Study the damping and vibrational properties of polycarbonate reinforced ZrO2

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ABSTRACT
In this paper, the effect of nano zirconia particles on damping characteristics of polycarbonate composites was investigated experimentally. The nanoparticles were added to a polycarbonate matrix with five pure and modified Zirconium dioxide different weight percentages (wt. %) prepared by injection molding method. The samples were studied before and after the damage process and, the high-velocity impact was applied on all samples. The half-power bandwidth method was used to estimate the damping ratio experimentally. The experiments were designed based on an impulse actuator signal generated by the shaker, and the responses were recorded using accelerometer sensors. The results of experiments showed that the damping properties of the composite were increased by adding nanoparticles to 3 wt. % and decreased gently for samples with the upper content of nanoparticles. Transmission electron microscopy (TEM) pictures were used to investigate the distribution of nano zirconia on the polycarbonate matrix and showed a homogeneous mixture of nanocomposites and strong bonding between zirconia and polycarbonate that increased damping properties and decreased vibration. Finally, the experimental modal analysis test was done after the high-velocity impact damage process to investigate the effect of defection on the nano polycarbonate composites. The results showed a great decline in vibration and increased damping properties.

1. INTRODUCTION

Polycarbonate (PC)is a kind of amorphous thermoplastic polymer that has been widely used in various industries such as electronics, automotive, aircraft, houseware. Heat distortion temperature, high transparency, high specific stiffness, high impact resistance, and excellent flexibility over a wide temperature range are polycarbonate's most excellent mechanical properties [1-5]. also, materials which are produced by PC are impact resistant as well as has machining ability. PC is transparent, which is used nowadays in medical and electronic equipment such as CDs, DVDs, and optical lenses, but, despite the good ability and mechanical and physical properties of PC, its weak tribological properties have limited some of its applications [1, 6-12]. PC thermoplastic can be a good replacement for float glasses due to its lightweight and safety. Many studies have recently focused on thermoplastic-based composites due to their superior strength over neat polymer, including better manufacturability, recyclability, and higher toughness characteristics with retaining its low weight. Most of the research has been concentrated on Nano filler to enhance the strength of PC composites [1, 2, 7, 8, 13-17].

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Nanomaterials, which have been used as nanofiller in the new generation of composites materials, are due to enhancing the mechanical properties of PC, recovering the poor tribological properties, and modifying these types of composites [13-16, 18-21]. Nanofiller has been added to thermoplastic matrices and made a homogeneous nanocomposite with high mechanical properties.[22] In recent years, increasing demand for all-ceramic restorations led to the development of ceramic materials with optimized mechanical properties, such as densely sintered aluminum oxide and zirconium dioxide (Zirconia) ceramics [6, 9, 14, 23]. These materials' inherent aesthetic and functional advantages have increased the range of clinical indications. Zirconia particles are frequently employed as the toughening agent for other ceramic composites, and this zirconia toughened ceramics have received great attention in the last two decades. Yttria-stabilized zirconia (YTZP) used based composites with carbide (WC) content up to 50 vol.% from nano powders utilizing conventional hot pressing. The hardness increased from 12.3 GPa for pure Y-TZP up to 16.4 GPa for the composites with 50 vol. % WC, whereas the bending strength reached the maximum of 1551 MPa for 20 vol % WC composites. Zirconium dioxide (Zirconia) is one of the most studied ceramic materials [15]. The main application of zirconia is in the production of ceramics which other applications including as a protective coating. Zirconia has high ionic conductivity and low electronic conductivity, making it one of the most useful electro ceramics. Also, Zirconia particles are used in new composite materials to enhance their mechanical properties because of its hardness and infusibility. Some researcher used nano Zirconia to improve high velocity impact resistance of Polycarbonate composites; after surveying, the results can be obtained that adding 1–3 wt. % of nano-ZrO2 into polycarbonate, significantly increased the impact resistance of the composite [15, 16, 20, 24, 25]. The same studies that other researchers have conducted reported that the effect of nano Zirconia particles on PC composites' mechanical and thermal properties is significant. Results showed that both the hardness and elastic modulus increased with increasing ZrO2 content, up to 20 wt. %, which was related to the reinforcing role of the ZrO2 nanoparticles. [9, 14] Many engineering composite structures made from PC are often prone to vibrations during their normal operations under dynamic load, leading to fatigue and fracture due to the vibration and declining the structures' durability. So, in engineering design, it is essential to reduce vibration, increasing the lifetime working of structures [5, 10, 22]. One of the solutions is to use high damping materials to reduce vibration in related structures. Hence, dynamic testing has been widely used to control the quality of the dynamic structures in new industries [2]. Damping is an important parameter for vibration control. The damping property of a material is one of the principals and critical factors for designing and manufacturing structural components in dynamic applications in order to optimize designed constructions considering their dynamical response and can prevent mechanical vibration of structure elements and reduce noise and increase the stability of structural systems [5, 8, 18, 26-28]. In recent years, many studies have been focused on the damping analysis of composite structures. used finite element method to predict the damping characteristics of GFRP and CFRP laminates. Ritz method was applied to perform the dumping calculations and experiments of various composites, including unidirectional glass/Kevlar fiber composites and orthotropic composites with interleaved viscoelastic layers, and further completed the damping analysis of composite plate and structures by using this method [1, 5, 8, 19, 28]. Using nanofillers is a useful method in order to enhance the damping properties of composites, same time maintain the other mechanical features. by detecting the properties of nanomaterials, it may be possible to control the vibration absorbent in nanocomposite structures [2, 6, 7, 19, 29].

The influence of adding silica nanoparticles and rubber particles into the glass-epoxy laminates on damping and Experimental results has been analyzed, which has been found that, with the incorporation of the silica nanoparticles and the rubber particles, the reduction of flexural stiffness of fiber composites, especially for the laminates decreased. In contrast, the damping properties of laminates improved [20, 21, 28, 30]. utilized a numerical approach to investigate the dynamic properties of nanocomposite beams. developed a method to determine the orientation distribution function of montmorillonite clay in nylon 6 nanocomposite films [1, 28]. Dynamic tests typically involve applying a measured force excitation along a natural direction (degree of freedom) of the system, measuring the system response at the desired location, and measuring other critical degrees of freedom. In experimental modal analysis (EMA), information primarily consists of natural frequencies, modal damping, and mode shapes. EMA is an experimental method to obtain the dynamic characteristics of a mechanical component of a machine tool [16, 18, 22, 26, 31-32]. This test aims to determine the dynamic behavior of the object that information can be used for diagnosing fault, design improvement, and evaluation of the operational capability of a system. In this paper, to directly impact the field of vibration damping, structure, or system, the level approach was used to examine the damping mechanism and characteristics of PC-ZrO2 composites.the effect of MWCNT on polycarbonate .in order to study the vibrational effect of PC, High-pressure Fourier-transform infrared absorption spectroscopy has been performed on polycarbonate, the vibrational modes have been measured as a function of pressure for six modes, and the Grüneisen parameters were determined.

