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Research paper

Investigation of elastic properties of PE/CNT injected composites

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Abstract

The aim of this research was to investigate the effect of the addition of carbon nanotubes on the mechanical properties of polyethylene/carbon nanotube nanocomposites. To do so, polyethylene and carbon nanotube were mixed in different weight percentages containing 0, 0.5, 1, and 1.5% carbon nanotube in two screw extruder apparatus by fusion. The effects of carbon nanotube addition in 4 different levels on the tensile strength, elastic modulus and elongation of the nanocomposite samples were investigated. The results showed that the addition of carbon nanotube had a significant effect on improving tensile strength of the nanocomposite samples such that by adding 1% w/w carbon nanotube, the tensile strength 23.4% , elastic modulus 60.4% and elongation 29.7% of the samples improved. Also, according to the results, Manera approximation model at percentages about 0.5% weight and modified Halpin-Tsai at percentages about 1% weight lead to favorite and reliable results.

Keywords: *Carbon Nanotube; Polyethylene; Injection Molding; Mechanical Properties.*

1. Introduction

The discovery of carbon nanotubes by Iijima [1] in 1991 has inspired the promise of a new generation in diverse engineering, materials science, and reinforced composite structures due to superior mechanical and physical properties of carbon nanotubes over any other known materials. One of the most useful applications of this new material is the use of it as strong, light-weight and high-toughness fibers for nanocomposite structures. A large number of theoretical and experimental researches using carbon nanotubes as reinforcing fibers have been carried out [2-4]. Sahmani et al. [6-8] investigated size dependent and nonlocal theory by using shear deformation method in thermal environment and then they used molecular dynamics simulations for biaxial instability analysis of 3D metallic carbon nanosheets [9]. In the other works Sahmani et al. [10-11] studied nonlocal anisotropic shear deformable plate model for uniaxial instability of 3D metallic and nonlinear axial instability of zirconia nanosheets.

In the last decade of 20th century a new area called nanocomposite found its way to science and composite technology. Nanocomposites are composite materials which at least one of their constituents has nano dimensions (between 1 and 100 nanometers). In the last few years, nanocomposites have advanced significantly compared to composite materials in conventional scales due to the changes in the composition and structure of the materials in nano scale and presenting unique and special properties. Improvement of mechanical and other properties of such composites strongly depends on the particle content, particle shape and size, surface characteristics and dispersion degree [12-13]. Moreover, physical properties like surface smoothness and barrier properties cannot be improved by conventional micron-sized particles. Therefore, in recent years, nanoparticle-based composites have received considerable attention, the most promising of which include polymer/clay nanocomposites [14-18]. Carbon nanotubes exhibit exceptional mechanical, thermal and electrical properties. Accordingly, it can be suggested that development of these nano-level particles can offer tailor ability of desired properties in a material. Fattahi et al. [19] investigated Post-Buckling Behavior of Nanopanels Made of FGM by Considering Surface Elasticity theory, and in the other work they studied on mechanical properties of PE/CNT composites.

Increasing economic need for fuel in different areas has increased demand for using lighter new materials such as polymers. On the other hand because of lower strength of polymers compared to metals, their reinforcement seems inevitable. Nylon 6 was the first polymer which was used to produce nanocomposite by Toyota Company in 1990; but today thermosetting polymers such as epoxy and poly amide, and thermoplastic polymers such as poly propylene, polyethylene, and poly styrene are being used as matrix materials in composites. Among the nanocomposites, most attention has been paid to polymer based nanocomposites. One of the reason for the progress of polymer nanocomposites is their unique mechanical, chemical, and physical properties. Polymer nanocomposites generally have high strength, low weight, high thermal stability, high electrical conductivity, and high chemical resistance [21-31]. The strength and electrical properties of carbon nanotubes are significantly different from those of graphite nanolayers and other filling materials. Supreme mechanical and physical properties of carbon nanotubes along with their low density, has made carbon a perfect candidate for strengthening the composites.

