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Experimental Study on Dynamic Behavior of Acrylonitrile-Butadiene-Styrene (ABS) Based Nano Composite Reinforced by Nano Silica Addition

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ABSTRACT

In the present research, an experimental study was carried out to assess the vibrational behavior of Acrylonitrile-Butadiene-Styrene (ABS) based Nano composites reinforced by Nano-silica particles. Therefore, the twin extruder methodology was used to fabricate the Nano composite samples. The silica content and extrusion temperature were considered as variable parameters. The samples were prepared based on bending test standards and then subjected to dynamic mechanical and thermal analysis machines. To identify the effect of SiO₂ content and presence of defects in the fabricated samples, 12 experiments were carried out and the obtained results analyzed based on scanning electron microscopy (SEM) images of the samples' cross section and the graphs, which were obtained from the aforementioned tests. As a result, it was found from the results that by increasing the silica content up to 2%, the static and dynamic strength of the fabricated Nano-composite were significantly enhanced. However, by a further increase of silica content, it was found that the fabricated samples showed brittle behavior causing reduction of strength properties. On the other hand, for defected samples, the static and dynamic forces of the fabricated composite reached a maximum at 3% and 4% of Nano-silica content, respectively. It was also found from the results that the increase of silica content caused a reduction in the damping behavior of fabricated composites for both the perfect and defected samples. This trend could be attributed to the fact that an increase of silica content increased the storage modulus in common surfaces between polymeric layers and the reinforcement material.

1. Introduction

Nowdays, in many advanced applications, several desirable properties of a certain material are required simultaneously. Composite materials can provide various desired properties. For example, in aerospace industries, lightweight materials with high strength and high abrasion resistance as well as high weathering and high-temperature resistance are required.

One of such materials is Acrylonitrile Butadiene-Styrene (ABS) which is usually used as a commercial material due to its desirable physical properties as well as low fabrication cost. ABS is extensively used in industries such as automobile parts, household items and electrical housing. The

main advantages of an ABS polymer are; impact resistance even at low temperatures, desirable abrasion resistance, and high toughness. However, this material suffers from degraded mechanical properties at elevated temperature [1]. Addition of nano ceramics such as silica, clay, mica, alumina, etc., can be used as an effective method to enhance the mechanical properties of ABS at high temperatures [2, 3].

Many studies have been performed on this topic, for example, Dual et al., [4] incorporated 4 wt% graphene nanoplatelets in acrylonitrile-butadiene-styrene (ABS) filaments obtained by a solvent-free process consisting of melt compounding and extrusion. The results revealed that elastic modulus and dynamic storage moduli of 3D print-

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ed parts along three different build orientations were increased by the presence of graphene in the ABS matrix. Furthermore, in work carried out by Saleh et al., [5] a nanocomposite of well dispersed carbon nanotube (CNT) in the ABS matrix was prepared by solution processing. CNT dispersibility in four different solvents was studied both, experimentally and theoretically and the best solvent was selected to prepare the nanocomposite. As a result of the perfect dispersion and selective localization of CNT in the the SAN phase of the ABS matrix, the electrical conductivity of the nanocomposite as a function of the filler content showed that the nanocomposite exhibited a typical percolation behavior with a percolation threshold of only 0.06 vol.%. Also, Weng et al., [6] prepared Acrylonitrile butadiene styrene (ABS) nanocomposites with organic modified montmorillonite (OMMT) which was prepared by melt intercalation. ABS nanocomposite filaments for fused deposition modeling (FDM) 3D printing were produced by a single screw extruder and printed by a commercial FDM 3D printer. After that, the 3D printed samples were evaluated by tensile, flexural, thermal expansion and dynamic mechanical tests. It was found that the addition of OMMT significantly increased the tensile modulus, flexural strength, flexural modulus and dynamic mechanical storage modulus, and decreased the linear thermal expansion ratio and the weight loss of TGA. In a further study by Shishavan et al., [7] they analyzed the effect of process parameters of foam injection molding on the morphological properties of acrylonitrile butadiene styrene (ABS)-nanoclay polymeric foam. An X-ray diffraction (XRD) test was carried out to analyze the dispersion of nanoclays with different percentages in the polymeric matrix. Based on the results, 2 wt % of nanoclay along with injection and holding pressures of 140 MPa was beneficial in order to have polymeric foam with small cell size. Mohyeddin et al., [8] produced ABS based nanocomposite foams using carbon dioxide through the solid-state batch process. The effects of the processing conditions on the density, morphology, and flexural properties of ABS and its nanocomposite foams were studied. It was found that nano-clay particles, as nucleating sites, played an important role in reducing the size of cells and increasing their number in the unit-volume of the foamed polymer, as well as increasing the flexural modulus of foam through reinforcing its matrix. In addition, Mura et al., [9] investigated tribological performance of graphene-coated ABS. Tribological performance was evaluated by ball on disk tests, taking into consideration different travelled distances in order to further evaluate the coating wear strength. Results showed that graphene coat may reduce coefficient of friction of the tested materials, alt-