2. THEORY

2.1. Common methods:

In engineering, damping implies the reduction of the amplitude magnitude of vibration of a system. The amplitude would be decreased quickly by producing vibration in a system, and the energy has absorbed in structure. The damping ratio is related to the properties and type of components structure, so this ratio is significant to predict a structure's vibrational behavior [33]. There are two standard experimental methods to obtain the damping ratio, first is the free vibration method, and the second is forced vibration or $\sqrt{2}$ methods. The first method can accomplish the damping ratio of all the fundamental modes, but the second method can only compute the damping ratio of a few of the first modes.

2.2. The logarithmic decrement:

Notably, the vibrational response of each complex system would be decreased gently when the last decay phase is confused. This phenomenon represents the same response as the fundamental mode.

Figure 1 shows a general schematic of a free vibration. The time of a complete oscillation is a natural period. Also, the natural period can be used as an index to calculate the time difference between two consecutive peaks of the vibrational structure response measured in seconds [34].

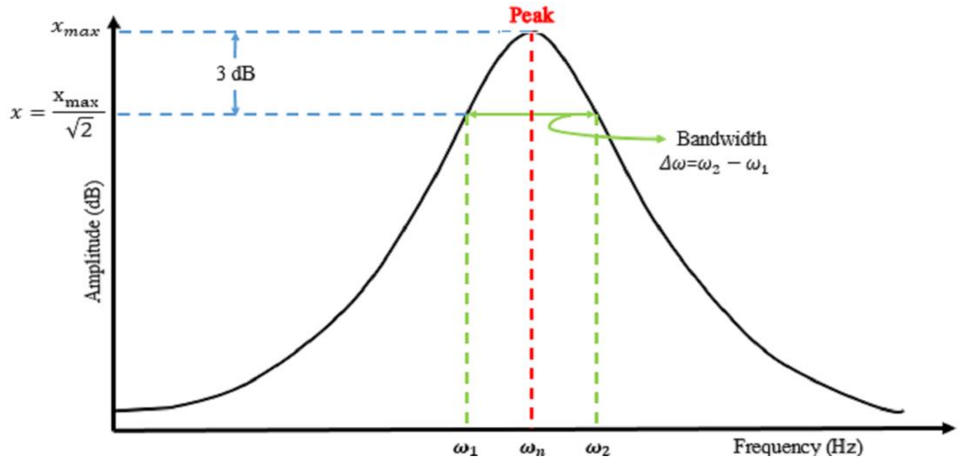


Figure 1: The Q-factor (or Half-Power) Method of Damping Measurement

$$\omega_1 = \frac{2\pi}{T_1}\left[\frac{rad}{s}\right] \tag{1}$$

$$f_1 = \frac{1}{T_1} = 2\pi\omega_1[H_Z] \tag{2}$$

$$\delta = \text{In}\left(\frac{r_i}{r_{i+1}}\right) \tag{3}$$

$$\frac{x_1}{x_2} = \frac{e^{-\zeta\omega_n t_1}}{e^{-\zeta\omega_n(t_1+\mathcal{T}_d)}} = e^{\zeta\omega_n t_d} \tag{4}$$

where in:

$$t_2 = t_1 + \mathcal{T}_d \tag{5}$$

log reduction is calculated as follows:

$$\delta = \text{In}\frac{x_1}{x_2} = \zeta\omega_n t_d = \omega_n t_d \frac{2\pi}{1-\zeta^2} = \frac{2\pi}{\omega_d} \bullet \frac{c}{2m} \tag{6}$$

assuming a small amount of damping:

$$\delta \simeq 2\pi\zeta \quad \text{if} \quad \zeta \ll 1 \tag{7}$$

where x_1, x_2 are first, the second number of cycle respectively and f is the frequency, and T_1 is the period, and f_1 is the repeating oscillation, and δ is the logarithmic decrement, and ω_n is the natural frequency, ω_d is the damped natural frequency in rad s^{-1} and f_d in Hz and also $\mathcal{T}_d$ called the time for one cycle (the damped period) of the damped vibration, thus c is damping coefficient, also t_1 and t_2 are the first and second period

2.3. Determination of ζ by √2 Method:

The peak-picking is the simplest single-degree-of-freedom (SDOF) method for modal analysis. It is also called the Half-Power method. The following method is based on the SDOF assumption. In this method, it is defined that the data in the resonance area and the SDOF system data are the same15.

The half-power methods were used to obtain the damping ratio of all modes; in this paper, according to each natural frequency, there is a peak point in the system's fundamental frequency amplitude. Two points correspond to the half-power point at 3 dB down from the peak (Figure 1). to determine the damping ratio of half-power points at ω_1, ω_2, firstly, the frequencies of each side of the identified peak with amplitude $\frac{H_{max}}{\sqrt{2}}$ were selected. Damping loss factor or damping ratio can later be obtained from the width of the resonance peak, and also damping ratio is calculated by using the following equation:

$$\zeta = \frac{\omega_2(x_{max}/\sqrt{2}) - \omega_1(x_{max}/\sqrt{2}).}{2\omega_n(x_{max}).} \tag{8}$$

$$\zeta = \frac{\omega_2^2-\omega_1^2}{4\omega_n^2} = \frac{\omega_2-\omega_1}{2\omega_n} \tag{9}$$

$$2\zeta = \frac{\omega_2-\omega_1}{\omega_n} \tag{10}$$

where ω_1 and ω_2 are the frequencies corresponding to the half-power point, ω_n is the natural frequency corresponding to the peak value, and ζ is the damping ratio. Alternatively, if ζ is not assumed negligible, the relationship becomes:

$$\zeta = \sqrt{0.5 - \sqrt{0.25 - 0.0625\left(\frac{\omega_2-\omega_1}{\omega_n}\right)^2\left(\frac{\omega_2-\omega_1}{\omega_n}\right)^2}} \tag{11}$$

Also, the Q-factor, which measures the sharpness of resonant peak, is defined by:

$$\text{Q factor} = \frac{|X|}{F_{0\,/\,K}} \tag{12}$$

$$Q=\frac{\omega_n}{\Delta\omega} = \frac{1}{2\zeta} \tag{13}$$

where $\Delta\omega$ is the distance between half-power (–3dB) points, ω_n is the un-damped natural frequency, and ζ is the damping ratio.

$$H(f) = \frac{Y(f)}{X(f)} \quad (14)$$

where H(f) is the frequency response function, Y(f) is the system's output in the frequency domain, X(f) is the input to the system in the frequency domain, K is the stiffness of spring, X is the amplitude of the vibration, and F_0 is the force.

