigue limit of such steels, for high-loaded crankshaft applications as in sport vehicles, a nitriding thermal treatment is done after the tempering treatment. The nitriding determines high surface hardness (above 750 HV) and increased mechanical properties on the surface, but maintains the same material alloy toughness in the shaft core. This is done mainly to improve fatigue resistance behavior. Bainitic transformation has both the features of martensite transformation and perlite transformation; the former is developed between two specific temperature limits inside which bainite can develop, that are Bs (bainite start) and Bf (bainite finish), while the latter is a time depending transformation. This means there is an incubation time and a completion time for the bainite generation. All these parameters are strongly affected by the alloying element concentration. When increasing the carbon content, the Bs temperature decreases as demonstrated by Steven and Haynes (1956) and Garcia-Mateo et al. (2005),

while reducing alloying element concentrations speeds up the time of transformation – which means accelerating the kinetics of transformation.

3. (Jiao et al., 2020) Experimental analysis of fracture failure With the continuous advancement of engine technology, engine design is moving toward high efficiency, increased reliability, reduced quality, reduced fuel consumption and reduced emissions. The mechanical load continuously increases which makes the working conditions of the crankshaft more and more demanding and causes the crankshaft to be susceptible to bending fatigue damage and torsional fatigue damage. Due to the facts that the crankshaft is often excited by complex Vol-7 Issue-6 2021 IJARIIE-ISSN(O)-2395-4396 15737 www.ijariie.com 983 alternating shock loads during operation, the crankshaft is subjected to transverse, longitudinal and torsional vibrations. When the frequency of some motivating force was same or similar with the first order natural frequency of the crankshaft, the resonance of the shaft system occurs, which is sufficient for cause fatigue fracture of the crankshaft. Modal analysis can avoid resonance and vibration at a specific frequency. The crankshaft is an asymmetrical or anti-symmetric body. Therefore, the whole crankshaft must be taken as the research object when carrying out finite element modal analysis. They have applied boundary condition and meshed in FEA and found the static analysis.

3.MODELLING USING CATIA:

CATIA is Computer Aided Three-dimensional Interactive Application. It is one of the leading 3D software used by organizations in multiple industries ranging from aerospace, automobile to consumer products. CATIA is a multi-platform 3D software suite developed by Dassault System encompassing CAD, CAM as well as CAE. Dassault is a French engineering giant active in the field of aviation, 3D design, 3D digital mock-ups, and product lifecycle management (PLM) software. CATIA is a solid modelling tool that unites the 3D parametric features with 2D tools and also addresses every design-to-manufacturing process. In addition to creating solid models and assemblies, CATIA also provides generating orthographic, section, auxiliary, isometric or detailed 2D drawing views. It is also possible to generate model dimensions and create reference dimensions in the drawing views. The bi-directionally associative property of CATIA ensures that the modifications made in the model are reflected in the drawing.

The CATIA suite is a powerful design tool that is growing in popularity due to the powerful functionality it offers. Since the software is vast, it is better to get professional training in CATIA to make maximum use of its features. Cities like Pune, Bengaluru, Hyderabad and Satara have competent, Dassault certified institutes that offer CATIA training.

The 3D model of Engine Crankshaft was designed in CATIA with their respective geometrical dimensions.

Table No.3 Geometrical Dimensions Of Engine Crankshaft

S NO	DESCRIPTION	VALUES
1	Crankshaft length(mm)	589
2	Crankshaft height(mm)	160
3	Crank pin length(mm)	38
4	Crank pin diameter(mm)	27
5	Diameter of shaft(mm)	72
6	Maximum pressure	100 MPa
7	Fixed support	Both ends of the shaft

