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Retraction

Retracted: Modeling and Analysis of Automotive Engine Crankshaft Made of Composite and Functionally Graded Materials

Advances in Materials Science and Engineering

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] S. Asiri, "Modeling and Analysis of Automotive Engine Crankshaft Made of Composite and Functionally Graded Materials," *Advances in Materials Science and Engineering*, vol. 2022, Article ID 4005368, 15 pages, 2022.

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Research Article

Modeling and Analysis of Automotive Engine Crankshaft Made of Composite and Functionally Graded Materials

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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 know that power transmission systems in the mechanical industries and, namely, in automotive machinaries, 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 [1–3]. 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 (2021) (MiSUMi Mech Lab). The parameters for choosing a material for an engine shaft are

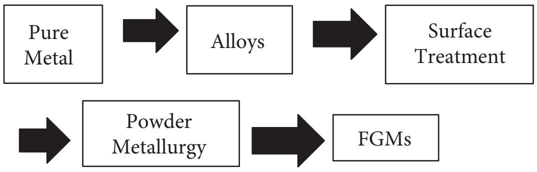

Figure 1: FGM production process.

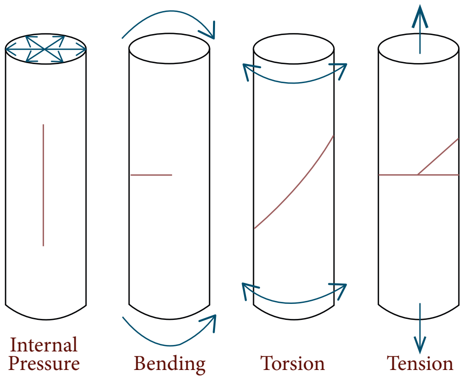

Figure 2: Fracture planes caused by general fatigue forces.

Table 1: Geometrical dimensions of the 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

Table 2: Properties for carbon composite.

Properties	Values
Density (kg/m^3)	4500
Elastic modulus (GPa)	0.85
Poisson's ratio	0.499
Shear modulus (GPa)	0.284

Table 3: Mechanical and physical properties of the FGM (316 steel + Al_2O_3).

Property	Value
Density (kg/m^3)	$8000\,(1 - r/r_0) + 3800\,(r/r_0)$
Young´s modulus (Pa)	$1.93x10^{11}\,(1 - r/r_0) + 3.204x10^{11}\,(r/r_0)$
Poisson´s ratio	$0.27\,(1 - r/r_0) + 0.26\,(r/r_0)$
Shear modulus	$78\,x\,10^9\,(1 - r/r_0) + 127.14\,x\,10^9\,(r/r_0)$

Table 4: Mechanical and physical properties of Al_2O_3.

Property	Value
Density (kg/m^3)	3800
Young´s modulus (GPa)	320.4
Poisson´s ratio	0.26
Compressive yield strength (MPa)	400
Shear modulus	127.14 GPa

Table 5: Physical properties for stainless steel 316

Property	Value
Mass density (kg/m^3)	8000
Young's modulus (GPa)	193
Poisson's ratio	0.27
Shear modulus (GPa)	78

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 [1].

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 [2, 3]. The production technique for functionally graded materials has been mentioned in Figure 1.

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 [3]. 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 [4].

This paper is about the production of composite materials in the manufacturing aspect of functionally graded materials (FGM). The requirement for innovative materials

Table 6: Material properties of FGM (316 steel + Al_2O_3).

Layers	1	2	3	4	5	6	7	8
Radial coordinate (mm)	0	10	20	30	40	50	60	70
Mass density (kg/m^3)	8000	7475	6950	6425	5900	5375	4850	4325
Young's modulus (GPa)	193	208.9	224.8	240.8	256.7	272.6	288.5	304.5
Poisson's ratio	0.27	0.269	0.2675	0.266	0.265	0.2638	0.2625	0.2613

Table 7: Modal analysis results of stainless-steel crankshaft.

Modes	Frequency	Deformation (mm)
1	329.31	9.35
2	751.29	19.13
3	962.65	12.496
4	1737.5	15.33
5	2346.4	17.17

Table 8: Modal analysis results of carbon composite crankshaft.

Modes	Frequency	Deformation (mm)
1	318.41	12.386
2	742.33	25.288
3	931.12	16.88
4	1669.8	19.51
5	2244.5	21.835

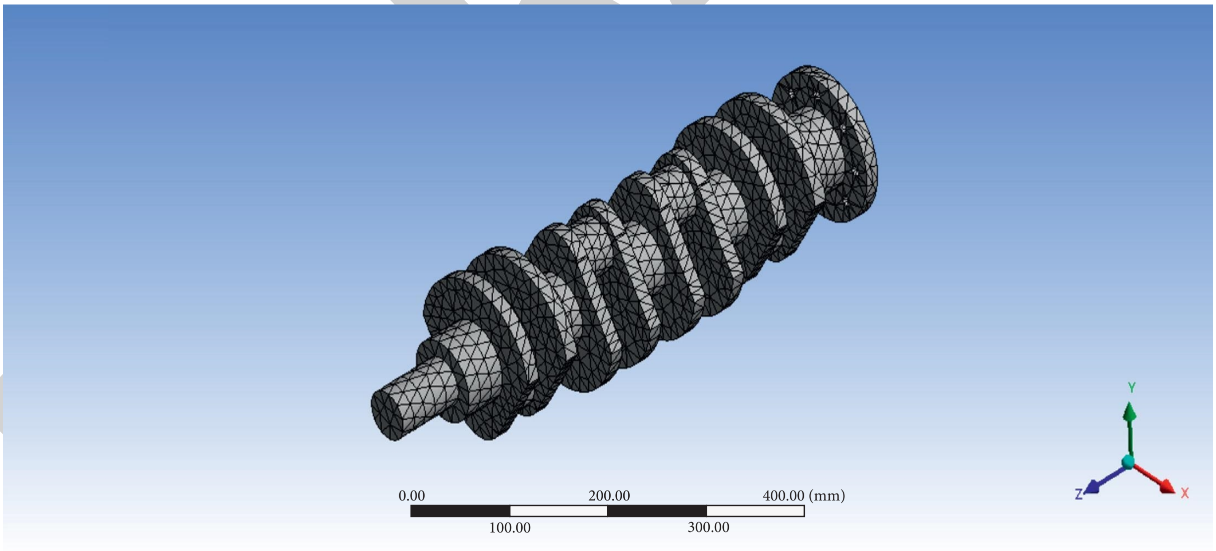

Figure 3: 3D model of a meshed crankshaft created in ANSYS software.

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 [5].