hough the wear strength of the coating was quite weak.

Additionally, several inorganic fillers are widely used as reinforcements in thermoplastic polypropylene (PP) matrix to prepare composites. Silica nanocomposites as inorganic additives have been attracting some interest from scientists as well, due to the advantages of low cost of production and high-performance features [10]. The addition of nanosilica into thermoplastic polymers enhances mechanical durability, which has been widely utilized in the current anti-scratch and mar technologies and results in a reduction of the glass transition temperature [11]. Furthermore, nanosilica has been extensively used for fabrication of different polymeric based composites. In this regard, Awad and Khalaf [12] developed a polypropylene/silica composite with different amounts of reinforcement. The results were assessed by thermogravimetric analysis (TGA), Differential Scanning Calorimeter (DSC), tensile tests, and water absorption tests. From the results of TGA, significant improvements in the thermal stability were noticed with an increase in the percentage of nanosilica particles.

Moreover, Devi and Maji [13] studied the fabrication of wood polymer nanocomposites (WPNC) based on nano-SiO₂. They reported that mechanical properties, water uptake and thermal stability were improved by addition of SiO₂ particles in the Wood/Polymer matrix. Hsu and Lin [14] also reinforced the ABS matrix by addition of SiO₂ nanoparticles through the Sol-Gel method. They used a different type of catalyst for preparation of the composite material. It was reported that the ABS/SiO₂ which was fabricated in the presence of NH₄F as the catalyst material, had higher strength, a finer structure and a smoother surface compared to those prepared by HCl catalyzer. In other research, Zheng et al., [15] studied the synthesis of silica-graft acrylonitrile-butadiene-styrene (ABS) nanocomposites. The silica-graft ABS composites were prepared by an open ring reaction and radical grafting copolymerization of modified silica, styrene, and maleic anhydride (MAH) in an ABS/THF solution. Differential scanning calorimetry (DSC) results showed that the glass transition temperature (T_g) of ABS-graft-SiO₂ shifted significantly towards higher temperatures with increasing of the silica content.

It was found from the literature survey that ABS and nanosilica had been widely used for enhancing the mechanical, thermal and physical properties of nanocomposite materials. However, according to the author's knowledge, association of these elements together i.e. ABS as matrix and nanosilica as reinforcement had hardly been reported in the literature. Furthermore, in the above literature, many of the analyses were focused on compatibility, microstructure, mechani-

cal and tribological properties and thermal resistance. However, dynamic mechanical thermal analysis ABS-SiO₂ had not been reported. Hence, in the present study, an attempt was made to prepare an ABS matrix Nano-composite reinforced by Nano-silica particles. Here, the effect of SiO₂ content on strength and vibration behavior of fabricated samples was also assessed. The effect of the DMTA test temperature was also studied on damping behavior of the fabricated composite and the results were further analyzed through scanning electron microscopy.

2. Materials and methods

2.1. Materials

Acrylonitrile Butadiene Styrene (ABS) was used as the matrix material. Table 1 shows physical and mechanical properties of the matrix. The nano-sized silica particles obtained from NOTRINO CO. (IRAN) were used as reinforcement material with average particle diameter of 50 nm, density of 3.97 g/cm³, and 2050 °C melting point. Note that the silica particles were added in lower amounts in volume as compared with conventional polymeric composites. This meant that the current nanocomposites would not alter the process ability or density of the ABS matrix significantly

