CREATIONOF AN OPTIMAL POLYMER NANOCOMPOSITEFOR USE IN PARALLELENVIRONMENTAL NOISE BARRIERS

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Abstract - In recent years, following the use of parallel noise barriers in control of urban noise pollution, acoustic engineers have made their attempts to create an optimal material based on nano-composites as a Sound-absorbing material. They can be used in the structure of parallel noise barriers in order to reduce multiple reflections. Accordingly, the present study was performed to create an optimized absorber transparent polycarbonate/poly methacrylate-based polymer nanocomposite in parallel environmental noise barriers in order to reduce multiple reflections. For this purpose, a twin-screw extruder was used to mix 0.3 wt% SiO_2, ZnO, and TiO_2 nanoparticles with pc and PMMA polymers.Scanning electron microscopy (SEM) was used to study the surface morphology of thenanocomposites. In order to test the sound absorption coefficient of the specimens, Two-microphone impedance tube was used. Finally, due to optimize the acoustic properties of the specimens and to reduce any surface defects caused by molding, the surface was roughed by sand blasting machine. Mechanical properties were characterized by tensile, flexural strength, izodimpact, and Shore hardness tests. The transparency of the nano-composites was checked by UV-vis spectroscopy. The morphology results described dispersion of the nano-particles in the polymer matrix. The obtained results showed that the pcsi3-r nano-composite, compared to the other specimens, had the highest acoustic absorption coefficient at the middle frequencies of 500 Hz. According to the tensile modulus and hardness test results, the mean tensile modulus and hardness of the nano-composites was higher than that in pure polymers. Also, the flexural modulus of nanocomposites was always higher than the net PC and PMMA, except for the pczn3 specimen. The transparency test results showed that adding nanoparticles to the PC and PMMA matrix considerably decreased the transparency of the specimens, compared to the pure polymers.In conclusion, adding 0.3 wt% of nanoparticles to the polycarbonate and poly methyl methacrylate-based matrix and roughening the rigid surface of the specimens increased the mechanical properties and also sound absorption coefficient in the middle frequencies.

Keywords - Nanocomposites, Environmental Noise Barriers, Absorption Coefficient, Transparency, Mechanical Characteristics

I. INTRODUCTION

One of the solutions to reduce noise pollution is using noise barriers in residential areas. Noise barriers placed between the source and receivers can prevent sound waves from reaching direct wave to the receiver in the shadow zone. The noise barriers can be used as single or paralleled based on the residential area situation. Previous researches showed that installing parallel noise barriers in both sides of roads, affect the overall performance of barriers due to sound reflection caused by each barrier. Multiple reflections cause a significant rise in noise level in the screened area. Using proper absorptive materials on the surface of parallel noise barriers causes improvement in insertion loss[1].In recent years, polycarbonate and polymethyl methacrylate, due to useful features such as resistance to temperature and shock, optical properties, and high transparency, have found a special place among engendering and commercial plastics,as an efficient material. Therefore, in many industries, including automotive, aviation, industrial machinery, and environmental noise barriers, are used in abundance.Nowadays, nanoparticles are of great use to enhance the mechanical properties of polymers. Several studies have suggested that adding a small percentage of nanoparticles to a pure polymer provides a significant improvement in mechanical properties[2]. The nanoparticles are dispersed throughout the polymer matrix to improve the overall properties of the polymer. Much research has been done in this regard. As such, Zhou in 2009 found that adding 2% silicon dioxide into the polycarbonate polymers increases tensile strength compared to pure polycarbonate[3]. Fengin 2015 showed that the addition of 1 wt% SiO_2 to polycarbonate caused an increase in tensile strength and toughness, compared to net polycarbonate [2]. Silva in 2016 studied the mechanical properties of polycarbonate/ TiO_2 composite and concluded that adding TiO_2 to polycarbonate polymer increases tensile strength and strength at yield[4].Studies have shown that adding nanoparticles with defined weight percent to an opaque polymer, such as polyurethane foam, foam silica, and polyvinyl alcohol increases the noise absorption coefficient and mechanical properties, such as thermal stability, impact strength and so. However, there was found no study on the acoustic and mechanical features of the composites of silica

