INFLUENCE OF STACKING SEQUENCE AND NANOCCLAY CONTENT ON MACROSCOPIC BEHAVIOUR OF NANOCCLAY/EPOXY COMPOSITES

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ABSTRACT

A refined impact finite element approach in conjunction with the Reddy's higher-order shear deformation theory and Hertz's contact law is applied to study the influence of stacking sequence and nanoclay content on impact response of nanoclay/epoxy nanocomposite of 20 layers and 5 mm thickness. Combinations of four typical stacking sequences and six nanoclay contents inside epoxy, namely, the stacking sequences $[0_{20}]$, $[90_{20}]$, $[0/45/0/-45/0]_{2S}$, $[90/45/90/-45/90]_{2S}$, and nanoclay contents 0, 1, 3, 5, 7, 9wt.% at $[0/45/0/-45/0]_{2S}$ are considered. The results of this analysis for four stacking sequences show that the unidirectional layup ($[0/45/0/-45/0]_{2S}$ and $[90/45/90/-45/90]_{2S}$) and cross-ply layup ($[0_{20}]$ and $[90_{20}]$) in this nanocomposite plate indicate, the same impact response, respectively. In addition, from results of nanoclay contents 0, 1, 3, 5, 7 and 9 wt. % at $[0/45/0/-45/0]_{2S}$, it can be seen that the greater the rigidity of between 0 to 7wt. %, the greater the contact force and the smaller the deflection, the smaller the COR becomes. However, at 9wt. %, the rigidity is reduced, causing the opposite effect of all impact responses.

KEYWORDS: Nanoclay/Epoxy Composites, Macroscopic Behaviour, Stacking Sequence & Nanoclay Content

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INTRODUCTION

Composite materials are widely used in many industries due to mechanical properties such as high strength to weight ratio, wear resistance and fatigue etc. On the other hand, nanocomposites with nanoscale particles have become one of many areas of interest over the past decade. The use of nanoclay to reinforce polymer-based composites is attracting a lot of interest in research and industry as adding a small amount of nanoclay can significantly improve the mechanical properties of the original composites. Nevertheless, there has been little research on the dynamic behaviour of nanocomposites so far. Most of the studies on the low-velocity impact on nanocomposites have been conducted experimentally. Wuite et al. [1] used the classical laminate theory to analyze nanocomposite beam and to not link them to the Hertz's contact law. Recently, Meybodi et al. [2] investigated low-velocity impact response of a nanocomposite beam by using Euler-Bernoulli beam theory and Hertz's contact law. However, there has been a strong need to introduce a high-order theories to increase the accuracy of the analysis results. Higher-order shear deformation theories (HSDT) [3] for plate can represent the kinematics better, may not require shear correction coefficients used in the first-order shear deformation theories (FSDT) [4], and can yield more accurate interlaminar stress distributions as shown in Figure 1. However, they involve considerably more computational effort.

In this study, a refined impact finite element approach in conjunction with the Reddy's higher-order shear deformation theory and Hertz's contact law [5] is applied to study the influence of stacking sequence and nanoclay content on impact response of nanoclay/epoxy nanocomposite. Combination of four typical stacking sequences and six nanoclay contents inside epoxy, namely, the stacking sequences $[0_{20}]$, $[90_{20}]$, $[0/45/0/-45/0]_{2S}$, $[90/45/90/-45/90]_{2S}$, and nanoclay contents 0, 1, 3, 5, 7, 9wt.% at $[0/45/0/-45/0]_{2S}$ are considered. In addition, the results of analysis is compared with wave propagation method (WPM).

Figure 1: Concept of a Transverse Normal According to the Classical (CLPT), First-Order (FSDT) and Higher-Order Shear Deformation Theories (HSDT) [3]

THEORETICAL INVESTIGATION

Nanoclay/epoxy nanocomposite is composed of the 20 layers with a layer thickness 0.25mm and arbitrary stacking sequences, and initial velocity of the steel ball is V_0 . The displacement field by Reddy's higher-order shear deformation theory [3] and Hertz's contact law are considered. The following simulation processes not described here are well illustrated in the Ref. [6,7].