Numerous works have been done on polymer based nanocomposites [32-34] which among the most significant works Navidfar can be mentioned [35]. In his work, he produced poly (methyl methacrylate) carbon nanotube nanocomposites with different weight percentages of carbon nanotube using injection molding method and the effect of different parameters including carbon nanotube weight percentage, injection temperature, and maintenance pressure on the mechanical properties of the samples were investigated. According to his results, increasing the concentration of carbon nanotube in the nanocomposites slightly increased their hardness and the impact strength. In the present study the effect of the addition of carbon nanotubes and the process conditions on the tensile strength of polyethylene carbon nanotube nanocomposite samples with different carbon nanotube weight percentages was investigated.

2. Experimental

2.1. Materials and equipment

In this study polyethylene polymer, produced in Iran Petrochemical Company, was used as matrix. Also carbon nanotubes with inner diameter of 5-10 nm, outer diameter of 10-30 nm and 90% purity, produced by US Research Nanomaterials, USA, were used as reinforcing phase. Following a primary manual mixing with certain weight percentages, polyethylene and carbon nanotubes were melt compounded in a twin screw extruder (ZSK-25, Coperion Werner & pfleiderer, Germany and the nanocomposites were obtained in granules shape. Then the samples were produced using a plastic injection machine (NBM HXF-128) obtained from Neckou Behine Mashin Company and were undergone tensile test. GOTECH AI-7000M tensile testing machine, shown in Fig.1 was used to tensile testing of samples.

Fig. 1: GOTECH AI-7000M Tensile Testing Machine Used in This Research.

2.2. Preparing samples

In order to produce nanocomposite samples, first polyethylene and carbon nanotubes were manually mixed and then melt compounded in four considered weight percentages (which are presented in Table .1) in a twin screw extruder at 170-185 ºC and the nanocomposites were produced as granules shape. The granules were dehydrated in the hopper of the injection machine at 80ºC for 20h before injection process and then the samples were injected into standard mold and produced according to ASTM D6110. Constant parameters of injection molding machine are presented in Table.2 and some of the produced samples are shown in Fig.2 and Fig.3.

Table 1: Weight Percentages of Materials in Different Levels

Parameter	Injection Temperature (°C)	Holding Pressure (MPa)	Holding Pressure Time(s)	Cooling Time(s)	Mold Temperature (°C)
Adjusted value	130-160	40	2	60	15

Table 2: Constant Parameters of Injection Molding Process

Level	1	2	3	4
Carbon nanotube (wt %)	0	0.5	1	1.5
Polyethylene (wt %)	100	99.5	99	98.5

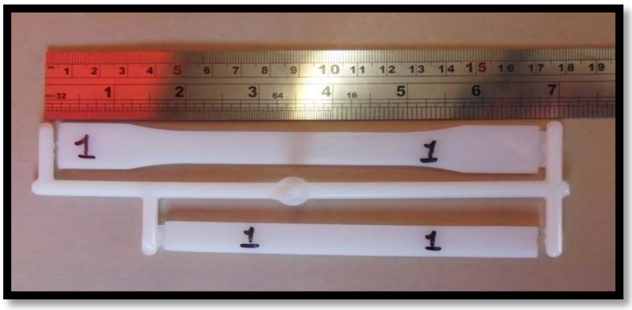

Fig. 2: Standard Tensile (Up) and Impact (Down) Testing Samples of Pure Polyethylene.

Fig. 3: The Produced Nanocomposite Samples Containing [1] wt. % Carbon Nanotube and 99 wt. % Polyethylene.

3. Results and discussion

3.1. Tensile test

Samples required in accordance with ASTM-D638 standard injection pressure of 80 MPa were produced and by performing tensile test on them at a speed of 10 mm per minute, the results were obtained according to Table 3 and are presented in the charts of Fig. 4, 5 and 6.