3.MATERIALS PROPERTIES

3.1 Details of Materials:

Polycarbonate and nano zirconia powder used in the current study are as follows: Grade: HI1002ML, produced by LG Chem (South Korea), and nanoparticles (ZrO2, high purity 99.95%, 20 nm), produced by US-Nano co. (USA). The Zirconia and polycarbonate properties have shown in Table 1. Before mixing, these materials dried at 110°C for 12 hours in a dehumidifying oven. Also, the mechanical properties for both PC and ZrO2 can be found in Table 1.

Table. 1. Zirconia and polycarbonate properties

Material	True Density	Molding Shrinkage	Tensile Strength	Flexural Modulus
PC	5.89 g/cm^3	0.5~0.7 %	580kg/cm^2	23000kg/cm^2
Material	**Specific Gravity**	**APS**	**SSA**	**Crystal Phases**
ZrO2	1.2	20 nm	30-60m^2/g	monoclinic

3.2 Sample preparation:

1) The nanoparticles with four different weight percentages (1-5 wt. %) have added to the PC matrix. Materials were stirred well with a mechanical stirrer for two hours to the better mixture; the rotation speed of the mixture was set at 2000 rpm. After mixing the mixture, the mixture was placed in the ultrasonic homogenizer suit (ultrasonic SONOPLUS-HD3200, 50% amplitude, 20 kHz, and pulsation; ON for 10s and OFF for 3s) for 8 minutes due to avoid nanomaterials agglomeration and to make a homogenous mixture.
2) The extruder: This process starts by feeding the material (PC/ZrO2) from a hopper into the barrel of the extruder. Then the material has gradually melted by turning screws and heaters arranged along the barrel. Then the melted polymer forced into a die, which shapes the polymer into a pipe; in other words, it can be more complicated and formed during cooling and ultimately transformed into the solid granular.
3) After extrusion, raw demanded materials custodied to prevent moisture; high-temperature PC is susceptible to absorbing water in this step; granular dried again by humidity absorber system at 100-120°C for 24 hours.
4) Molding process: by comparing to another method, this method is one of the low-cost molding methods, such as transfer molding and injection molding; moreover, few materials can be wasted. It can also be mentioned as an advantage when working with high cost compounds.

In the last step, the samples have generated by compression molding. For 5 minutes, Granular poured into the pre-designed molding and placed in hot-press at 250°C – 25MPa minutes and afterward the temperature and pressure have decreased to the room condition and after that, specimens prepared by machining. The machining process was done to cut the burrs.

3.3 TEM micrographs:

The TEM micrographs of the PC–ZrO2 Nanocomposite contains 3 wt. % of zirconia has reported in shapes. TEM pictures have been used to evaluate nanoparticles' dispersion in the PC matrix.

This could be a consequence of the interaction between the nanoparticles and the polymer matrix. The TEM micrographs process was as follows: the materials have sliced with the thickness of 15nm at a temperature of -120°C (cooled down with liquid Nitrogen) using Leica-EM UC7 microtome (Germany). The slices have put on a Formvar carbon-coated grid (Cu Mesh 300) with a diameter of 3.05mm. A Zeiss EM10C TEM microscope (Germany) with 80 kV acceleration voltage was utilized to take TEM micrographs.

4. EXPERIMENTS

4.1. Oscillator devices and Modal Testing:

Five types of composite impact resistance of polycarbonate laminates investigated where these composites have been fabricated by using the hot molding press method. Equipment:

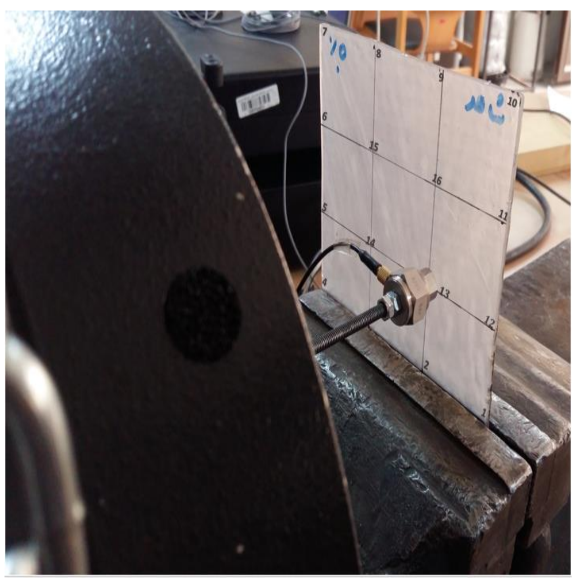
1) Brüel&Kjær FFT Analyzer Type 3560-c
2) Brüel&Kjær PM Vibration Exciter Type 4808
3) Brüel&Kjær Power Amplifier Type 2719

The specimen dimensions are (five 120-mm x 120-mm x 2.5-mm formed Nanocomposite plates). Before testing, plates were secured with a C-Clamp fixture to the desk, as shown in Figure 2. Plates on the fixture are tightened to 0.2 ft-lbs., so the plate is placed between two fixture halves. The experimental model of the sheets has been divided into 12 equal elements and tested in a fixed end configuration. Laminates polycarbonate were tested in the laboratory to validate the shaker-stinger-structure model. The Modal shaker is kept ready by a force transducer to excite the sheet at the singular points.

The FFT spectrum analyzer attached to a power amplifier is always needed to provide the necessary energy to drive the shaker. Many factors can emerge when the shaker's proper power amplifier has been selected. As electrodynamics shakers, which are usually low-impedance devices, one of the most ensure selected amplifier can indeed drive the shaker to its desired performance. Compatibility between the shaker and amplifier is fundamental and other requirements, such as broad frequency range, low-frequency response, power rating, power efficiency, low harmonic distortion, safety features, interlocks, etc. Using recommended shaker is the safe choice; it typically guarantees the performance of shaker system characteristics (sine or random force capability), which can only affirm once a shaker and pair amplifier has selected.