nanoparticles and transparent polymers, such as polycarbonate and poly methyl methacrylate. This clarifies the necessity of such projects. Accordingly, the present research was conducted to construct an optimal transparent polycarbonate/poly methacrylate-based polymer nanocomposite in order to study the effect of glowing nanoparticles on transparency, mechanical, and acoustical properties of polymer composites.

This paper shows that how a significant advance could achieve in mechanical and acoustic properties of transparent polymer composites by direct combination of nanoparticles of titanium dioxide, zinc oxide, and silicon dioxide in the melt PC and PMMA polymers. The produced material can be used in the design of environmental transparent noise barriers in order to reduce multiple reflections. In the next section of the article, the acoustic and mechanical properties of the specimens are described. Then, the theoretical foundations of the research methods and their implementation procedures are explained briefly. In the third section, the results of experiments and calculations are presented and discussed. Finally, the conclusions are provided at the final section where some recommendations for future studies are suggested.

II. DETAILS EXPERIMENTAL

2.1. Materials and Procedures

The main input materials used in this research to prepare the 16 specimens include the polycarbonate, PC-110, the product of Chi Mei Corporation in Taiwan (with the density of 1.2 g/cm3 and the melt flow index of 10 g/10), polymethyl methacrylate, CM-205, the product of Chi Mei Corporation (with the density of 1.19 g/cm3 and the melt flow index of 1.8 g/10), silicon dioxide nanoparticles with an average particle size of 20-30 nm, zinc oxide with an average particle size of 10-30 nm, and titanium dioxide, with an average particle size of 20 nm, manufactured by an American company.

2.2. Sample preparation

For preparation of the specimens, a twin screw extruder (brabender, TSE20 model1655-2 N40010-EXT, Germany, with L/ D = 40 and D = 20 mm), with an average temperature profile of 240 °C for polycarbonate and 200 °C for PMMA, was used. In this method, the melt PC and PMMA were separately mixed with 0.3 wt. % nano particles of titanium dioxide, zinc oxide, and silica dioxide. The formulation of samples is depicted in table 1. After cooling the molten materials in a cold water bath, they were cut as granules by a cutting machine. To measure sound absorption, each of the mixed specimens was poured separately into a mold to a thickness of 15 mm for compression molding by a Collin P400P Hydraulic Press, made in Germany. Once preparing the nanocomposite plates, in order to measure the absorption coefficient of the 30- and 100-mm specimens were cut by a water jet cutting machine (a product of DWJ King Co) to the dimensions of the Two-microphone acoustic impedance tube Fig.1. Finally, in order to optimize the acoustic properties of the specimens and to reduce any surface defects caused by molding, the surface of the specimens was roughed by sand blasting machine (Blast-N-PEEN Model, Germany)and then, the sound absorption coefficient of the roughed surface specimens was re-measured by the impedance tube. To study the mechanical properties, tensile, flexural modulus, impact strength, and hardness of the specimens, an injection molding machine (AL-7000M Model, Taiwan) was used to prepare the specimens in accordance with ASTM D790, ASTMD D256, ASTMD D2240, and ASTM D-638. The transparency specimens were prepared by the compression molding machine (model P400P, Germany), in accordance with ASTM-D1003.

