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Research Article

Investigating the Effect of Nanoclay on Polypropylene-Made Cellulose Composite

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Abstract: This study investigates the effect of adding the nanoclay particles on the mechanical properties of polypropylene-made cellulose composite. Based-on-polypropylene composites are mixed with the particles of wheat stalk flour with the dimensional size (mesh 80), nanoclay at three different levels (0, 2 and 4) per hundred compounds (phc) and also with Maleic Anhydride-grafted Polypropylene (MAPP) as compatibilizer by Dr. Colin machine at 180°C and 60 rpm and the standard test samples were made by injection molding method. Then the mechanical properties such as the tensile strength, flexural strength and impact strength were measured. Finally, the cellulose composite was examined by the X-Ray Diffraction method (XRD) in order to study the structure and function of nanoclay particles and particles of wheat stalk flour with dimension 80 mesh. The results of mechanical test indicate that with an increase in the nanoclay amount up to the level 2 phc, the tensile and flexural strengths and tensile and flexural modulus of composite will be increased. However, these strengths will be decreased by increasing the amount of nanoclay to the level 4 phc. Moreover, the impact strength of composite is decreased by increasing the amount of nanoclay. Survey, conducted by the transmission X-ray diffraction on the nanocomposites indicates that the samples containing 2 phc nanoclay in the combination with the polymer have reached the intercalated structures. Furthermore, the samples with 4 phc nanoclay have shown the intercalated-flocculated structures. In general, the results showed that the best combination of materials for making the composite contained 2 phc nanoclay in terms of mechanical properties.

Keywords: Cellulose composite, mechanical properties, nanoclay, polypropylene

INTRODUCTION

Nanoscience and nanotechnology have opened a completely new way in the development of wood-plastic composites. Nanotechnology is a very promising field for improving the properties of wood-plastic composites with the nanoscale fillers. These advances include the high modulus, high tensile strength and thermal stability, low gas permeability, improved flammability properties, low water absorption and high biodegradation of biodegradable polymers (Ashori and Nourbakhsh, 2011). Nanoclay particles are among these nano particles and they can improve the properties of polymer composites in small quantities due to the certain dimensions and high apparent coefficient compared to other fillers (Kord, 2010). It should be noted that the composites are considered as the high-tech materials; hence, there is a significant correlation between the consumption of these materials and the industrial development of societies. Thus if any organization, agency or institution invest in this industry systematically, it will be the winner because the products of this industry can be produced by the simplest method (Rezadoust, 2009).

In Material Engineering, the composite is called a material which contains one or more discontinuous phases within a continuous phase. Discontinuous phase is usually harder and stronger than the continuous phase and is called the Reinforcing Phase, while the continuous phase is called the matrix material (Shokrieh and Sonbolestan, 2007). Reinforcing Phase improves the mechanical properties and matrix phase in the composites results in the power transmission to the reinforcing phase, heat resistance and resistance to the chemical agents. Plastic industries are willing to use the wood and other natural fibers such as jute, cotton and because these fibers are considered as the renewable resources. Furthermore, the lower prices, being lighter and less wear of production equipment are their other appropriate properties compared to the mineral or synthetic fillers. Cellulose composites are also important in terms of environmental perspective and

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have numerous advantages including the following cases: These materials create very little waste and have the ability to be re-used, have no formaldehyde and volatile organic compounds, have the recyclability and can be put back in the production cycle after the useful life, they do not produce significant hazardous toxic waste which can also be cleaned up through the standard methods (Tajvidi, 2003). The range of applying these composites is very broad. These materials can be used in internal and external areas (Tajvidi, 2003). Polymer matrix material plays an important role in strengthening the composite-manufacturing systems and its exact choice is significantly important due to the specific needs of production processes. For instance, the good flow of polymer in the mold is as the basic requirement of injection molding process, thus the applied polymer should have low molecular weight so that its viscosity maintains high (Ghaffarian, 2003).