Table 3: Results of Tensile Test

CNT (wt. %)	Tensile Strength (MPa)	Elastic Modulus (MPa)	Elongation (%)
0	25.043	2020.601	39.855
0.5	29.774	2375.537	49.465
1	30.911	3240.924	51.693
1.5	26.467	2642.060	40.667

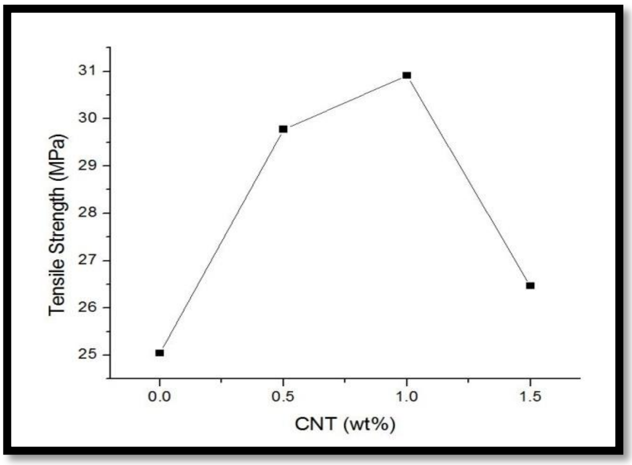

Fig. 4: Tensile Strength Chart in Terms Of Weight Percent of Carbon Nanotubes.

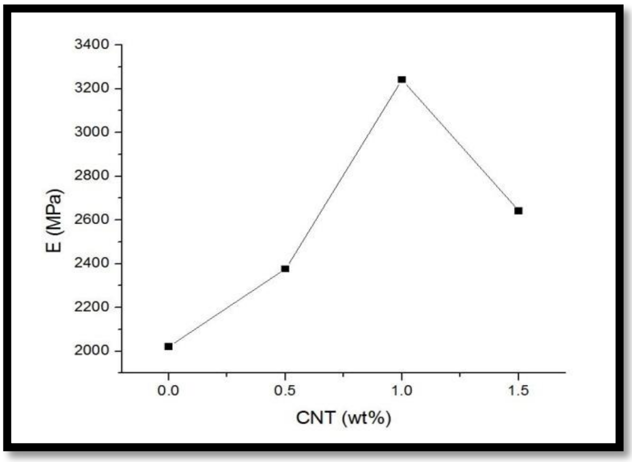

Fig. 5: Elastic Modulus Chart in Terms of Weight Percent of Carbon Nanotubes.

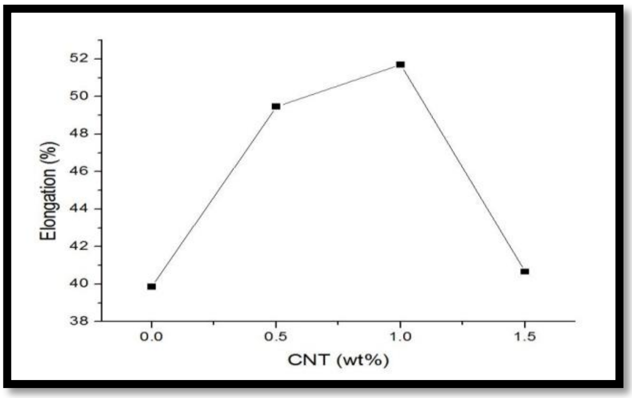

Fig. 6: Elongation Chart in Terms of Weight Percent of Carbon Nanotubes.

As the results show, with the addition of carbon nanotubes to polyethylene matrix, the tensile properties improve. This improvement to the second level containing %1 weight of carbon nanotubes is observed. Therefore, by adding %1 weight of carbon nanotubes in the polymer matrix, the tensile strength, modulus elastic and elongation improves to %23.4, %60.4 and %29.7 respectively. The reason for the improvement of these properties can be attributed to the extraordinary properties of carbon nanotubes to compare with polyethylene that by adding a small amount of it, the mechanical properties of the polymer rose significantly.
The considerable point in results is the observed reduction in the mechanical properties by further increasing of weight percent of carbon nanotube to %1.5 compared to the other two levels, even though the properties of nano composites are still more than a pure polymer.