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 [6]. This potential implies that the originator is not generally restricted to a scope of existing homogeneous materials, albeit many investigations have

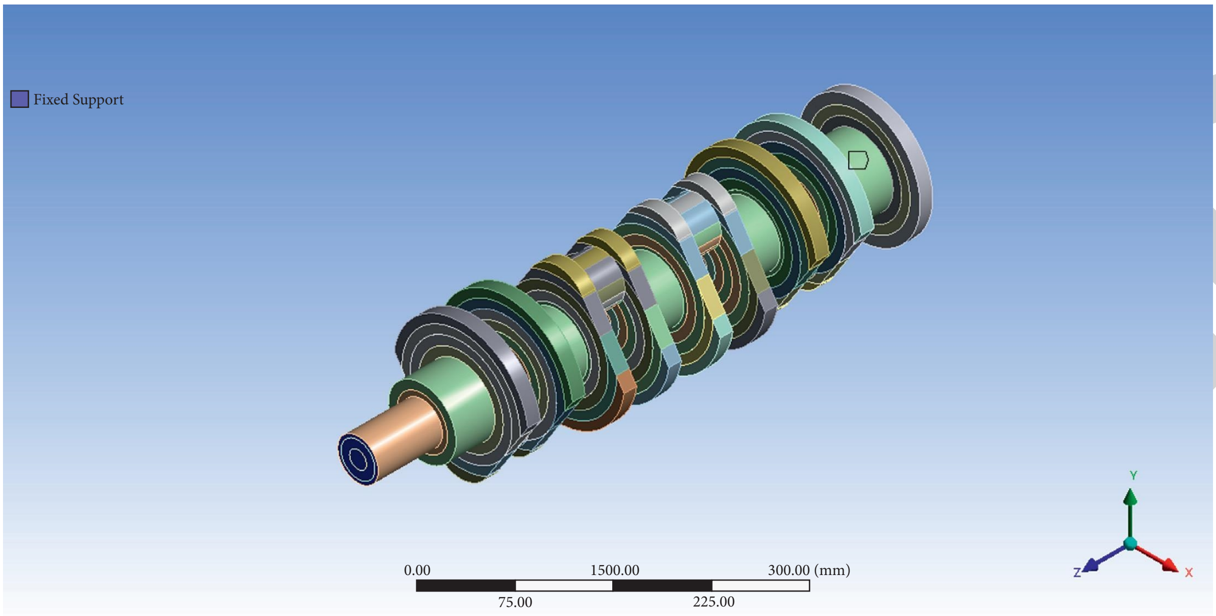

Figure 4: Engine shaft (FGM).

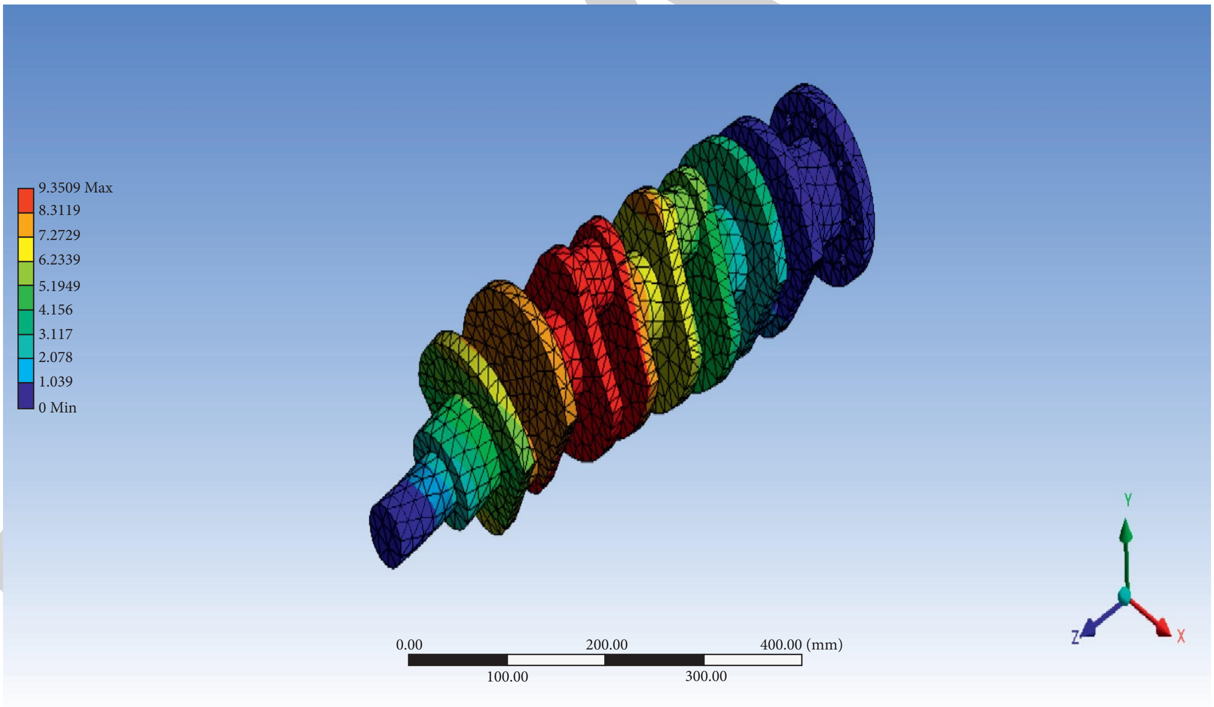

Figure 5: Deformation of stainless-steel crankshaft at the first mode of vibration.

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 [7].

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.

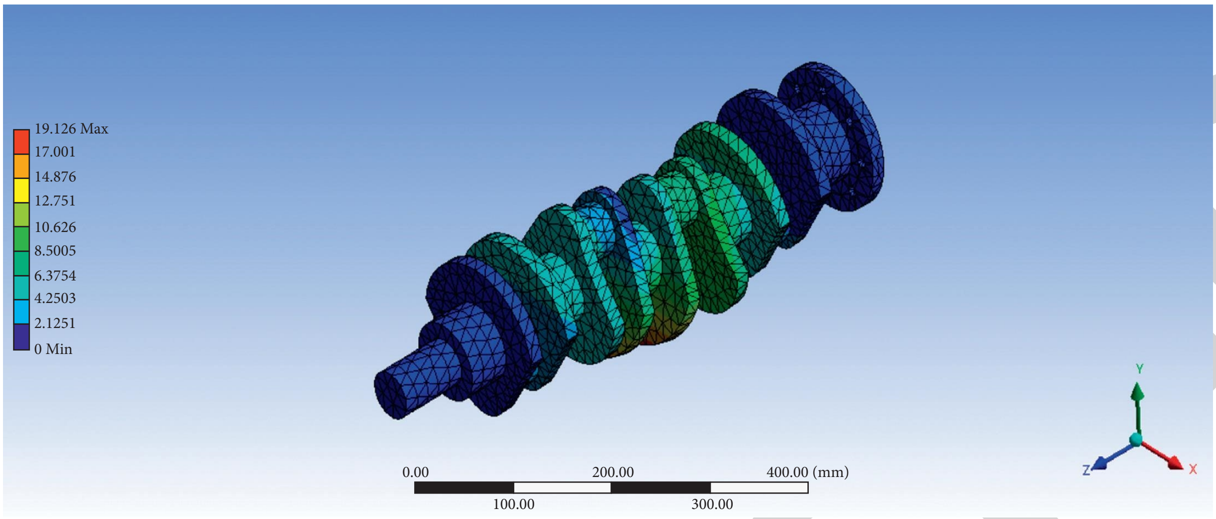

Figure 6: Deformation of stainless-steel crankshaft at the second mode of vibration.