Clay has been created by the hydrothermal conversion of alkaline volcanic ash and the rocks of The Cretaceous Period (85 to 125 million years ago). Various geological processes may result in creation of clay during million years. Clay is classified based on the crystal structure and the amount and location of (missing or extra) electrical charge in the original cell. In terms of Polymer nanocomposites, the amorphous clay is considered as a big nuisance because of the difficulty of separating them from the crystalline samples. Crystal clay is ranged from the kaolins, which have the relatively uniform chemical composition, to smectites which have wide ionic properties and different expansion abilities in chemical composition. Most of the crystal clays are formed of the small plate crystals with thickness of 1 nm and high apparent rate and have high specific surface area (Jahromi *et al*., 2010).

The intercalation rate of nanoparticles in the matrix is the most important parameter affecting the rheological behavior and the physical and mechanical properties of polymer nanocomposites. Therefore, for investigating this degree of diffraction we need the tests of which the X-ray diffraction is the most important one. By obtaining the spectra and detailed study, the effects of diffraction and distribution of nanoclay particles can be investigated in the polymer nanocomposites. The height and shape of obtained peaks are the functions of structure and the diffraction percentage of nanoparticles. Since the structures of nanoparticles are different from each other, the diffraction of radiation is done with various angles and the peaks will be different (Chowdhury *et al*., 2006).

LITERATURE REVIEW

Tajvidi and Ebrahimi (2008) used the cellulose fibers in their studies on wood-plastic composites. In this study, the alpha cellulose fiber, waste paper fiber and wood fiber were mixed with polypropylene with the weight ratios 15, 25, 35% and Maleic anhydride-grafted polypropylene was used as a compatibilizer at the level 2%. The results indicate that with an increase in the amounts of cellulosic material, the impact strength and elongation of composites will be decreased and the amount of modulus of elasticity and hardness will show a significant increase. Qin (2002) studied the mechanical properties of wood powder- polypropylene composites. The results indicate that with an increase in the wood powder, the modulus of elasticity and tensile and flexural strengths are increased, while the elongation at the rupture point and the impact strength are decreased by increasing the amount of wood powder. Celmons (2002) concluded in his study that the rigidity of composite is increased compared to the plastic by adding the cellulose fiber in to the plastic; however, the resulting composite is more brittle. In this regard, the effect of wood fibers is more than the wood flour. The mentioned survey found that the impact of raw material in the final production and process of product directly affect the composite role. By investigating the polymer composites reinforced with the nanoclay, Chowdhury *et al*. (2006) declared that the highest amount of flexural strength was achieved in the obtained composite while applying 2% of nanoclay; moreover, the glass transition temperature was increased to 9°C. Lei *et al*. (2007) studied the influence of nanoclay on crystallization behavior, mechanical properties, water absorption, thermal stability and pine-High Density Polyethylene composite (HDPE). They stated that with the crystal thickness is hardly changed by adding 2% nanoclay to the composite, but the rate of crystallization temperature and the crystallinity level are decreased. When 2% coupling agent is added, the crystal thickness is slightly reduced and the crystallinity is further reduced despite the increase in crystallization. Tensile and flexural strengths are increased equal to 24.2 and 19.6%, respectively, with adding 1% nanoclay, but when its amount is increased to 3%; the above amounts will be reduced slightly. Furthermore, tensile modulus is increased equal to 11.8 by adding 1% nanoclay and the tensile elongation is equal to 13%. Flexural and tensile moduli are slightly increased with increased nanoclay content. Despite the fact that the impact strength is reduced 7.5 by adding 1% nanoclay, no further decrease is observed while increasing the nanoclay from 1 to 3%. Kanny and Moodley (2007) stated that all mechanical properties of Montmorillonite- polypropylene-based polymer nanocomposites including the flexural, tensile strengths and the hardness and impact were increased while adding 2% nanoclay, while the higher amount of nanoclay reduced these properties. They concluded that the properties are improved in the amounts up to 2% because of the high coefficient of Montmorillonite as well as creation of intercalated structure, while the mechanical properties was decreased by increasing the nanoclay content due to the density of clay.

