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Natural frequency response to the angle and size of oblique crack in an isotropic hyper composite beam

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Abstract
The present work investigates beam natural frequency that includes the effect of oblique crack damage with variable parameters such as crack size and location. This study was investigated both numerically and experimentally. The predicted results were compared to the measured data, where a good agreement has been observed. The beam natural frequency is evaluated for beam composite materials compound from polyester resin materials reinforced with two materials, which are glass short fiber and glass powder. The natural frequency is evaluated for different design parameters, which for composite material are the volume fractions of resin, fiber, and powder; while for crack effect they are the location, size, and orientation of the crack. The experimental results of natural frequency were evaluated through manufacturing composite beam samples, forming crack on it, testing it with vibration machine to measure the natural frequency. To numerically predict the natural frequency, tensile test samples of composite materials are manufactured firstly and then tested by tensile machine to find their mechanical properties, which are required as input data to the ANSYS Mechanical APDL commercial code. The natural frequency comparison has shown that the maximum error between the experimental and numerical data does not exceed 10.63%. The results reveals that increasing the crack orientation results in an enhancement in the natural frequency due to the reduction in the vertical crack component, while the increase in the crack size and location causes a decrease in the natural frequencies.

Keywords: Composite materials; Vibration beam; Hyper composite materials; Mechanical properties; Finite element; Vibration ANSYS; Crack beam; Oblique crack.

1. Introduction
The significant applications of beam in the engineering field are self-evident. Beam experiences several loads. Numerous sorts of loading may cause cracks in beam. These cracks and their locations have impact on the shapes and estimations of the beam frequency. As of late, these themes are so overarching in the business of rocket, planes, turbines, robot arm, wind turbines and numerous different implementations [1]. The crack challenge is the essential issue in the investigating of material resistance. Considering the crack as a significant form of such harm, its modeling is an important step in studying the behavior of damaged structures [2].
All framework are disposed to harm, might be expected to over stressing in operation or because of extraordinary ecological conditions or any inadvertent occasion. Introduce the crack in the segment may develop amid administration and bring about the part disappointment once they develop past a basic

utmost. It is alluring to research the harm happened in the structures at the early level to shield the structures from conceivable disastrous disappointments, [3].

Cracks or different imperfections in an auxiliary component impact its dynamical conduct and change its properties of damping and stiffness. Subsequently, the structure's mode shapes natural and frequencies are containing data about the location and dimensions of the harm. Vibration investigation, which utilized to distinguish auxiliary imperfections, for example, cracks of any structures shows a compelling, cheap and quick method for nondestructive testing, [4].

Numerous studies were performed to analyze the vibration and element of cracked beams and hyper composite structure vibration,

Muhannad Al-Waily [5] and [1], in these explores a cracked beam natural frequency with various supported beam "clamped and simply", is examined analytically and numerically by "F.E.M. ANSYS program version fourteen", [5], "analytically and experimentally", [1], with various crack length and position impact and the outcomes are looked at. The expository after effects of a continuous beam crack are computed the proportionate firmness, "EI"; to the beam "rectangular shape" include a function of exponential with length and position of crack impact, with arrangement of expecting beam equivalent stiffness (EI) by utilizing the series technique "Fourier series". Also, the diverse materials of beam examined with various length, length and position impact of a crack.

Furthermore, 'Muhannad Al-Waily [6]', the determination beam equation of motion is recommended solution "analytical solution" to impact of oblique crack on the beam frequency with included the impact orientation of crack stiffness beam "EI" with figured the proportionate stiffness beam to include an function with length, position and appointment of crack orientation impact, with arrangement of expecting beam equivalent stiffness "EI" by utilizing strategy of Fourier series. A cracked beam frequency "simply supported beam" is researched analytically, with arrangement of public condition of movement pillar with slanted break impact, and numerically by ANSYS, for various crack length, position and crack orientation impact and the outcomes are thought about.

Notwithstanding,'Muhannad Al-Waily and Alaa Abdulzahra Deli, [7]', in this examination the buckling load of a cracked beam is researched analytically by arranging the beam general equation with impact of crack and numerically by "F.E.M. ANSYS program version fourteen" with various crack length and position impact and the outcomes is analyzed. The analytical consequences of the impact of a continuous beam crack by ascertaining the rectangular beam identical stiffness to include an exponential function with length and impact the position of crack, with arrangement of accepting comparable beam stiffness utilizing the strategy of Fourier series. Also, the materials of beam are examined diverse materials of beam with various beam length, width and length beam.

Kaushar H. Barad et al [3], amid the most recent couple of decades, extreme research on the identification of crack utilizing the vibration based procedures has been completed and different methodologies have been created by specialists. In the displayed paper, discovery of the break nearness on the beam exterior sort auxiliary component utilizing natural frequency is exhibited. Initial two cracked beam natural frequency are gotten tentatively and utilized for identification the size and position of crack. Additionally, the impact of position and length of the crack on the natural frequency is introduced.

Ashish K. Darpe [8], a rotor with modal of finite element contained crack inclination is exhibited. In view of break mechanics, another adaptability lattice for the inclination crack is inferred that records for the extra stretch stress calculates because of introduction of the break contrasted with crack transverse. Examination between rotor with inclination and crack transverse is made as to the stiffness and coupled vibration reaction qualities. Contrasted with transverse break, the matrix of stiffness for inclination crack is more populated with extra cross coupled coefficients. The impact of edge for introduction of the inclination crack on the stiffness qualities is additionally explored.

The motivation behind the present work is assessed the beam natural frequency with impact of crack angle orientation with various crack length and position. The displayed paper examined the experimental and numerical examination of oblique crack impact of hyper composite materials beam. The fundamental diverse between this work and other worked of crack beam is the contemplated the impact of crack angle on the vibration beam hyper composite materials beam with experimental study and correlation the outcomes with numerical strategy.

2. Experimental work

The experimental work includes two sections. The first concerns with measuring the mechanical properties, i.e. modulus of elasticity, for the hyper composite materials made out of polyester resin, short fiber, and powder reinforcement having different volume fractions of reinforcement and resin materials. The second part includes natural frequency assessment for hyper composite beam under various crack sizes, locations, and orientations.

2.1 Tensile test sample made with dimensions

The tensile test of hyper composite beam includes evaluation of the modulus of elasticity for hyper composite beam with different volume fraction effect dependents onto the ASTM Number (D3039/D03039M), [9]. The weight required for resin, reinforcement fiber and powder for tensile samples manufactured is presented in Table 1, it evaluated with depending onto the density of resin and reinforcement fiber and powder and the volume of sample made, and evaluated by,

$$w_{reinf} = \rho_{reinf} * Length * Width * Thickness * Reinforcement\ Volume\ Fraction$$
$$w_{resin} = \rho_{resin} * Length * \mathrm{Width} * Thickness * Resin\ Volume\ Fraction \quad (1)$$

Where, w_{reinf}, w_{resin} weight of resin and reinforcement required, respectively, and, ρ_{reinf} *and* ρ_{resin} density of reinforcement and resin materials, respectively, can be using as, [10],

- Glass short reinforcement fiber density $= \rho_s = 2000\ \mathrm{kg/m^3}$
- Glass powder reinforcement density $= \rho_p = 2400\ \mathrm{kg/m^3}$
- Polyester resin density$= \rho_{resin} = 1200\ \mathrm{kg/m^3}$ (2)

Where, the tensile sample made with dimensions,

- Length of total tensile sample $l_s = 20\ cm$
- Width of total tensile sample $w_s = 18\ cm$
- Thickness of total tensile sample $t_s = 5\ mm$ (3)

Table 1. Weight required for tensile test sample shown in Eq. 3.