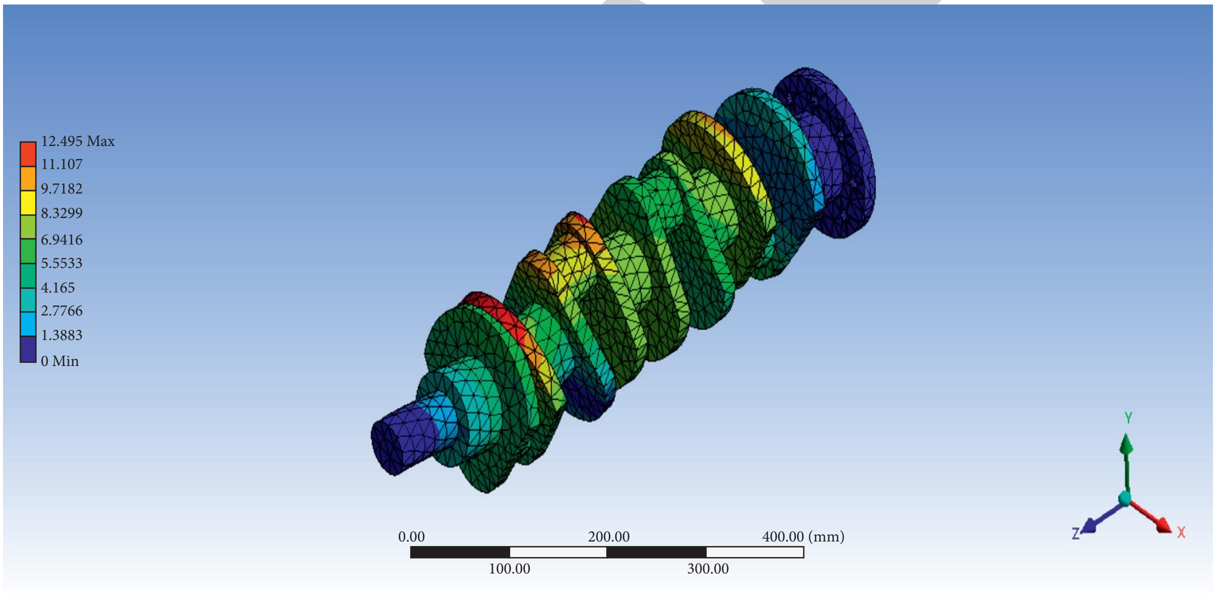

Figure 7: Deformation of stainless-steel crankshaft at the third mode of vibration.

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 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 [8].

2. Methodology

2.1. Finite Element Modeling and Simulation. Using ANSYS Workbench 2021, this research aims to perform the numerical simulations of engine crankshaft made of 316 stainless steel, carbon composite, and FGM material to reveal the material with optimum performance. The

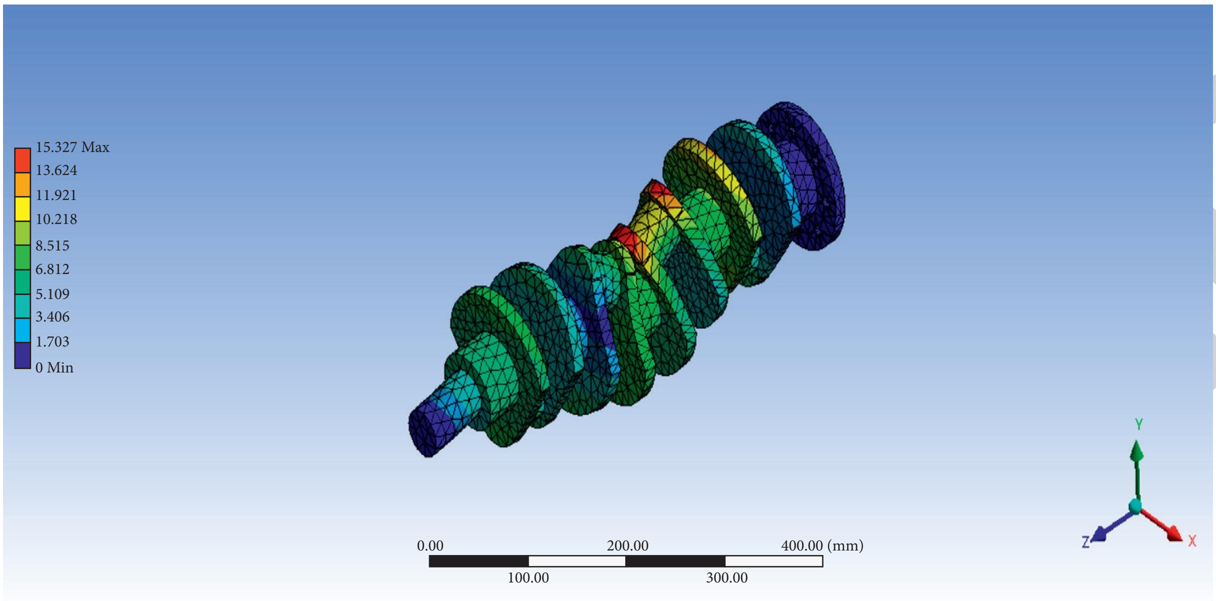

Figure 8: Deformation of stainless-steel crankshaft at the fourth mode of vibration.

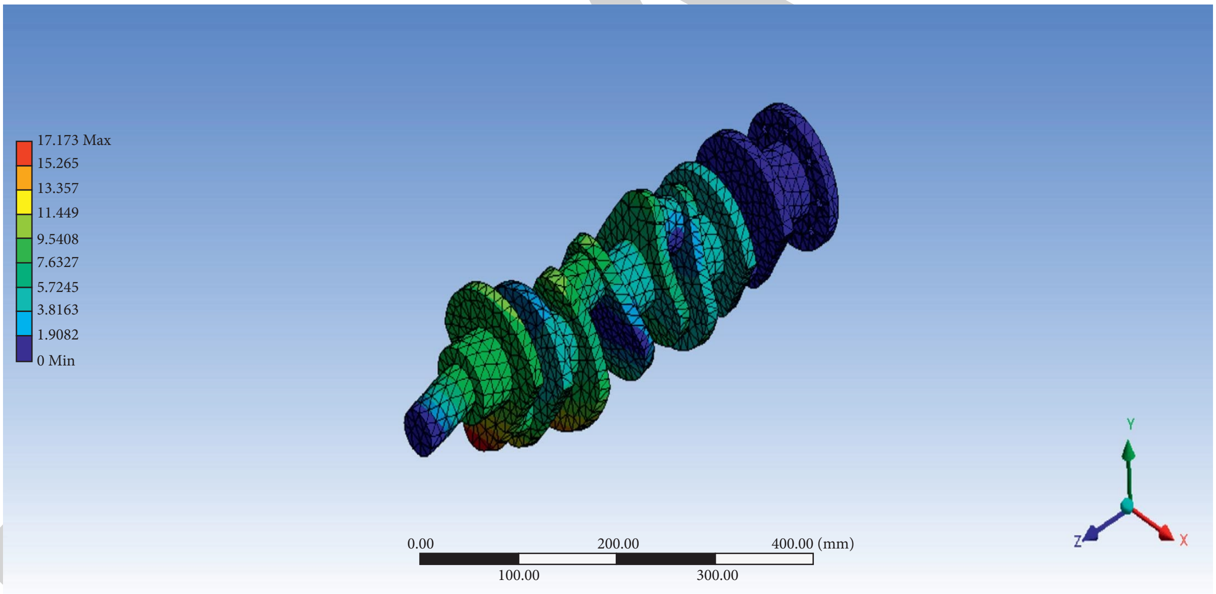

Figure 9: Deformation of stainless-steel crankshaft at the sixth mode of vibration.

harmonic analysis and response spectrum 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 [9].

