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Mechanical Characterization of Clay Reinforced Polypropylene Nanocomposites at High Temperature

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Abstract

This paper focuses on the influence of temperature conditions and the clay contents on enhancement of mechanical characterization of polypropylene (PP) nanocomposites. The nanocomposites were prepared using the melt mixing technique in a co-rotating intermeshing twin screw extruder followed by injection moulding. Nanocomposites properties such as impact strength and ultimate tensile strength, yield strength, failure strain, Young's modulus and toughness are calculated. The addition of clay to PP matrix was showed remarkable enhancement in mechanical properties at the temperature of 25°C and 120°C. Nearly 36% and 160% increase in the Young's modulus and about 45% and 62% increase in the impact strength were observed at both room temperature (RT) and high temperature (HT), respectively. But, the tensile strength was not affected much. The basal spacing of clay in the composites was measured by X-ray diffraction (XRD). Scanning electron microscopy (SEM) was used to assess the surface morphology of the fractured surfaces and dispersion of the nanoclay.

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Keywords: Polypropylene, Nanocomposite, Nanoclay, Tensile, Impact, High temperature

1- Introduction

In recent years, a significant aspect of global growth in polymer materials has been the innovative production components and their use in various areas of application such as automotive, construction, aerospace, healthcare and electronics. This growth has been largely driven by combinations of polymers with inorganic materials, which is called as polymer composites [1]. An important branch of the composite fields concentrates on using nanometer-sized filler-particles. Polymer nanocomposites (PNCs) are a new class of materials with a great deal of future promise for potential applications as high-performance materials. In this new class of materials, nanosized fillers (at least one dimension) are dispersed in polymer matrix in which tremendous improvement in performance properties of the polymer can be observed.

The interaction between filler components of nanocomposites at the nanometer scale enables them to act as molecular bridges in the polymer matrix [2]. This is the basis for enhanced mechanical properties of nanocomposites as compared to conventional microcomposites. PNCs often exhibit excellent mechanical, thermal, electrical and optical properties, because they combine the performances of both polymers and inorganic or organic nanoparticles [3]. Nanoparticles, such as carbon nanotubes and nanoclay are attracted great interest due to their nanoscale dimensions and remarkable prospect for improvement of mechanical, thermal, electrical, and chemical properties, when introduced a small quantities in polymer matrix composites. Nanoclay is one of the most affordable materials that have shown promising results in polymers, that it is made from

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montmorillonite mineral known to have platelet structure with average dimension of 1 nm thick and 70 to 150 nm wide.

Nanoclays are known to enhance properties of many polymers such as nylon 6, epoxy, polyethylene terephthalate, polyethylene and PP. This leads to better clarity, stiffness, thermal stability, barrier properties to moisture, solvents, vapours and gases, reduced static cling and UV transmission in films and bottles, improved chemical, flame and scratch resistances, and dimensional stability in injection moulded products [4]. Nanomer® and Cloisite® are the popular nanoclays available in the market. Cloisite additives are used in injection-moulded parts, films, bottles, trays, blister packs, and wire and cable coatings [5].

PP is one of the fastest growing classes of polymers due to its good balance of physical and chemical properties, its low cost, light-weight, favourable processing and recycle characteristics. PP is a thermoplastic polymer, used in a wide variety of applications, including food packaging, textiles, laboratory equipment, loudspeakers, automotive components, and polymer banknotes [6]. In order to disperse nanoclay layers into polymer matrix, it is very important to consider the polymer-clay compatibility. This means that to provide organophilic character to the clay by a compatibilizer in order to successful formation of polymer-clay nanocomposite. PP-g-MA was added as a compatibilizer agent for increasing the compatibility between the nanoclay and PP matrix [7,10].