Sample No.	Short fiber Materials		Powder Materials		Resin Materials	
	Volume Fraction $\forall_s$ (%)	Weight (g)	Volume Fraction $\forall_p$ (%)	Weight (g)	Volume Fraction $\forall_{resin}$ (%)	Weight (g)
1	0	0	0	0	100	216
2	20	72	0	0		
3	10	36	10	43.2	80	172.8
4	0	0	20	86.4		
5	30	108	0	0		
6	15	54	15	64.8	70	151.2
7	0	0	30	129.6		

Then dividing the sample to five tensile samples, as shown in Figure 1, and testing to evaluate the modulus of elasticity of composite materials to five samples for each volume fraction. Afterward, the average values of modulus of elasticity of each volume fraction can be computed, as shown in Table 2. The tensile test sample testing by tensile test machine, shown in Figure 2, are made with dimensions as, [11],

- Length of tensile sample $l_t = 20\ cm$
- Width of total tensile sample $w_t = 3\ cm$
- Thickness of total tensile sample $t_t = 5\ mm$ (4)

2.2 Vibration beam samples made with dimensions

The experimental vibration work includes manufacturing the vibration beam sample combined from polyester resin materials, short reinforcement fiber and powder reinforcement with different volume fraction and with various crack angle, size, and location, shown in Figure 3. The beam composite material natural frequency with effect of crack parameter's and different reinforcement's volume fraction can be evaluated then by using vibration test machine.

Table 2. Modulus of Elasticity for hyper composite materials with different volume fraction (GPa).

Testing Sample	Tensile Test Sample No.						
	1	2	3	4	5	6	7
S_1	3.61	9.41	7.88	5.42	12.58	10.35	6.9
S_2	3.58	9.28	7.62	5.67	12.67	10.28	7.25
S_3	3.82	9.65	7.67	5.92	12.58	10.21	7.18
S_4	3.91	9.84	7.28	5.27	12.74	9.84	7.11
S_5	3.43	9.92	7.95	5.92	12.83	10.12	7.36
Average	3.67	9.62	7.68	5.64	12.68	10.16	7.16

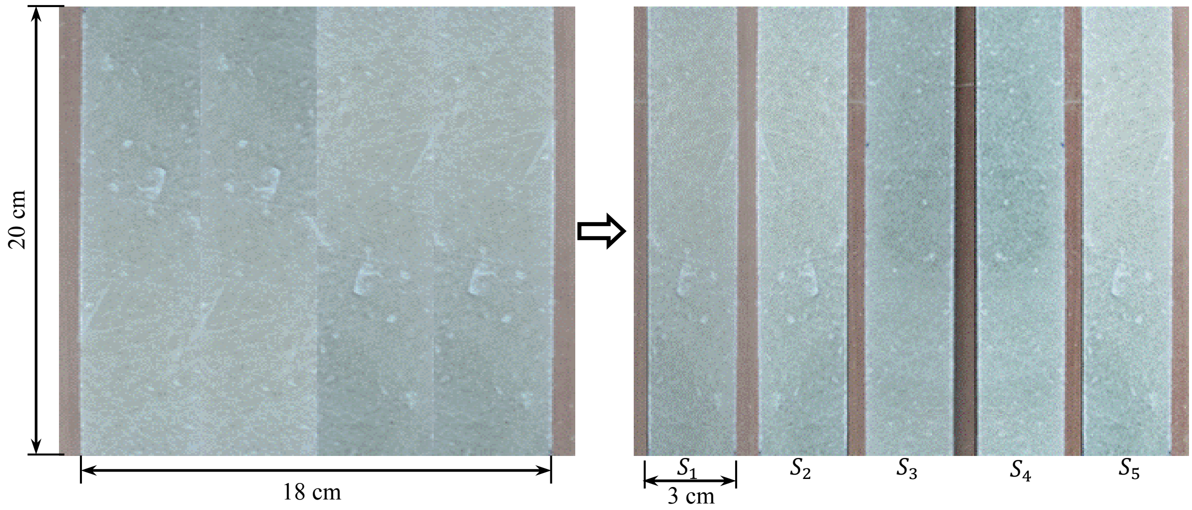


Figure 1. Tensile test sample.

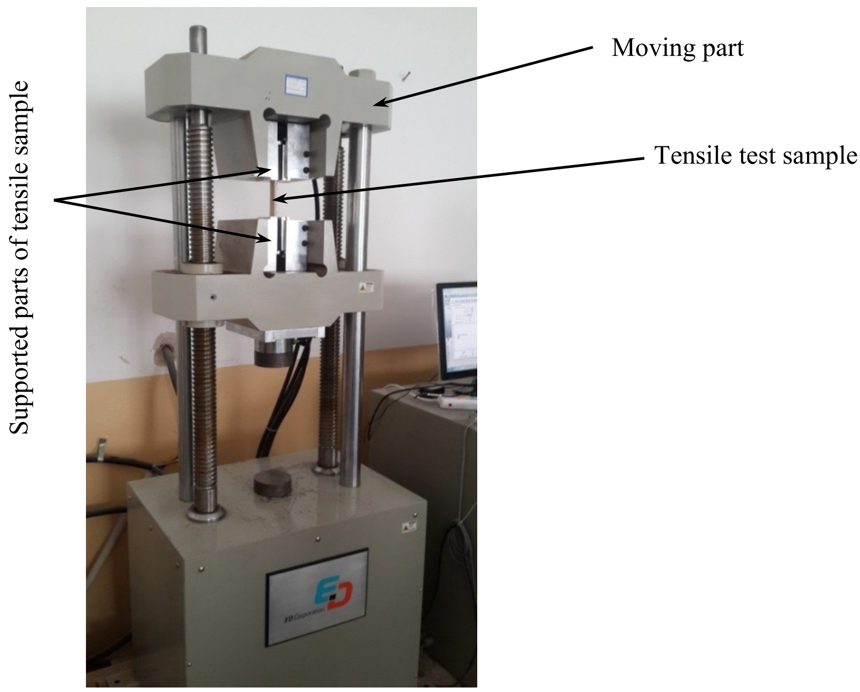
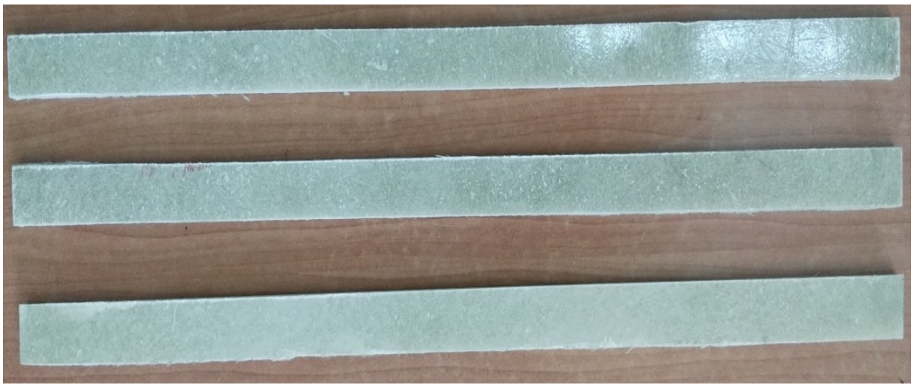


Figure 2. Tensile test machine.