MATERIALS AND METHODS

Applied Polypropylene in this study is manufactured by Tabriz Polynar Corporation and is a homopolymer which is suitable for injection. The Melt flow index of this polymer is about 16 g/10 min and its density is equal to 0.9 $\frac{g}{cm^3}$. Wheat Stalk flour was used as a cellulose filler in the composite. Wheat Stalk flour was tested in the dimensional size 80 and the nanoclay powder, produced by Southern Clay Company of USA with the brand Cloisite 15A, was used as the mineral filler. Polymer percentage, type of cellulosic material and its percentage and the amount of coupling factor and dimensional size (largeness) of cellulosic material were considered as the constant factors and the percentage of mineral material (nanoclay) was considered as the variable factor. The excess moisture of cellulose fibers were removed from them before mixing with polypropylene.

Mixing process: Mixing process was done by using counter-rotating twin-screw extruder, manufactured by Dr. Collin in Iran Polymer and Petrochemical Institute and at the temperature 180°C. Extruder screw rotation was adjusted at 60 rpm and the thermal areas were adjusted at temperatures 160, 165, 170, 175, 180 and 175°C, respectively, which make 6 thermal areas from the beginning to the end of feed entering. The obtained product was changed to the form of granule after cooling and hardening by the semi-industrial mill machine, model WG-LS 200/200, manufactured by German Wieser Company, in Iran Polymer and Petrochemical Institute. Obtained granules were put in the dryer for 24 h at the temperature 80°C in order to remove the moisture and be ready for injection. The test samples were produced by using the injection molding. The semi-industrial injection machine, manufactured in Imen Mashin Tehran and located in Iran Polymer and Petrochemical Institute, was used. Injection cylinder temperature was equal to 160, 170 and 180°C in three regions, respectively. Injection time was considered less than 20 sec and injection pressure considered 80 times. The samples were removed from the mold after 2 min. Designing the mold of injection system was in a way that the standard samples were obtained for the tensile, flexural and impact tests in each injection.

Measurement of mechanical properties: Flexural and tensile tests were done by the experimenter Instron 4486 in the faculty of Natural Resources at University of Tehran. Tensile test was done according to the standard ASTM D-790 and in three points. Loading rate was 10 mm/min and the dimension of standard sample was 13×5×10; the maximum flexural stress and the flexural modulus were calculated by the computer. Tensile test was performed according to the standards ASTM D-638. Test samples were under tension with the speed 5 mm/min. At the end of each experiment, the maximum tensile stress and tensile modulus were presented by the computer. Izod impact strength with the standard ASTM D-256 was performed by the impact testing machine SANTAM located in the laboratory of Natural Resources faculty at University of Tehran. In this test, the machine provides the required energy for fracture in Joule and based on it the impact strength of samples can be calculated in J/m. In this experiment, the amount of work or required energy for a sample fracture is measured. Charpy and Izod methods are the most important and common methods for testing the impact.

X-ray diffraction test: X-ray diffraction test was done on the samples by the X-Ray Diffraction machine, Model STADI MP, manufactured by Germany STOE Company located in Plasma Physics Research Centre in Science and Research branch of the Islamic Azad University of Tehran. The test was performed by the radiation of Cu tube with the wavelength λ = 54.1 Å. Angle of radiation was θ2 and at the range 2 to 12. The generating electric options of machine include 30 mA and 40 KV. Samples were prepared for testing with dimensions 1×10×10 mm^3.

RESULTS

The effect of variable factor including the nanoclay content (at three levels: 0, 2 and 4%) was investigated on the mechanical properties of cellulose composite made of Propylene. Samples were prepared in the form of 9 treatments which were tested for the tension and flexural tests with replications and four replications for the impact strength test. The software SPSS was used in order to analyze the results obtained from the mechanical test in the form of the completely randomized statistical project. Duncan's Multiple Range test at the confidence level 95% (significance level 5%) was used in order to compare the means and the software EXCELL was used for drawing the diagrams. Raw results of mechanical tests are listed in Table 1.

Flexural strength: The results of analysis of variance indicate that the increased nanoclay at the confidence level % has had a significant effect on the composite flexural strength compared to the control sample (Pure PP) and the results are provided in Table 2. In fact, the flexural test determines the amount of resistance to bending while applying the vertical force to the sample. While bending the plastic, the polymer chains are compressed and condensed at the point to where the force is applied. However, the polymer chains are moving and pulled on the other side. When the cellulose filler is added to the composite matrix, it will reduce the polymer chain mobility, thus the composite strength against breakage and bending will be increased (Khosravian, 2009). As indicated by the results of this study, the flexural properties are increased compared to the control sample, pure polypropylene, by adding the cellulosic filler.

