Static structural and dynamic analysis of cracks in composite materials

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Abstract - *Dynamic material damage analysis is very complicated work and the significance of various alternative pathways is currently unclear. This is primarily due to the difficulties in assessing the complex behaviour of inside material fractures. By modelling of the behaviour of multiple structures such that fundamental mechanics can be understood and vibrations and acoustic signatures can be established. Static & dynamic analysis (simulation) of cracks in composites is done by using FEM method. The static linear & dynamic analysis of CFRP has been done and the case studies of Bicycle Crank Arm grounded on numerical simulation of the functions, which are being used in partition unity framework for modelling tip/crack singularity & discontinuity in the classical FEM.*

With these work model FEM study developed the finite cracked beam and delaminated plate element. The fatigue crack and delamination influence were analysed & studied on developed models with respect to the dynamic characteristics of the CFRP composite. It is observed, there is a strong influence of parameters of material on the changes which are common in anisotropic materials and not exist in isotropic materials. Static structural analysis and dynamic analysis to find natural frequency using Ansys workbench 19.2

Key Words: **simulation, crack, FEM, Ansys and Bicycle Crank Arm**

1.INTRODUCTION

Composite structures with fibre reinforcement became more commonly employed in several diverse areas of manufacturing in recent decades. Composites are becoming more common because of their light wright, high strength, resistance to corrosion, impact resistance and resistance to fatigue loading. In the other side it may be beneficial for structural purposes to use laminated composite materials as replacement for the isotropic material, such as minimizing friction and noise in the machine frames of sheet metal and to improve wear resistance on contact surfaces. Similar to other structural elements, beams are dynamically excited. Reducing the vibration of these systems is a fundamental necessity for engineers.

To ensure that forced loading frequencies and natural frequencies vary significantly for each system, it is important to establish the natural frequencies; in other words, to prevent resonances. Composite materials are an outstanding opportunity to develop components with specifications of dynamic behaviour in relation to these diverse factors. All systems are exposed during service to degenerative implications that may trigger structural flaws, such as fractures, to be triggered which in time contribute to catastrophic structural deficiencies or structural collapse. The value of inspection is also well known in checking the quality of finished goods. The fractures or different faults in elements affect the structure behaviour which are complex in nature and the damping properties and rigidity gets hampered due to this. The natural frequencies of structure therefore provide details on size and location of the damage. The inconvenience of existing inspection technologies prompted engineers to explore alternative methods of continuous surveillance and global structural condition evaluation.

Dynamic structural reactions may provide unique knowledge regarding defects in the structure elements. Modifications in the physical and structural properties attributable to disruption can modify complex reactions, like damping, fashion forms & frequencies. These changes in physical parameters are used to identify the knowledge about injury.

1.1 Fracture and harm mechanics

Many systems and materials suffer from fractures and defects that often contribute to catastrophic effects. The Fracture mechanics approach has been designed to establish deep consideration of these issues in propagation of fractures. Fracture mechanics investigate how cracks or defects spread with the loads in application. It compares experimental findings with the analytical predictions of crack growth and failure. Calculating fracture parameters including stress & strength factors of the crack area, from which crack rate can be measured, allows analytical predictions.

1.2 Advantages of FRP

The advantages of composite materials have led to the advancements of new technologies in building, corrosive, infrastructure, aviation etc. industries. High strength, less weight, the resistance to corrosion, structural versatility are the unique advantages of FRP.

1.3 Mechanism of failure

The FRP beam structures or elements will show following failure modes.

i. Rupture in the FRP: In the max. movement zone the stress in the FRP plates go over its tensile strength.

ii. Failure due to compression: The real strain which is experienced tops the ultimate strain & yield stress will be greater than stress of reinforcement. In this case, due to more compression strain crushing happens.

iii. Failure due to tension: The fibres in the tension zone begin to yield, causing the beam to undergo large inelastic rotations.

iv. Shear failure: If the shear resisting capacity of the beam near the support is lower than the actual shear stress generated on it, shear failure will occur. This may be due to inadequate strength of fibres of the elements.