For the purpose of this work, the geometrical dimension and physical properties of the 316 stainless and carbon composites and FGM to be used for the analysis are all presented in Tables 1 to 8. Also, presented in Figures 3 and 4 is the 3D model of the meshed crankshaft in ANSYS workbench.

2.2. Engine Shaft (316 Steel + Al_2O_3) FGM Modeling. The effective material properties of FGMs can be mathematically modeled as [10, 11]

$$P_{eff}(T,\xi) = P_m(T)V_m(\xi) + P_c(T)\left(1 - V_m(\xi)\right), \tag{1}$$

where P_{eff} is the effective material property of FGM; P_m is the temperature-dependent properties of the metal; P_c is the temperature-dependent properties of the ceramic; and V_m is

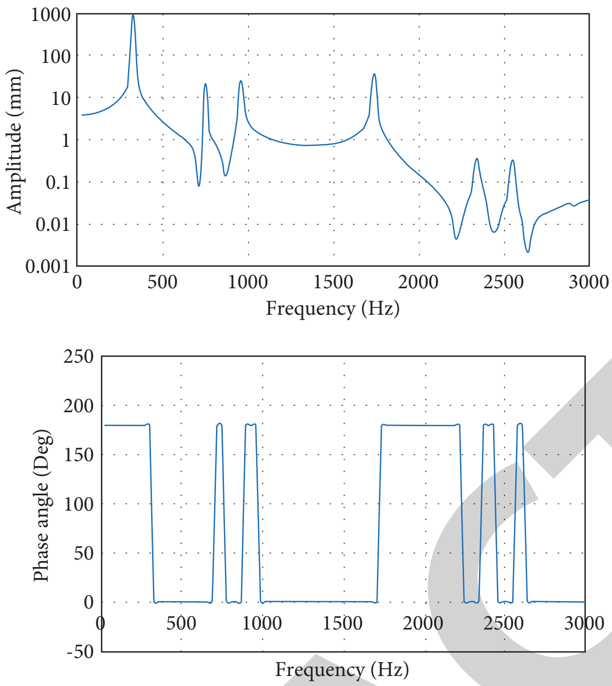

Figure 10: Frequency response diagram of stainless-steel crankshaft.

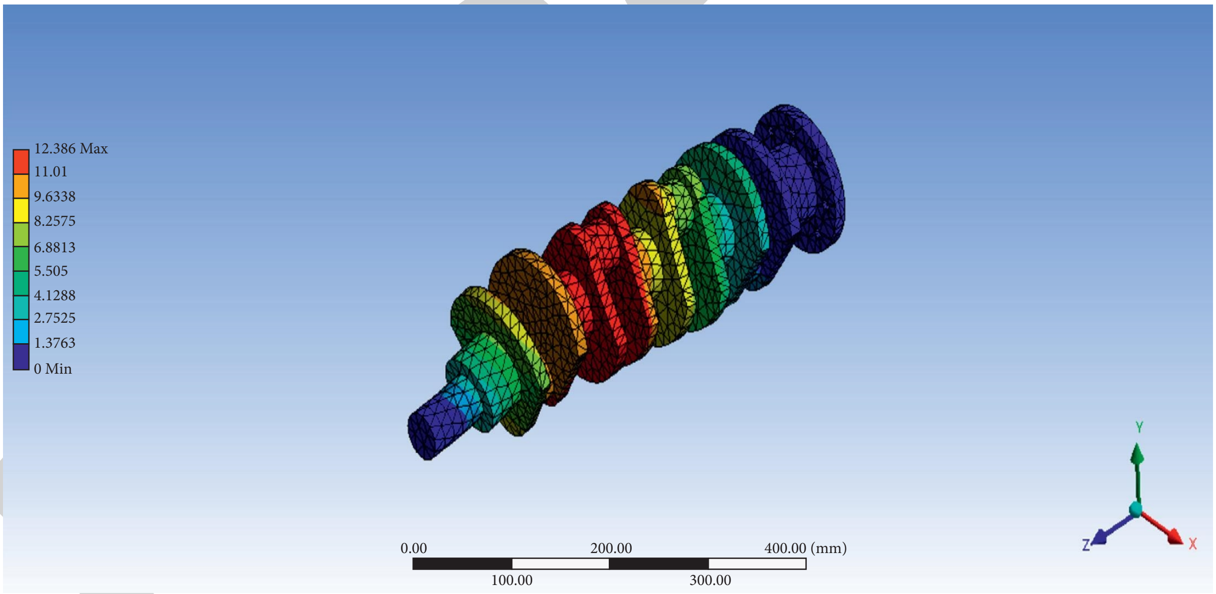

Figure 11: Deformation of carbon fiber composite crankshaft at the first mode of vibration.

the volume fraction of the metal constituent of the FGM. Additionally, a simple power-law exponent of the volume fraction distribution is used to express the amount of metal in FGMs [12]. The expression of an axisymmetric cylinder for the volume fraction of ceramic V_c is

$$V_c = \left(\frac{r - r_i}{r_0 - r_i}\right)^n, \tag{2}$$

where r_o is the cylinder outer radius; r_i is the cylinder inner radius, r is the radial coordinate $(r_i \le r \le r_o)$, and n is the index of power-law. In this way, the preceding distribution, the material of the shaft gradually changes from ceramic-rich in the outer surface to metal-rich in the inner surface [13, 14]. In this paper, it was considered a power-law index (n) equivalent to 1. As a result, the grading relations for the mechanical and physical properties of the FGM compound developed from stainless steel in addition with aluminum

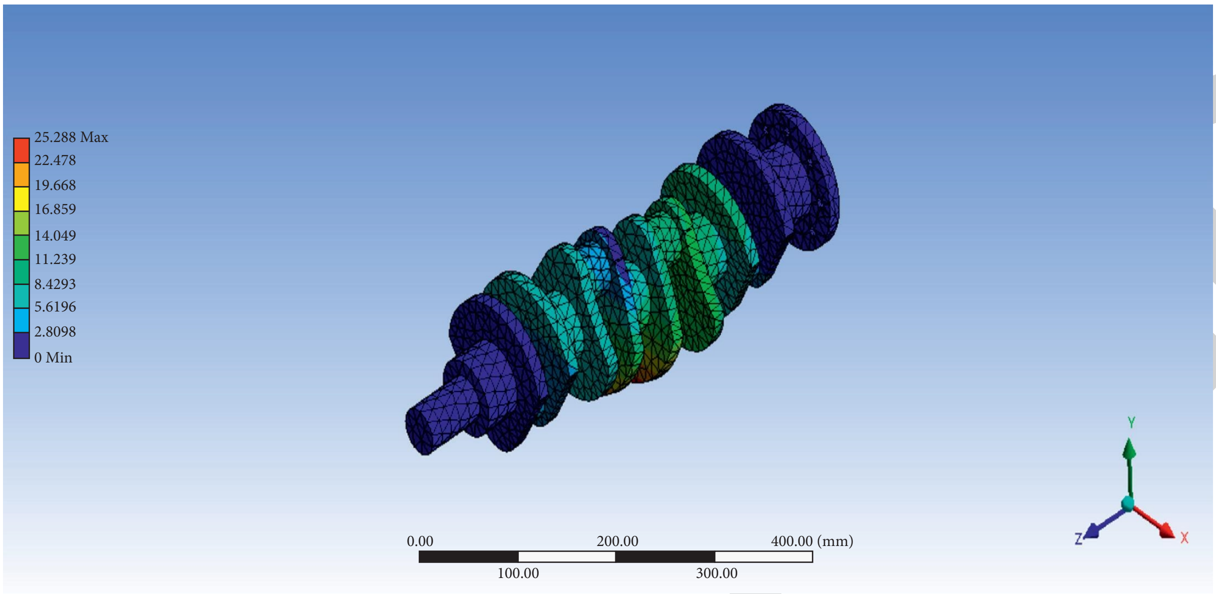

Figure 12: Deformation of carbon fiber composite crankshaft at the second mode of vibration.