Table 1: Average mechanical properties of composite

	Flexural properties (MPa)		Tensile properties (MPa)		
Treatment	Flexural modulus	Flexural strength	Tensile modulus	Tensile strength	Impact strength (J/m)
Pure-pp	733.80	24.28	1259	21.39	106.53
1	21.82	29.99	2701.30	17.51	33.07
2	2417.66	30.41	2949	19.35	26.92
3	2342.66	28.85	2845	18.12	25.57
4	2337.66	29.98	2768	19.11	36.92
5	2516.33	30.35	3258.33	19.74	33.84
6	2393.66	30.36	2928.66	19.36	31.53
7	2386.66	29.12	2889.66	19.34	37.69
8	2682.33	32.01	3069.33	20.38	34.61
9	2500.33	31.51	2975.66	19.55	32.30

Table 2: Analysis of variance of flexural strength

Significance level	F statistics	M.S.	Degrees of freedom	S.S.	
0.04	4.068	13.678	9	123.104	Inter-group
		3.363	20	67.256	Intra-group
			29	190.360	Total

M.S.: Mean square; S.S.: Sum of square

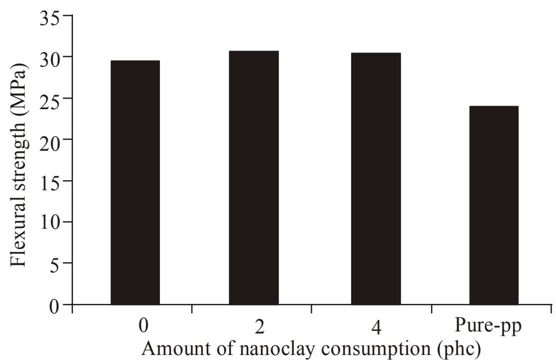

Fig. 1: Effect of nanoclay content on the flexural strength

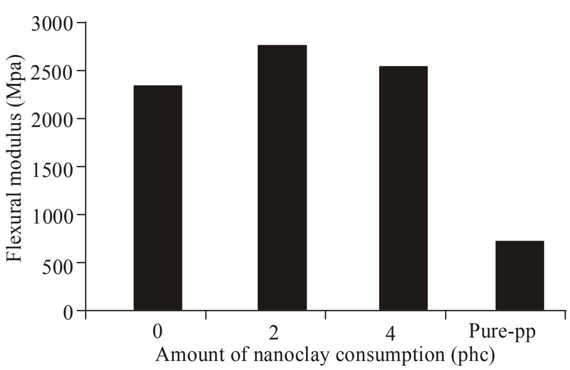

Fig. 2: Effect of nanoclay content on the flexural modulus of cellulose composite

Independent effect of nanoclay on flexural strength: Despite increasing the flexural strength of cellulose nanocomposites by enhanced nanoclay content compared to the nanoclay-free samples, as seen in the Fig. 1, the flexural strength of composite is increased by enhanced nanoclay content from 0 to 2 Phc and then the amount of this strength is reduced by adding 4 Phc nanoclay.