1.4 Definition of problem and objectives

The design of the component needs to be verified in FEM for principal stress, mode shapes and natural frequencies and also It is necessary to do a material selection activity based on comparison of potential candidates using FEM approach. This will help to optimise the cost, weight and design of the component.

Many experiments have carried out on the impact of crack on complex characteristics, such as normal frequencies and vibration modes of isotropic radiation. However, literature is sparse with studies on the complex behaviour of composite beam with crack. The current study discusses:

1. To study static and dynamic analysis of fibres and matrix of graphite fibre-reinforced polyamide composite with open transverse crack i.e. V-notch for the ANSYS program for the finite element method. To study results of notched and non-notched behaviours.
2. To conduct a case study on behaviour of crack in bicycle crank made up of CFRP material.

2. FINITE ELEMENT APPROACH

Crack effect and different other parameters on the composite's functional properties are studied. The composite beam has been analyzed and linked to the findings previously studied to verify the consistency of the present study. The composite beam has been expected to be unidirectional graphite polyamide fiber-reinforced. The geometric attributes and composite beam's material properties are alike the Krawczuk & Ostachowicz (1995).

The fibers and matrix of the graphite fiber-reinforced polyamide composite properties are shown by f and m, respectively, in below table

Table -1: Graphite fibre-reinforced polyamide composite properties

Modulus of Elasticity	Em	2.756GPa
	Ef	275.6GPa
Modulus of rigidity	Gm	1.036GPa
	Gf	114.8GPa
Poison's ratio	Vm	0.33
	Vf	0.2
Mass density	ρm	1600Kg/m3
	ρf	1900Kg/m3

2.1 Case 1: Analysis of beam without crack

2.1.1 Geometry: A small CFRP block of rectangular cross section (15mm x 30mm x 10mm) has been selected for the study.

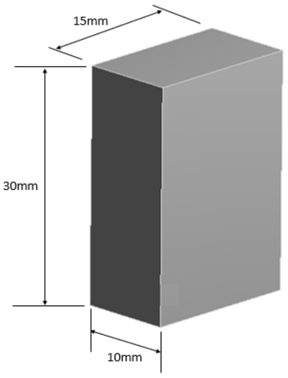


Fig 1: Isometric view of composite model

2.1.2 Meshing: Meshing is done on the selected body with 5143 nodes and 1020 elements

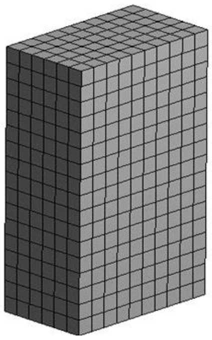


Fig 2: 3D Meshed model of case 1

2.1.3 Boundary condition: Appling boundary condition one end selecting with fixed support and other end applied with force of 2500 N

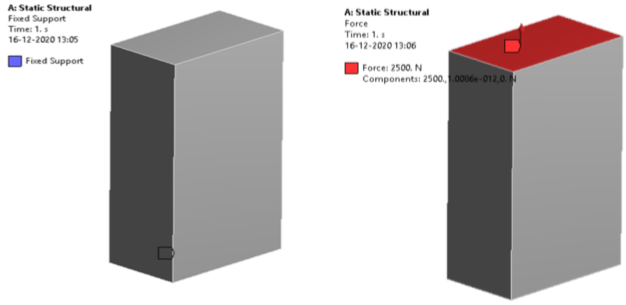


Fig 3: Boundary condition and force application of case 1

2.1.4 Results and observations: Composite body is analysed to understand the Von-Mises Max stress & summarized that the derived Von-Mises Max stress is less than allowable or yield stress (207MPa) and hence the designed CFRP model is safe under applied loading condition.