3.2. Theoretical prediction of elastic modulus

Model theories are used to describe the general situation of a material and are designed to express its behavior. At this point, theoretical models are collected to predict the behavior of composites and the number of the most widely used tensile behavior is explained.
In all of these equations, the elastic modulus of composites is E_c , elastic modulus of the matrix is E_m , the elastic modulus of carbon nanotubes is E_n , matrix volume percentage is V_m , carbon nanotubes volume percentage is V_n .

1) Approximation Model Manera [36]:

The relational model is used to predict the elastic properties of composites with short reinforcing fibers which are accidentally oriented.

$$E_c = V_n\left(\frac{16}{45}E_n + 2E_m\right) + \frac{8}{9}E_m \tag{1}$$

Where E_c , E_n , E_m are nanocomposite elastic, nano particles elastic modulus and matrix elastic modulus respectively.

2) Model of Pan or fibers density equation [37]:

This model is efficient for the composites with long fibers and regular orientation. In this model, Pan established an equation based on irregular orientation of fibers in two-dimensional and three-dimensional space by using expanded simple mixing rule and a hypothetical density equation.

$$3D: E_c = E_n\frac{V_n}{\pi} + E_m(1 - \frac{V_n}{\pi}) \tag{2}$$

$$2D: E_c = E_n\frac{V_n}{2\pi} + E_m(1 - \frac{V_n}{2\pi}) \tag{3}$$

Where E_c , E_n , E_m and V_n are nanocomposite elastic, nano particles elastic modulus , matrix elastic modulus and nano particles volume friction respectively.

3) Hirsch's model [38]:

Hirsch's model presents the elastic modulus composite equation with combination of vertical longitudinal modulus of composite as the following:

$$E_c = \frac{3}{8}[V_nE_n + (1 - V_n)E_m] + \frac{5}{8}[\frac{E_nY_m}{E_mV_n + (1 - V_n)E_n}] \tag{4}$$

Where E_c , E_n , E_m and V_n are nanocomposite elastic, nano particles elastic modulus , matrix elastic modulus and nano particles volume friction respectively.
The first term is the coefficient of the longitudinal modulus and the second term is the coefficient of the vertical modules of the composite.

4) Modified Halpin-Tsai [39]:

In the equation of [4], if the values of the longitudinal and vertical pressure of composite are replaced with the values of Halpyn-Tsai equation [40], we will get Modified Halpin-Tsai Relation that is suitable for the reinforced composite materials. These equations are:

$$E_c = E_m[\frac{3}{8}\frac{1+\frac{l}{d}\eta_l V_n}{1-\eta_l V_n} + \frac{5}{8}\frac{1+2\eta_T V_n}{1-\eta_T V_n}] \tag{5}$$

And

$$\eta_l = \frac{\frac{E_n}{E_m} - 1}{\frac{E_n}{E_m} - 2\frac{l}{d}} \quad \eta_T = \frac{\frac{E_n}{E_m} - 1}{\frac{E_n}{E_m} + 2} \tag{6}$$

where l is the length of a fiber in one direction, d is the diameter of fiber, η_l is length efficiency factor and η_T is thickness efficiency factor.

Table 4: Experimental and Theoretical Results of Elastic Modulus

CNT (wt %)	experimental	Model 1	Model 2	Model 3	Model 4
0.5	2375.7	2484.7	2630.1	2740.8	2536.3
1	3240.9	3346.1	3392.8	3641.8	3184
1.5	2642.1	4164.4	4117.3	4497.8	3791.9

Regarding the results of the experimental and theoretical results derived from equations, the predicted error rates of each type at different percentages are given in Table 5.