The impact of nanoclay particles on the mechanical properties of polymer nanocomposites depends on the shape, size, apparent coefficient, type and quantity, crystal structure, quality and quantity of nanoclay particles diffraction and the way of their binding with the polymer (Shokrieh and Sonbolestan, 2007; Kord, 2010; Ashori and Nourbakhsh, 2011). Therefore, the increased flexural strength of nanocomposite while using 2 phc nanoclay can be attributed to the high apparent coefficient of nanoclay particles and created intercalated and exfoliated structure in the nanocomposite. High apparent coefficient of nanoclay particles plays the role in its reinforcing ability in the composite and enhances the interface of the two phases and thus the flexural strength of composite is increased. Furthermore, created intercalated structure in the nanocomposite, strong bonds at the interface of polymer and the nanoclay particles and the orientation of these particles increase the flexural strength of composite (Kord, 2010; Ahmadi and Mohadespour, 2005). On the other hand, the flexural strength of composite was reduced by increased nanoclay content from 2 to 4 phc due to the concentration of nanoclay particles and created inside-together flocculates. The results of X-ray diffraction and transmission electron microscopy confirmed the formation of intercalated-Flocculated structure. Despite the fact that the results of this research are consistent with the results of other studies including the research by Chowdhury *et al.* (2006), Kanny and Moodley (2007), Kord (2010) and Ziaei *et al.* (2011), some researchers also declared the negative impact of nanoparticles in the flexural strength of wood flour/polypropylene composites (Yeh *et al.*, 2005). Although, the researchers found no reason for the weakness of wood flour-filled polypropylene nanocomposites, they raised the uneven distribution of cellulosic fillers and clay particles as a hypothesis.

Flexural modulus: The results of analysis of variance have indicated that the increase in the nanoclay content on the flexural modulus of composites is significant at the confidence level 95% as shown in Table 3.

Independent effect of nanoclay on the flexural modulus: The independent influence of nanoclay is

Table 3: Analysis of variance of flexural modulus

Significance level	F statistics	M.S.	Degrees of freedom	S.S.	
0.000	45.177	902565.53800	9	8123089.841	Inter-group
		456.19978	20	113.399569	Intra-group
			29	8522658.955	Total

M.S.: Mean square; S.S.: Sum of squares

Table 4: Analysis of variance of tensile strength

Significance level	F statistics	M.S.	Degrees of freedom	S.S.	
0.001	5.364	3.448	9	31.031	Inter-group
		0.643	20	12.857	Intra-group
			29	43.888	Total

M.S.: Mean square; S.S.: Sum of squares

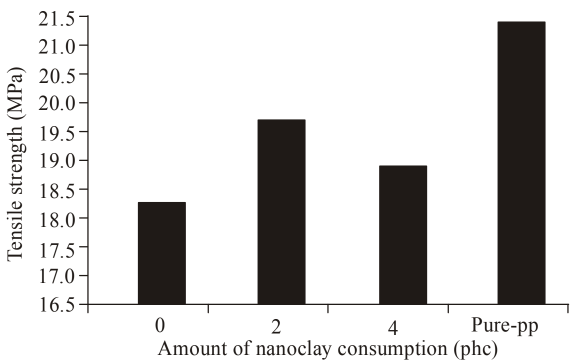

Fig. 3: Effect of nanoclay content on the tensile strength of cellulose composite

significant on the flexural modulus of cellulose composite as seen in Fig. 2. With an increase in the nanoclay content from 0 to 2 Phc, the flexural modulus of composites is increased and then its amount is reduced to 4 Phc nanoclay by adding the amounts. It seems that the elasticity modulus of wood-plastic nanocomposite is affected by two opposite phenomena. In the first case, if the clay particles are migrated to the interface of wood and plastic, it reduces the reinforcing property of nanoclay particles. Moreover, the increased amount of clay will enhance the probability of high density and concentration of particles and this will reduce the modulus. The second phenomenon is related to the reinforcing property of nanoclay particles in the interface of nanoclay and plastic (Han *et al*., 2008) because this filler can create strong connections with the polymer matrix and this increases the mechanical strength and modulus (Kord, 2010). This study indicates that the flexural modulus is increased with increasing the nanoclay content up to 2 phc level. This increase is related to the high apparent coefficient of nanoclay particles and created intercalated structure. However, the amount of flexural modulus was decreased at high levels of nanoclay and at the level 4 phc due to the concentration and density of nanoclay particles and created flocculated structures. The results of research by Chowdhury *et al*. (2006), Lei *et al*. (2007), Han *et al*. (2008) and Kord (2010) are consistent with the results of this research.