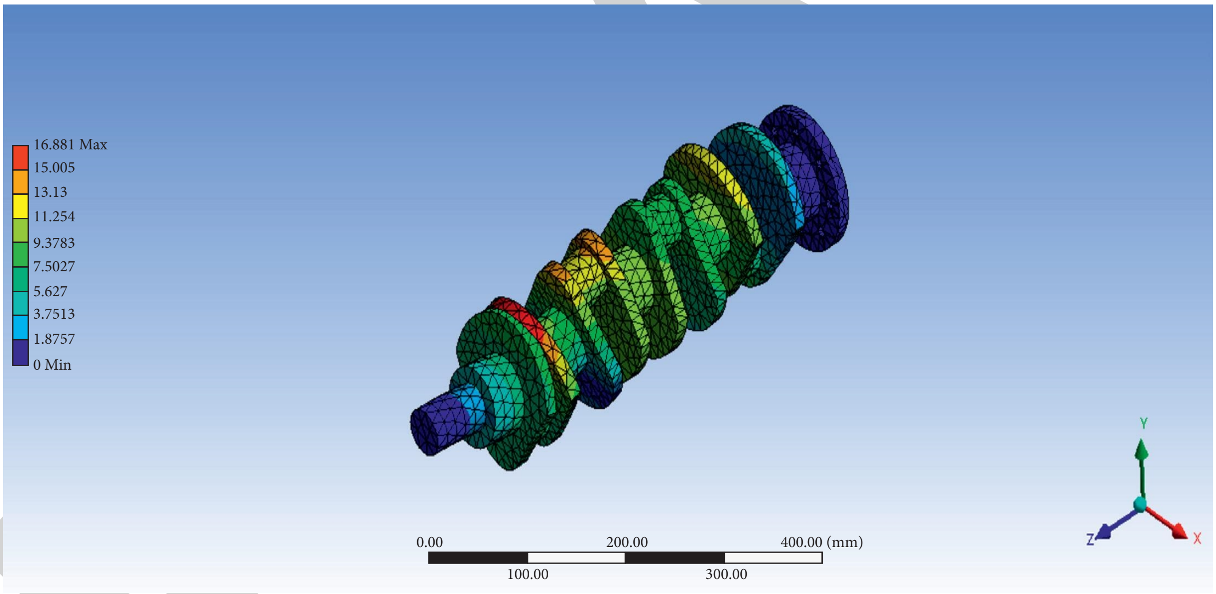

Figure 13: Deformation of carbon fiber composite crankshaft at the third mode of vibration.

oxide (Al_2O_3) and considering equations (1) and (2) are defined and presented in Tables 3 to 6

3. Results and Discussion

3.1. Engine Shaft (Stainless Steel). Stainless steel is an appreciable material for the low torque and power transmission shafts. The following are some essential properties of the engine's selected material [15]

Due to its corrosion resistance, high strength, and capacity to resist fracture, stainless steel is the suitable material to be selected [16]. As a result, it is an excellent choice for working in hostile environments. The set of simulated results from the modal or free vibrations analysis and harmonic analysis or forced vibrations analysis of the stainless-steel crankshaft in ANSYS are presented in Figures 5 to 9 and Table 7. Finally, Figure 10 depicts the frequency response diagram of the engine shaft during vibrations.

The frequency acquired from the mode shapes in ANSYS is represented graphically in Figures 5 to 9. The possible maximum vibrational intensity that will be experienced by the crankshaft is determined by the natural frequencies of

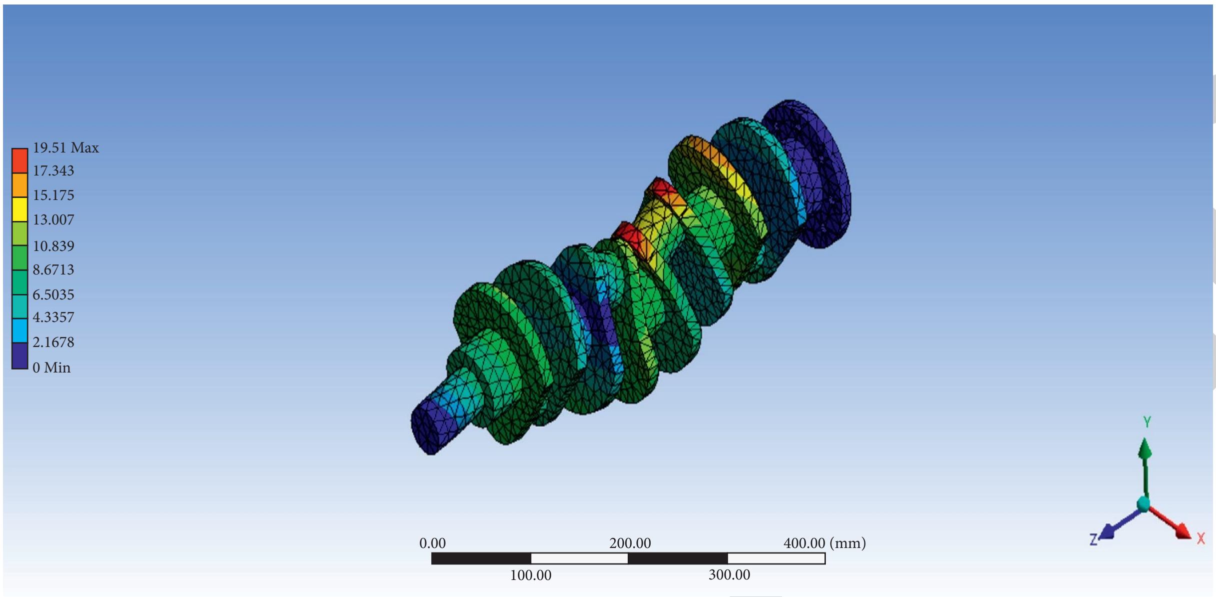

Figure 14: Deformation of carbon fiber composite crankshaft at the fourth mode of vibration.