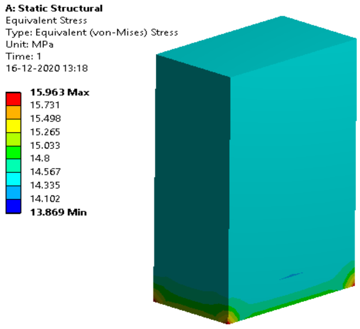


Fig 4: Max. equivalent stress is 15.96 Mpa

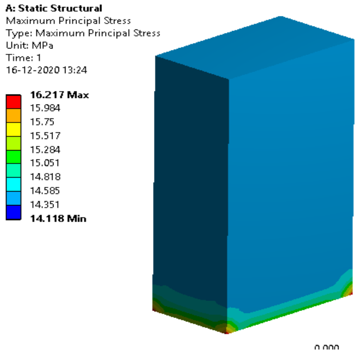


Fig 5: Max. Principal stress is 16.217 Mpa

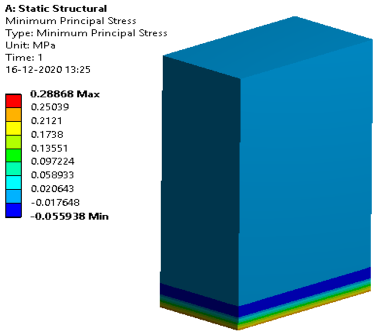


Fig 6: Min. principal stress is 0.28 Mpa

Composite model is analysed to find max. principal stress under given loading condition, min. stress is 0.28866 MPa

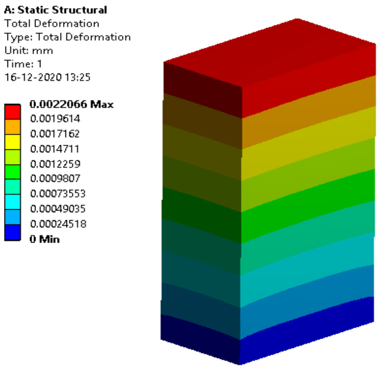
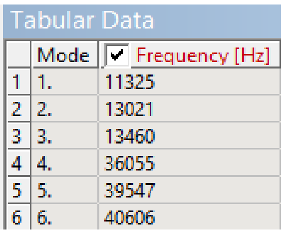


Fig 7: Total deformation is 0.0022 mm

Total maximum deformation is 0.0022 mm for composite material beam without crack for the applied loading conditions

2.1.5 Dynamic analysis: Vibration characteristics, mode shapes & natural freq. can be understood by modal analysis. hence an object is not disturbed by the outside force, the rate at which the object vibrate is called as natural freq. for every DOF there should be unique natural frequency of each object. The designed model can be evaluated whether it's safe or not by carrying out modal analysis. In modal analysis diff. modal freq. are calculated under vibrating conditions. The designed beam element is safe within vibrating conditions as the calculated modal frequencies are not exceeding max. vibrating conditions

Table 2: Six initial modes and corresponding natural freq.


Tabular Data

	Mode	☑ Frequency [Hz]
1	1.	11325
2	2.	13021
3	3.	13460
4	4.	36055
5	5.	39547
6	6.	40606

2.2 Case 2: Analysis of beam with crack

2.2.1 Geometry: A small **cracked** CFRP block of rectangular cross section (15mm x 30mm x 10mm) has been selected for the study.

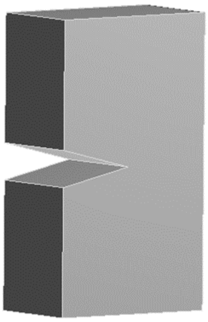


Fig 8: Isometric view of cracked composite material beam-case 2

2.2.2 Meshing: Meshing is done on the selected body with 8565 nodes and 5954 elements

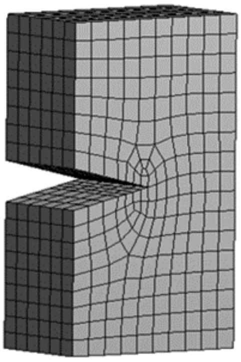


Fig 9: 3D Meshing FEM model which is Hex Dominant is utilised.