Tensile strength: The results of analysis of variance indicate that the increased nanoclay content as well as the dimensional size of wheat stalk flour particles on the tensile strength of composite is significant at the confidence level 95%; the results are shown in Table 4. Unlike the tensile modulus, which is largely dependent on filler properties, the tensile strength of composites is largely dependent on the matrix properties. The low stress concentration and the filler orientation can be mentioned as the factors influencing the appropriate chemical bonding among the composite components. When the composite is faced with the force, this force is first entered into the matrix and then transferred to the filler particles by the matrix particles. In the load transfer mechanism, the stress is reduced at the end of filler particles. However, it is difficult to direct the filler particles and control them, thus the volume percent of applying them should be controlled. At the time of tensile stress, the load transfer between the matrix and filler particles is performed as the fracture in the interface between the matrix and filler particles. Therefore, the interface between the filler particles and matrix should be able to do this transfer effectively (Svab *et al*., 2005).

Independent effect of nanoclay on the tensile strength: As shown in Fig. 3, it is observed that with an increase in the amount of nanoclay from 0 to 2 phc, the tensile strength of cellulosic composite is increased and then it is reduced with increased nanoclay content to 4 phc level. Moreover, the tensile strength of control sample (Pure PP) is at a higher level than the composite samples.

It was observed here that with an increase in nanoclay content from 2 to 4 phc, the tensile strength of composite is increased and then is reduced by adding 4 phc nanoclay. Since the influence of nanoparticles on the mechanical properties of polymer nanocomposites depends on the factors such as shape, size, apparent coefficient, type and quantity, crystal structure, quality and quantity of nanoclay particles diffraction and the way of their binding with the polymer with the polymer, the increased flexural strength of nanocomposite while using 2 phc nanoclay can be attributed to the high apparent coefficient of nanoclay particles and created intercalated structure in the nanocomposite. High apparent coefficient of nanoclay increases the interface of two phases; moreover, the orientation of intercalated silicate particles leads to the increased tensile modulus and strength of composite

Table 5: Analysis of variance of tensile modulus

Significance level	F statistics	M.S.	Degrees of freedom	S.S.	
0.000	14.887	911685.467	9	8205169.200	Inter-group
		61239.700	20	1224794.000	Intra-group
			29	9429963.200	Total

M.S.: Mean square; S.S.: Sum of squares

Table 6: Analysis of variance of Impact strength

Significance level	F statistics	M.S.	Degrees of freedom	S.S.	
0.000	218.052	2251.586	9	20264.266	Inter-group
		10.326	30	309.777	Intra-group
			39	20574.043	Total

M.S.: Mean square; S.S.: Sum of squares

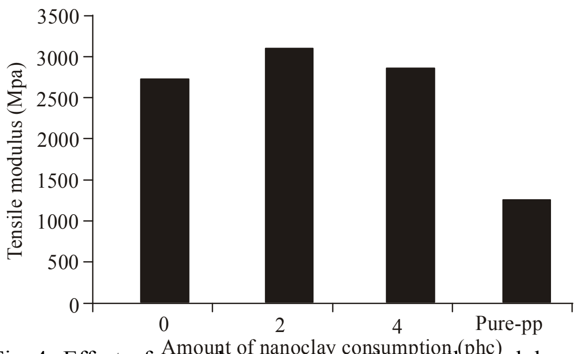

Fig. 4: Effect of nanoclay content on the tensile modulus of cellulose composite

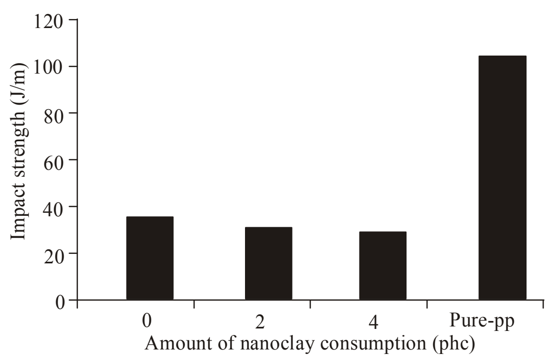

Fig. 5: Effect of nanoclay content on the impact strength of cellulose composite

(Kanny and Moodley, 2007; Nourbakhsh *et al*., 2010; Ziaei *et al*., 2011).