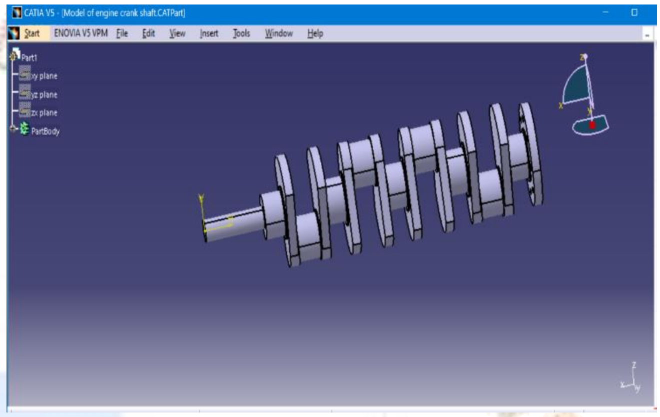


Figure 3: 3D Model Of An Automotive Engine Crankshaft

4.METHODOLOGY

4.1. Finite Element Analysis and Simulation

Using ANSYS Workbench 2021, this research aims to perform the numerical simulations of engine crankshaft made of gray cast iron, 316 stainless steel, carbon composite, and FGM material to reveal the material with optimum performance. The harmonic analysis and modal analysis will be performed on the shafts to investigate the behavior of the shaft under the action of the loading, which produces frequencies that are unique to each material. Such frequencies are known as the fundamental or natural frequencies of vibrations, and when it coincides with the frequency response of vibration, there will be resonance, which if attained, can lead to the cause of fracture development within the surface.

For the purpose of this work, the physical properties of the gray cast iron, 316 stainless steel, carbon composites and FGM(GCI+316 SS) to be used for the analysis are all presented in Tables 2 to 5. Also, presented in Figure is the 3D model of the meshed crankshaft in ANSYS workbench.

PROPERTIES	VALUES
Density	7200 Kgm-3
Young’s Modulus	110 Gpa
Poissoin’s Ratio	0.27911
Bulk Modulus	83 Gpa
Shear Modulus	43 Gpa

Table 2: Properties Of Gray Cast Iron

Table 3: Properties Of 316 Stainless Steel

PROPERTIES	VALUES
Density	8000 Kgm-3
Young's Modulus	193 Gpa
Poisson's Ratio	0.27
Bulk Modulus	139.86 Gpa
Shear Modulus	75.984 Gpa

Table 4: Properties Of Fgm

PROPERTIES	VALUES
Density	7600 Kgm-3
Young's Modulus	151.5gpa
Poisson's Ratio	0.2705
Bulk Modulus	110.02gpa
Shear Modulus	59.62gpa

Table 5: Properties Of Carbon Fiber(395gpa)

PROPERTIES	VALUES
Density	4500 Kgm-3
Young's Modulus	183 Gpa
Poisson's Ratio	0.23
Bulk Modulus	112.96 Gpa
Shear Modulus	74.39 Gpa

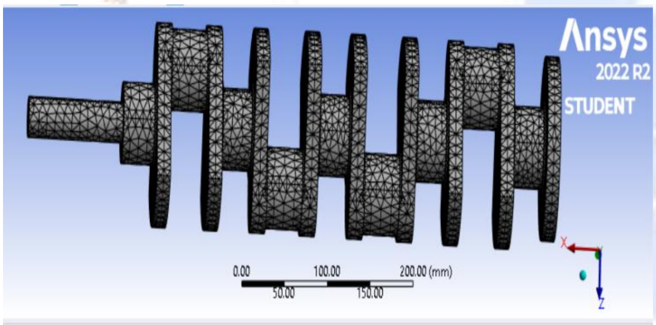


Figure 3: 3D Model Of The Meshed Crank Shaft In Ansys Workbenc

5. ANALYSIS RESULTS USING ANSYS

Modal Analysis Of Gray Cast Iron Engine Crankshaft:

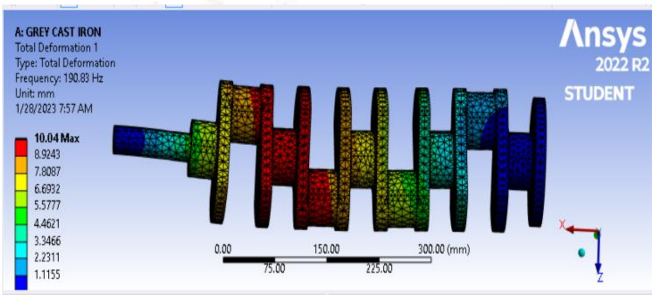


Figure 5.1: Deformation At the first mode of vibration

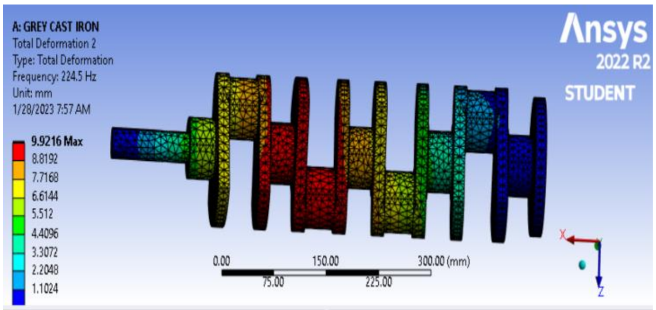


Figure 5.2: Deformation At The Second Mode Of Vibration

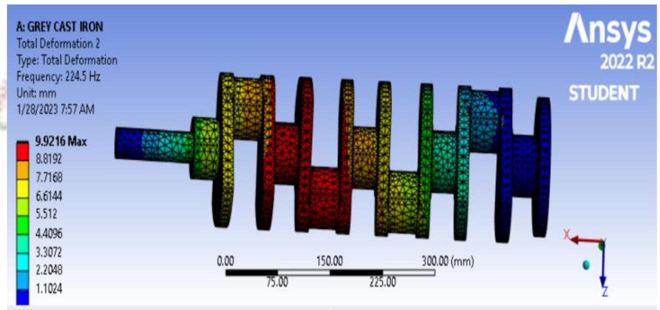


Figure 5.3: Deformation At The Third Mode Of Vibration

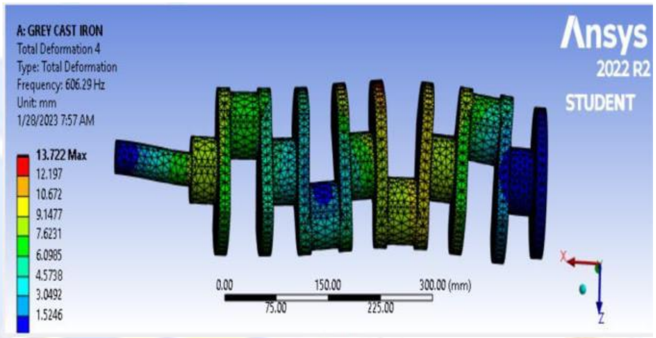


Figure 5.4: Deformation At The Four Mode Of Vibration

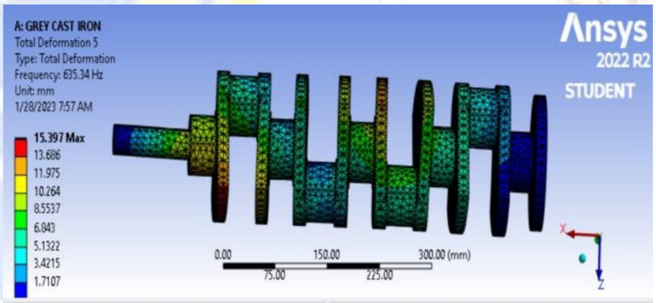


Figure 5.5: Deformation At The Fifth Mode Of Vibration

5.2 Modal Analysis Of Carbon Fiber (395 GPa) Engine Crankshaft:

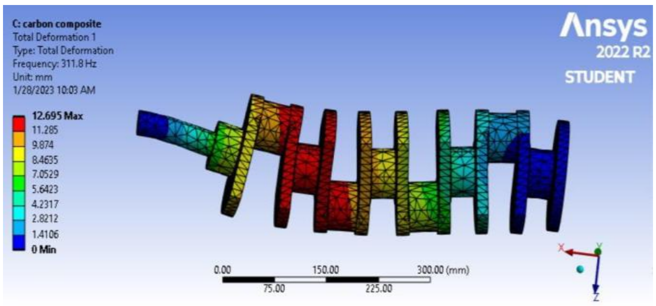


Figure 5.2.1: Deformation At The First Mode Of Vibration