Before the surface roughness process	
Sample name	**Type**
PC	neat
PCSI3	PC/SiO_2 (0.3wt%)
PCZN3	PC /ZnO (0.3wt%)
PCTI3	PC /TiO_2 (0.3wt%)
PMMA	Neat
PMSI3	PMMA /SiO_2 (0.3wt%)
PMZN3	PMMA /ZnO (0.3wt%)
PMTI3	PMMA /TiO_2 (0.3wt%)
After the surface roughness process	
Sample name	**Type**
PC-R	neat
PCSI3-R	PC /SiO_2(0.3wt%)
PCZN3-R	PC /ZnO (0.3wt%)
PCTI3-R	PC /TiO_2(0.3wt%)
PMMA-R	Neat
PMSI3-R	PMMA /SiO_2(0.3wt%)
PMZN3-R	PMMA /ZnO (0.3wt%)
PMTI3-R	PMMA /TiO_2 (0.3wt%)

Table1: Formulation of the samples

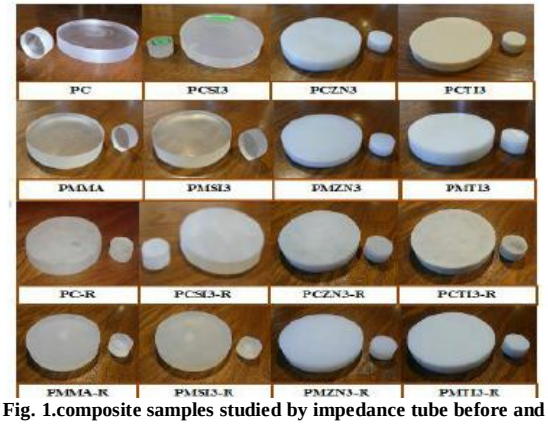


Fig. 1.composite samples studied by impedance tube before and after the surface roughness process

2.3. Characterizations

A microscopic analysis was performed on the surfaces of specimens. The sample surfaces were coated with layer of gold. Then the morphology of the samples was investigated using a scanning electron microscopy (VEGA2and Czech Republic). The absorption coefficient was measured by the two microphone impedance tube, in accordance with ISO 10534-2 and ASTM E 1050[5]. As seen in Fig. 2, the device is composed of a cylindrical asbestos tube with a speaker at one end. The speaker is connected to a pure tone generator and an amplifier. During the test, sound wave is propagated from the speaker towards the other end of the cylinder and reflected after hitting the specimens. The standing wave tube sets, manufactured by B & K Danish Company, is capable to measure to the absorption, reflection, and transmission coefficients of sound as well as the insertion loss of different materials in the frequency range of 50 to 6300 Hz. It is worth mentioning that before placing the specimens inside the acoustic tubs, the calibration function from pulse soft was used to configure the microphones and calibrate them[6].

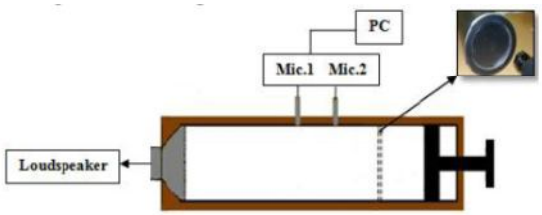


Fig. 2. Schematic view of the experimental set-up

The tensile properties, including modulus, tensile strength and elongation at break, were characterized in accordance with ASTM D-638 and the flexural modulus in accordance with ASTMD D790, and both by Gotech Mechanical Testing Machine (AL-7000M Model, made in Taiwan) at two speed levels of 50 and 1.300 mm/min. The hardness was measured in accordance with ASTM D2240, using Gotech machine (GT-GS-MB Model, made in Taiwan) and a counter weight of 5 kg. In addition, Izod impact was tested by device in accordance with ASTMD D256. The width of notch was approximated to be 10.11 mm. In order to measure the spectral transmission of the polymer nano-composite specimens, the Gretag Macbeth Spectrophotometer (CE7000 Model) was used. It should be mentioned that all of the tests were conducted under the identical conditions (temperature 24.2^{o}C, humidity 47.6%). Another non-acoustic indicator was the cost of consumable materials per each of the specimens with the diameters of 30 and 100 mm and the thickness of 15 mm. It is expected that the selected optimal material, in addition to having suitable acoustic and non-acoustic feature, benefits from affordable price. This can leave a considerable effect on the economy of the community and the viewpoint of the customers.