2.2. Compounding and sampling

Firstly, composite samples for DMTA tests were prepared by mixing of preweighed quantities of ABS granules and Nano silica powder at different volumes percents (0-5). They were initially mixed manually, and then prepared by melt mixing in an 18mm double screw Extruder (BRABENDER 6300) with L/D ratio of 24/1. The melt temperature during this process was varied between 180°C and 210°C and screw rotational speed was kept constant at 60 RPM for all of the composition period. In order to improve mixing of materials, the raw ABS was dried at 60°C in a vacuum oven for at least 12 hours to remove moisture and impurities. The Nano silica was also dried at 90 °C for 10 hours to prevent water uptake. The continuous mixing was performed during extrusion. The extruders were cooled by water at the exit of the die. After cooling the composite rods cut into graduals form in uniform size through the Pelletizer machine, they were air cooled. The nanocomposite samples were prepared by the Injection Molding process for mechanical characterization. The bending test samples were fabricated according to ASTM-D790-07 standards. Also, the dynamic behavior of samples was studied on bending test samples according to ASTM D4065 standards. Fig. 1 illustrates DMTA machine and the extruded samples for DMTA test.

2.3. Morphology analysis

Table 1. Physical and mechanical properties of ABS

Properties	Value
Tensile strength (MPa)	6.8
Notched impact strength (kJ/m ²)	3-30
Thermal coefficient of expansion (1/°C)	100-150×10 ⁻⁶
Melting point (°C)	160
Density (g/cm ³)	0.905

Subsequently, scanning electron microscopy (SEM) was used to determine dispersion morphology of nano silica particles in the polymeric matrix. For this purpose, the TESCAN MV2300 microscope at 20 KV was utilized to observe the dispersement of nano silica reinforcements at different contents throughout the matrix phase.

2.4. Mechanical testing

The dynamic mechanical and thermal analysis of fabricated samples was carried out by means of the Tritec 2000 DMTA machine. As explained, the composite samples were prepared according to bending test standards i.e. ASTM-D790 and then placed in the DMTA test machine. The DMT analysis was carried out according to ASTM D4065. The machine demonstrated the variation of static and dynamic strength of the samples in time domain.

2.5. Research methodology

The main aim of the present work was to find the effect of silica content on the dynamic mechanical and thermal behavior of the ABS-Silica Nano-composite. The samples were fabricated in two different types. One type included the intact samples, and the other type comprised of those subjected to damage in their cross section. Hence, in order to study the effect of silica content (0, 1, 2, 3, 4 and 5% weight), 12 bending samples were prepared. In other words, six perfect samples along with six defected samples were fabricated according to ASTM D790-07 bending test standards and subjected to DMTA analysis. The reason for selection of six levels of silica content was based on out of laboratory observations.

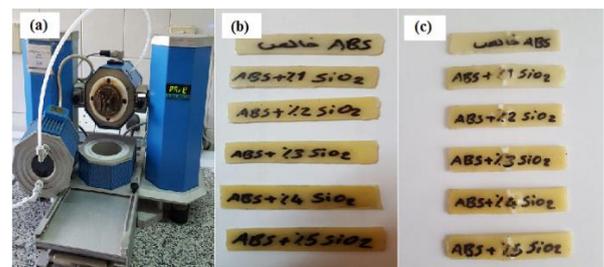


Fig. 1. (a) DMTA machine (b) Perfect samples for DMTA test (c) Damaged samples for DMTA test

According to our experience, as the silica content exceeded the 5% point, the brittleness in the fabricated samples was significantly increased and the samples reached the fracture point at a very low Charpy load. For this reason, it was required to select the level of silica content up to a maximum of 5%.

3. Results and discussion

3.1. Morphological analysis

In order to analyze the morphology of the surface composite, the specimens were cut from their cross section and subjected to scanning electron microscopy (SEM). Fig. 2 illustrates SEM images of the cross section, which were obtained under different silica content. As can be observed in Fig. 2a, when the silica content was close to zero and the sample was made of pure ABS, the surface of composite was flat and empty of any dimples in the cross section. However, it was observed that by addition of silica to ABS, dimples were formed in the ABS matrix and the silica was dispersed uniformly in the matrix. It can also be seen from Fig. 2b to Fig. 2d that increasing of the Nano-silica content caused an increase in the number of dimples. However, even at 3% silica content, the dispersion of the ceramic phase in the ABS matrix was uniform and without any augmentation. This type of dispersion caused a significant enhancement in the strength properties of the fabricated composite [16]. However, by further increase of silica content, in Fig. 2e and 2f, it can be seen that the uniform distribution of the reinforcement phase in the ABS matrix was restricted. Agglomeration of silica was observed in various locations of the matrix phase. This type of augmentation acted as a stress concentration location that drastically reduced the strength of fabricated composites. Also, it caused the composite to demonstrate brittle behavior and restricted the impact strength [17]. Therefore, it could significantly influence the vibration behavior.