Table 5: Predicted Error Rate of Elastic Modulus by Theoretical Models

CNT (wt %)	Model 1	Model 2	Model 3	Model 4
0.5	%4.6	%10.7	%15.4	%6.8
1	%3.2	%4.7	%12.4	%1.8
1.5	%57.6	%55.8	%70.2	%43.5

According to the table, Models 1 and 4, which are respectively Manera approximation model and modified Halpin-Tsai have the acceptable percentages of ability to predict the properties of nano composites polyethylene and carbon nanotubes, used in this study possess. According to the results, Manera approximation model at percentages about 0.5% weight and modified Halpin-Tsai at percentages about 1% weight lead to favorite and reliable results.
Another important result predictable then is high percentage of errors in all the models at %1.5 weight percent. According to the theory models, by increasing the percentage of carbon nanotubes weight, the mechanical properties of nano composites increases while in practice the results are reversed and as it is mentioned.

4. Concluding remarks

In this work the polyethylene-carbon nanotube nanocomposites were produced according to injection molding method. The effect of the addition of carbon nanotubes at four different levels of 0, 0.5, 1, and 1.5 on tensile strength of the nanocomposite samples was investigated. By adding 1% w/w carbon nanotube into the polymer significantly increased the tensile strength of the samples. Also, according to the results, Manera approximation model at percentages about 0.5% weight and modified Halpin-Tsai at percentages about 1% weight lead to favorite and reliable results.

References

[1] Iijima S. (1991). Sybthesis of carbon nanotubes, Nature, 354:56–8. https://doi.org/10.1038/354056a0.

[2] Fattahi, A.M., Safaei, B. (2017). Buckling analysis of CNT-reinforced beams with arbitrary boundary conditions, Microsystem Technologies 23(10), 5079–5091. https://doi.org/10.1007/s00542-017-3345-5.

[3] Sahmani, S., Fattahi, A.M. (2017). Thermo-electro-mechanical size-dependent postbuckling response of axially loaded piezoelectric shear deformable nanoshells via nonlocal elasticity theory, Microsystem Technologies 23(10), 5105–5119. https://doi.org/10.1007/s00542-017-3316-x.

[4] Fattahi, A.M., Sahmani, S. (2017). Nonlocal temperature-dependent postbuckling behavior of FG-CNT reinforced nanoshells under hydrostatic pressure combined with heat cnduction, Microsystem Technologies 23(10), 5121–5137. https://doi.org/10.1007/s00542-017-3377-x.

[5] Sahmani, S., Fattahi, A.M. (2016). Size-dependent nonlinear instability of shear deformable cylindrical nanopanels subjected to axial compression in thermal environments, Microsystem Technologies 23(10), 4717–4731. https://doi.org/10.1007/s00542-016-3220-9.

[6] Sahmani, S., Fattahi, A.M. (2017) Nonlocal size dependency in nonlinear instability of axially loaded exponential shear deformable FG-CNT reinforced nanoshells under heat conduction, The European Physical Journal plus 132 (5), 231. https://doi.org/10.1140/epjp/i2017-11497-5.

[7] Sahmani, S., Fattahi, A.M. (2016) Size-dependent nonlinear instability of shear deformable cylindrical nanopanels subjected to axial compression in thermal environments, Microsystem Technologies 23 (10), 4717-4731. https://doi.org/10.1007/s00542-016-3220-9.

[8] Sahmani, S., Fattahi, A.M. (2017). Imperfection sensitivity of the size-dependent nonlinear instability of axially loaded FGM nanopanels in thermal environments, Acta Mechanica 228 (11), 3789-3810. https://doi.org/10.1007/s00707-017-1912-6.

[9] Sahmani, S., Fattahi, A.M. (2017). An anisotropic calibrated nonlocal plate model for biaxial instability analysis of 3D metallic carbon nanosheets using molecular dynamics simulations, Materials Research Express 4(6), 1-14. https://doi.org/10.1088/2053-1591/aa6bc0.

[10] Sahmani, S., Fattahi, A.M. (2017) Calibration of developed nonlocal anisotropic shear deformable plate model for uniaxial instability of 3D metallic carbon nanosheets using MD simulations,Computer Methods in Applied Mechanics and Engineering 322, 187-207 https://doi.org/10.1016/j.cma.2017.04.015.