III. RESULTS AND DISCUSSION

3.1. Microscopic analyses

SEM images of nanocompositessurfaces are reported in Fig. 3.As shown in Fig. 3,SEM analysis indicates that the nano- particles were almost homogeneously dispersed inside the polymer matrix.

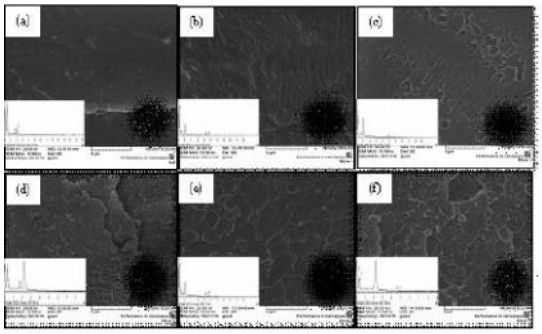


Fig.3.SEMs of the Samples with 0.3wt. % of nano particles obtained from formulations a(pcsi3) b (pczn3) c (pctio3)d(pmsi3) e(pmzn3)f(pmti3)

3.2. Acoustical properties

As depicted in Fig. 4, the absorption coefficient of all of the specimens, except for pmsi3, in low and intermediate frequencies, was almost identical and equal to 0.02 wt. % before the surface roughness process. The obtained results showed that the absorption frequency increased at the frequencies close to the upper frequency range of 4000-6000 Hz. However, after the surface roughness process, the pcsi3-r specimen had the greatest absorption coefficient of 0.08% in the intermediate frequency range of 500 Hz.

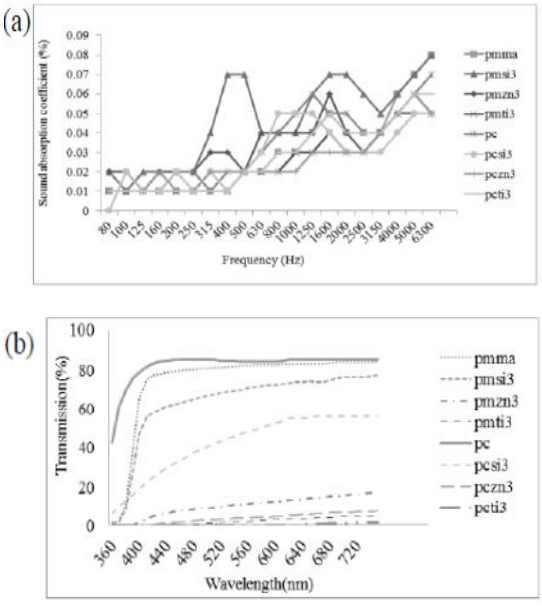


Fig. 4.Sound absorption coefficient curve of the specimens (a) before the surface roughness process, (b) after the surface roughness process

This means that the surface roughness process optimizes the absorption coefficient of the specimen in the intermediate frequencies. Considering to the sensitivity of human ear in the 250-2000 Hz-frequency range, the absorption coefficient of the specimens was compared in the intermediate frequency range of 500 Hz, as the dominant frequency of traffic noise[5]. This result was in line with the results of other relevant studies. As such, Rabbi in 2013 showed that when the poly cyril and nitrile nano-fibres were added to the not-so-hard polymers, air permeability and flexibility of nanocomposites were increased. Nano-composites, due to their greater flexibility, absorb more sound energy. thus, sound absorption coefficient, compared to the pure polymer, especially at intermediate frequencies of 1000 Hz [7], [8].