In order to study the macroscopic behaviour of nanocomposites based on the stacking sequence and nanoclay content, four typical stacking sequences and six nanoclay contents inside epoxy, namely, the stacking sequences $[0_{20}]$, $[90_{20}]$, $[0/45/0/-45/0]_{2S}$, $[90/45/90/-45/90]_{2S}$, and nanoclay contents 0, 1, 3, 5, 7, 9wt.% at $[0/45/0/-45/0]_{2S}$ are considered. And the Young's modulus at different % of nanoclay is based on Chan's paper [8], and other mechanical properties are further calculated according to the MROM (the modified rule of mixture) as shown in Table 1.

Table 1: Mechanical Properties of Nanocomposites at Stacking Sequence $[0/45/0/-45/0]_{2S}$ and Different % of Nanoclay

Stacking Sequences	N wt.% Nanoclay Inside Epoxy	Young's Modulus* $E_{eq, m}$ (GPa)	E_{11} (GPa)	E_{22} (GPa)	G_{12} (GPa)	ν_{12}
$[0/45/0/-45/0]_{2S}$	N=0	2.120	43.560	6.675	2.604	0.29
	N=1	2.474	43.737	7.692	3.000	0.29
	N=3	2.625	43.813	8.117	3.166	0.29
	N=5	2.841	43.921	8.718	3.400	0.29
	N=7	3.334	44.167	10.058	3.922	0.29
	N=9	2.431	43.715	7.569	2.953	0.29
*Chan Mo-lin <i>et al.</i> , [8]			Results by MROM [9]			

RESULTS AND DISCUSSIONS

To verify the reliability of the analysis results of this dynamic behavior, the analysis results of the theoretical analysis (WPM) [10] are compared and reviewed before studying the dynamic behavior according to the stacking sequences. The analysis results of this study are shown in Figures 2-4, and the data that is compiled from these are well presented in the Table 2 and Figure 6. Figure 2 shows the histories of (a) contact force-deflection (b) ball displacement and (c) indentation of nanocomposites at various stacking sequences and 0 wt.% nanoclay. From the results shown in Table 1, we can see that the unidirectional layup ([0/45/0/-45/0]_{2S} and [90/45/90/-45/90]_{2S}) and cross-ply layup ([020] and [9020]) in this nanocomposite plate indicate the same impact response, respectively. The reason for this is that L (300) has very little effect on the impact response compared to $L \gg 10b$ ($10 \times 180 = 1800$) which is the case for beam with a length-to-width ratio of ($300/180 = 1.67$). In case of beam, length-width ratio is large with $L \gg 10b$, so the length-oriented layup has a significant impact on the impact response, but the width direction is minimal [2]. Figure 6 from Table 2 shows that there are some errors in maximum contact durations (2 times of time at maximum contact force of present results and contact duration of (WPM) but the over all trend is well matched, and the maximum contact force is pretty much the same. The present results show a contact duration of 1.5 times the WPM result due to the tail portion, which is called a wave-controlled impact that the plate deflection is localized to the region around the impact point, and the contact force and deflection are never in phase [11, 12].

Table 2: Comparisons of Present Simulation and Wave Propagation Method of Nanocomposites at Various Stacking Sequences and Different % of Nanoclay

Stacking Sequences	N wt.% Nanoclay Inside Epoxy	Present Results		Wave Propagation Method (WPM)
		Max. Contact Force(N) (at Time(μ s))	Contact Duration(μ s)	Max. Contact Force(N) (Contact Duration(μ s))
[0 ₂₀]	N=0	459 (46)	122	452 (79)
	N=3	498 (42)	113	490 (73)
	N=5	511 (41)	110	504 (71)
	N=7	545 (38)	105	534 (67)
	N=9	481 (44)	116	476 (75)
[90 ₂₀]	N=0	458 (46)	121	452 (79)
	N=3	497 (42)	112	490 (73)
	N=5	510 (41)	109	504 (71)
	N=7	544 (38)	104	534 (67)
	N=9	480 (44)	115	476 (75)
[0/45/0/-45/0] _{2S}	N=0	477 (42)	120	478 (79)
	N=1	503 (40)	114	504 (75)
	N=3	513 (39)	112	514 (73)
	N=5	527 (38)	108	528 (71)
	N=7	556 (36)	104	557 (67)
	N=9	500 (40)	115	501 (75)
[90/45/90/-45/90] _{2S}	N=0	477 (42)	119	477 (79)
	N=3	513 (39)	111	513 (73)
	N=5	527 (38)	107	527 (71)
	N=7	556 (35)	102	557 (67)
	N=9	500 (40)	114	500 (75)