2.2.3 Boundary condition: Appling boundary condition one end selecting with fixed support and other end applied with force of 2500 N

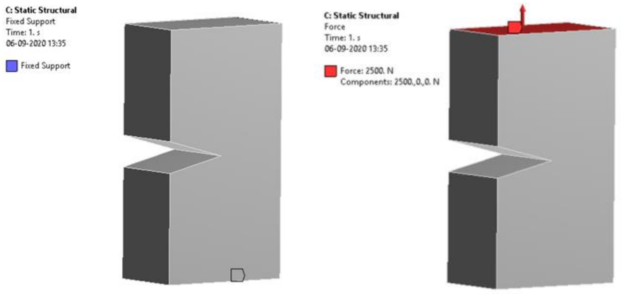


Fig 10: Boundary condition and force application of case 2

2.2.4 Results and observations

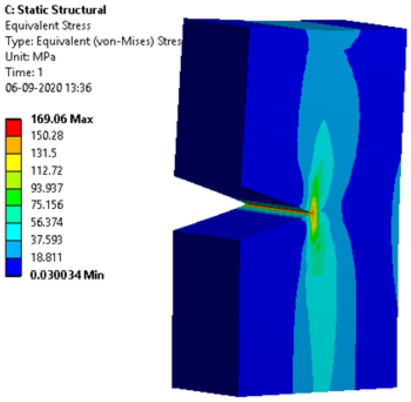


Fig 11: Max. equivalent stress is 169.06 Mpa

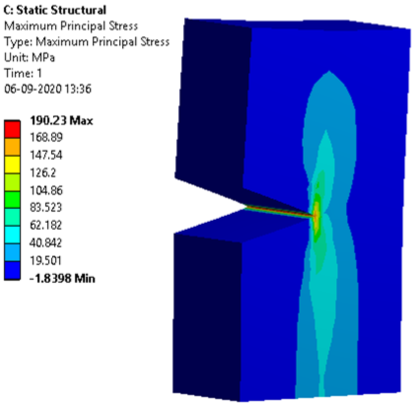


Fig 12: Max. Principal stress is 190.23 Mpa

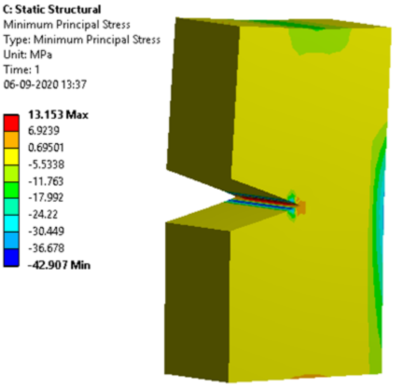


Fig 13: Min. principal stress is 13.153 Mpa

Composite model is analysed to find max. principal stress under given loading condition, min. stress is 13.153 MPa

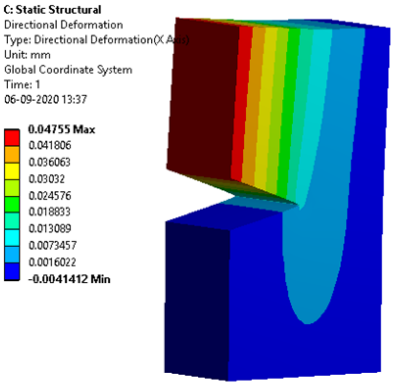
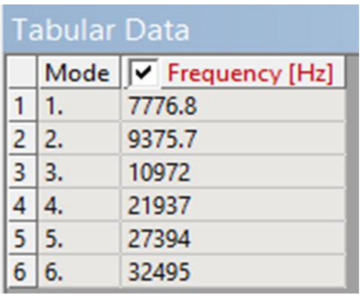


Fig 14: Total deformation is 0.047 mm

Total maximum deformation is 0.047 mm for composite material beam with crack for the applied loading conditions

2.2.5 Dynamic analysis:

Table 3: Six initial modes and corresponding natural freq.