3.2. Transparency properties

The light transmittance spectra of the PC and PMMA nanocomposites before and after the surface roughness process are illustrated in Figs. 5. As observed in Fig. 5-a, in the frequency range of 550 nm, light transmittance of net PC and PMMA are 85.5% and 79%, respectively. The specimens, containing silicon dioxide, have higher transparency than the other PC and PMMA-based specimens with other types of nanoparticles. Fig. 5-b shows the transparency of the specimens after the surface roughness process. According to the figure, the transparency was decreased from 85.5% to 79% in pure PC and from 80% to 60% in PMMA. By roughening the surface, the transparency of the specimens was decreased up to 15% compared to the before surface roughness process. As such, the transparency of the pmzn3-r and pmti3-r specimens was dropped down to less than 10%. Therefore, adding 0.3 wt. % silicon dioxide, zinc oxide, and titanium dioxide to the net polymer decreased considerably the transparency compared to the net polymer. This was intensified by roughening the surface of the specimens.

It is obvious that the transparency of nanocomposites depends on the amount and size of nanoparticles in the polymer matrix. The sizes of the three nanoparticles used in this study were 20-30, 10-30, and 3 nm, which according to the literature, causes the loss of light transmission, unless the size is reduced to less than 20 nm. These results are consistent with the findings of the studies done by many researchers on different polymer composites in different years. As such, Zhou and Burkhart in 2010 declared that the addition of silicon dioxide to the net polycarbonate, the transparency was decreased considerably compared to the net polycarbonate, while the haze was increased[3]. Demir and Wegner in 2012 found that adding 1.24% zinc oxide to PMMA causes a lower transparency in the wavelengths of 300-800 nm, compared to the net PMMA[9].

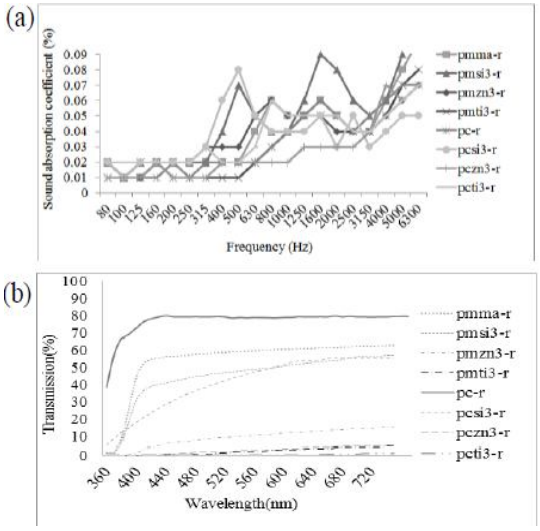
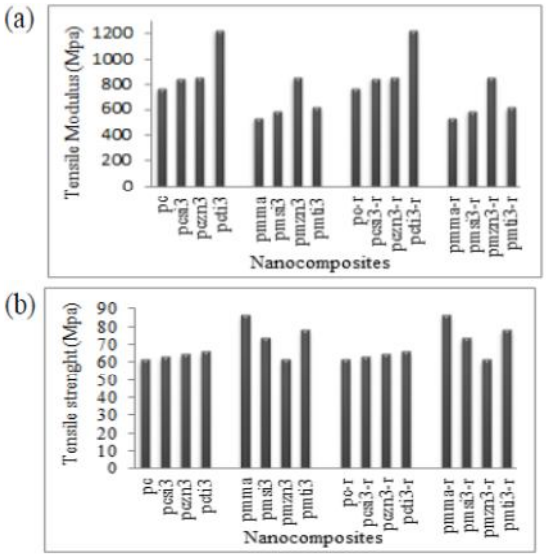


Fig.5. a comparison on the transparency of the specimens (a) before the surface roughness process, (b) after the surface roughness process

