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Free Vibration Analysis of Polyproplyne- Nanoclay Composite Beam with Crack

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Abstract: *Vibration analysis is one of the most promising techniques to detect the crack. In this paper, Poly Propylene - Nano Clay is analyzed for it's free vibration. The proposed composite beam is modeled with crack. Analysis is done by using Finite element package ANSYS-14.5. The Nano Clay in composite is varied from 0 to 15 percentage (0,1,3,5,7,9,11,13,15) and crack depth to width ratios are chosen as, 0,0.25,0.5,0.8. Impact of varying percentage of NC and varying crack depths on natural frequency are analyzed using free vibration analysis.*

Keywords: *Nano Clay-Poly Proplyne composite Cantilever beam, Free vibration Analysis.*

I. INTRODUCTION

Fiber Reinforced Plastics (FRP) are commonly used in aerospace, automotive and other engineering applications mainly because of their high strength-to-weight ratio, high stiffness, good resistance to fatigue, and corrosion resistance. Reinforced fibers are usually added in the form of continuous or chopped fibers in a polymer matrix. Each type of these reinforcement fibers has their benefits and limitations in applications. A short fiber reinforced composites can have better processing properties and can be moldable into complex shaped components. Long fiber reinforced composites, on the other hand, provide enhanced strength and stiffness properties as per the desired directions. Various types of synthetic and natural fibers reinforced plastics are presently studied in literature, namely, glass fiber, carbon fiber, boron, alumina, oxide/carbide and sisal/jute based fibers in a polymer matrix. In addition to these fiber reinforced composites, particle reinforced polymer composites are also widely investigated.

In these particle filled composites, various types of nano- and micro-scale particles are used. Nano particle reinforced polymer composites gained special attention due to their superior and improved properties when compared to their corresponding micro-scale particles. Nano clays, carbon nano tubes and alumina/oxide based particles are widely used as nano particle reinforcements in polymer matrices. Polymer-Clay Nano composites (PCN) are a relatively new area of research in particle filled composites, and consists of Nano Clay (NC) as the reinforcement and a polymer serves as the matrix material.

The addition of small amounts of clay (0 to 15% wt) in a polymer matrix leads to improved mechanical, thermal and barrier properties. The addition of nano clays in a polymer matrix may result in the formation of two types of nano composite structures, namely, intercalated and exfoliated nanostructures. In an intercalated structure, the host polymer matrix enters into the interlayer spacing of the nano clay and increases the interlayer spacing but maintains the parallel arrangement of the nano layers of clay in the matrix. If the nano layers of clays are randomly dispersed in the matrix, then the structure is called an exfoliated structure. In practice, exfoliated structures provide enhanced and improved properties due to their excellent dispersions and improved aspect ratio.

The addition of the NC in the Ply Propylene (PP) matrix increases the thermal stability in air medium, increases physical properties (dimensional stability), improves flame retardant properties increased thermal-oxidative stability, and improves mechanical properties, fracture properties and gas barrier properties. Several studies were conducted with various types of clay concentrations and compatabilizers.

The main applications of PP materials are home appliances such as, chairs and toys, clothing, medical, EPP toy air craft. Crack is initiation of the wrecking of material in some cases. Strength plays very key role for crack growth. If material has high strength, crack will grow slowly otherwise, crack will propagate quickly. And frequency analysis is one of the most promising techniques to detect crack depth. If crack depth increases, then, frequency will down in free vibration. In this paper, efforts have been going made through PP-NC composite beam for un-cracked and cracked with different crack to depth ratios.

A -Material Properties

Material properties were extracted from research papers by *J. Yan1*[15] and density was calculated from Rule of mixture. Properties of material for different percentages of nano clay with Poly propylene are listed in table 1.

Table 1: Mechanical properties of Poly Propylene - Nano Clay for different % of NC

% of NC	**Yong's Modulus (Gpa)**	**Poisons ratio**	**Density (Kg/m^3) X 10^3**
0	1.56	0.35	1.45
1	1.7	0.34	1.45
3	1.72	0.28	1.45
5	1.81	0.28	1.46
7	1.92	0.29	1.46
9	1.96	0.31	1.47
11	1.83	0.36	1.47
13	2.26	0.36	1.47
15	2.27	0.33	1.48

B- Steps involved in detecting frequencies of cracked beam main steps involved to detect frequencies of cracked beam are,

1) Natural frequencies of un-cracked beam for different composition are determined theoretically.
2) Natural frequencies of un-cracked beam for different compositions are estimated in ANSYS 14.5.
3) Theoretical results are compared with ANSYS 14.5 Results.
4) Natural frequencies of composite beam for different % of NC are estimated using ANSYS 14.5 for different crack depths.