Tabular Data

	Mode	☑ Frequency [Hz]
1	1.	7776.8
2	2.	9375.7
3	3.	10972
4	4.	21937
5	5.	27394
6	6.	32495

Table 4: Below table explains the behaviour difference between the crack and without crack composite materials

	CASE STUDY'S	EQUIVALENT STRESS (Mpa)	TOTAL DEFORMATION (mm)
01	Case 1 (without crack)	15.30	0.0022
02	Case 2 (with crack)	169.06	0.0470

Table 5: Natural frequencies of case1 and case 2

Sl. No	Modes	$F_{(n)}$ Case 1- without crack (Hz)	$F_{(n)}$ Case 2 – with crack (Hz)
1	1	11325	7776.8
2	2	13021	9375.7
3	3	13460	10972
4	4	36055	21937
5	5	39547	27394
6	6	40606	32495

3. CASE STUDY: Modelling and Analysis of Bicycle crank

The In recent years, the bicycle industry has seen a breakthrough. The industry's technical advancement is due to the need for more result-oriented demands, Cycling is affordable, safe, balanced and healthy way of transportation. To increase the success of elite cycling athletes, required is a lesser weighing and heavy rigid frame. Several of bicycle's structural components are made up of some materials like titanium, carbon fibre & aluminium alloy. Furthermore, any improvement on a bicycle must take into account. It is important to consider safety and security of the person who is doing cycling as serious injury can happen to the rider if any parameter is missed in designing the bicycle.

The crank arm is an essential part of a bicycle. It transmits the force applied to the pedal by the rider in turn to the crank. One should select materials for the construction of crank needs be strong enough to withstand torsion loading and withstand mixed flexion with no cracks and no other damages. Damage will be caused by the gradual degradation of stiffness as a result of operating loadings, which results in an accidental failure. The crank handle, according to the Standardization Committee of Europe, for technical use a crank member has to withstand 1000,000 load cycles and there should not be any failure.

Aluminium alloys 7000 (cold finished or rolled bar) are being widely used in industry for manufacturing the crank. Aluminium alloys provide mechanical properties such as good machinability, good efficiency in cyclic loading and less cost. Simulation models were utilised to reduce the cycle time of new product development and expense while maintaining product durability. However, tests are needed to validate and verify computational models.

ANSYS was utilised to build a computational representation of cycle crank. The model can be validated using FEM findings that account for possible causes of ambiguity. According to the simulation, the crank may meet required safety criteria while still exhibiting plastic strain areas. This causes residual discomfort, which increases the chance of premature crank arm collapse and, as a result, damage to the passenger.

Fig 15: Bicycle crank with chain sprocket

3.1 Geometry: Following is the Model of Bicycle crank. Analysis of the crank is being done to study the strength of CFRP with crack.

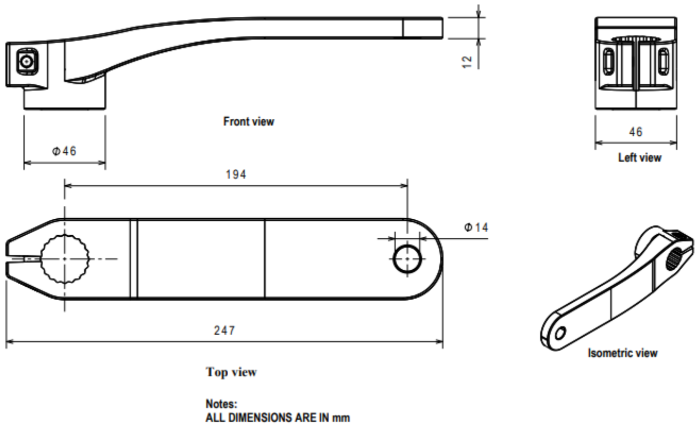


Fig 16: Bicycle crank design for the study

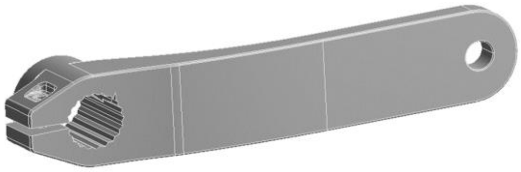


Fig 17: Bicycle crank design ISO view for the study

The existing crank in market have been measured and studied to prepare the CAD model in Catia V5. Hypermesh and ANSYS as post processor are being utilised to conduct the finite element analysis