3.3. Mechanical properties

The effect of adding nanoparticles on the mechanical attributes of the specimens is shown in Fig. 6. As observed, the tensile modulus was increased in the specimens containing PC and PMMA-based nanoparticles, compared to the net polymers and the highest increase was observed in the specimens with nano TiO2/PC. As such, Vani and Chand in 2012 reported that the tensile modulus, with the addition of titan to PC and PMMA was increased compared to the net matrix [10]. Dai Prè in 2015 confirmed that the addition of zinc oxide and titanium dioxide to PMMA, the tensile modulus was increased, compared to the net PMMA[11]. Also, Rashahmadiin 2017 demonstrated that the addition of silicon dioxide and titanium dioxide to poly methyl methacrylate to tensile modulus compared to pure polymer[12]. According to the foregoing, the tensile strength has an upward trend in the specimens with PC-based polymers, while it drops in the specimens with PMMA polymer matrix. What is evident from various studies is that the tensile strength is strongly influenced by the interface between filler and matrix. In this study, the very strong interaction between the nanoparticles and polycarbonate seems to be due to the compliance of the polar structure of the two composite Martials. However, in the PMMA matrix, the filler-filler interaction, or in other words, between nanoparticle with nanoparticle, is more than the interaction between the nanoparticles with polymer. Therefore, this agglomerate can be considered a defect in the matrix, resulting in loss of tensile strength. Zhang and his colleagues in 2012 reported the same results. They found that tensile strength of PMMA in combination of 1 to 7% titanium dioxide was significantly lower than that in the net PMMA[13]. With increasing the weight percent of nanoparticles, the average elongation at break of the specimens was decreased in both PC and PMMA

matrixes .It is mainly because of the decreased mobility of the chains and their resilience, due to the presence of nanoparticles in the polymer chains. Although the higher stiffness of the polymer matrix leads to an increase in the tensile strength of the composites, however, it generally causes an obvious reduction in the elongation at break. Poor adhesion between filler and polymer matrix causes a decrease in the elongation at break of specimens[14]. Feng and his colleagues in 2015 achieved the same results about the effect of increasing the nanoparticle content on the decreasing trend of elongation at break[2]. According to the results, by adding nanoparticles to the PC and PMMA matrices, the flexural modulus kept an upward trend all specimens, except for those containing PC-based zinc oxide. Wang in 2014 declared that by the addition of silicon dioxide nanoparticle to PMMA, flexural modulus, compared to the net polycarbonate, was increased as 127.3%[15]. Hunashyal in 2015 revealed that by increasing the titanium oxide content from 0.1% to 0.5%, the flexural modulus was increased[16]. In other hand, Moskalyuk in 2017 acknowledged that flexural modulus is increased with addition of silicon dioxide to Poly methyl methacrylate[17]. The results of impact strength test showed that the average impact resistance decreases with increasing wt. % of nanoparticles. This is due to filling of the open spaces between the polymer chains by nanoparticles and subsequently, preventing the loss of impact energy causes stress concentration and rapid break of the specimens. In other words, increasing the filler content leads to low fracture toughness and a higher fragility of the specimens. Biswal and his colleagues in 2013 achieved similar results. They found that the impact strength in 0.1% SiO_2/PC was decreased in comparison to net PC[18]. The results from hardness test showed that with increasing the weight percent of nanoparticles, the hardness was almost increased in all the specimens.