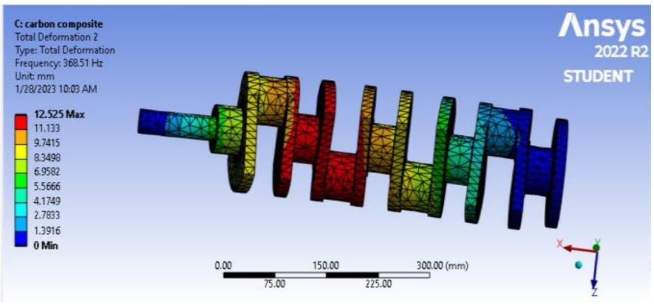


Figure 5.2.1: Deformation At The First Mode Of Vibration

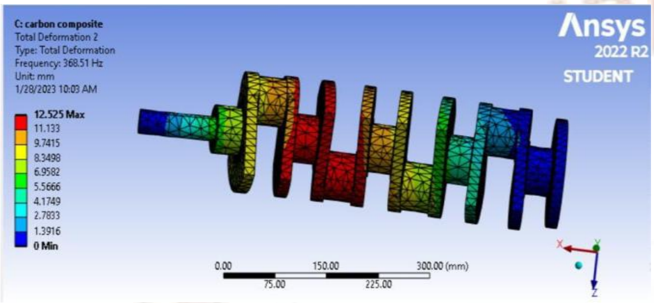


Figure 5.2.2: Deformation At The Second Mode Of Vibration

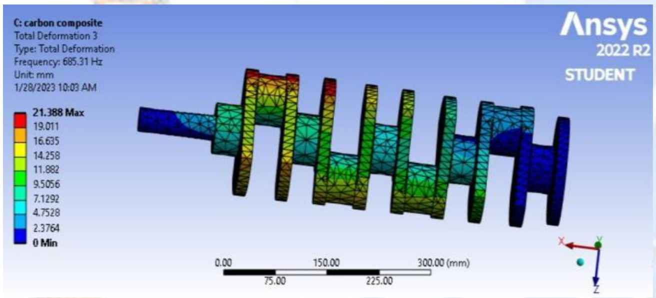


Figure 5.2.3: Deformation At The Third Mode Of Vibration

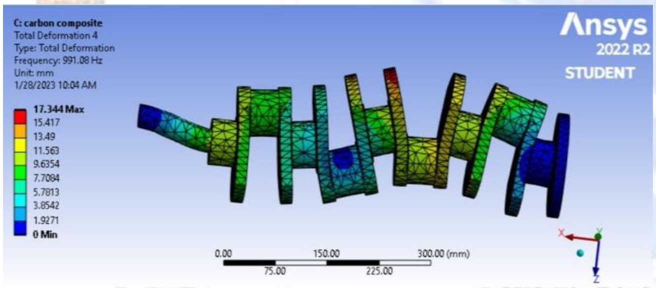


Figure 5.2.4: Deformation At The Fourth Mode Of Vibration

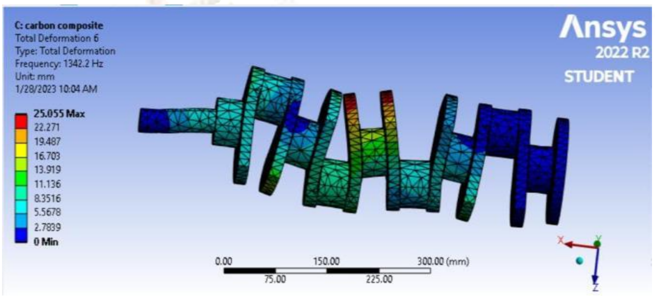


Figure 5.2.5: Deformation At The Sixth Mode Of Vibration

5.3 Modal Analysis Of FGM (GCI + 316 SS) Engine Crankshaft:

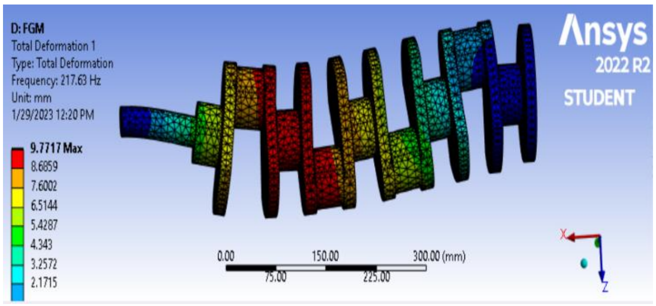