II. THEORETICAL CALCULATIONS

Theoretical calculations are made through the following formulae for four modes of natural frequencies and results are shown in table 2.

$$\text{freequency of first mode } f_1 = \frac{3.52}{2\pi L^2}\sqrt{\frac{EI}{A\rho}}$$

$$\text{freequency of second mode } f_2 = \frac{22}{2\pi L^2}\sqrt{\frac{EI}{A\rho}}$$

$$\text{freequency of third mode } f_3 = \frac{61.7}{2\pi L^2}\sqrt{\frac{EI}{A\rho}}$$

$$\text{freequency of fourth mode } f_4 = \frac{121}{2\pi L^2}\sqrt{\frac{EI}{A\rho}}$$

Where,
L=Length of the beam,
E=Young's modulus of material,
I=Moment of inertia of cross section,
A=Area of cross section,
ρ=Density of material.

Table 2: Variation of frequency with change in NC % with theory

% of NC	**frequency of 1^{st} mode(Hz)**	**frequency of 2^{nd} mode(Hz)**	**frequency of 3^{rd} mode(Hz)**	**Frequency of 4^{th} mode(Hz)**
0	1.76	11.060 6	31.019 9	60.833

1	1.8474	11.5262	32.3818	63.5041
3	1.8574	11.6087	32.5571	63.8478
5	1.9054	11.9087	33.3984	65.4978
7	1.9624	12.265	35.4775	69.575
9	1.9819	12.3868	34.7393	68.1274
11	1.915	12.9687	33.5667	65.8278
13	2.1282	13.3025	37.3039	73.1568
15	2.1319	13.3243	37.3686	73.2836

III. Finite Element Modeling

The ANSYS 14.5 finite element program was used for free vibration of the cracked beams. A 20-node three-dimensional structural solid element under SOLID 186 was selected to model the beam. The beam was discredited into 1045 elements with 2318 nodes. Geometrical shape of the beam is shown in figure 1. Cantilever boundary condition was considered by constraining all degrees of freedoms of the nodes located on the left end of the beam. The subspace mode extraction method was used to calculate the natural frequencies of the beam and mode shapes are shown in figure 2 and results are in table 3.

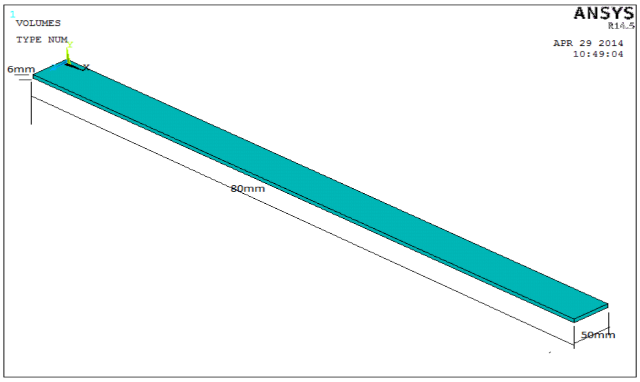
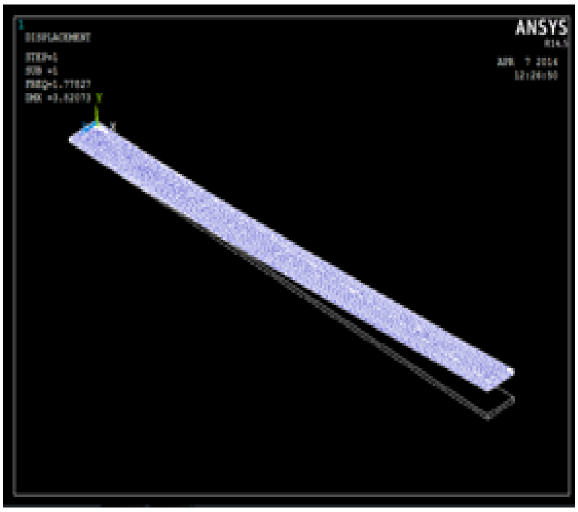
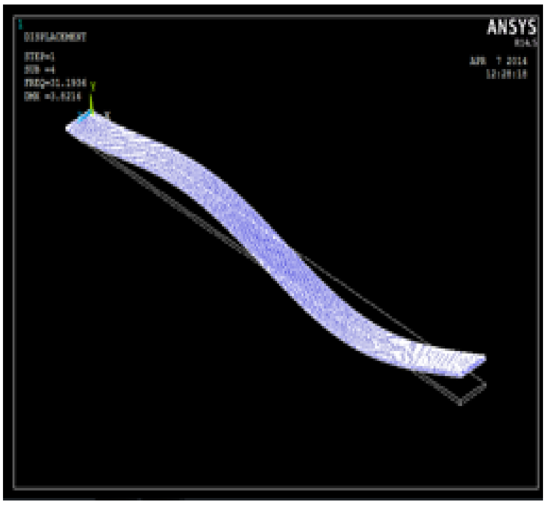