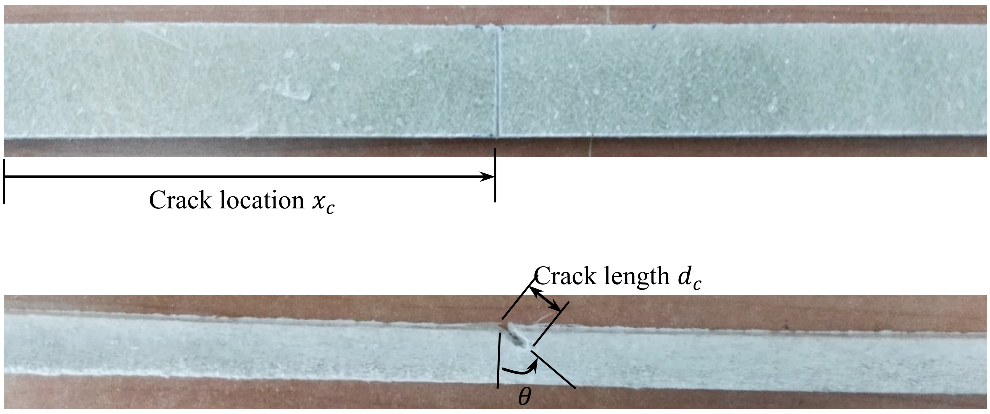
The vibration test of beam sample (simply supported beam) is done by using the vibration test machine shown in Figure 4, where, the vibration test machine has the following parts, ‘structure rig’, ‘accelerometer, model "(352C68)", with sensitivity (10.2mV/(m/s^2) measurement domain (491m/s^2), mounted resonant frequency "(≥35KHZ), non-linearity "(≤ 1%)"’, ‘amplifier, type 480E09)"’, and ‘digital storage oscilloscope, model (ADS1202CL) and serial No.01020200300012., with max. frequency (200MHz), max. read of sample per second (500MSA/s), (F.F.T.) spectrum analysis and two input path’. The vibration beam manufactured with dimensions, as,

- The length of beam= $l = 50\ cm$
- The width of beam= $w = 2\ cm$.
- The depth of beam= $h = 1\ cm$.

The required weight of resin and reinforcement powder and fiber required to manufacture vibration beam samples depended on the volume fraction are shown in Table 3.
The natural frequency of the beam evaluated by supplying impact load on the beam and read the signal from storage oscilloscope given from Accelerometer and Amplifiers, as shown in flow chart in Figure 5. The signal taken from the storage oscilloscope with FFT are then analyzed by using sig-view program and evaluated the natural frequency of beam, as shown in Figure 6.
Therefore, the parameters studied for crack effect onto the natural frequency evaluated for beam are shown in Table 4, with different volume fraction resin and reinforcement effect.



(a) Beams without crack.



(b) Beam with crack effect.

Figure 3. Dimensions vibration beam Sample with and without crack.

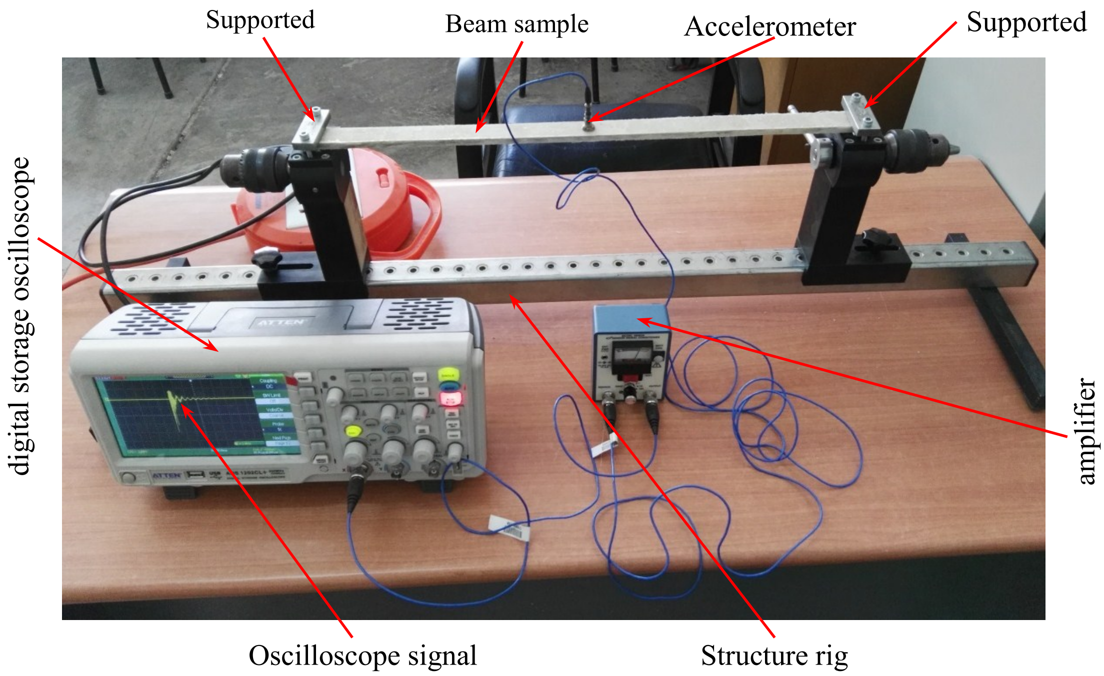


Figure 4. Vibration test machine.

Table 3. Required weight of resin and reinforcement powder and short fiber of beam sample.

Sample No.	Short fiber Materials		Powder Materials		Resin Materials	
	Volume Fraction (%)	Weight (g)	Volume Fraction (%)	Weight (g)	Volume Fraction (%)	Weight (g)
1	0	0	0	0	100	120
2	20	40	0	0	80	96
3	10	20	10	24		
4	0	0	20	48		
5	30	60	0	0	70	84
6	15	30	15	36		
7	0	0	30	72		