The sheets were excited by a shaker at point 2. Also, the response was measured at 12 points. It can be excited by using an accelerometer with the 0.5g weight attached to the plate and the fixture. The accelerometer was fixed by wax to the cantilever sheet among the nodal points on the sheet at the test node. A small amount of wax was used to preliminary test the different accelerometers on the composite plates. Wax is the ideal adhesive method due to its negligible weight, easy removal, and transmit acceleration. The connections of the FFT analyzer, laptop, transducers, modal shaker, and the requisite power connections were created.

(a)



(b)

Figure 2: Shaker-stinger-structure model

The software employed to collect the vibration data was Brüel&Kjær PULSE™ Lab shop Corporation's Sine Controller with data in ASCII format. It records frequency, input acceleration, and responsive acceleration. Figure 3 shows a schematic picture of the measurement system setup.

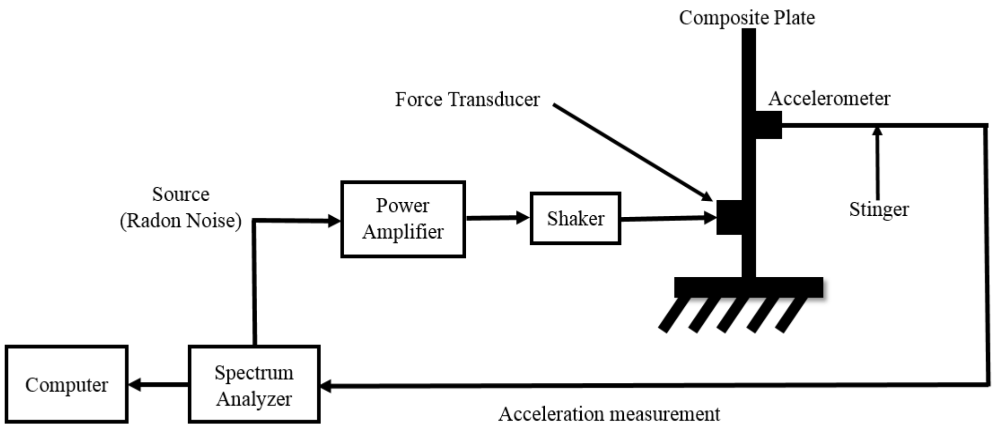


Figure 3: Schematic picture of the measurement system

Both the excitation and response signals were sent to the Dual-Channel FFT Analyzer. The frequency response functions are observed as complex-valued curves in the software Pulse Lab shop. Pulse Lab shop is the fast Fourier transform analyzer that receives the digital signal from the shaker and the accelerometer, and it converts the various parameters also checked with the Pulse Lab shop; the software was:

1) Frequency Response Function
2) Coherence
3) Time weighting signals

The data was exported into the comma-separated-value format, then imported into the software.

5. RESULTS AND DISCUSSIONS

5.1. Vibration and damping results:

Experimental modal testing was conducted to evaluate and compare the vibration properties of composite plates of PC-ZrO2 with 1, 2, 3, and 5 wt. % of nanoparticles and a neat sample (without nano). Figure 4 shows the frequency characteristics of the specimen with 0, 3, 5 wt. % of nanoparticles. The results of the tests are shown in Figure 5. According to this plot, it obtained that, the damping ratio has increased with increasing the nano ZrO2 to 3 wt. % in all four modes and the neat samples had the less damping characteristic. The maximum damping ratio belonged to the samples with 3 wt. % of nano zirconia. Also, it observed that the damping ratio decreased significantly with increasing the nanoparticles by more than 3 wt. %. The damping ratio has been calculated by Eqs. 1-7.

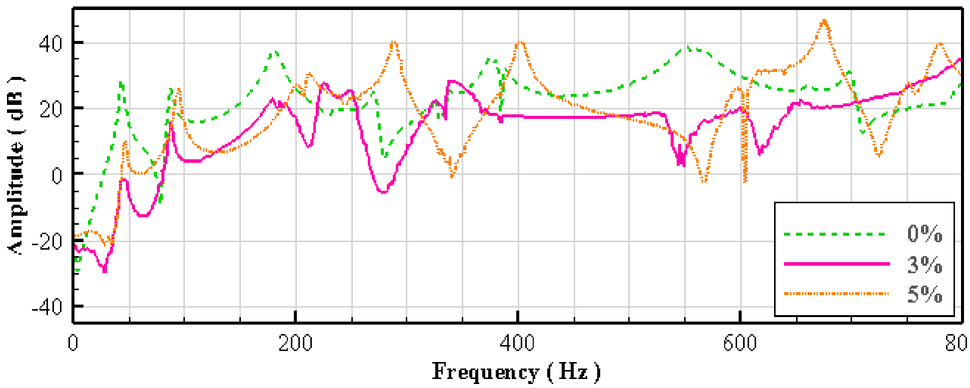


Figure 4: Frequency response function at 0%, 3% and 5%wt. composite plates

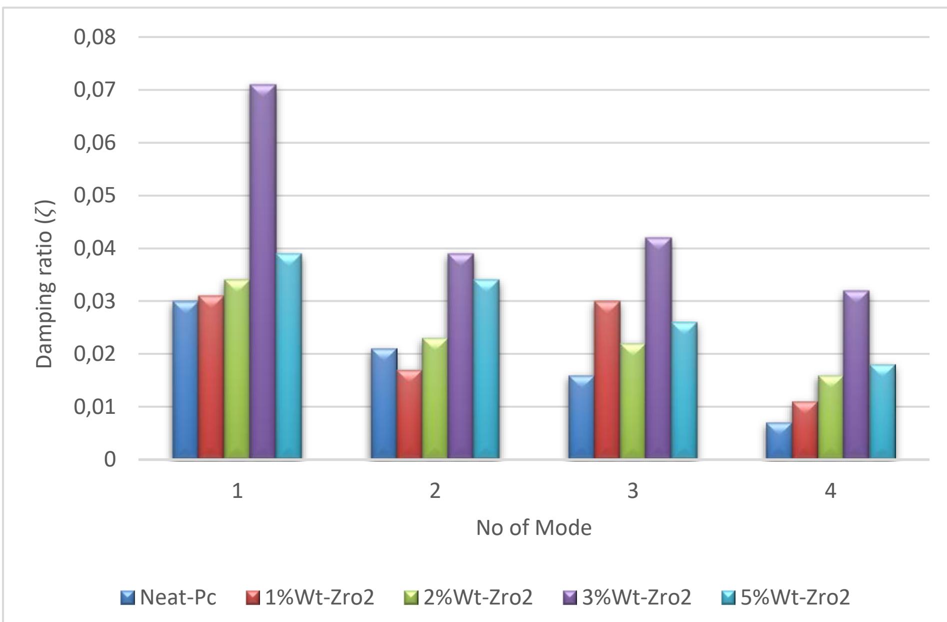


Figure 5: The 0 wt. % - 3 wt. % and 5 wt. % the PC-ZrO2 sheets for the 1-4 natural frequencies