Flexural modulus: The results of analysis of variance have indicated that the increase in the nanoclay content on the flexural modulus of composites is significant at the confidence level 95% as shown in Table 5. In general, the inherent stiffness of natural fibers is approximately 26,207 to 120,000 MPa (Klyosov, 2007). Therefore, the application of natural fibers in composite matrix will increase the modulus (Celmons, 2002; Razavi *et al*., 2006). Reinforcement and increased tensile modulus of plastics is also one of the main reasons for adding the wood to them. Considering the high modulus of wood, the composite modulus will be significantly increased (Ghasemi *et al*., 2008).

Independent effect of nanoclay on the flexural modulus: The independent influence of nanoclay is significant on the flexural modulus of cellulose composite as seen in Fig. 4. With an increase in the nanoclay content from 0 to 2 Phc, the flexural modulus of composites is increased and then its amount is reduced to 4 Phc nanoclay by enhancing the contents. Furthermore, the tensile modulus of control sample (Pure PP) is at a higher level than the composite samples. In addition, the nanoparticles reinforce the composite and this depends on the filler particle surface. The surface of filler particles is dependent on the surface topography and porosity of filler particles. The surface of filler particles is defined as the grams of filler which is existed in each square meter of composites (Jahromi *et al*., 2010). This increase up to the level 2 phc has been because of the high apparent coefficient of nanoclay particles and created intercalated structure in the nanocomposite; moreover, a slight decrease is observed in higher amounts according to the of concentration and density of nanoclay particles and created dense flocculated structures and access to the intercalated-flocculated structure.

Impact strength: The results of analysis of variance have indicated that the impact of increased nanoclay content on the impact strength of composite is significant at the confidence level 95% as shown in Table 6. Impact strength of wood-Plastic composite represents its stiffness and toughness which is in fact associated with the strength of composite materials against the fracture. Fracture-resistance of composites depends on numerous factors some of which are described as follows:

Properties of matrix, dispersion of composite components, accumulation and orientation of the filler particles and the most importantly the interaction between the filler particles and the matrix. Basically, the impact strength is reduced because of decreased toughness and increased brittleness of samples by adding the cellulose fillers and minerals to the composite content (Klyosov, 2007; Razavi *et al*., 2006) and as the results of this study indicate the impact strength is decreased by adding the cellulose filler to the polymer matrix as well as adding the mineral filler to the composite.

Independent effect of nanoclay on the impact strength: The independent effect of nanoclay is significant on the cellulose composite impact strength;

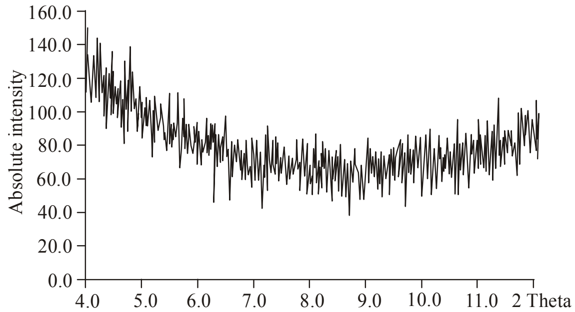

Fig. 6: X-ray spectrum of cellulose nanocomposite (0 phc, 80 mesh)

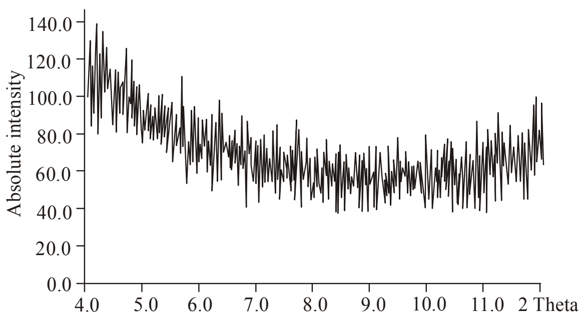

Fig. 7: X-ray spectrum of cellulose nanocomposite (2 phc, 80 mesh)