3.2. DMTA of perfect samples

Figures 3 to 5 demonstrate the variation of static force, dynamic force and elasticity modulus and loss of fabricated composite under different silica content. It is clear from the Fig. 3a that for a pure ABS matrix, the maximum limit load was about 1.183 N, and the temperature where the material lost the static strength was about 103°C. On the other hand, by addition of 1% Nano-silica, it was found that the static load enhanced to 1.34 N; however, there was no change observed in glass temperature in which the material lost its properties. By further addition of Nano-silica content to 2 and 3 %, it was seen that the composite static strength improved about 60% and reached to a maximum value of 1.667 N when the silica

content was 3%. However, it was also observed that no significant enhancement in glass temperature occurred by an increase in silica content. On the other hand, when the silica content reached 4 and 5%, it was seen that the static force reduced to 1.5 N.

Furthermore, it can be noted that, for intact samples the static force increased by an increase in the silica content up to 3% weight percent. On the other hand, by a further increase in reinforcement content the strength of the composite slightly decreased. As shown in Fig. 2, in pure ABS samples, the distance between polymeric layers was very high which increased the porosity. However, by raising the silica content to 3%, the degree of porosity was reduced and the vacant locations in the ABS matrix were filled and reinforced. Additionally, due to the existence of the ceramic phase in the fabricated composite, the strength of composite was significantly enhanced and caused an improvement of static force. However, when the silica content went beyond a critical value (i.e. 4 and 5 %), the static force was reduced. As shown in Fig. 2, it is seen that when the silica content was relatively high, the distribution of the ceramic phase in the polymeric matrix was restricted. In other words, the silica content was excessively high. The agglomeration of the ceramic phase in the matrix acted as a concentration center that limited the static strength. For this reason, at elevated silica contents the static force was reduced.

Figure 3b also illustrates the static displacement of fabricated samples at different silica content. It is seen that by increasing the silica content up to 2%, the displacement of fabricated composite increased, which was due to enhancing the composite strength by addition of Nano-silica. However, by further increase of Nano-silica it was seen that the static displacement was significantly reduced. This reduction was due to the formation of brittle structures in the fabricated composite. Because the Nano-silica is a ceramic material, addition of this material to polymeric matrix caused the fabricated specimens to act as a brittle material. However, as discussed, agglomeration of Nano-composites at higher silica contents intensified the brittleness of fabricated samples. Hence, the static displacement of material was reduced at higher degrees of silica content.

Dynamic force

Fig. 4a illustrates the variation of dynamic force and dynamic displacement by temperature under different silica contents. It is seen from the figure that by increasing the silica content to 3% the dynamic force increased and reached to the maximum value. However, by further increase of silica content, the dynamic force decreased slightly.

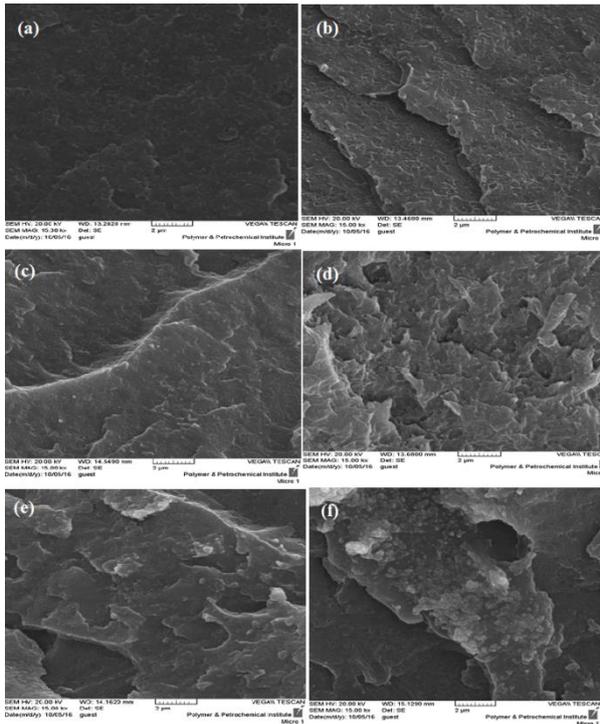


Fig. 2. SEM image of fabricated samples' cross section at different silica content (a) 0% (b) 1% (c) 2% (d) 3% (e) 4% (f) 5%