From the comparison of the damping ratio, it is clear that the damping ratio of the Nanocomposite sheet increased at all of the mode frequencies. However, there is little change in the mode frequencies, which means that there is only a slight change in the stiffness of the composites. This confirms an advantage of PC-ZrO2 nanocomposite over neat PC. Therefore, it can be concluded that incorporating zirconia Nano powder could result in a significant increase in structural damping of conventional resistance of polycarbonate laminates.

5.2. Comparison the vibration and damping properties at the free-end and fixed-end section:

In order to investigate the vibration and damping response of composite plates, FRF measurement was done at two different points of the sample. Figure 6, shows the modal frequency for each plate. According to this figure, the natural frequency decreased at the free end of the sample, indicating that the natural frequency decreased with the increase of the plate length. This revealed that a more significant length plate has the more considerable.

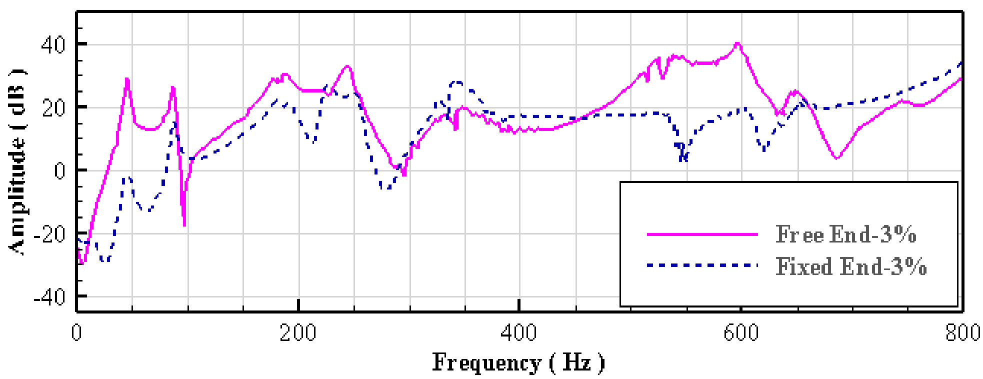


Figure 6: Frequency response function comparable at 3 %wt. PC-ZrO2 Nanocomposite

Amount of mass and greater mass decreases the frequency, but the damping ratio indicated to be the lost patterns between modes and plate lengths. The amplitude is almost negligible for the first mode and increases with an increase in the modal frequency after measuring the free end vibration results decreased for the subsequent fourth modes.

Also, it has been seen that the damping ratio and amplitude have increased and decreased respectively at the sample fixed end. The amplitude of the free end for all modes is greater than the amplitude for the modes measured from the fixed end.

Most of the nodes occur at the phase angle, not near 0° nor 180° degrees. If the phase angle is exactly 0°, the plate would be moved proportionally to the input acceleration. The input acceleration is opposite of the motion of the plate if the phase angle is exactly 180°, which effectively absorbs the kinetic energy in the structure. Resonance occurs when the signal has allowed be amplified and grows unbounded. In other words, when the plate's phase angle is close to +/- 90° degrees, the plate is in an unstable vibration, which leads to resonance.

The first thing to notice in this study is much more signal attenuation at the fixed end. This plot shows that the shorter plates produce the most damping and negligible amplitude at higher frequencies than the more extraordinary plates. Interestingly, the phase angle changes much more quickly at this accelerometer position, so there is a shorter period of instability. Even so, from Figure 7, the damping ratios at each of the modes seem to be comparable

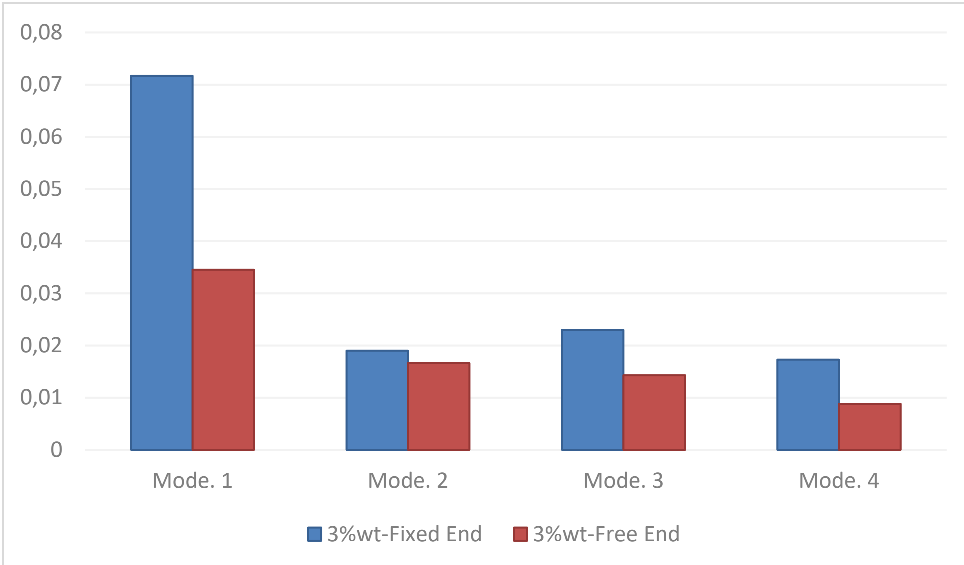
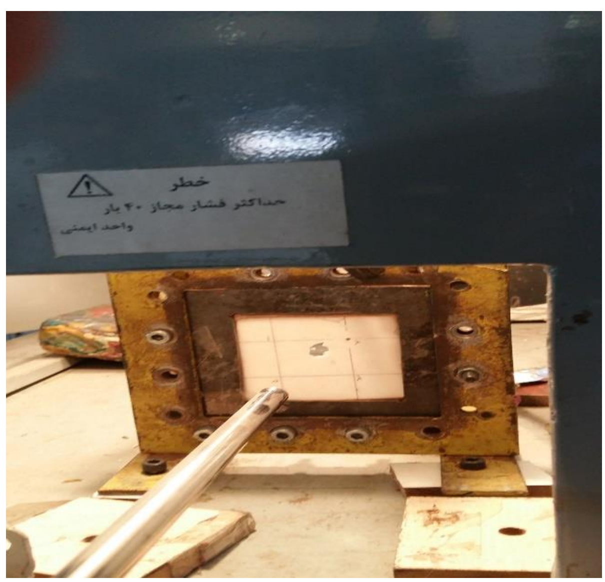