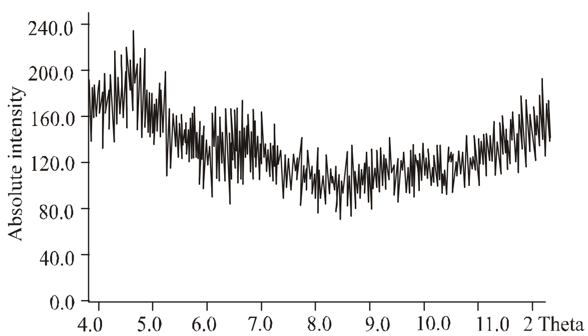

Fig. 8: X-ray spectrum of cellulose nanocomposite (4 phc, 80 mesh)

as shown in Fig. 5, the impact strength of cellulose composites is reduced by increasing the amount of nanoclay from 0 to 4 phc. Moreover, the impact strength of control sample (Pure PP) is at a higher level than the composite samples. Given that the nanoclay particles create the stress concentration points and starting points of fracture, thereby the impact strength of composite is reduced by increasing the nanoclay content. Furthermore, the existence of nanoclay increases the energy absorbed by the composite. Therefore, the increased nanoclay content creates the points in the polymer matrix that they enhance the stress concentration and begins the crack expansion from that area (Han, 2008). Obtained results were consistent with the results obtained by Lei *et al*. (2007), Han *et al*. (2008) and Kord (2010).

X-Ray Diffraction test (XRD): The results of X-ray diffraction test of cellulose composite in this study indicate that the distance between the silicate layers is increased while using 2 phc nanoclay and the nanocomposites structure represents the Exfoliated structure. In other words, the distance between the nanoclay silicate layers is increased because of the influence of polymer chain and the clay layers are completely fractured. As a result, no peak is remained in the curve due to the collapse of crystal structure. Figure 6 shows the X-ray spectrum of cellulose nanocomposites containing 0 phc nanoclay and Fig. 7 shows the X-ray spectrum of cellulose nanocomposites containing 2 phc nanoclay and wheat stalk flour particles with dimensions of 80 mesh. Moreover, Fig. 8 shows the X-ray spectrum of cellulose nanocomposites containing 4 phc nanoclay and the wheat stalk flour with dimensions of 80 mesh. As it can be seen, the obtained spectrum reflects an intercalated-flocculated structure. In other words, the polymer chains are not able to penetrate between the silicate layers in several parts of this composite and these layers are remained dense and flocculated; in the other parts, the polymer chains have penetrated the distance between the silicate layers, but they have failed to fracture the layers completely. In Fig. 8, the first peak of X-ray diffraction is created at $2\theta = 4.843°$ and the distance between the layers equal to $d = 18.24556$ nm and the second peak of X-ray diffraction is created at $2\theta = 6.861°$ and the distance between the layers $d = 12.8830$ nm. The Figures, obtained from the X-ray diffraction, confirm the results of physical and mechanical tests on the cellulose nanocomposites in this study.

CONCLUSION

This study investigates the effect of nanoclay particles on the mechanical properties of wood-plastic composites obtained from polyethylene. The results of this study indicate that the increase in nanoclay content up to 2 phc level will enhance the flexural strength and modulus, but the increase in nanoclay content from the level 2 to 4 phc will decrease these properties. Layered Silicates increases the flexural strength and modulus through strong hydrogen bonds with the polymer chains and also due to the high apparent coefficient. The rate of these properties is slightly reduced by adding the nanoclay amount from 2 to 4 phc levels because of dense and condensed nanoclay particles. The tensile strength of composite is increased by enhancing the nanoclay content from 2 to 4 phc and then reduced by adding 4 phc nanoclay. Since the impact of nanoparticles on the mechanical properties of polymer nanocomposites depends on the factors such as shape, size, apparent coefficient, type and quantity, crystal structure, quality and quantity of nanoclay particles diffraction and the way of their binding with the polymer, the increased flexural strength of nanocomposite while using 2 phc nanoclay can be attributed to the high apparent coefficient of nanoclay particles and created intercalated and exfoliated structure in the nanocomposite. High apparent coefficient of nanoclay increases the interface of two phases and also the orientation of layered silicate particles will lead to the increased tensile strength and modulus of composite. Observations in the field of impact strength indicate that by increasing the nanoclay content from 0 to 4 phc, the cellulosic composite impact strength will be decreased. Given that the nanoclay particles create the points of stress concentration and fracture, the impact strength of composite will be decreased by increasing the nanoclay content.

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