Figure 5.3.1: Deformation At The First Mode Of Vibration

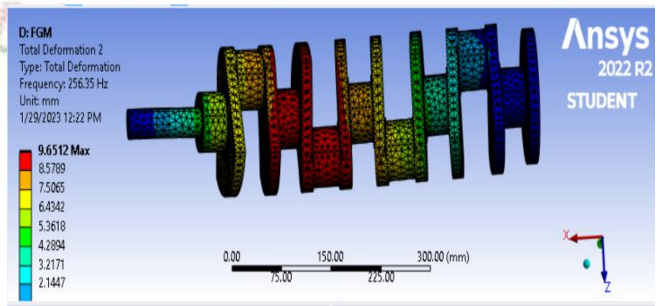


Figure 5.3.2: Deformation At The Second Mode Of Vibration

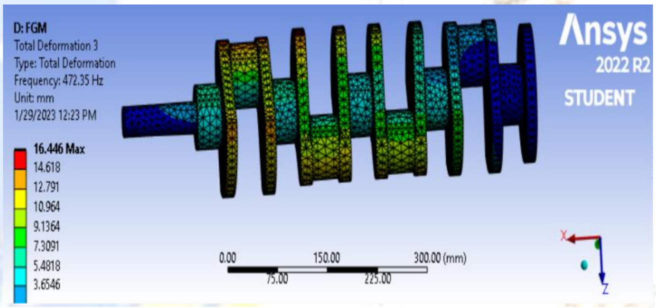


Figure 5.3.3: Deformation At The Third Mode Of Vibration

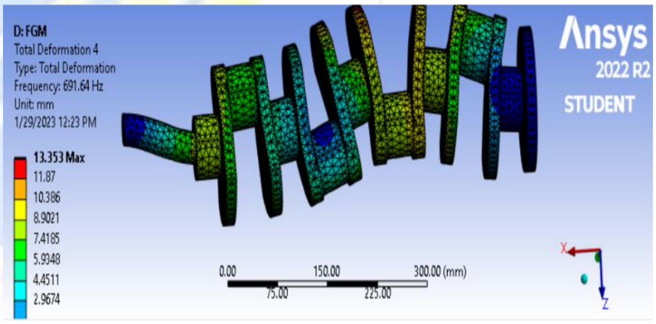


Figure 5.3.4: Deformation At The Fourth Mode Of Vibration

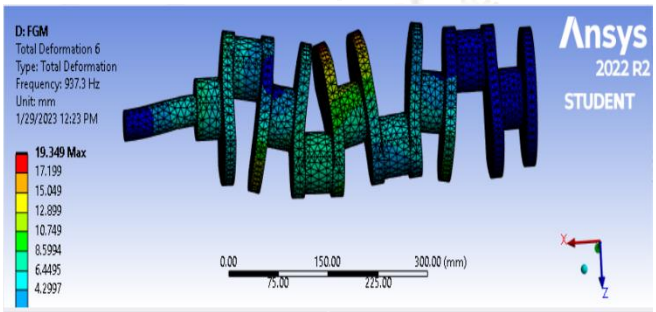


Figure 5.3.5: Deformation At The Sixth Mode Of Vibration

5.4 Harmonic Analysis Of Engine Crankshaft:

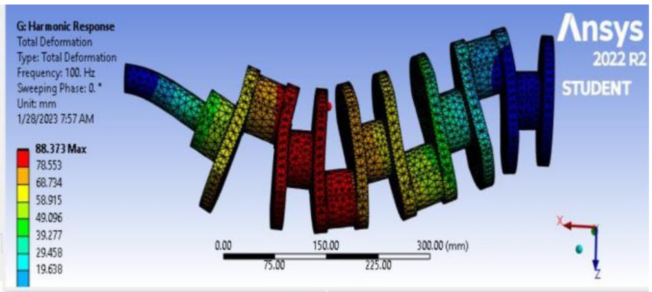


Figure 5.4.1: Total Deformation Of Gray Cast Iron Crankshaft At The Pressure(100mpa)