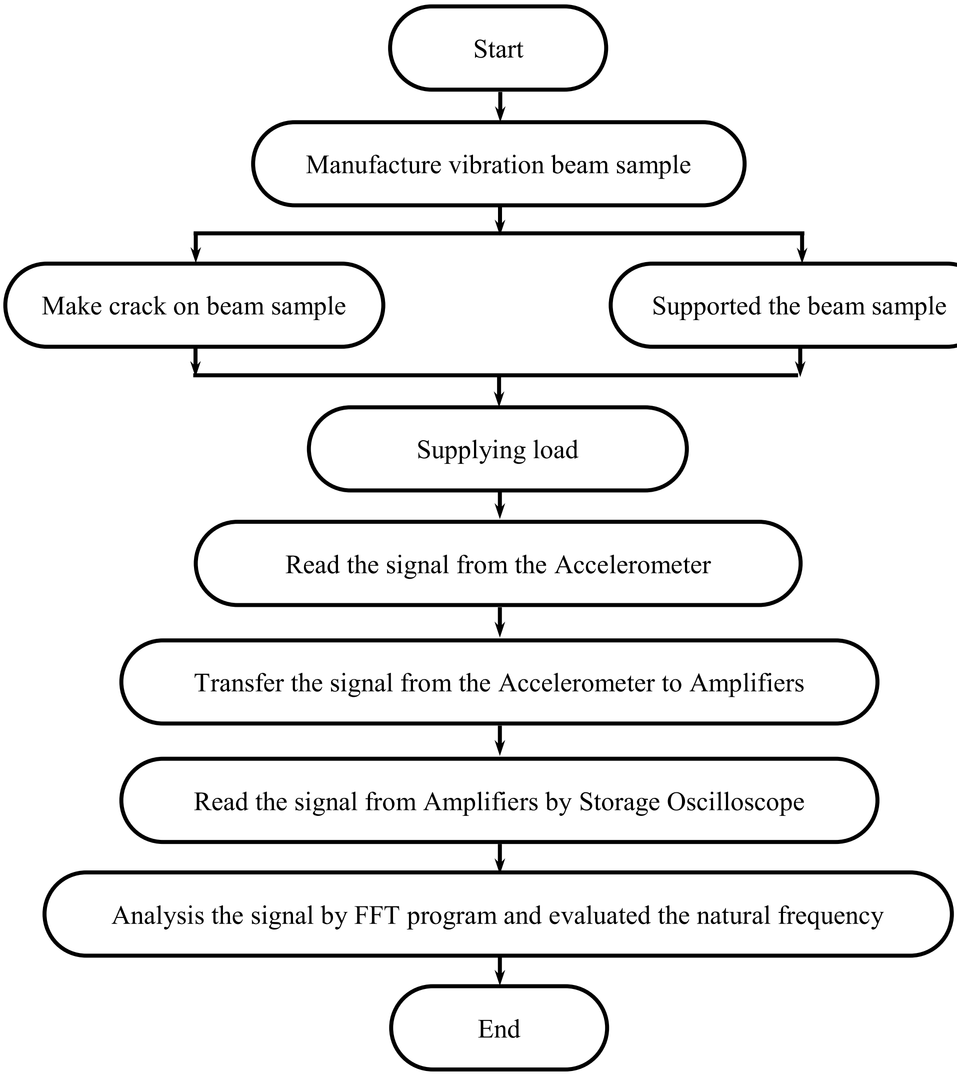


Figure 5. Flow Chart of stepping of vibration test beam.

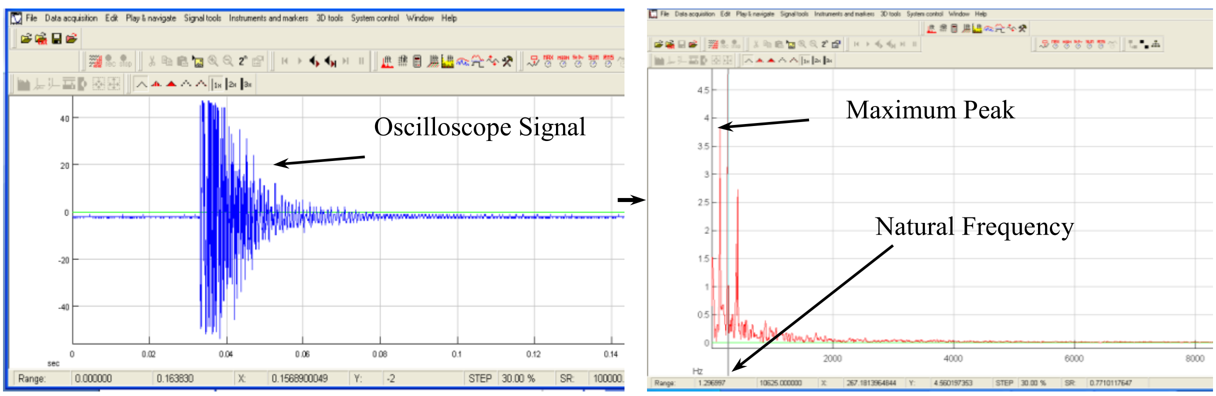


Figure 6. Analysis of storage oscilloscope signal by FFT.

Table 4. Crack Parameters Studied in experimental work.

Crack location x_c	Crack length d_c	Crack angle
$0.15 * l$	$0.25 * h$	$0^o, 15^o, 30^o, 45^o, 60^o, 75^o, 90^o$
	$0.5 * h$	
$0.5 * l$	$0.25 * h$	
	$0.5 * h$	

3. Numerical modeling

The numerical investigation of oblique crack beam focuses on assessing the beam natural frequency taking into account the impact of crack orientation for various crack positions and sizes through utilizing the ANSYS Mechanical APDL commercial code. The "F.E.M. ANSYS program version fourteen" is utilizing the three dimensional model were assembled and the component (SOLID185), [6].
SOLID185 is utilized for 3-D modeling of strong structures. It is characterized by eight hubs having three degrees of flexibility at every hub: interpretations in the nodal x, y, and z bearings. The component has plasticity, hyperelasticity, stress stiffening, crawl, expansive redirection, and extensive strain capacities. It additionally has blended detailing ability for reenacting distortions of almost incompressible elastoplastic materials, and completely incompressible hyperelastic materials. The geometry and hub positions for this component are appeared in Figure 7. The component is characterized by eight hubs and the orthotropic material properties. The default component arranges structures is along worldwide headings. Component burdens are portrayed in Nodal Stacking. Weights might be contribution as surface loads on the component confronts as appeared by the hovered numbers in Figure 7.

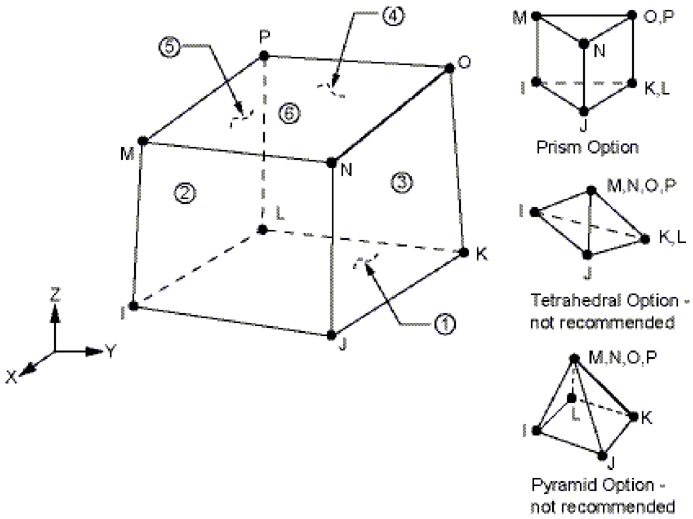


Figure 7. SOLID185 homogeneous structural solid geometry.