3.2 Three-dimensional CAD model: The parametric model is being created by studying the common entry level crank in market. There is no attempt to add the cosmetic or additional features to the model.

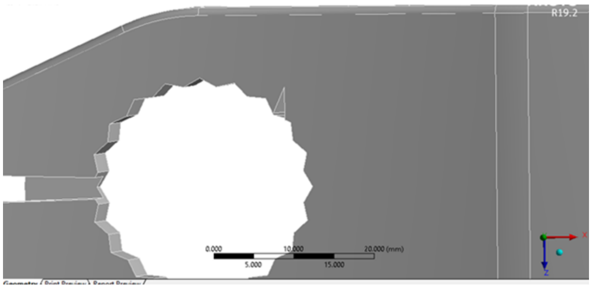


Fig 18: Bicycle crank design zoomed view for the study

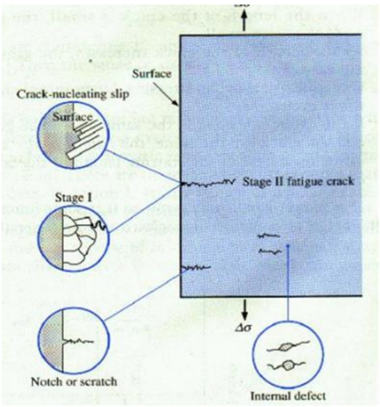


Fig 19: Crack growth stages

Stress field magnitude and material of the component are the two variables which decide the time need for initiation of the crack and grow sufficiently furthermore to cause failure.

3.3 Meshing model:

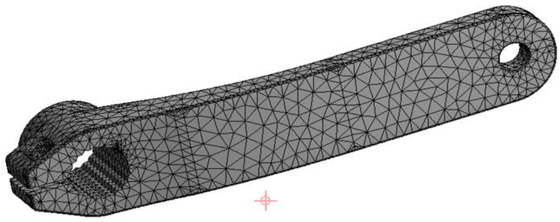


Fig 20: Crack Meshing model

Referring to above figure, using tetrahedral elements, the crank is being meshed automatically in the s/w Ansys workbench. Using three element sizes (0.2, 0.3, 0.4 inch) the mesh convergence study is done. 1% difference is seen in the static Von Misses results.

Every component is made up of finite number of particles so they would need to be divided in finite number of units. The meshing process divides a part in finite numbers which helps calculation of stress, strain and deformations.

3.4 Boundary conditions: The created model is applied with the boundary conditions. 1960N vertically downward force is acting vertically downwards on the end of pedal. Other side of the crank is fixed.