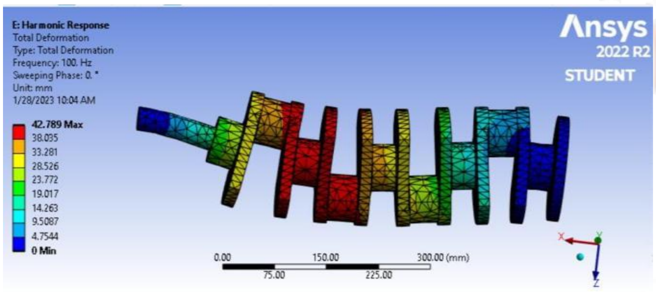


Figure 5.4.2: Total Deformation Of FGM (GCI + 316 SS) Crankshaft At The Pressure(100mpa)

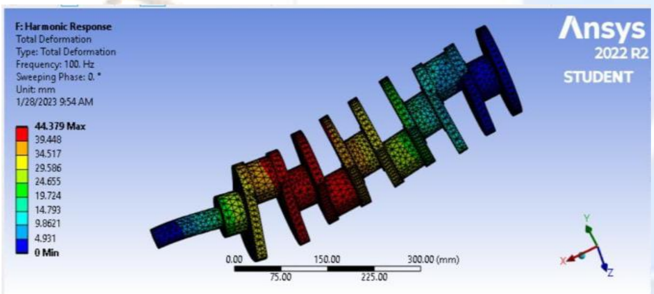


Figure 5.4.3: Total Deformation Of Gray 316 Stainless Steel Crankshaft At The Pressure(100Mpa)

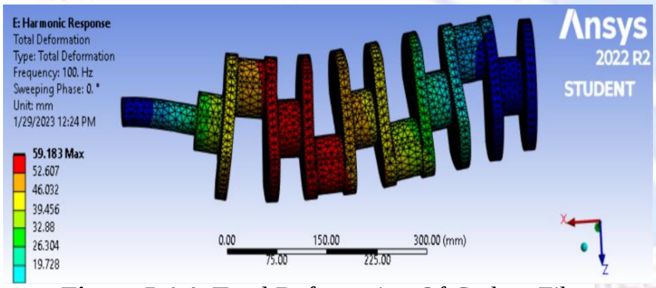
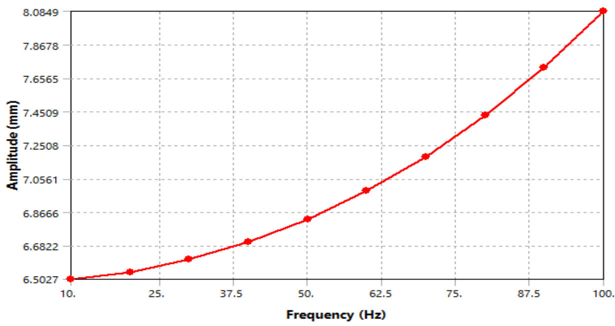


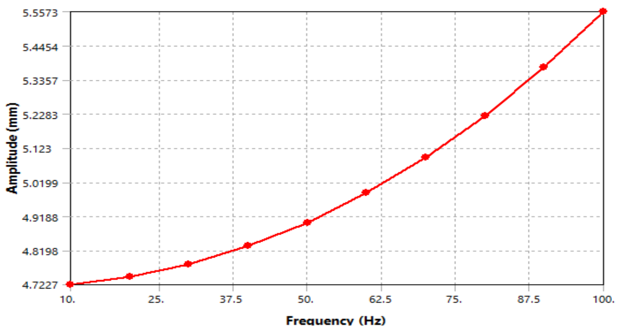
Figure 5.4.4: Total Deformation Of Carbon Fiber Crankshaft At The Pressure(100Mpa)