Figure 2: Histories of (a) Contact Force-Deflection (b) Ball Displacement and (c) Indentation of Nanocomposites at Various Stacking Sequences and 0 wt.% Nanoclay

Figure 3: Relationship of (a) Contact Force-Indentation (b) Plate Deflection-Indentation and of Nanocomposites at Various Stacking Sequences and 0 wt.% Nanoclay

Figure 4: Relationship of (a) Contact Force-Plate Deflection and (b) Contact Force-Ball Displacement of Nanocomposites at Various Stacking Sequences and 0 wt.% Nanoclay

Figure 5 shows the histories of (a) velocity and (b) energy of nanocomposites at stacking sequence [0/45/0/-45/0]_{2S} and different % of nanoclay. The velocity and energy at time zero represent the initial velocity and energy when the impactor collides with the nanocomposite plate. The velocity curve in Figure 5(a) remains constant after being reduced to a negative value indicating the rate of rebound of the impactor. And the minimum kinetic energy in Figure 5(b) occurs when the velocity is zero, the lowest point of the curve represents the minimum kinetic energy, and the end of the curve represents the rebound energy. Also, the difference between the initial energy and the rebound energy represents the absorbed energy of the nanocomposite plate. In Figure 5, it is shown that the larger the content of nanoclay, the smaller the rebound energy and the greater the absorbed energy. But from Figure 6 of variation of max. contact force, COR (Coefficient Of Restitution) and wt.% NC, we can see that as the wt.% NC increases, max. contact force increases but COR decreases. In addition, from results of nanoclay contents 0, 1, 3, 5, 7 and 9 wt.% at [0/45/0/-45/0]_{2S}, it can be seen that the greater the rigidity between 0 to 7 wt.%, the greater the contact force and the smaller the displacement, the smaller the COR becomes. However, at 9 wt.%, the rigidity is reduced, causing the opposite effect of all impact responses. The results clearly indicate that the nanocomposites (1-7 wt.% NC) have a greater capability to absorb the kinetic energy (with up to 7.2% decreases in COR, that is, 51.8% increases in dissipated energy) with respect to the original laminate (0 wt.% NC).

Figure 5: Histories of (a) Velocity and (b) Energy of Nanocomposites at Stacking Sequence [0/45/0/-45/0]_{2S} and Different % of Nanoclay

Figure 6: Variation of COR According to Wt. % Nanoclay of Nanocomposites at Stacking Sequence [0/45/0/-45/0]_{2S}

CONCLUSIONS

To study the influence of stacking sequence and nanoclay content on macroscopic behavior nanoclay/epoxy nanocomposite, a refined impact finite element approach in conjunction with the Reddy's higher-order shear deformation theory and Hertz's contact law was applied. Finally, the results of this analysis show that the unidirectional layup

([0/45/0/-45/0]_{2S} and [90/45/90/-45/90]_{2S}) and cross-ply layup ([0₂₀] and [90₂₀]) in this nanocomposite plate indicate the same impact response, respectively. In addition, from results of nanoclay contents 0, 1, 3, 5, 7 and 9 wt.% at [0/45/0/-45/0]_{2S}, it can be seen that the greater the rigidity between 0 to 7 wt.%, the greater the contact force and the smaller the displacement, the smaller the COR becomes. However, at 9 wt.%, the rigidity is reduced, causing the opposite effect of all impact responses. The results clearly indicate that the nanocomposites (1-7 wt.% NC) have a greater capability to absorb the kinetic energy (with up to 7.2% decreases in COR, that is, 51.8% increases in dissipated energy) with respect to the original laminate (0 wt.% NC).

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