PP/clay nanocomposites are of great interest for various industrial applications such as automobile interior and exterior accessories and civil constructions. Properties of these nanocomposites improved at very low contents of clay compared with conventional filler composites. For instance, mechanical properties, thermal stability, flame retardation, and heat

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distortion are all improved only by a few weight percent clay [11,12]. Addition of calcium carbonate ($CaCO_3$) nanoparticles to PP matrix resulted in some improvement in the modulus and impact strength and reducing costs, but the tensile properties of PP was slightly reduced and also poor dispersion of the $CaCO_3$ within the PP matrix was observed [13,14]. Addition of silica powder to the PP matrix resulted in aggregated silica particles and also there was no any outstanding improvement of the mechanical properties of PP/SiO_2 nanocomposites [15], but when poly methyl methacrylate (PMMA) grafted on nano-silica was added to PP matrix, improved the dispersion of the nanoparticles and interfacial adhesion and decreased the size of PP spherulites in nanocomposites. Finally, it leads to increase the Young's modulus and toughness of PP/silica nanocomposites [16].

Carbon nanotube (CNT) particles are more rigid and PP/CNTs interfacial adhesion is weak. Therefore, when PP-g-MA was added to PP matrix, a better dispersion and good adhesion were attained between the nanotubes and the PP matrix as compared to neat PP. This leads to increase in tensile and flexural moduli and Charpy impact strength [17]. Metal oxides have different behaviors in its physical, mechanical and chemical properties. Nanoparticles such as titanium dioxide (TiO_2) and zinc oxide (ZnO) were coated with maleic anhydride grafted styrene ethylene butylene styrene (SEBS-g-MA) and silane, respectively, to obtain better surface adhesion besides their fine dispersion [18]. The elongation of the composites with TiO_2 that has higher hardness than ZnO, was higher than that with ZnO. This is probably due to the better compatibility of TiO_2 with SEBS-g-MA [18].

Different organoclays were prepared using various fatty nitrogen compounds and natural clay, sodium montmorillonite (MMT). The clay modification was carried out by stirring the clay

particles in an aqueous solution of fatty amides (FA), fatty hydroxamic acids (FHA), and carbonyl difatty amides (CDFA). Poly (lactic acid) (PLA) modified clay nanocomposites showed significant improvement of mechanical properties in comparison with pure PLA. The highest tensile strength, modulus and elongation at break of the PLA/FA-MMT, PLA/FHAMMT and PLA/CDFA-MMT nanocomposites were obtained when 5 % of the FA-MMT or the FHA-MMT and 3 % of the CDFA-MMT loadings are used. The enhancing effect on the mechanical properties was probably due to the increase of the amount of the incorporated PLA chains in the clay layers [19].

A close look at the MMT dispersion in the nanocomposite depending on the polymer matrix (polyurethane and nylon 66) the compatibilizer content was taken. SEM of the polymer matrix/compatibilizer demonstrated that nylon due to the higher hydrophilicity than polyurethane blends better with compatibilizer. It is found from this investigation that the deterioration of mechanical properties and the severe aggregation of clay particles that occurred frequently, if a polymer matrix was blended with micometersize clay particles, were obviated by adopting both nanometersized particles and compatiblizer, and some mechanical properties could be even improved [20].

When the optimum epoxy polymer concrete (which has the highest mechanical performances and the lowest cost) is exposed to temperatures higher than 150°C, showed a significant loss of strengths mainly due to the thermo-oxidative degradation of the epoxy polymer and to the debonding between aggregates and the binder. These degradations are accompanied by a gas release. Cement based concrete has lower mechanical properties compared to polymer concrete. Results showed that when they are exposed to temperatures less than 250°C, the epoxy polymer concrete is still more efficient than cement based concrete [21]. With increase in temperature,

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several changes occurred in the cemented matrix. The flexural strengths of the cementitious composites (mortar) reduced under high temperature. However, with fibre addition, they increased relatively. All fiber types contributed to the flexural strengths of mortars under high temperature. However, this contribution decreased as the temperature increased [22].