The modulus of elasticity required for fill out field ANSYS can be extracted from the experimental work of tensile test, Table 2, while the Poisson's ratio and shear modulus can be extracted from the theoretical way, [12]. Thus, these mechanical properties for a beam made from hyper composite materials with various short fiber's volume fraction, powder reinforcement and resin polyester materials can be shown in Table 5. Also, the parameters studied numerically are shown in Table 6.
Also, the density required for hyper composite beam can be evaluated from,

$$\rho = \forall_s . \rho_s + \forall_p . \rho_p + \forall_{resin} . \rho_{resin} \qquad (5)$$

Where, $\rho_{resin}, \rho_p, \rho_s$ density of resin materials, powder reinforcement and short reinforcement, respectively, can be evaluated from Eq. 2.

Table 5. Experimental and theoretical input data of mechanical properties required for Ansys.

Sample No.	$\forall_s$ (%)	$\forall_p$ (%)	$\forall_{resin}$ (%)	E (GPa)	G (GPa)	ν	ρ (Kg/m^3)
1	0	0	100	3.67	1.4	0.25	1200
2	20	0	80	9.62	3.75	0.39	1360
3	10	10		7.68	3.06	0.37	1400
4	0	20		5.64	2.32	0.33	1440
5	30	0	70	12.68	5.01	0.4	1440
6	15	15		10.16	4.01	0.37	1500
7	0	30		7.16	2.90	0.33	1560

Table 6. Crack Parameters Studied in numerical work.

Sample name	Crack location x_c	Crack length d_c	Crack angle
S_{v1}		$0.1*h$	
S_{v2}	$0.15*l$	$0.25*h$	
S_{v3}		$0.5*h$	
S_{v4}		$0.1*h$	
S_{v5}	$0.3*l$	$0.25*h$	$0^o, 15^o, 30^o, 45^o, 60^o, 75^o, 90^o$
S_{v6}		$0.5*h$	
S_{v7}		$0.1*h$	
S_{v8}	$0.5*l$	$0.25*h$	
S_{v9}		$0.5*h$	

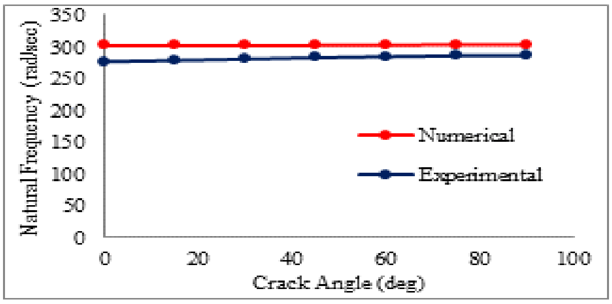
4. Results and discussion

The results evaluated include finding the influence of crack orientation on vibration behavior for hyper composite material beam having various volume fractions of resin and reinforcement. It was observed that the crack is quite sensitive to its size and location. Experimental and numerical methods were used for evaluating the results. The results evaluated by experimental works were compared then with the results evaluated by numerical work with using finite element method by ANSYS. The experimental work includes evaluating the mechanical properties of hyper composite material as shown in Table 5, which are then used to determine the beam natural frequency numerically. In addition, the natural frequency has already been evaluated experimentally through analyzing the output response of beam using FFT method, as illustrated in Figure 6.

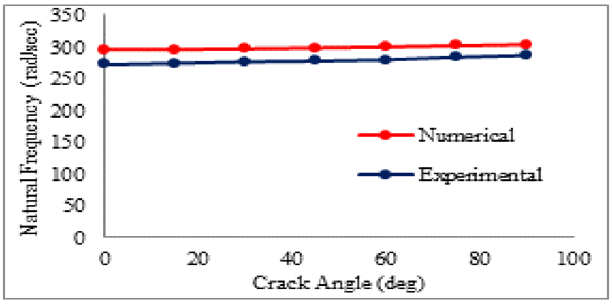
The results of natural frequency include comparison between the numerical and experimental results with different effects of crack length, location and angle for simply supported hyper composite beam made of various volume fractions of resin materials and reinforcement, as shown in Figures 8 to 13. Where, the figures show that the acceptance results between experimental and numerical with error reach maximum about 10.63%. In addition, the effect of crack length, location and angle for various resin materials and volume fractions reinforcement of simply supported beam are shown in Figures 14 to 19. The figures showed that the beam natural frequency is increasing with an increase in the crack angle as the crack length is divided to horizontal and vertical effect. In another word, the increase in the crack angle, cause a reduction in the vertical crack effect, and hence increasing the frequency of beam. The figures also showed that when length of crack modifying, the frequency decreasing due to decreasing the stiffness of the beam. In addition, the influence of crack position increasing when the crack is near the middle point of the beam, and the effect of crack decreasing when the crack is close to the beam ends.

Furthermore, Figures 8 to 19 showed that the beam frequency increasing with an increase in the reinforcement (powder and fiber), but the increasing in the short fiber has more effects on the natural frequency than that of the powder reinforcement. However, the beam natural frequency is enhanced while increasing the powder reinforcement and/or reducing the resin materials of composite beam (with same short reinforcement fiber volume fraction) as the effect of powder reinforcement onto stiffness of beam is higher than the effect of resin material. This is because the modulus of elasticity of glass powder materials is higher than the modulus of elasticity for polyester resin materials.

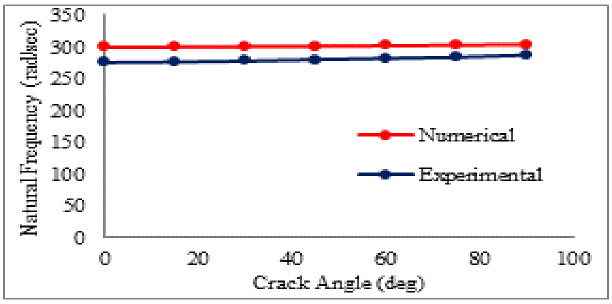
Moreover, it can be seen that the powder reinforcement has the same influence on both the beam natural frequency and hyper composite material mechanical properties, as shown in Table. 2. Thus, it is clearly seen that the composite material modulus increasing with an increase in the reinforcement. The modulus of elasticity of composite material also increases with increasing the powder reinforcement and/or decreasing the resin materials.