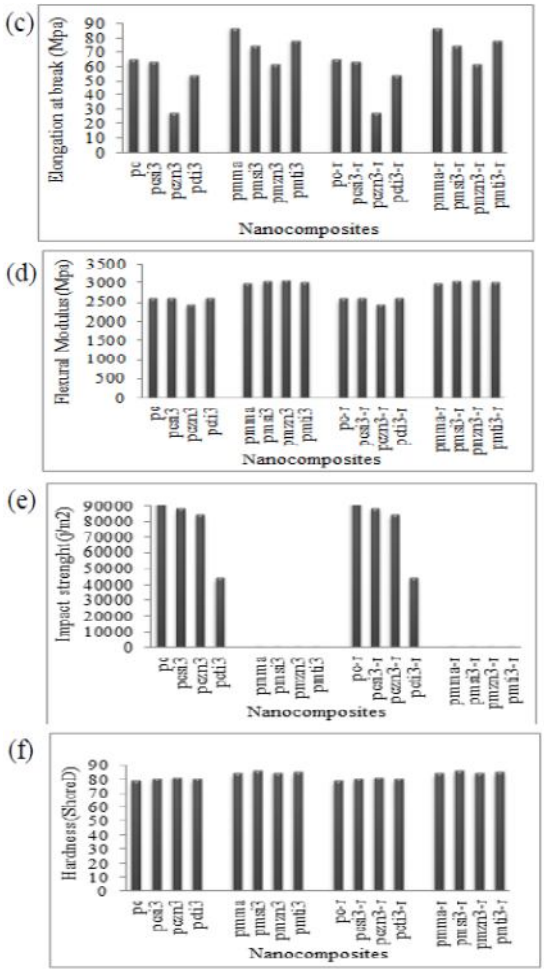


Fig.6. Mechanical properties of the samples: (a) Tensile modulus, (b) Tensile strength, (c) Elongation at break, (d) Flexuralmodulus, (e) Impact strength, (f) Hardness

CONCLUSIONS

The present study investigated acoustical, mechanical, and transparency properties of PC and PMMA nanocomposites, containing 0.3wt% of silicon dioxide, zinc oxide and titanium dioxide. The obtained results are as follows:

Combination of PC and PMMA with 0.3 wt. % of nanoparticles of titanium dioxide, zinc oxide, and silicon dioxide can improve acoustic absorption coefficient at upper frequency range, compared to the net polycarbonate and poly methyl methacrylate. Improvement of intermediate frequency is of high importance for controlling traffic noise due to the sensitivity of the human ear. Accordingly, in order to optimize the acoustic properties of the composite polymer in a way that the nanoparticles can better absorb noise waves, the surface of the specimens were roughened. This led to less reflection and therefore a greater absorption in the intermediate frequency range. Therefore, the roughened surface specimen with 0.3 wt. % of SiO_2 (pcsi3-r) had the highest absorption in the intermediate frequency,

compared to the other specimens. This optimized material, due to its capability in absorption of noise waves in intermediate frequency, can be used in future in the construction and design of environmental noise barriers. Transparency in all made samples is significantly reduced before and after the roughness process by adding 0.3 wt. % of silicon dioxide, zinc oxide and titanium dioxide nanoparticles in both pure polymers. According to all findings of the present study, a combination of tested materials can be improved in the future for achieving a good transparency. The results also showed that the average tensile modulus in the specimens was higher than that in net polymers, while the tensile strength was increased only in the specimens with polycarbonate matrix. The elongation at break and impact strength of the specimens decreased with adding the weight percent of the zno, sio_2 and tio_2, indicating that the flexibility of neat pc and pmma is somewhat reduced. The flexural modulus was higher than the net PC and PMMA in all of the nanocomposite specimens, except for pczn3. The Shore hardness of the nanocomposite specimens showed an increase in the nanocomposite specimens, compared to the specimens with PC and PMMA matrix. According to the foregoing, polycarbonate/poly methacrylate-based polymer nanocomposite with 0.3wt. % of silicon dioxide, zinc oxide and titanium dioxide, in addition to the improvement of some of the mechanical properties, increases the absorption coefficient in the intermediate frequencies. However, transparency was decreased by the addition nanoparticles. Further research is recommended to produce more transparent nanocomposites with enhanced acoustic characteristics, through the use of appropriate additives, well dispersion of nanoparticles in polymer matrix, and the use of smaller size nanoparticles, and creating more pores in the surface of specimens. This would increase the sound absorption coefficient of the specimens in the low and intermediate frequencies. Therefore, installing absorptive materials like an optimal transparent polycarbonate/poly methacrylate-based polymer nanocomposite on paralleled noise barriers is recommended to increases the efficacy of barriers and leads the effective frequencies to lower frequencies.

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