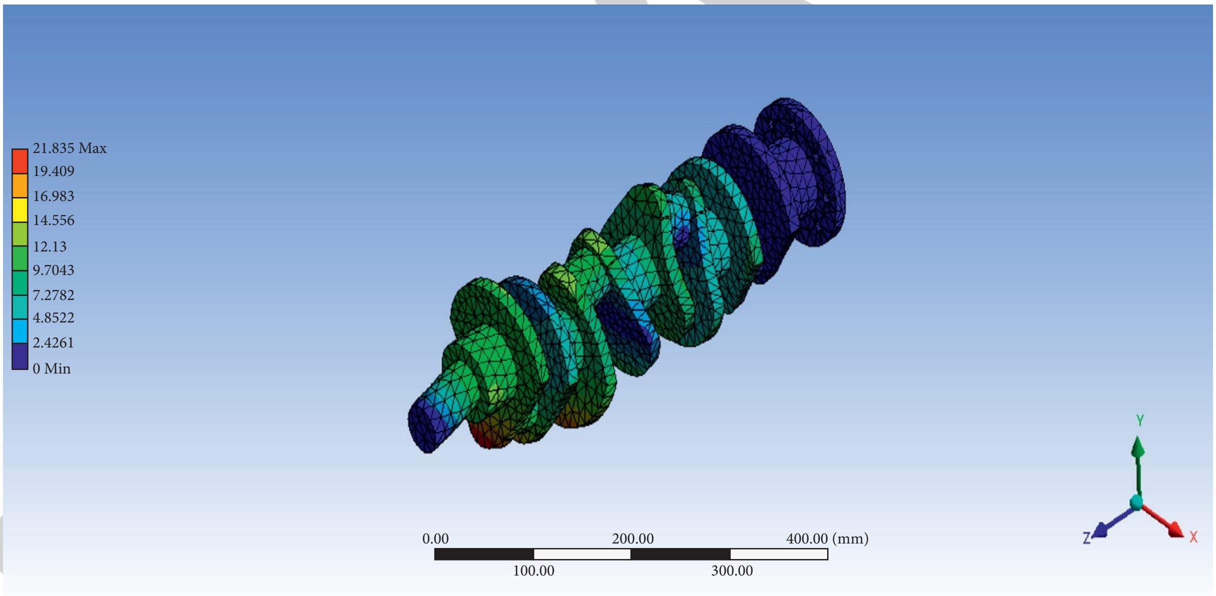

Figure 15: Deformation of carbon fiber composite crankshaft at the fifth mode of vibration.

vibration. In contrast to the minimum, both factors, as well as the number of cycles, have a significant impact in determining the overall deformation. The natural frequencies and vibrational deformation for the three scenarios will then be compared to determine which material shows the best performance for the engine shaft [17, 18].

3.2. Engine Shaft (Carbon Fiber Composite). In this section, we have presented the results of modal and harmonic analysis of the crankshaft made with carbon fiber composite; we will look at whether the material is the best for our engine shaft development. Various tests are undertaken on the three models created in the chase, and the conclusions are expressed later [19, 20]. Carbon composite is known for its stiffness, and it will be compared with other materials in this study.

Figures 11 to16 present the results of modal and harmonic analysis for the carbon composite crankshaft.

While Figures 11 to 15 present deformations at each mode of vibration for the carbon composite crankshaft, the natural frequencies for carbon fiber are shown in Table 8.

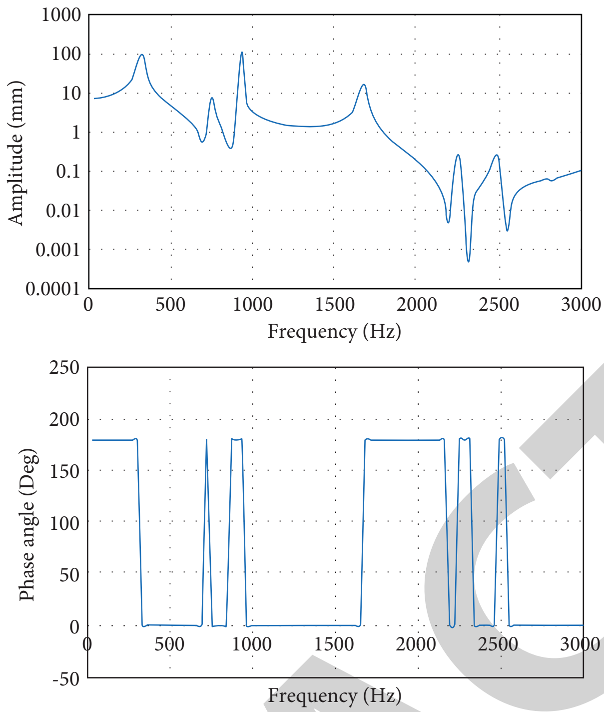

Figure 16: Frequency response diagram of carbon composite crankshaft.

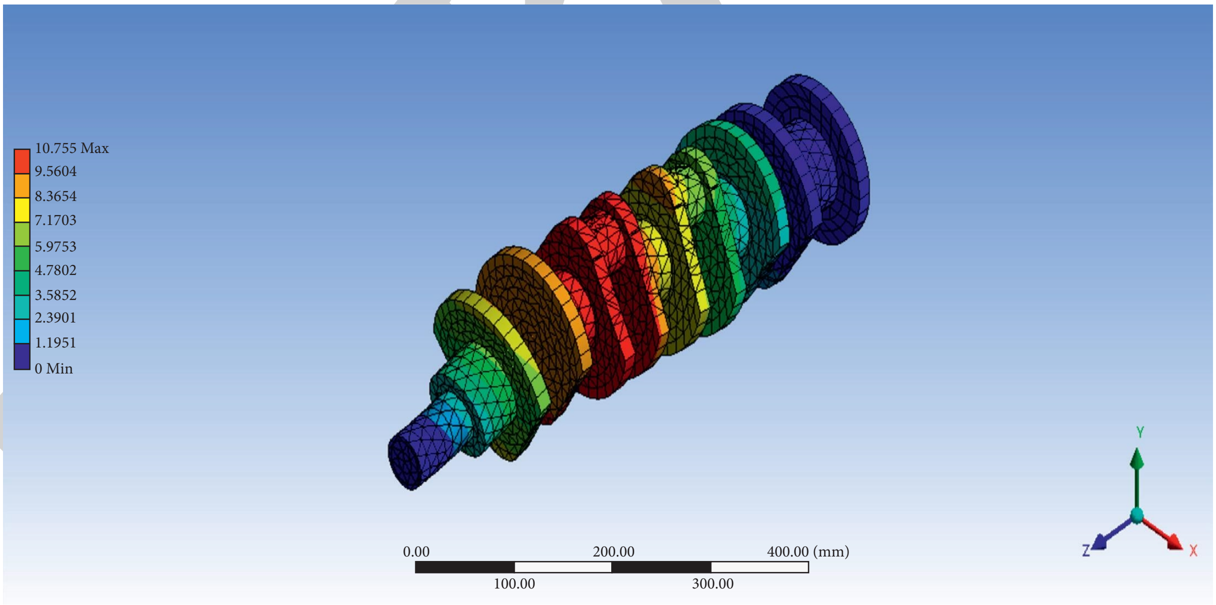

Figure 17: Deformation of FGM crankshaft at the first mode of vibration.

The system response of carbon fiber in frequency domain has been determined using ANSYS shown in Figure 16. The system behavior of the shafts in steady-state reactions will be explored further down [21, 22]. It entails determining how well a thing performs when it is subjected to loads.