Poly-ether-ether-ketone and polyetherimide filled with short carbon fibres and graphite flakes could effectively enhanced both the wear resistance and the load-carrying capacity of the base polymers. With the addition of sub-micro particles (TiO_2 and ZnS), the frictional coefficient and wear rate of the composites were further reduced especially at elevated temperatures [23]. The inclusion of clay had little effect on the temperature operating for the polyethylene terephthalate/clay, but it had a major effect on deformation behaviour which necessitates the use of much higher forming forces during processing. The strain hardening behaviour of both the filled and unfilled materials is well correlated with tensile strength and tensile modulus. Increasing the stretching temperature to reduce stretching forces had a detrimental effect on clay exfoliation, mechanical and O_2 barrier properties [24]. The annealing experiments revealed that the incorporation of Zirconium dioxide (ZrO_2) into the Silicon oxycarbide-based materials (SiOC) matrix remarkably increased the thermal stability of the composites with respect to crystallization and decomposition at temperatures exceeding 1300°C. The results indicated that the synthesized SiOC/ZrO_2 nanocomposites are candidate materials for high-temperature applications, due to the fact that the presence of zirconia within the SiOC ceramic matrix was found to strongly suppress the carbo-thermal decomposition up to 1600°C [25].

Since, no article was found to investigate the effect of nanoparticles on PP nanocomposites at high temperature, the aim of the present paper is focused on the use of PP at high temperature and

its reinforcement by nanoclay for their applications at medium load-high temperature conditions for the first time.

In this paper, PP/clay nanocomposites were prepared by melt mixing in a co-rotating intermeshing twin screw extruder followed by injection moulding with different weight percentage of clay content. PP-g-MA is added to matrix PP as a compatibilizer agent. The effect of adding various amounts of nanoclay in matrix PP is investigated. Mechanical properties such as tensile and impact as a function of clay concentration are studied at both RT and HT. Impact and tensile tests are carried out according to ASTM standards. The mechanical properties of nanocomposites are compared to the properties of neat PP at both RT and HT. The surface morphology of the fractured surfaces of nanocomposite specimens and dispersion of the nanoclay in matrix PP are investigated using SEM.

2-Experimental

2-1- Materials

For the preparation of PP nanocomposites, the commercialized PP with the trade name of Jampilen HP 500M from Iran Petrochemical, JAM Products (melt flow rate (MFR) 230°C, 2.16 kg = 9 g/10 min) was used. Anti peroxide Ciba-Irganox B215 from Iran Petrochemical, JAM Products was added to matrix PP and PP-g-MA with the trade name of Karabond® PCH (Melt index 190°C, 2.16 kg = 6±0.5 g/10 min, melting point (1kg) = 165°C and graft efficiency = 0.6-1%) from Karangin Company (Iran). The nanoclay, Cloisite® 15A (Pishgaman Fanavari Asia, Iran), is a natural montmorillonite modified with quaternary ammonium salt containing organic modifier,

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dimethyl dehydrogenated tallow, where (ht) is hydrogenated tallow with approximate composition of 65% C18, 30% C16 and 5% C14. The d-spacing of Cloisite® 15A is 34.7 A°.

2-2- Preparation of the PP Nanocomposites

For melt compounding of nanocomposites, fully intermeshing twin-screw extruder (plasticorder pl2002 with L/D = 40, Germany) was used in the corotating mode. The barrel temperatures were set at 165–195°C (feed zone to die zone), and the screw speed was fixed at 150 rpm. After that, injection-moulding machine (Imen machine Co., Tehran, Iran) at temperatures of 175–205°C and injection pressure of 96 bar was used for the preparation of tensile and impact specimens. The X-ray diffraction (Philips Analytical, model XPert MPD with Co radiation from Japan (0.154 nm wavelength at a generated voltage of 40 kV and current of 30 mA) of powder specimen was used. XRD were taken on Cloisite® 15A nanoclay particles and on PP/ clay nanocomposites. The nanoclay was dried at 80 °C for 4 h in air-circulated oven prior to compounding to remove moisture. PP nanocomposites were included 0.2 wt.% anti peroxide, 5 wt.% PP-g-MA and different amount of clay contents (1, 3 and 5 wt.%). The specimens were cut from the injection-moulded parts (7.2 mm thickness, 12.5 mm width and 63.5 mm length and a notch with the depth of 3.50 mm) and (3 mm thickness, 13 mm width and 165 mm length) for impact and tensile tests considering the recommendations of standard ASTM-D 256 and ASTM-D 638, respectively.