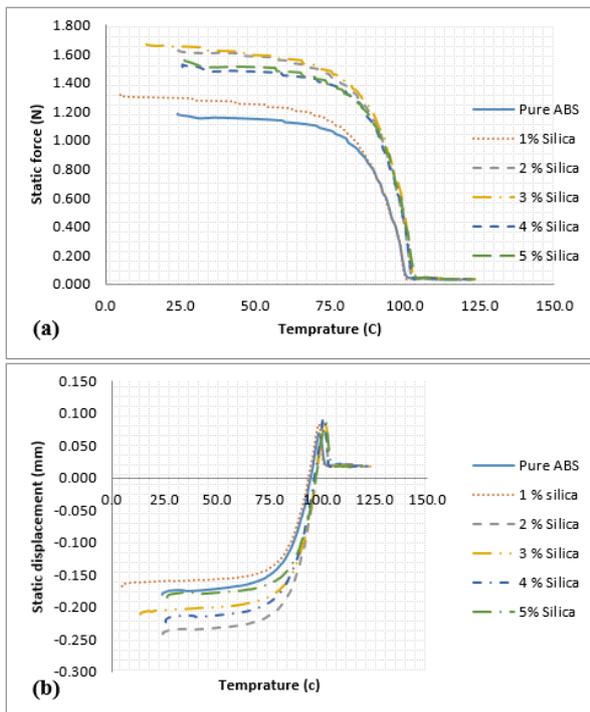


Fig. 3. Variation of (a) static load and (b) static displacement by testing temperature under different silica content

The dynamic force in the testing of material was significantly influenced by the extent of material defect and the degree of ductility. The higher the value of ductility as well as the lower the degree of porosity, the higher the value of dynamic strength. As the silica content was increased to 3%, the porosity value in the composite structure was reduced which caused a significant enhance-

ment in the dynamic force. On the other hand, the higher value of silica content caused the material to demonstrate brittle behavior during mechanical testing. In such a condition, the brittle structure caused by the agglomeration of ceramic phases resulted in a reduction of the composite dynamic strength. It was also seen from the figure, for all the fabricated samples that the glass temperature for dynamic loading was around 103°C. From Fig. 4b, it can be noted that no impressive difference existed between dynamic displacements of the fabricated composite at different temperatures.

Damping behavior

For viscoelastic material, the loss and storage modulus represent the dissipating of energy in the form of heat at the viscous portion, and loss of energy at the elastic portion. Hence, the ratio of $\tan\delta$ is defined as an index of sensitivity of material to damping. The $\tan\delta$ is the ratio of loss modulus to storage modulus. For $\tan\delta$ greater than 1, the material exhibits damping behavior whereas for a value lower than 1, it does not. In other words, if the ratio for a material is greater than 1, it implies that it can lose the induced energy and dampen the dynamic displacement.

It is clear from Fig. 5, that for a sample made of pure ABS, the $\tan\delta$ was relatively low. However, when the 1% silica was added to the pure ABS, it was found that the $\tan\delta$ value was significantly increased. By further addition of silica content, it was found that the damping behavior of material decreased.

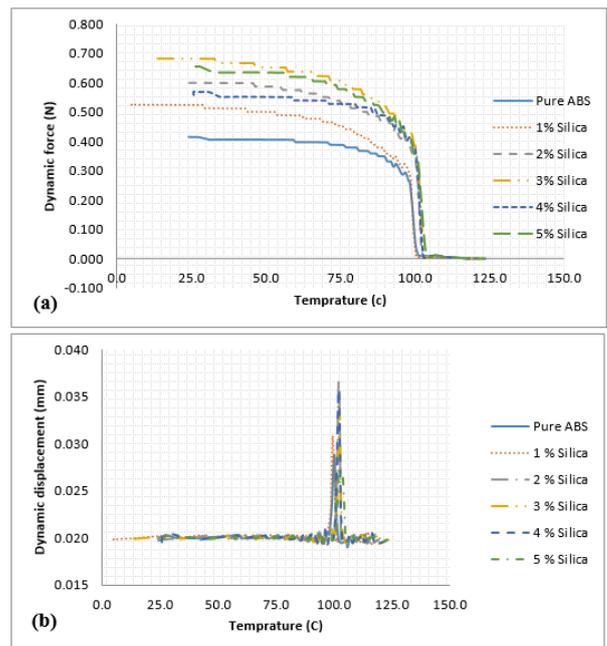


Fig. 4. Variation of (a) dynamic force and (b) dynamic displacement under different silica content