3.3. Engine Shaft (FGM). Figures 17 to 21 present the overall deformation of a functionally graded material engine shaft (FGM) during the first five modes of vibration. The overall deformation data from ANSYS show a colored depiction of the stress concentrations in the body. It provides information about the component's most susceptible part. The

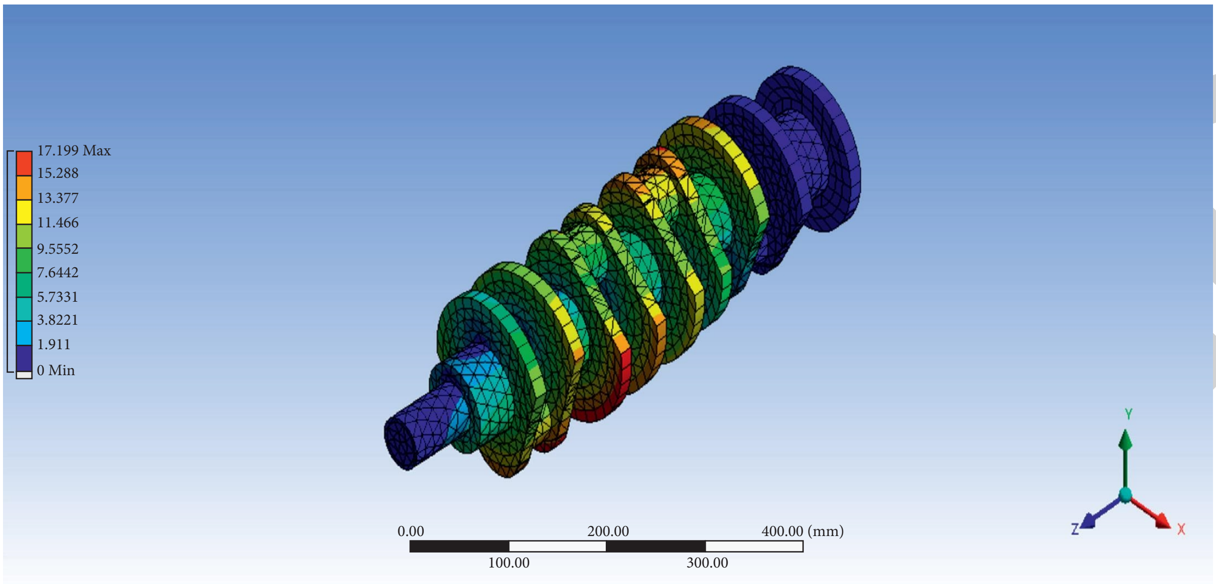

Figure 18: Deformation of FGM crankshaft at the second mode of vibration.

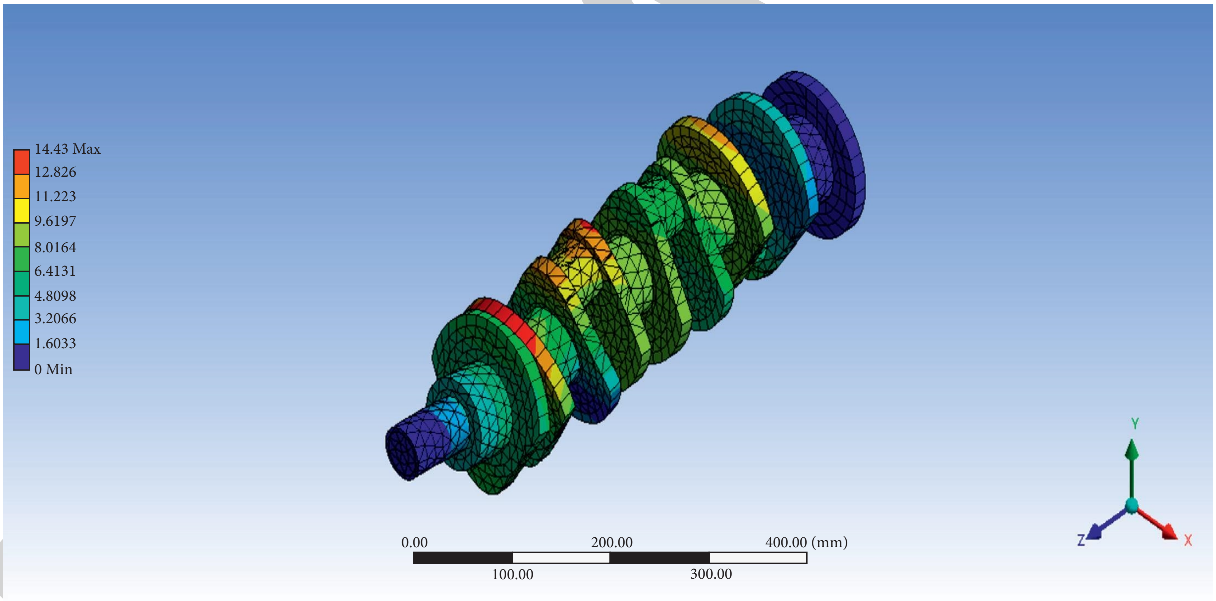

Figure 19: Deformation of FGM crankshaft at the third mode of vibration.

results are tabularized in Table 9 for more clarity. It can be observed that the deformation varies approximately sinusoidally as it increases and decreases interchangeably. In this scenario, stress concentration is largely towards the diameters' margins, resulting in a fatigue failure near the shaft's circumferential boundary [23, 24].

Figures 22 and 23 show the graph of comparisons of the frequency response and natural frequencies from the modal analysis results of the 316 steel, composite, and FGM crankshaft. Considering the amplitude of vibration as shown in Figure 23, the composite crankshaft suffers the highest deformation while on the average, FGM and 316 steel crankshaft suffers almost the same level of deformation. Also, as shown in Figure 24, the FGM crankshaft clearly possesses the far-highest natural frequencies during the first five modes of vibrations followed by 316 steel crankshaft. Such materials like FGM with high values of natural frequencies would certainly offer durability and optimum performance under loading. Going by this analysis, FGM has shown the best performance due to its highest set of natural frequencies and low deformations. This is a very important selection criterion in the design of engine crankshaft.

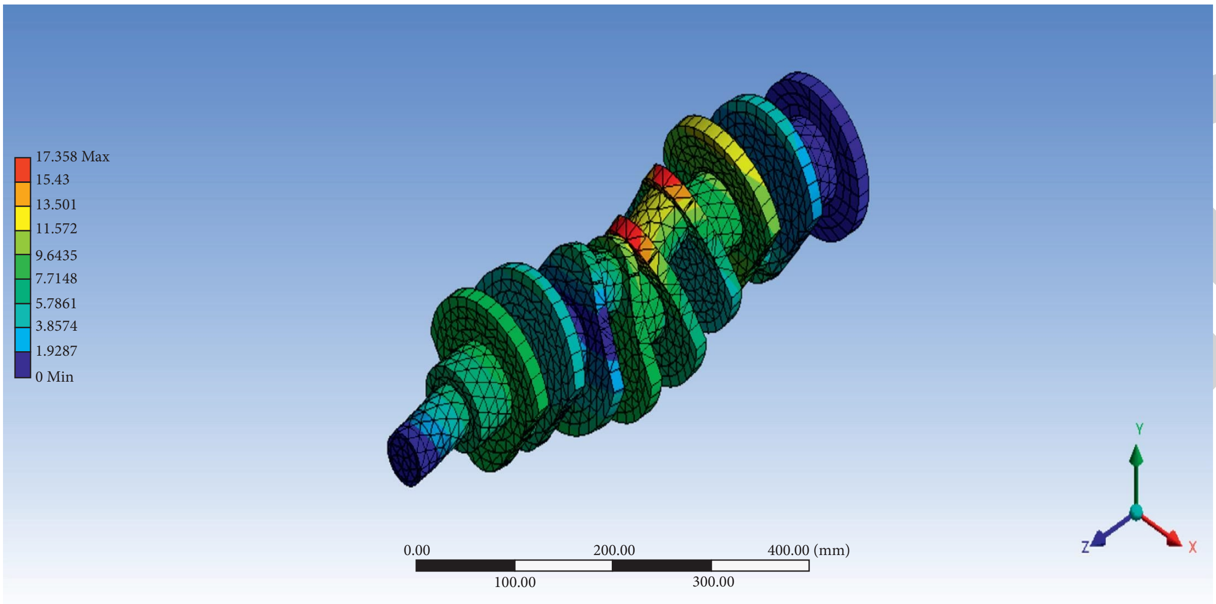

Figure 20: Deformation of FGM crankshaft at the fourth mode of vibration.