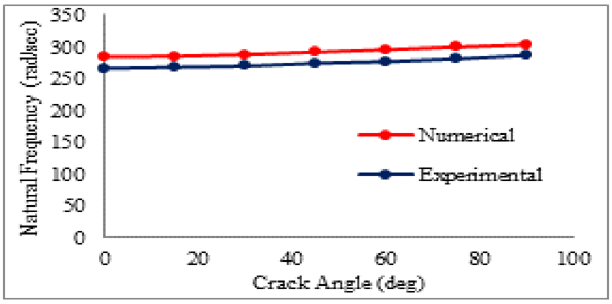
a. $x_c = 15\%l, d_c = 25\%h$



b. $x_c = 50\%l, d_c = 25\%h$

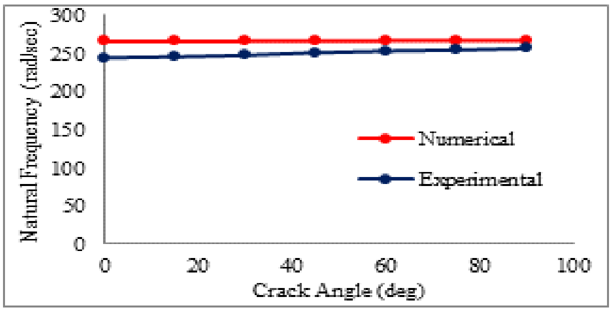


c. $x_c = 15\%l, d_c = 50\%h$

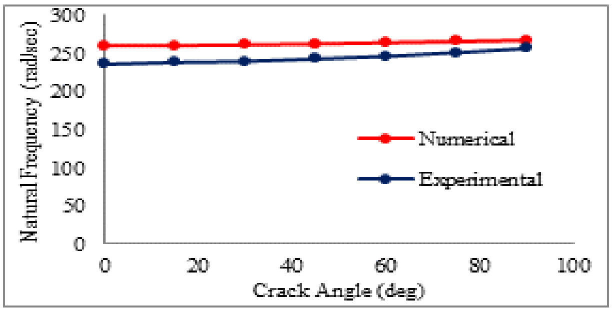


d. $x_c = 50\%l, d_c = 50\%h$

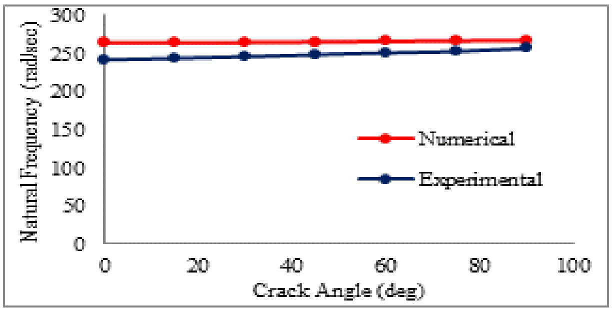
Figure 8. Numerical and experimental results for beam with $\forall_s = 20\%, \forall_p = 0\%, \forall_{resin} = 80\%$.



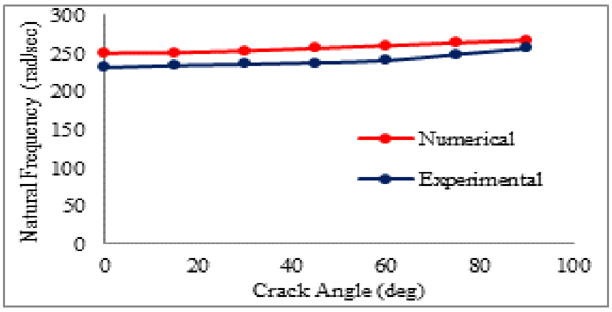
a. $x_c = 15\%l, d_c = 25\%h$



b. $x_c = 50\%l, d_c = 25\%h$

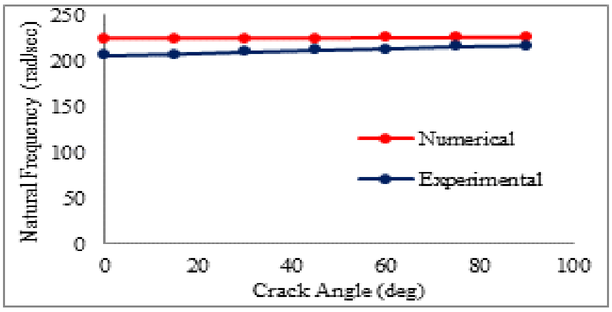


c. $x_c = 15\%l, d_c = 50\%h$

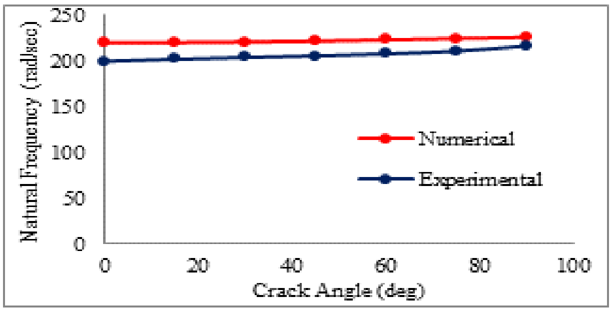


d. $x_c = 50\%l, d_c = 50\%h$

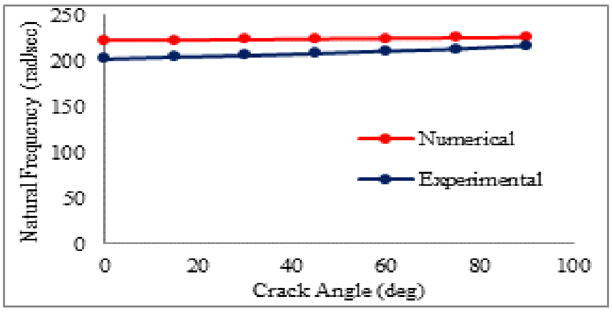
Figure 9. Numerical and experimental results for beam with $\forall_s = 10\%, \forall_p = 10\%, \forall_{resin} = 80\%$.



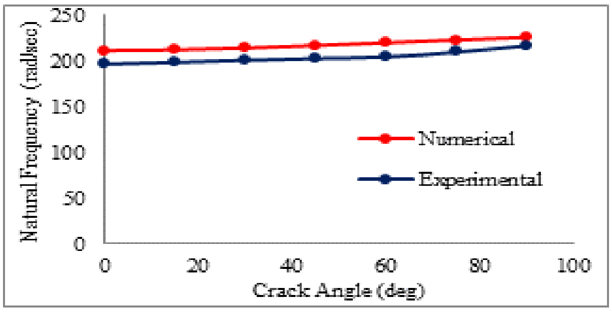
a. $x_c = 15\%l, d_c = 25\%h$



b. $x_c = 50\%l, d_c = 25\%h$

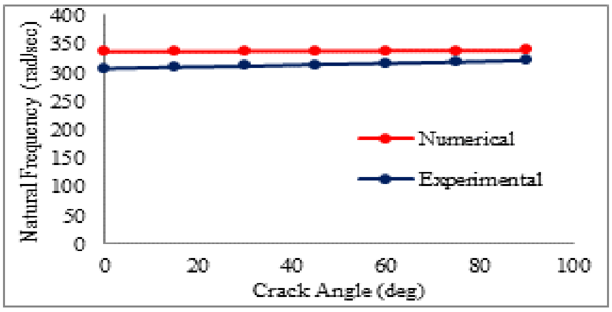


c. $x_c = 15\%l, d_c = 50\%h$

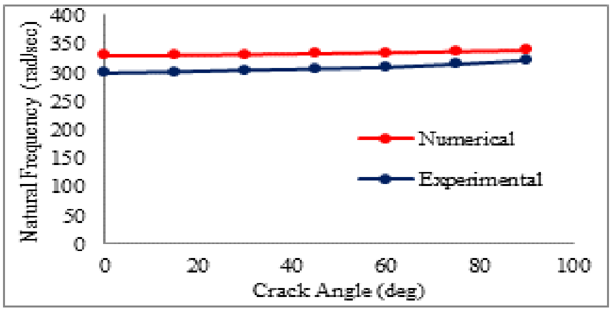


d. $x_c = 50\%l, d_c = 50\%h$

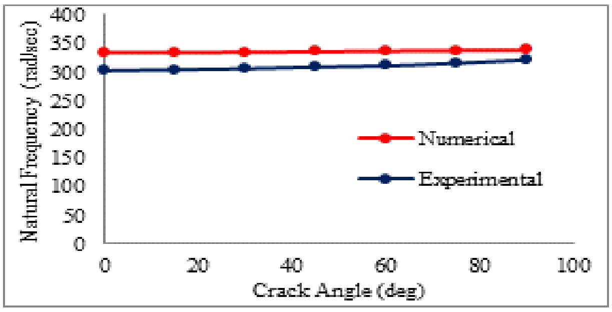
Figure 10. Numerical and experimental results for beam with $\forall_s = 0\%, \forall_p = 20\%, \forall_{resin} = 80\%$.