Figure 7: Damping ratio of the 3 wt. % Nano composites at the free end - fixed end specimen are compared for the 1-4 natural frequencies

5.3. Results of the Vibrational properties of damaged and undamaged samples:

In this section, the high-velocity impact tests were conducted using a high-pressure gas gun (Figure 8). Then, the plate is placed between the two halves of the fixture, and one horizontal fastens bolt the two fixture halves mutually due to preparing samples (Figure 9). This paper presented vibration-based damage detection as an efficient and global tool for evaluating the plates. The experiments were designed based on an impulse actuator signal generated by the shaker and the responses recorded using accelerometer sensors. Dynamic behavior of specimens and changes in the modal parameters of the pc-zirconia plates to assess the structural health were studied. When a system is subjected to a particular degree of damage or deterioration, it experiences a change in stiffness. Subsequently, it caused that natural frequency to be changed. The magnitude of the changes is also an indicator of the severity or state of the damage experienced. By comparing to the undamaged plate, the changes in the natural frequencies of the damaged plate can be apparent. The values of natural frequencies for the test plates are shown in Figure 10, and the results are obtained from the two compared plates. Some of the frequency response functions and amplitude of test plates are shown in Figure 11. there is a higher decrement in natural frequency and amplitude for the damaged plates than undamaged plates. The maximum decrease in natural. The frequency at 18 %, 15 %, and the maximum amplitude decrease at 96 %, 92 % have been observed respectively in the first and second modes.

(a)



(b)