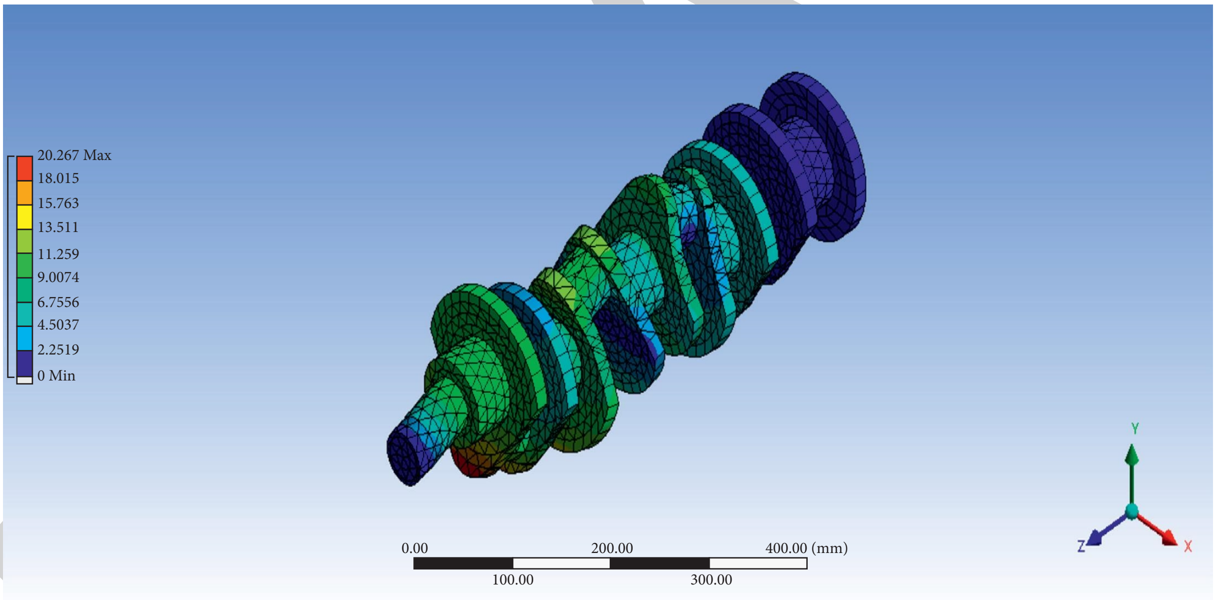

Figure 21: Deformation of FGM crankshaft at the fifth mode of vibration.

Table 9: Modal analysis results of FGM crankshaft.

Modes	Frequency	Deformation (mm)
1	432.26	10.755
2	943.56	17.199
3.	1234.8	14.43
4	2208.9	17.358
5	2943.5	20.267

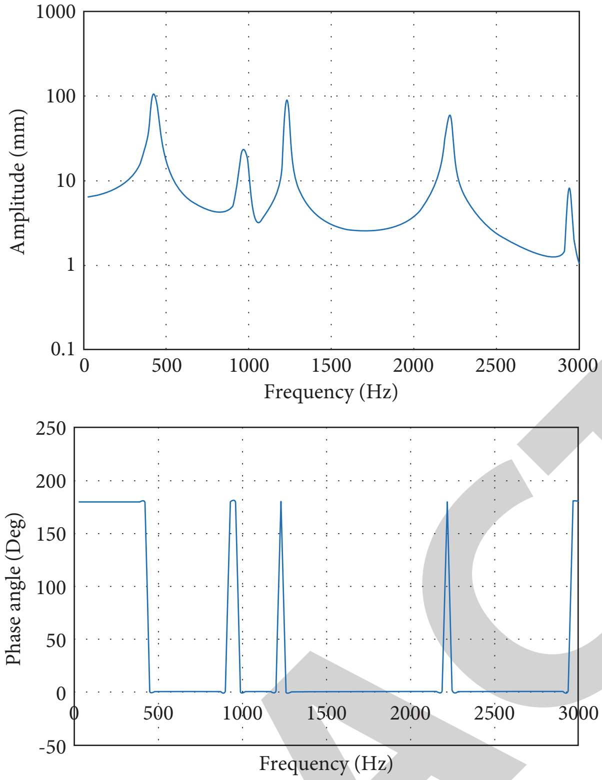

Figure 22: Frequency response of FGM crankshaft at the fifth mode of vibration.

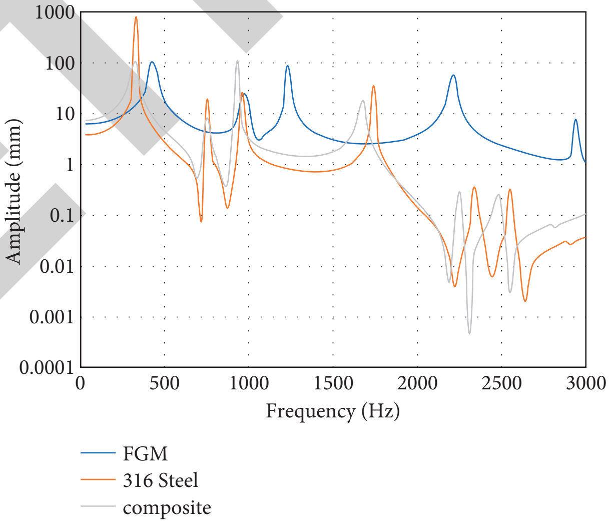

Figure 23: Frequency response diagram of the 316 steel, composite, and FGM crankshaft.

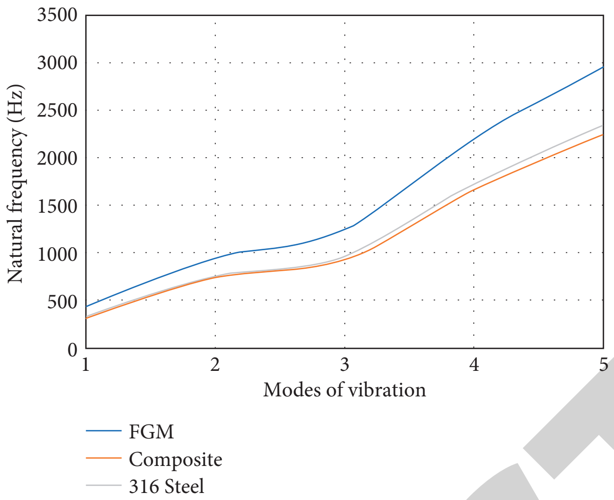

Figure 24: Natural frequencies of the 316 steel, composite, and FGM crankshaft.

4. 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 stainless steel, a composite, and a FGM 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 [25, 26].

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The author declares no conflicts of interest.

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