In polymeric based composites, the damping behavior was significantly influenced by the material and amount of the reinforcement phase; where, addition of reinforcement caused reduction of the damping behavior compared to pure polymeric material. This behavior could be attributed to the limitation of polymeric layer movement in the presence of silica addition [18]. On the other hand, by addition of silica content, the amount of ABS polymeric phase in the composite samples was decreased. In such conditions, the damping behavior was significantly restricted. In other words, an increase in the silica content caused a reduction of lost modulus due to brittle behavior of Nano-silica content. It is worth mentioning that during the DMTA test, the loss of mechanical energy occurred in the common surface between the composite layer and reinforcement phase. Hence, when the adhesion between the polymeric phase and ceramic was relatively high, the energy loss decreased and caused a reduction of damping behavior. Moreover, the results showed that the damping behavior increased by an increase in temperature. This trend could be attributed to the fact that an increase in temperature caused a reduction of adhesive force between the polymer, and reinforcement which increased lost modulus. In such a condition, the damping behavior was enhanced.

3.3. DMTA of defected samples

As explained in the previous section, sampling was carried out as intact and defected specimen to analyze how the silica addition influenced the dynamic and mechanical properties by variation of temperature. For this purpose, the maximum values of static force, dynamic force and loss coefficient of intact and defected samples under different silica content were obtained and compared. Fig. 6 represents a comparison between the values of static force versus silica content for both the intact and defected samples.

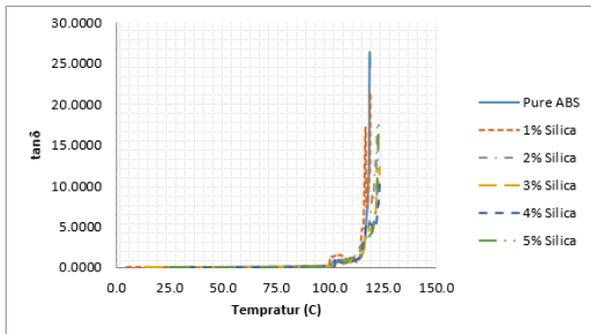


Fig. 5. Variation of loss coefficient i.e. $\tan\delta$ versus test temperature under different silica content

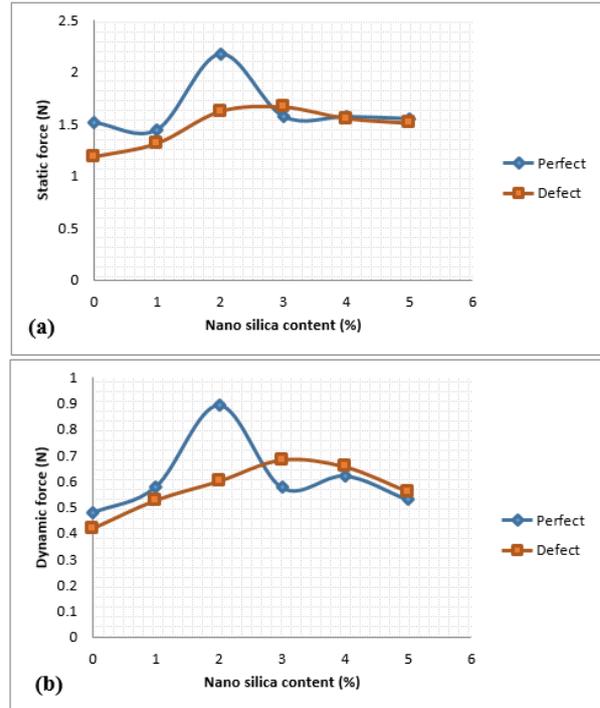


Fig. 6 variation of (a) static force and (b) dynamic force versus Nano silica content for perfect and defected samples