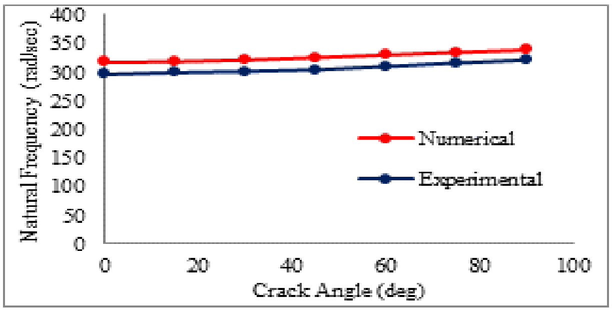
a. $x_c = 15\%l, d_c = 25\%h$



b. $x_c = 50\%l, d_c = 25\%h$

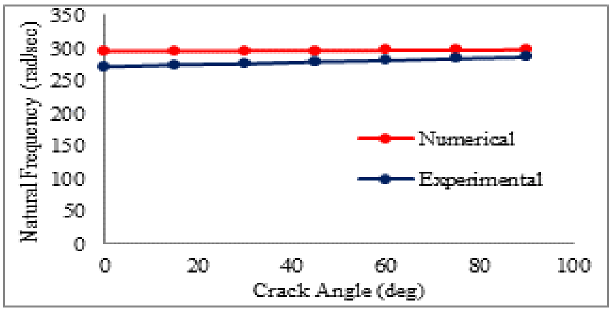


c. $x_c = 15\%l, d_c = 50\%h$

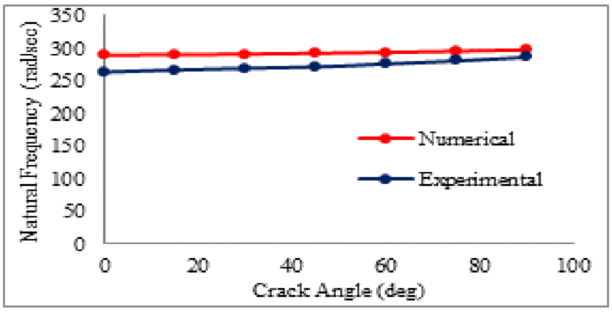


d. $x_c = 50\%l, d_c = 50\%h$

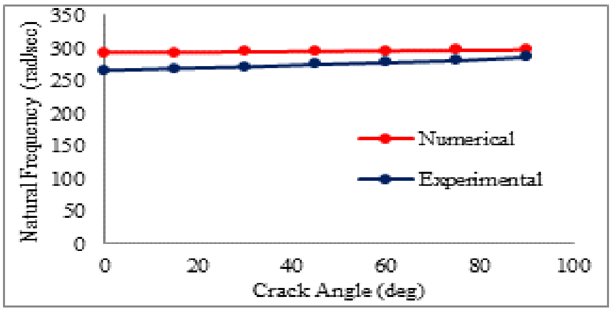
Figure 11. Numerical and experimental results for beam with $\forall_s = 30\%, \forall_p = 0\%, \forall_{resin} = 70\%$.



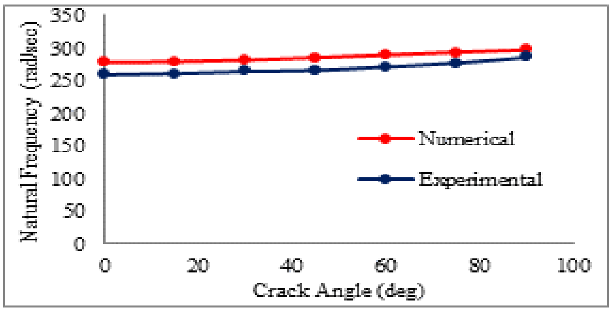
a. $x_c = 15\%l, d_c = 25\%h$



b. $x_c = 50\%l, d_c = 25\%h$

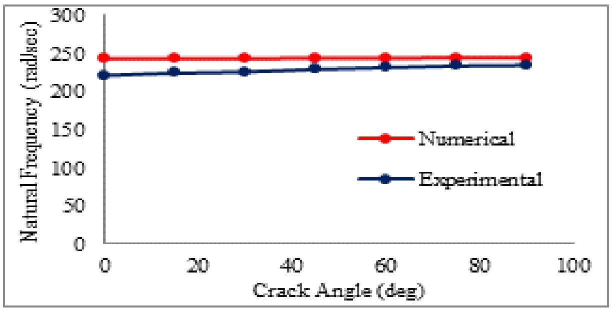


c. $x_c = 15\%l, d_c = 50\%h$

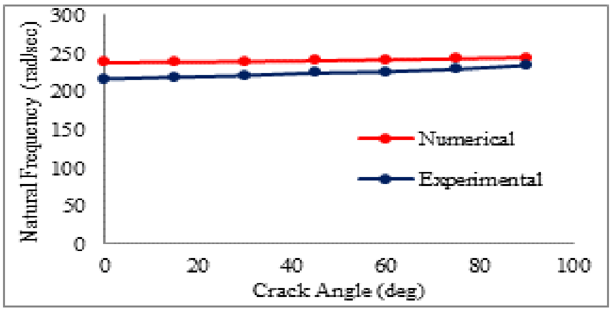


d. $x_c = 50\%l, d_c = 50\%h$

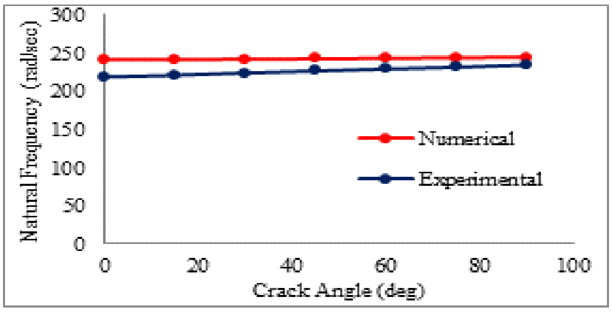
Figure 12. Numerical and experimental results for beam with $\forall_{\mathrm{s}}$= 15%, $\forall_{\mathrm{p}}$= 15%, $\forall_{resin}$= 70%.



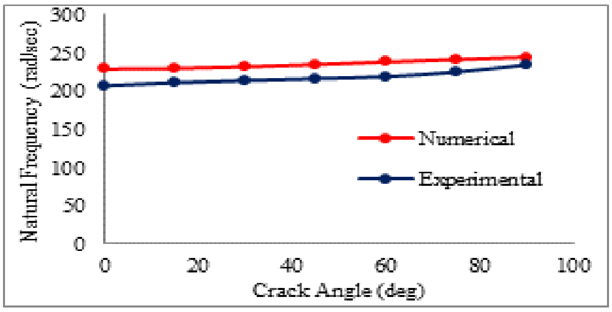
a. $x_c = 15\%l, d_c = 25\%h$



b. $x_c = 50\%l, d_c = 25\%h$



c. $x_c = 15\%l, d_c = 50\%h$



d. $x_c = 50\%l, d_c = 50\%h$

Figure 13. Numerical and experimental results for beam with $\forall_{\mathrm{s}}$= 0%, $\forall_{\mathrm{p}}$= 30%, $\forall_{resin}$= 70%.