5.5 FREQUENCY RESPONSE GRAPHS:

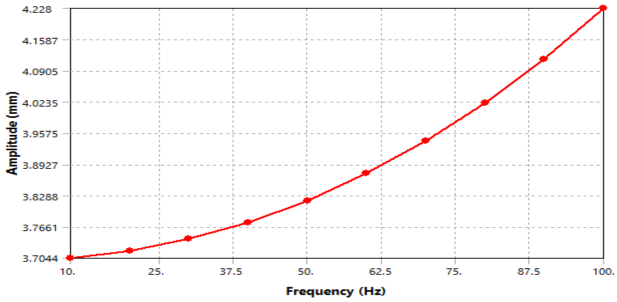


Graph 5.5.1 Directional Deformation of Gray Cast iron

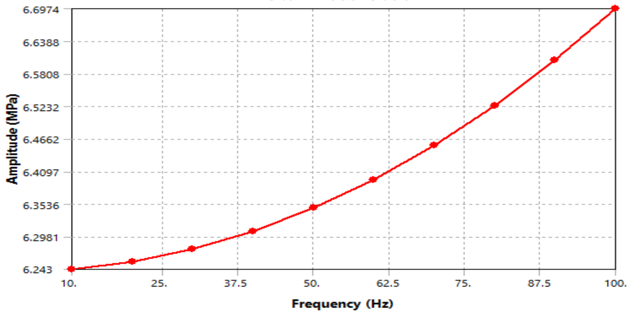
Graph 5.5.2 Directional Deformation of Carbon Fiber



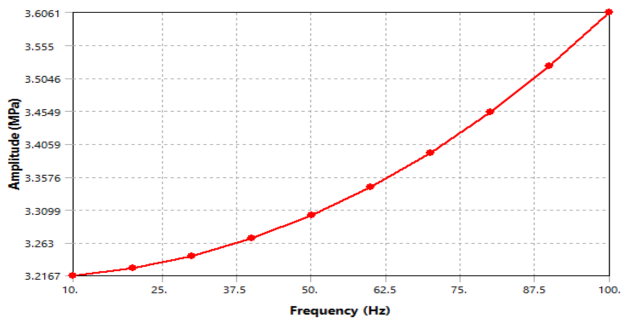
Graph 5.5.3 Directional Deformation of FGM(GCI+316SS)



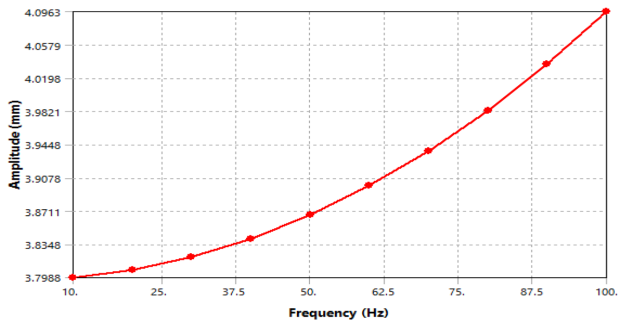
Graph 5.5.4 Directional Deformation of 316 Stainless Steel



Graph 5.5.2 Shear stress of Carbon Fiber



Graph 5.5.2 Shear stress of FGM(GCI+316SS)



5.6 PROPERTIES OF MATERIAL:

S. No	Material	Deformation
1	Gray Cast Iron	10.04
2	316 stainless Steel	9.8249
3	Carbon fiber	12.695
4	FGM (GCI + 316 SS)	9.7717

6.CONCLUSION

Functionally graded materials (FGM's) are the appreciable and distinctive types of materials that have different properties based on the varying dimensions of the materials. In this study, we have investigated the use of 316 stainless steel, gray cast iron, a composite, and a FGM (316 steel +GCI) in the design of crankshaft. The finite element model of the crankshaft was created using ANSYS to perform modal and harmonic analysis to visualize how the system behaves in real-world conditions. The ultimate objective is to guarantee that the shaft functions properly and that the component's life is extended. The contribution of study is to show that performance of stainless-steel crankshaft would be improved when it is functionally graded into a new material. Based on the results of the modal and harmonic analysis, it is concluded that FGM crankshaft would offer the best durability and show optimum performance when compared with the other two material crankshafts investigated in this study. It is recommended that more research works should be carried out on the modal and harmonic analysis of engine crankshaft using many more conventional and functionally graded material (FGM) types as this aspect is of great engineering importance.

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