It is clear from Fig. 6 that for intact samples, both the static and dynamic force increased by increasing the silica content up to 2%. When the silica contents increased up to 2%, the degree of porosity in the cross section of fabricated samples decreased which caused an increase in its density. In such conditions, voids in the cross section of the samples decreased and caused an increase in strength. When the SiO_2 content surpassed a critical value, the composite was saturated with reinforcement and SiO_2 leaked out of the composite matrix. In such conditions, the deposited SiO_2 could disturb the strength of the composite. Another point that can be interpreted from the Fig. 6 is that for defected specimens, the static force increased continuously by an increase in SiO_2 content up to 3%. Because the defect destroyed the strength of the composite, by increasing the silica content, the strength increased and the deposited silica could protect the samples from fracture. In other words, for defected samples, higher values of silica content were needed. On the other hand, it is clear from Fig. 6 that the dynamic force for defected samples reached a maximum value when the specimens were reinforced by 4% Nano silica. As explained previously, the dynamic force acted as an impact and caused the material to fail at a lower force. Hence, for defected samples, more amounts of Nano silica were needed to strengthen the material against dynamic forces.

The damping behavior of defected and intact samples are also compared and presented in Fig. 7. It is clear from the figure that for both the perfect and defected samples, the loss coefficient (i.e.

$\tan\delta$) decreased by increase of silica content. As described, increase of reinforcement caused tight adhesion between the polymeric phase and ceramic phase. In such a condition, the storage of mechanical energy in the composite increased. Also, increase of the ceramic phase caused a reduction of polymeric phase. Both the aforementioned reasons caused a reduction of $\tan\delta$ that implied a lower damping coefficient.

4. Conclusion

In the present research, an experimental study was performed to prepare Acrylonitrile-Butadiene-Styrene matrix composite reinforced by Nano-silica particles. The twin extruder method was utilized to fabricate the composite specimens used for dynamic mechanical and thermal analysis. Experiments were carried out to identify the effect of silica on static and dynamic strength as well as the damping behavior. The obtained results can be summarized as follows:

- It was found from the SEM analysis that by increase of silica content up to 3%, dimples were formed in the composite structure that impeded desirable bonding strength between the matrix phase and reinforcement. As the silica content increased from the critical values, the dimples were diminished and an agglomeration of the second phase in matrix was observed. This condition caused formation of the brittle structure and destroyed the strength properties of fabricated samples.

- Damping analysis of fabricated samples through $\tan\delta$ ratio showed that increase of silica content caused reduction of damping behavior of fabricated samples. It meant that by increase of the silica content the absorption of energy was restricted. The reason for this could be attributed to the fact that increase of silica content resulted in the formation of brittle structures and reduced the volume of polymeric material that was perfect in damping behaviour.

- Results indicated that both the static and dynamic forces increased by an increase in the SiO_2 content up to 3%. While by a further increase in the reinforcement content (i.e. 4 and 5%), the strength decreased. The reason for it being, improvement of strength caused the restriction of porosity. Additionally, a decrease in strength was due to the agglomeration of silica in the ABD matrix, which significantly decreased the strength.

- For defected samples, it was found that the static and dynamic forces reached maximum values when the silica contents were 3% and 4%, respectively. The change in the results compared to perfect samples was due to the presence of a defect in the composite surface. As the defect formed in the sample cross section, higher values of reinforcement should be used for fabrication of samples.

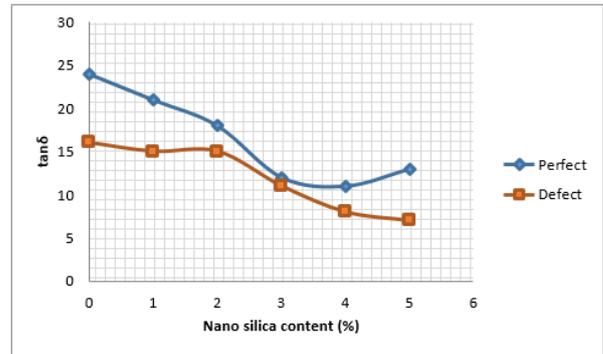


Fig. 7 Variation of loss coefficient versus silica content for perfect and defected samples

- Increase of Nano-silica content caused the adhesion strength between the polymeric layer and reinforcement to increase. In such a condition, the storage modulus increased which resulted in a reduction of damping behavior of the fabricated composite. This trend was observable for both the perfect and defected samples.