Figure 8: High-velocity impact test

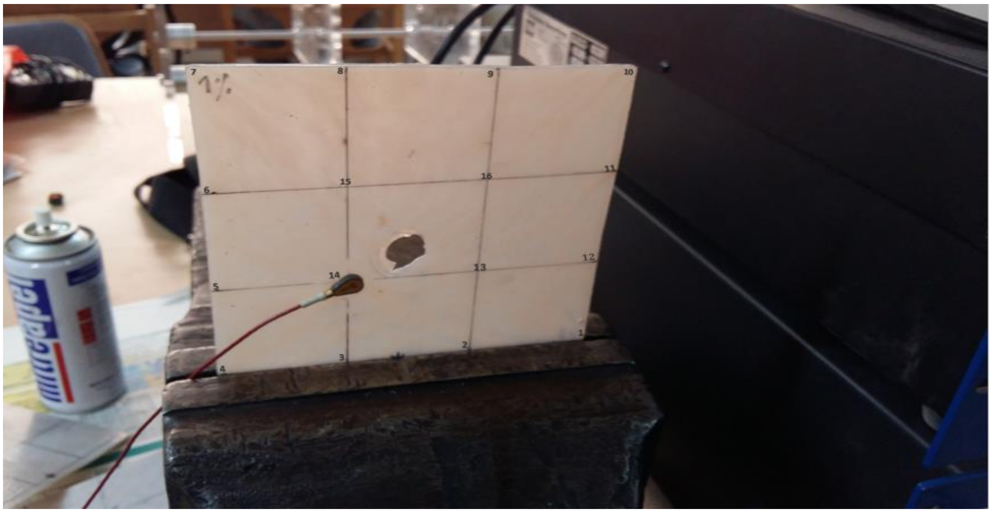


Figure 9: The modal test after high-velocity impact tests

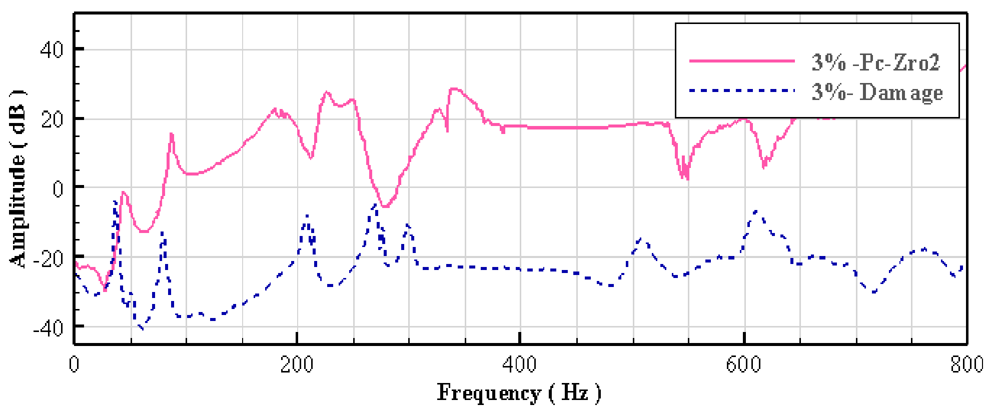


Figure 10: Comparison of modal parameters before and after the damage

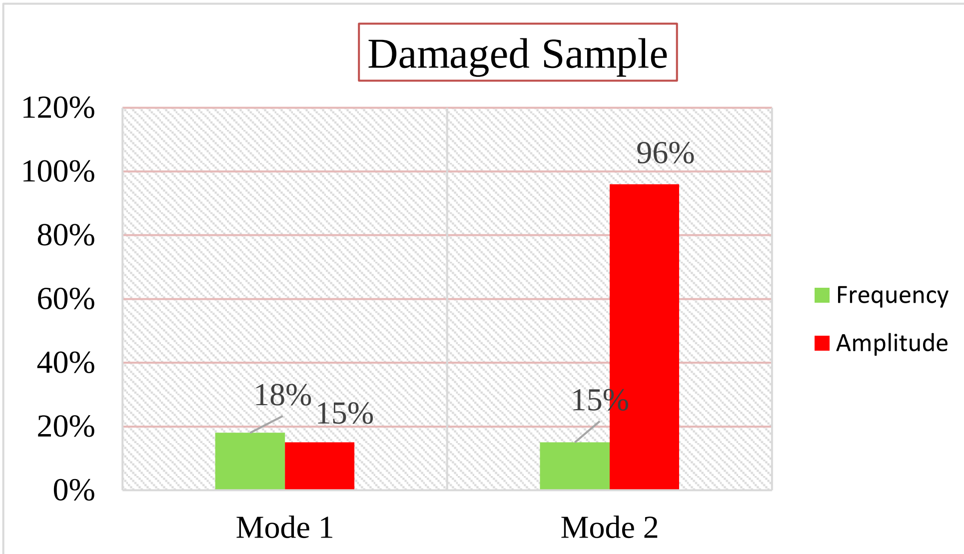
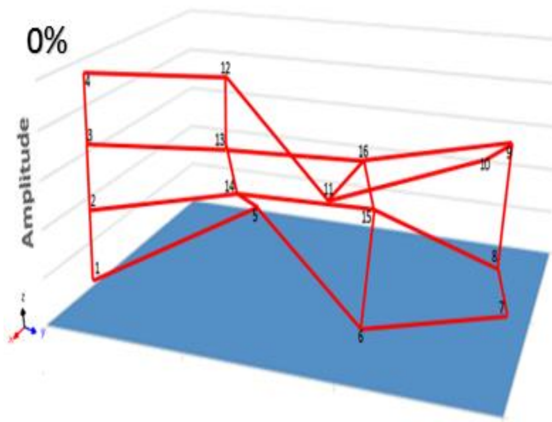


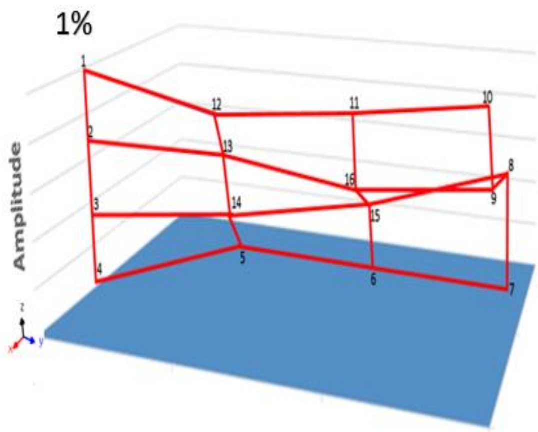
Figure 11: The maximum decrease in natural frequency and amplitude after high-velocity impact tests

5.4. Mode shape definition:

A mode shape is a specific vibration pattern executed by a mechanical system at a specific frequency. Different modes would be associated with different frequencies. The mode's shape was studied before and after strengthening with the nano particles. it was found that it could only affect the frequency and damping values. The comparisons between the 0-3 and 5 wt. % at the Fourth mode experimental, mode shapes of the pc-zirconia plate presented in Figure 12 shows the remarkable results, The detailed mode shapes of test plates are described as below, 0 and 1 wt. % were a twisting mode, 2 wt. % was a twisting-bending mode, and 3, 5 wt. % were a bending mode. Also, according to the modal test, more nodes have occurred near the 0° and 180° phases angles. The plate would be moved exactly proportional to input acceleration at 0° phase angle, and the input accelerator would deal with the plate movement at the phase angle of 180° and absorb all kinetic energy of the structure. In addition, if the phase angle of the structure is at ±90° causes unstable vibration, leading to the resonance phenomenon.



(a)



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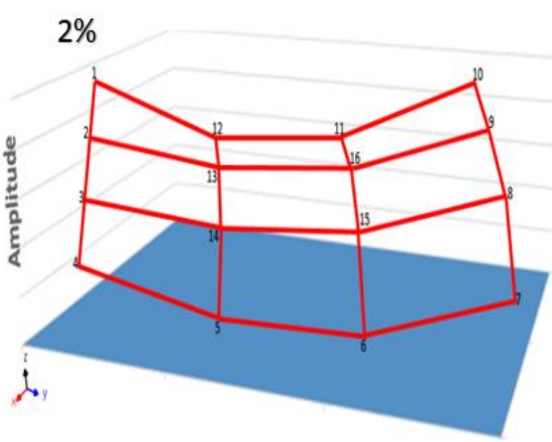

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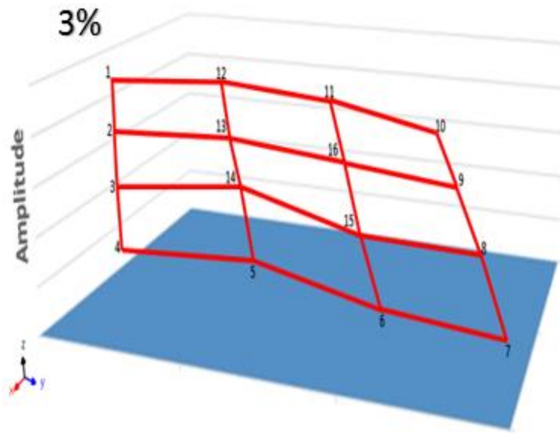

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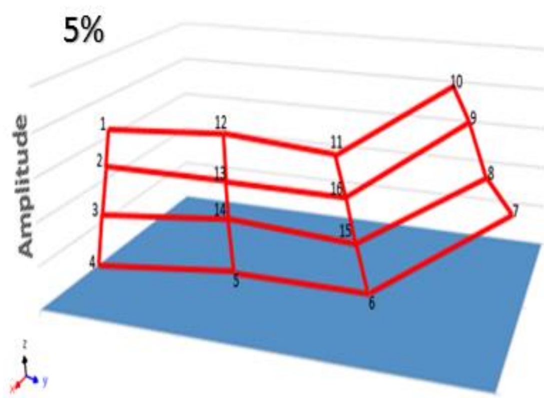


(e)

Figure 12: Five Shape modes for Pc- ZrO2 composite plate at fourth mode.

5.5. Representative TEM micrographs:

Transmission electron microscopy (TEM) was utilized to investigate the surface morphology of the composites. The samples with the 3 wt. % of ZrO2 had the most damping ratio and less vibration amplitude. The TEM pictures in Fig 13 reveals this behavior. According to this figure, it is clear that the nanoparticles were well distributed in the matrix and made a smooth surface and good bonding with the polycarbonate. However, when the content of nanoparticles exceeded more than 3 wt. %, the damping ratio was decreased, and the vibration amplitude increased. This is analyzed in Figure 14(a,b).