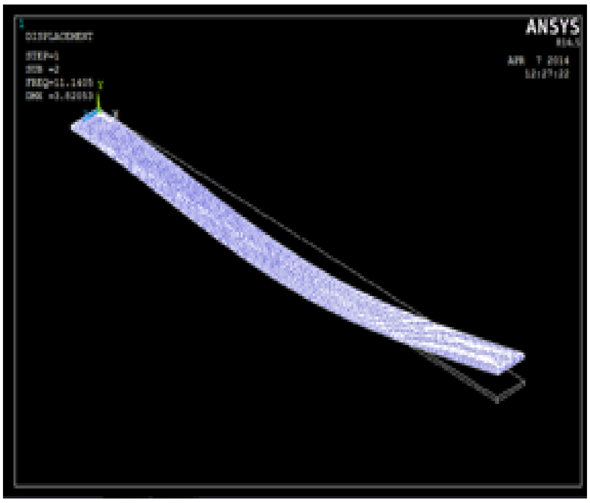
Figure 1 : Geometrical model for un-cracked beam



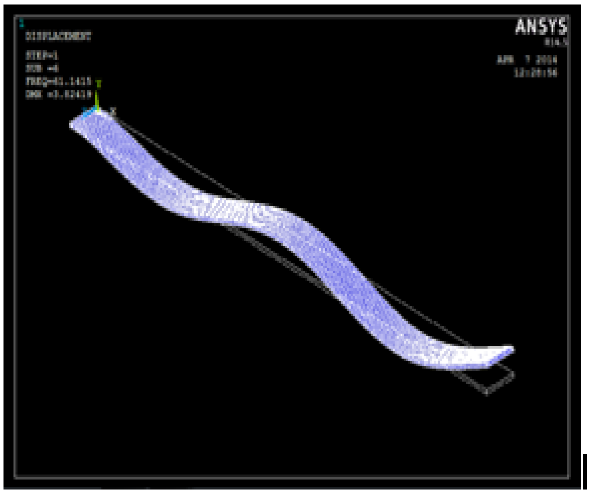
2-a: 1st mode-1.7783Hz frequency



2-b: 2nd mode-11.14Hz frequency



2-c: 3rd mode-31.194Hz frequency



2-d: 4th mode-61.142Hz frequency

Figure 2: Mode Shapes of un-Cracked Beam for 0% Nanoclay

Table 3: Variation of frequency with change in NC % with simulation

% of NC	**frequency of 1st mode(Hz)**	**frequency of 2nd mode(Hz)**	**Frequency of 3rd mode(Hz)**	**frequency of 4th mode(Hz)**
o	1.77827	11.1405	31.1936	61.142
1	1.85523	11.623	32.544	63.785
3	1.8621	11.666	32.662	64.004
5	1.9104	11.963	33.509	65.665
7	1.968	12.33	34.52	67.648
9	1.989	12.461	34.889	68.376
11	1.925	12.06	33.768	66.189
13	2.1391	13.401	37.523	73.549
15	2.141	13.413	37.556	73.607

IV. Comparison of results

After comparison of both theoretical and ANSYS-14.5 results, the difference between both results is negligible and comparison of frequency is shown in figure 3. Hence, the analysis of cracked beam is extended in ANSYS-14.5 package.

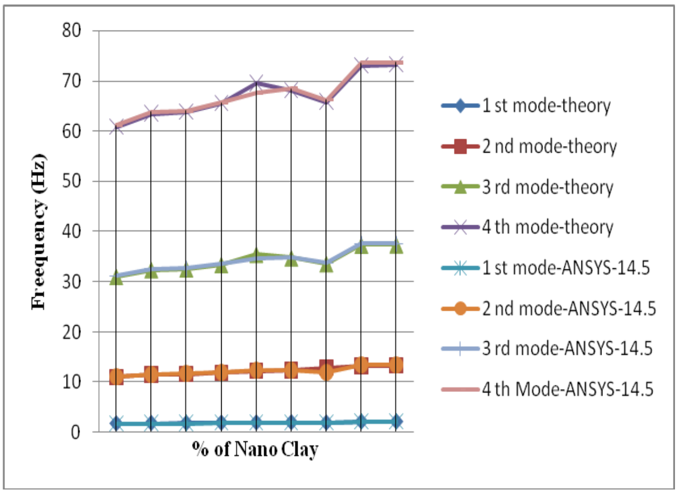


Figure 3: Comparision of theoritical and ANSYS-14.5 results for different % of Nano Clay.