[11] Sahmani, S., Fattahi, A.M. (2017) Development an efficient calibrated nonlocal plate model for nonlinear axial instability of zirconia nanosheets using molecular dynamics simulation, Journal of Molecular Graphics and Modelling 75, 20-31. https://doi.org/10.1016/j.jmgm.2017.04.018.

[12] Komarneni S. (1992). Nanocomposites, Journal of Materials Chemistry 2, 1219-1230. https://doi.org/10.1039/jm9920201219.

[13] Jeffrey Jordan, Karl I. Jacob, Rina Tannenbaum, Mohammed A. Sharaf, Iwona Jasiuk (2005). Experimental trends in polymer nanocomposites—a review, Materials Science and Engineering A, 393, 1–11 https://doi.org/10.1016/j.msea.2004.09.044.

[14] You-Ping Wu, Qing-Xiu Jia, Ding-Sheng Yu, Li-Qun Zhang (2004). Modeling Young's modulus of rubber–clay nanocomposites using composite theories, Polymer Testing, 23, 903–909. https://doi.org/10.1016/j.polymertesting.2004.05.004.

[15] Hu, H., Onyebueke, L., Abatan, A., (2010). Characterizing and Modeling Mechanical Properties of nanocomposites-Review and Evaluation, Journal of Minerals & Materials Characterization & Engineering, 9, 275-319. https://doi.org/10.4236/jmmce.2010.94022.

[16] Moradi-Dastjerdi, R., Payganeh G., (2017). Thermoelastic dynamic analysis of wavy carbon nanotube reinforced cylinders under thermal loads. Steel and Composite Structures 25, 315–26.

[17] Moradi-Dastjerdi, R., Payganeh, G., Tajdari, M., (2018). Thermoelastic Analysis of Functionally Graded Cylinders Reinforced by Wavy CNT Using a Mesh-Free Method. Polymer Composites 39, 2190–201. https://doi.org/10.1002/pc.24183.

[18] Moradi-Dastjerdi, R., Payganeh, G., (2018). Thermoelastic Vibration Analysis of Functionally Graded Wavy Carbon Nanotube-Reinforced Cylinders. Polymer Composites 39, E826–E834. https://doi.org/10.1002/pc.24183.

[19] Fattahi, A.M., Sahmani, S. (2017). Size Dependency in the Axial Postbuckling Behavior of Nanopanels Made of Functionally Graded Material Considering Surface Elasticity, Arabian Journal for Science and Engineering, 1-17.

[20] Najipour, A., Fattahi, A.M., (2017). Experimental study on mechanical properties of PE / CNT composites, Journal of Theoretical and Applied Mechanics 55(2), 719-726. https://doi.org/10.15632/jtam-pl.55.2.719.

[21] Azizi, S., Safaei, B., Fattahi, A.M., Tekere, M. (2015). Nonlinear Vibrational Analysis of Nanobeams Embedded in an Elastic Medium including Surface Stress Effects, Advanced in Materils Since and Engineering, 1-7.

[22] Azizi, S., Fattahi, A.M., Kahnamouei, J.T. (2015). Evaluating mechanical properties of nanoplatelet reinforced composites undermechanical and thermal loads, Computational and Theoretical Nanoscience 12, 4179-4185. https://doi.org/10.1166/jctn.2015.4334.

[23] Sahmani, S., Fattahi, A.M. (2017) Development of efficient size-dependent plate models for axial buckling of single-layered graphene nanosheets using molecular dynamics simulation, Microsystem Technologies 24 (2), 1265-1277. https://doi.org/10.1007/s00542-017-3497-3.

[24] Safaei, B., Fattahi, A.M. (2017). Free Vibrational Response of Single-Layered Graphene Sheets Embedded in an Elastic Matrix using Different Nonlocal Plate Models, Mechanics 23 (5), 678-687.