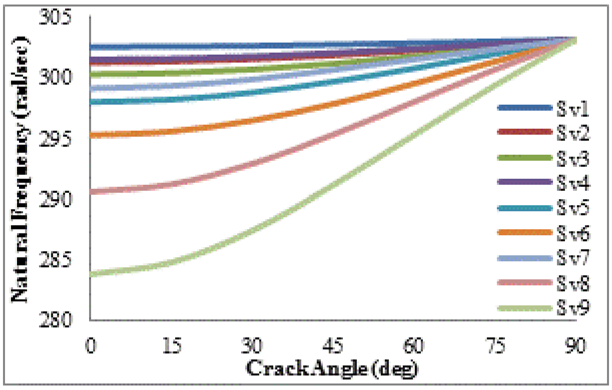


Figure 14. Numerical Results for hyper Composite beam's Natural Frequency with $\forall_s = 20\%, \forall_p = 0\%, \forall_{resin} = 80\%$.

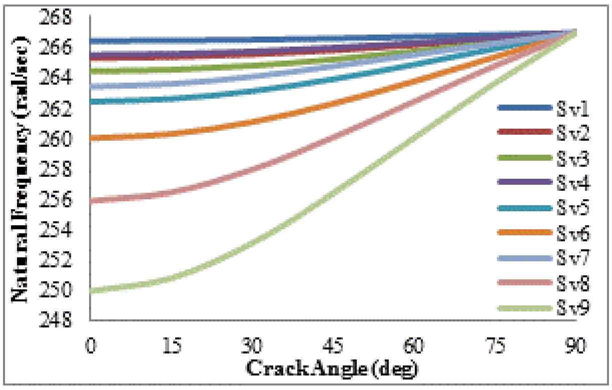


Figure 15. Numerical Results for hyper Composite beam's Natural Frequency with $\forall_s = 10\%, \forall_p = 10\%, \forall_{resin} = 80\%$.

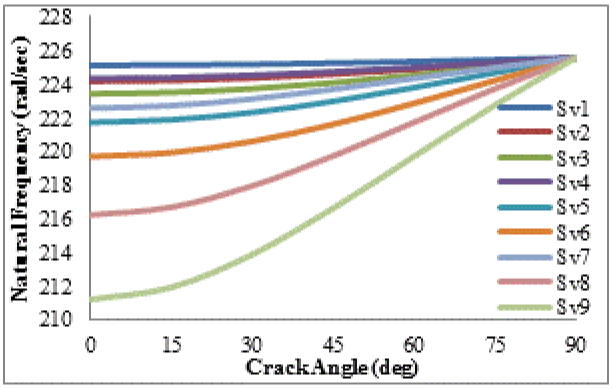


Figure 16. Numerical Results for Natural Frequency of hyper composite beam with $\forall_s = 0\%, \forall_p = 20\%, \forall_{resin} = 80\%$.

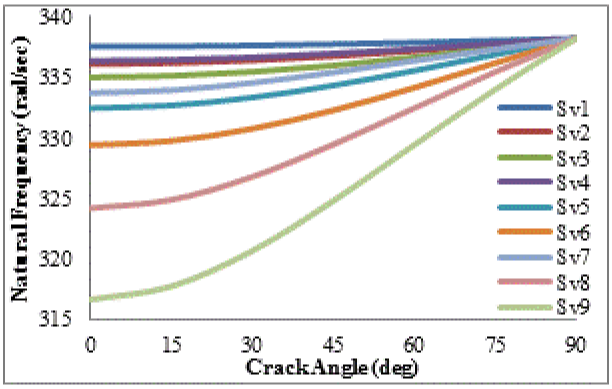


Figure 17. Numerical Results for Natural Frequency of hyper composite beam with $\forall_s = 30\%, \forall_p = 0\%, \forall_{resin} = 70\%$.

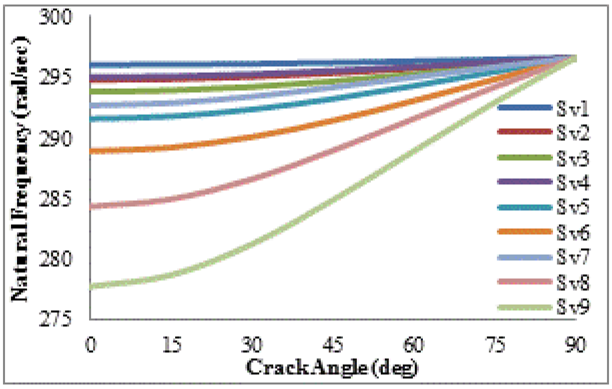


Figure 18. Numerical Results for hyper Composite beam's Natural Frequency with $\forall_s = 15\%, \forall_p = 15\%, \forall_{resin} = 70\%$.

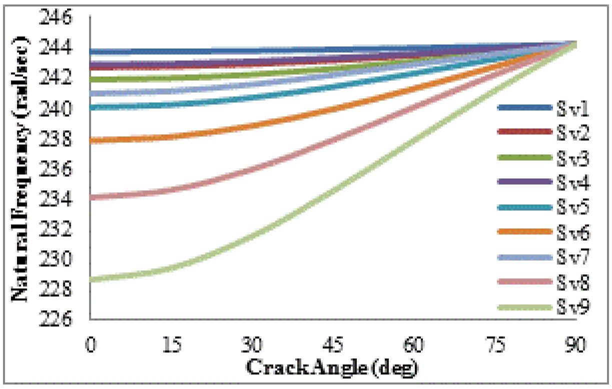


Figure 19. Numerical Results for hyper Composite beam's Natural Frequency with $\forall_s = 0\%, \forall_p = 30\%, \forall_{resin} = 70\%$.

5. Conclusions

The present study (experimental and numerical works) was conducted to investigate the effect of the beam oblique crack which made from hyper composite materials onto natural frequency. Major findings of this study are as follows:

1. The comparison between two methods used to evaluate the natural frequency (experimental and numerical) shows a good agreement with maximum error about (10.63%).
2. The orientation of crack can cause two compounds, one on the vertical effect and another on horizontal effect, therefore, the orientation of crack causes a reduction in the crack effect.
3. Increasing the crack angle results in decreasing the crack effect, and hence, increasing the natural frequency compared to its corresponding values for the same size vertical crack.
4. The increasing of crack size causes decreasing in the beam stiffness, due to decreasing the moment of inertia of beam at the crack location, therefore, decreases the beam natural frequency.
5. As the effect of crack location depends on how close the crack is to the supported beam, then, the crack away from the supported the beam natural frequency is decreasing.
6. Generally, the effect of powder and short fiber reinforcement causes increasing in the composite strength, therefore, increasing the reinforcement powder or fiber leads to an increase in the natural frequency. However, the effect of short fiber reinforcement is higher than the effect of powder reinforcement.

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