V. Results

After comparison of the both theoretical and ANSYS-14.5 results, Procedure could be verified in ANSYS-14.5 from the journal [19] for Aluminum material. Same results were obtained from that procedure. Hence, the same procedure is adopted for extracting natural frequencies of cracked beam as shown in figure 4 and 5 and obtained results are shown in table 4. The comparisons for different mode frequencies with varying percentage of NC for different crack depth are shown in figures 6 to 9.

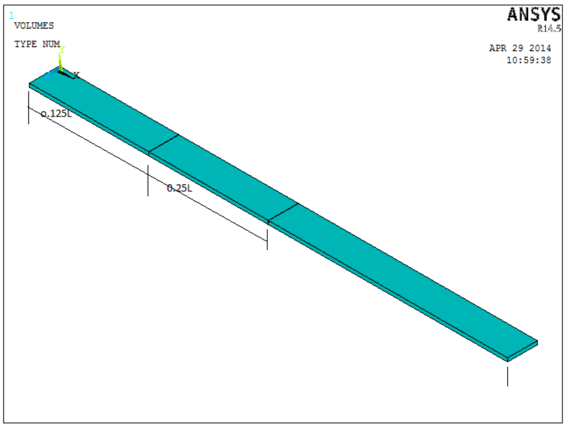


Figure 4: Location of cracks on composite beam

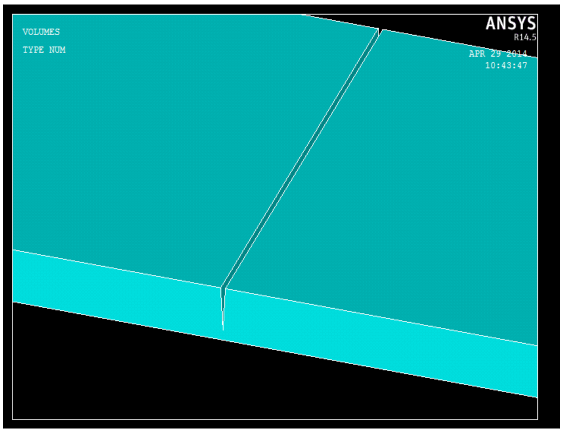


Figure 5: Geometrical model of crack

Table 4: Natural frequencies of Different Cracks

% of NC	Crack Depth to Width Ratio (a/w)	frequency of 1st mode(Hz)	frequency of 2nd mode(Hz)	Frequency of 3rd mode(Hz)	Frequency of 4th mode(Hz)	% of NC	Crack Depth to Width Ratio (a/w)	frequency of 1st mode(Hz)	frequency of 2nd mode(Hz)	Frequency of 3rd mode(Hz)	Frequency of 4th mode(Hz)
0	0	1.7783	11.14	31.194	61.142	1	0	1.8553	11.623	32.544	63.785
	0.25	1.7727	11.108	31.135	60.85		0.25	1.8506	11.596	32.502	63.522
	0.5	1.7511	10.977	30.915	59.674		0.5	1.8267	11.452	32.251	62.245
	0.8	1.6253	10.307	29.604	54.129		0.8	1.6947	10.746	30.871	56.429
3	0	1.8621	11.666	32.662	64.004	5	0	1.9104	11.969	33.509	65.665
	0.25	1.8564	11.633	32.603	63.702		0.25	1.9046	11.935	33.449	65.355
	0.5	1.8329	11.49	32.36	62.429		0.5	1.8805	11.789	33.2	64.051
	0.8	1.6983	10.767	30.944	56.518		0.8	1.7424	11.047	31.749	57.989
7	0	1.968	12.33	34.52	67.648	9	0	1.989	12.461	34.889	68.376
	0.25	1.9618	12.293	34.453	67.32		0.25	1.9832	12.427	34.83	68.061
	0.5	1.937	12.143	34.198	65.98		0.5	1.9584	12.277	34.576	66.72
	0.8	1.795	11.381	32.707	59.743		0.8	1.8157	11.513	33.081	60.443
11	0	1.925	12.06	33.768	66.189	13	0	2.1391	13.401	37.523	73.549
	0.25	1.9189	12.025	33.704	65.872		0.25	2.132	13.36	37.446	73.185
	0.5	1.8957	11.884	33.468	64.607		0.5	2.1061	13.203	37.183	71.777
	0.8	1.7602	11.162	32.056	58.628		0.8	1.9554	12.4	35.613	65.129
15	0	2.141	13.413	37.556	73.607	15	0.5	2.1082	13.216	37.221	71.834
	0.25	2.1346	13.376	37.49	73.264		0.8	1.9556	12.401	35.626	65.116