References

- [1] Bohatka, T. J., and A. Moet. "The effect of load level on the mechanism of fatigue crack propagation in ABS." *Journal of materials science* 30, no. 18 (1995): 4676-4683.
- [2] Lohar GS, Jogi BF. Influence of Carbon Black (CB) on Mechanical Behaviour and Microscopic Analysis of Poly-propylene (PP)/Acrylonitrile-butadiene-styrene (ABS) Nanocomposites. *Procedia Manufacturing*. 2018 Jan 1;20:85-90.
- [3] Weng Z, Wang J, Senthil T, Wu L. Mechanical and thermal properties of ABS/montmorillonite nanocomposites for fused deposition modeling 3D printing. *Materials & Design*. 2016 Jul 15;102:276-83.
- [4] Dul S, Fambri L, Pegoretti A. Fused deposition modelling with ABS-graphene nanocomposites. *Composites Part A: Applied Science and Manufacturing*. 2016 Jun 1;85:181-91.
- [5] Al-Saleh MH, Al-Anid HK, Hussain YA. CNT/ABS nanocomposites by solution processing: Proper dispersion and selective localization for low percolation threshold. *Composites Part A: Applied Science and Manufacturing*. 2013 Mar 1;46:53-9.
- [6] Weng Z, Wang J, Senthil T, Wu L. Mechanical and thermal properties of ABS/montmorillonite nanocomposites for fused deposition modeling 3D printing. *Materials & Design*. 2016 Jul 15;102:276-83.
- [7] Shishavan SM, Azdast T, Hasanzadeh R, Moradian M. Comprehensive Investigation of Morphological Properties of ABS/Nanoclay/PMMA Polymeric Nanocomposite Foam. *Polymer Science, Series A*. 2019 May 1;61(3):334-44.

- [8] Mohyeddin A, Fereidoon A, Taraghi I. Study of microstructure and flexural properties of microcellular acrylonitrile-butadiene-styrene nanocomposite foams: experimental results. *Applied Mathematics and Mechanics*. 2015 Apr 1;36(4):487-98.
- [9] Mura A, Adamo F, Wang H, Leong WS, Ji X, Kong J. Investigation about tribological behavior of ABS and PC-ABS polymers coated with graphene. *Tribology International*. 2019 Jun 1;134:335-40.
- [10] Awad SA, Khalaf EM. Evaluation of thermal and mechanical properties of Low-Density Poly Ethylene (LDPE)-Corn Flour (CF) composites. *Int J Chemtech Res*. 2017;10(13):230-5.
- [11] Shubhra QT, Alam AK, Quaiyyum MA. Mechanical properties of polypropylene composites: A review. *Journal of thermoplastic composite materials*. 2013 Apr;26(3):362-91.
- [12] Awad SA, Khalaf EM. Investigation of improvement of properties of polypropylene modified by nano silica composites. *Composites Communications*. 2019 Apr 1;12:59-63.
- [13] Devi, Rashmi Rekha, and Tarun K. Maji. "Effect of nano-SiO₂ on properties of wood/polymer/clay nanocomposites." *Wood science and technology* 46, no. 6 (2012): 1151-1168.
- [14] Hsu, Ying Gev, and Fung Jung Lin. "Organic-inorganic composite materials from acrylonitrile-butadiene-styrene copolymers (ABS) and silica through an in situ sol-gel process." *Journal of applied polymer science* 75, no. 2 (2000): 275-283.
- [15] Zheng, Kang, Lin Chen, Yong Li, and Ping Cui. "Preparation and thermal properties of silica-graft acrylonitrile-butadiene-styrene nanocomposites." *Polymer Engineering & Science* 44, no. 6 (2004): 1077-1082.
- [16] Kim, I. J., Kwon, O. S., Park, J. B., & Joo, H. (2006). Synthesis and characterization of ABS/silica hybrid nanocomposites. *Current Applied Physics*, 6, e43-e47.
- [17] Milionis, A., Languasco, J., Loth, E., & Bayer, I. S. (2015). Analysis of wear abrasion resistance of superhydrophobic acrylonitrile butadiene styrene rubber (ABS) nanocomposites. *Chemical Engineering Journal*, 281, 730-738.
- [18] Nayak, S. K., Mohanty, S., & Samal, S. K. (2009). Influence of short bamboo/glass fiber on the thermal, dynamic mechanical and rheological properties of polypropylene hybrid composites. *Materials Science and Engineering: A*, 523(1), 32-38.