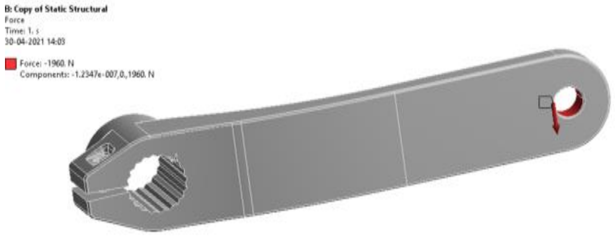


Fig 21: Application of force on the crank

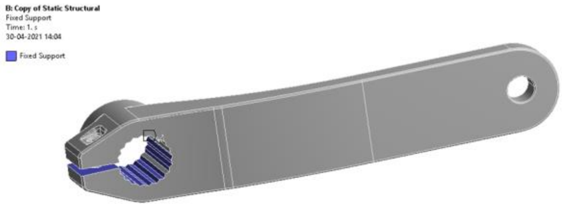


Fig 22: Fixed support of crank

3.5 Results and observations: Nonlinear static analysis

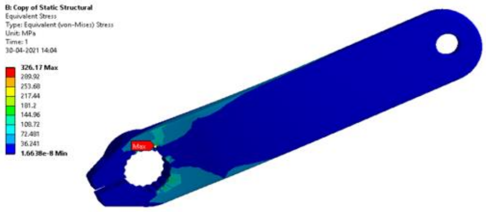


Fig 23: The maximum Von Misses stresses obtained is 326.17 N/mm^2 at the fillet or neck region indicated in red colour as shown in the figure for applied load condition

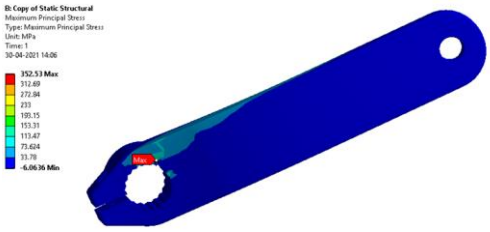


Fig 24: The maximum principal stresses obtained is 352.53 N/mm^2 at the fillet or neck region indicated in red colour as shown in the figure for applied load condition

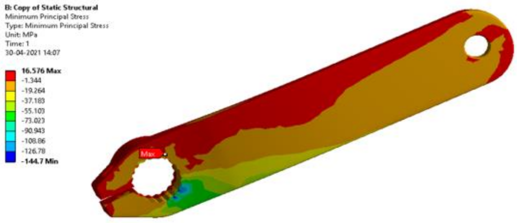


Fig 25: The minimum principal stresses obtained is 16.53 N/mm^2 at the fillet or neck region indicated in red colour as shown in the figure for applied load condition

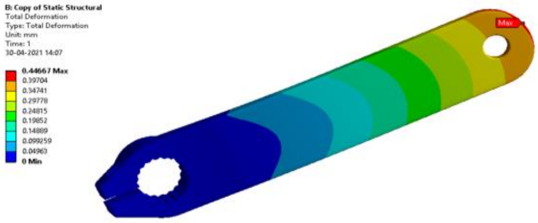
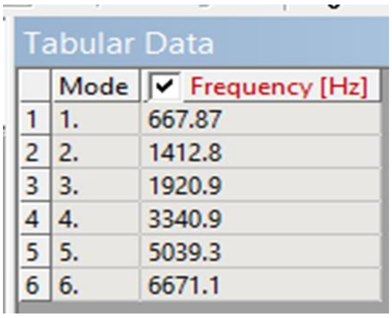


Fig 26: The Maximum total deformation 0.4466 mm for the applied load condition

3.6 Dynamic analysis:

Table -6: Initial six modes and corresponding natural frequency



Tabular Data

	Mode	☑ Frequency [Hz]
1	1.	667.87
2	2.	1412.8
3	3.	1920.9
4	4.	3340.9
5	5.	5039.3
6	6.	6671.1

4. CONCLUSION:

The following results may be arrived at by considering the latest studies of the finite portion of the composite beam getting a cross-cut open crack. This factor is flexible and can be used to evaluate the composite beam statically and dynamically.

- The equivalent stress of beam without crack is 10 times lesser than the equivalent stress of beam with crack. Also, the deformation has been increased by 20 times by adding the crack in the beam.

- For a composite cracked beam, as the fibre angle (α) raises the importance of Natural frequencies are also increasing. The most frequency variations arise.

- Decrease in natural frequency by adding the crack is being witnessed. Also Decline in natural frequencies when the depth is increased.

Future job spectrum

1. The effects of vibrations produced by ANSYS 19.2 can be confirmed by experiments.

2. The composite beam dimensional stability with cracks.

4. The study of vibration of substances by adding inclined cracks and transverse crack.

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