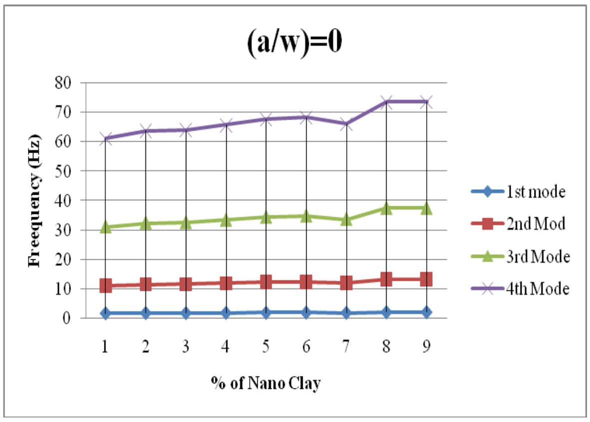


Figure 6: Comparison of Natural Frequency with different % of NC for 0 crack depth to width ratio

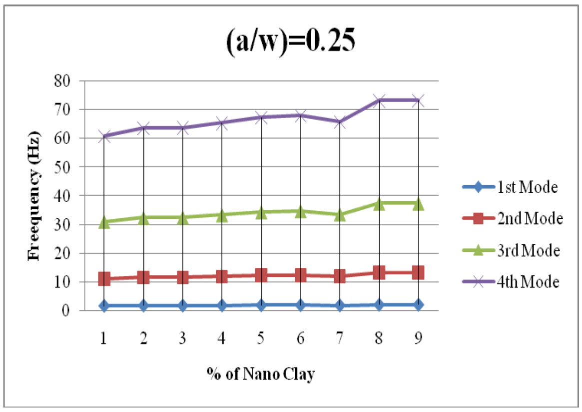


Figure 7: Comparison of Natural Frequency with different % of NC for 0.25 crack depth to width ratio

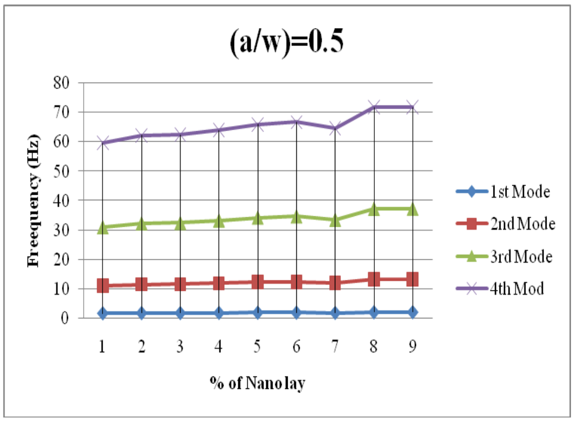


Figure 8: Comparison of Natural Frequency with different % of NC for 0.5 crack depth to width ratio

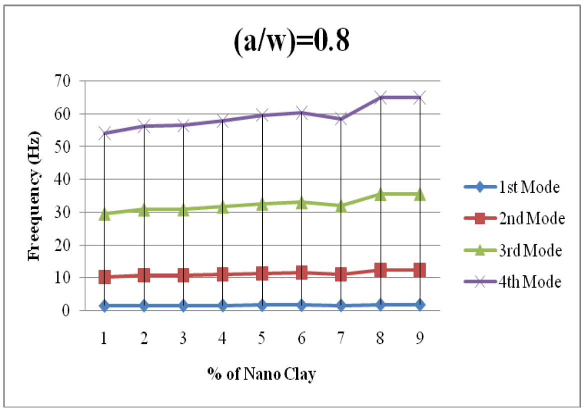


Figure 9: Comparison of Natural Frequency with different % of NC for 0.8 crack depth to width ratio

IV. Conclusions

After studying different compositions of NC in the composite beam with different crack depths, the following conclusions are there.

- Frequency of beam increases with increase in NC %.
- Frequency of beam decreases with increase in crack depth.
- Percentage of change of frequency is almost all negligible for variation of NC at same crack depth.

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