According to this graph, more nanoparticles content caused the agglomeration phenomenon, and also, the nanoparticles were not able to adequately distribute to the matrix surface to make a rough surface which is clear in Figure 14(b). In these samples, the fracture possibility would increase. Figure 15(a, b) clearly shows the poor interaction of nano powder and matrix, and also some agglomeration can be observed in Figure 15(b), which is clearly recorded by the TEM micrographs , also must be mentioned that cubic structure of ZrO2 would give advantages that even by attaching to PC still saved its bonding structure, also would not be easily destructed, but the aggregate of nanoparticles in PC would decrease the stiffness of composite, this is because , nanoparticles are more attending than a specific content, which weakening the stiffness of structure and structure strength, by surveying more on the subject , can be easily found that , more aggregate of ZrO2 makes the whole composite fine and would increase the damping ratio of more than 1 . on the other hand , nanoparticles still save the cubic structure, which structure plays an important role in improving the damping behavior of composite , but hexagonal structure of PC would give great and important advantages which, by attaching Nano ZrO2 to PC these two structure makes good bonding, which in higher contents this structure again helps to improve damping behavior , thus in higher content of Nano fillers would increase the agglomerations , basically , agglomeration would cause to decrease the toughening and stiffness features of material , also take whole composite into plasticity phase , by surveying the experimental details , found that increasing more contents of Nano ZrO2 , would increase agglomeration , this agglomeration would increase the damping behavior , that is because whole composite taken into plasticity phase and this phase assisted to increase the damping behavior , also by surveying the shape of PC and ZrO2 (cubic and hexagonal structure) found that by increasing the content of nano ZrO2 both structures meet their critical point of stiffness which significantly decrease the stiffness , this is because of stress concentration on composite specimens which agglomeration of ZrO2 caused stress concentrations , thus this aggregate would loosen the bonding of these two structure which cause to decrease the stiffness , that finally increase the damping behavior of composite in higher contents of Nano ZrO2.

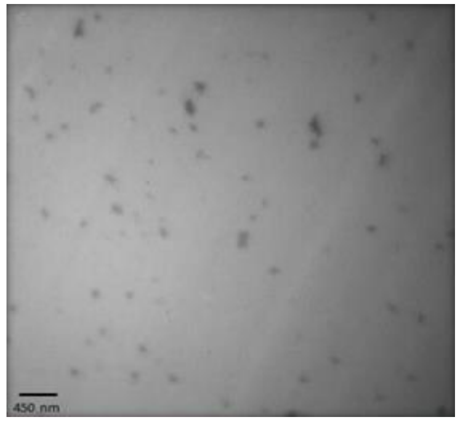
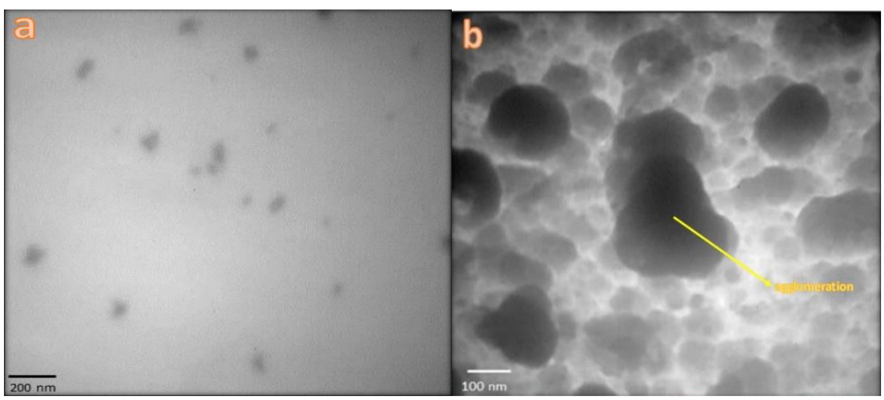
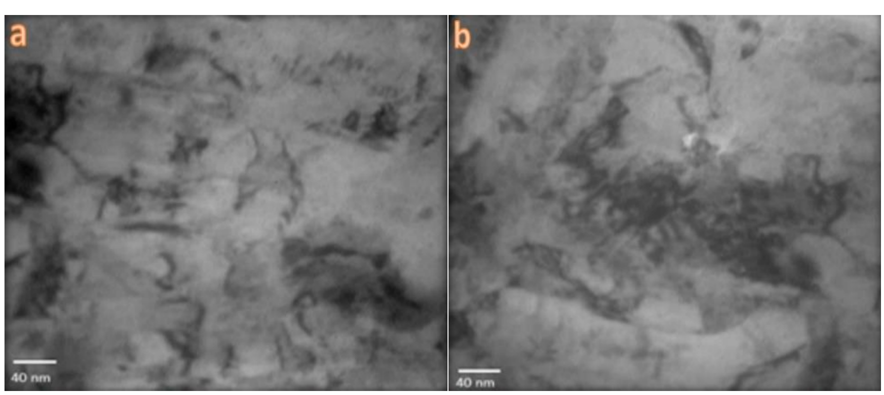


Figure 13: TEM micrographs at 5K X magnification



(a) 12.5K X magnification (b)25K X magnification

Figure 14: TEM micrographs



(a)the non-agglomerate (b) agglomerate section

Figure: 15: TEM micrographs at 63K X magnification

6. CONCLUSION

In this research, the effect of nano zirconia on the vibration and damping properties of the polycarbonate composite plates was investigated, according to the experimental modal analysis (EMA), and compared with the neat plates. The half-power algorithm was employed to evaluate the damping ratio of structures. The results showed the increase of damping properties by adding ZrO2 to 3 wt. % and a slight change in the natural frequency of the composite. The most increase in damping ratio belonged to the samples with 3 wt. % of nano zirconia with about 249 % more than the neat sample. TEM micrograph showed a good dispersion of nanoparticles and strong bonding on the matrix.

On the other hand, higher damping ratio zirconia-based composites have the largest interfacial contact area with the PC. Moreover, contributing in higher ZrO2 content would dissipate more energy with a greater frictional force and structural damping. the interfacial area between the zirconia and the polycarbonate is significant because of the nano size of zirconia. ZrO2 would cause greater frictional force and structural damping. Note that fillers have developed the capability to the matrix in applied loading, which could lead to more slippage and energy dissipation through friction. In other words, the increase in contact area dramatically increases the potential for energy dissipation due to interfacial friction. It also observed that the experimental modal analysis depends on the structure's physical condition, which was also different at the free-end and fixed-end points. Moreover, the results showed that the polycarbonate plate contained zirconia Nano powder, which could reduce the vibration amplitude on damaged plates. Furthermore, it could be used for lightweight and multifunctional benefits.

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