[25] Sahmani, S., Fattahi, A.M. (2018). Small scale effects on buckling and postbuckling behaviors of axially loaded FGM nanoshells based on nonlocal strain gradient elasticity theory, Applied Mathematics and Mechanics 39 (4), 561-580. https://doi.org/10.1007/s10483-018-2321-8.

[26] Safaei, B., Naseradinmousavi, P., Rahman, A., (2016). Development of an accurate molecular mechanics model for buckling be-

havior of multi-walled carbon nanotubes under axial compression, Journal of Molecular Graphics and Modelling 65, 43–60. https://doi.org/10.1016/j.jmgm.2016.02.001.

[27] Moheimani, R., Hasansade, M., (2018). A closed-form model for estimating the effective thermal conductivities of carbon nanotube–polymer nanocomposites, Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science 0, 1–11. https://doi.org/10.1177/0954406218797967.

[28] Damadam, M., Moheimani, R., Dalir, H., (2018). Bree's diagram of a functionally graded thick-walled cylinder under thermo-mechanical loading considering nonlinear kinematic hardening, Case Studies in Thermal Engineering 12, 644–54. https://doi.org/10.1016/j.csite.2018.08.004.

[29] Mohammadsalehi, M., Zargar, O., Baghani, M., (2017), Study of non-uniform viscoelastic nanoplates vibration based on nonlocal first-order shear deformation theory. Meccanica 52, 1063–77. https://doi.org/10.1007/s11012-016-0432-0.

[30] Ghanati, P., Safaei, B., (2018). Elastic buckling analysis of polygonal thin sheets under compression, Indian Journal of Physics 1-6. https://doi.org/10.1007/s12648-018-1254-9.

[31] Mohamed, A., Derrick, D., Merlin T., Jennifer, F., Elijah, N., Gary, P. (2010). Magnetically processed carbon nanotube/epoxy nanocomposites: Morphology, thermal, and mechanical properties, Polymer, 51, 1614–1620. https://doi.org/10.1016/j.polymer.2009.05.059.

[32] Peddini, S. K. (2015). Nanocomposites from styrene–butadiene rubber (SBR) and multiwall carbon nanotubes (MWCNT) part 2: Mechanical properties, Polymer 56, 443-451. https://doi.org/10.1016/j.polymer.2014.11.006.

[33] Yuqi, Li. (2015). In situ polymerization, thermal, damping, and mechanical properties of multiwalled carbon nanotubes/polyisobutylene-based polyurethane nanocomposites." Polymer Composites 36(1), 198-203. https://doi.org/10.1002/pc.22930.

[34] Zhiqiang, C. (2014). Improving the mechanical properties of multiwalled carbon nanotube/epoxy nanocomposites using polymerization in a stirring plasma system, Composites Part A: Applied Science and Manufacturing 56, 172-180. https://doi.org/10.1016/j.compositesa.2013.10.009.

[35] Navidfar, A. (2014). Experimental study of mechanical properties of nano-composites containing carbon nanotubes produced by injection molding. M.D. Thesis, Ourmieh University, Ourmieh.

[36] Manera M. (1977). Elastic properties of randomly oriented short fiberglass composites, Journal of Composite Materials 11(2), 235-47. https://doi.org/10.1177/002199837701100208.

[37] Pan N. (1996). The elastic constants of randomly oriented fiber composites: A new approach to prediction, Science and Engineering of composite materials 5(2), 63-72. https://doi.org/10.1515/SECM.1996.5.2.63.

[38] Thostenson ET., Ren Z., Chou T-W. (2001). Advances in the science and technology of carbon nanotubes and their composites: a review, Composites science and technology.61 (13), 1899-912. https://doi.org/10.1016/S0266-3538(01)00094-X.

[39] Tsai, S. W., Pagano, J. J., (1968). Composite Materials Workshop, Technomic Stamford,Conn.

[40] Halpin J. (1969). Stiffness and expansion estimates for oriented short fiber composites.