All the specimens were coded according to their constituents' wt.% contents and the temperature conditions. P corresponds to PP and 0 to 5 are weight percentage of the nanoclay particles and RT and HT, at the room temperature and high temperature, respectively and T and I are showed for tensile and impact test.

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2-3- Mechanical Test

Charpy impact tests at both RT (25°C) and HT (120°C) were conducted in accordance with the standard on Santam Instrumented Impact Tester (Model: ZBC1251, Santam Co., Iran). Tensile tests at the same RT and HT were carried out by Hounsfield testing machine (Model H25KS Co., England) with a load cell of 25 kN. The crosshead speed was set to 25 mm/min and five specimens were tested in each case. The high temperature condition was achieved by inserting the specimens in an Oven (Fan Azma Gostar Model BF55, Iran) for 20 min towards reaching at 120°C. The surface morphology of the fractured surfaces of nanocomposite specimens and dispersion of the nanoclay in PP matrix were investigated using a SEM (XL30 Philips, from Dutch) and the fractured surfaces photographs were obtained by the high magnified camera for detailed analysis.

3- Results and Discussion

3-1- Structure and Morphology of PP-Clay Nanocomposites

The structure of nanoclay filled PP composites was examined using XRD method. Figure 1, shows the XRD patterns of nanoclay powder and PP/clay nanocomposites. The Cloisite® 15A nanoclay shows a diffraction peak of 2θ at 2.9° and corresponds to an interlayer spacing of nanoclay (d-spacing) of 34.79Å (calculated from Bragg's diffraction law of $2d\sin\theta = n\lambda$). Characteristics of the Cloisite® 15A nanoclay powder's peak were given in Table 1. From 1 wt.% to 5 wt.% of nanoclay in the PP polymer, there is an absence of a diffraction peak, and this suggests that the matrix polymer has entered into the interlayer spacing of the nanoclay and increased the original nanoclay spacing above or the nanolayers of clays could have randomly dispersed in the

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PP polymer. Hence, it can be concluded that the nanoclays in the PP polymer from 1 to 5 wt.% formed an ordered exfoliated structure, or a randomly dispersed clay exfoliated structure.

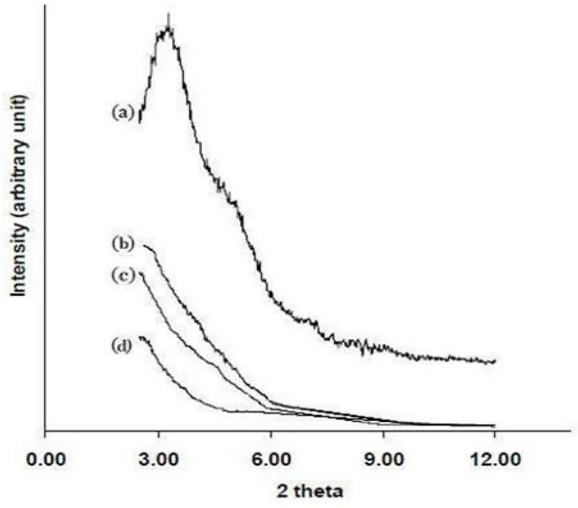

Figure 1- XRD diagramss of (a) Nanoclay powder, PP with (b) 5 wt.% nanoclay, (c) 3 wt.% nanoclay, (d) 1 wt.% nanoclay.

Table 1- Peak characteristics of nanoclay powder used in the present study

Position (2θ)	**d-spacing (A°)**	**Height (Counts)**	**Relative Intensive (%)**	**Background (Counts)**
1.7588	58.32523	156.78	32.42	34
2.9485	34.79395	483.51	100	34
5.589	18.36077	222.7	46.06	34
8.408	12.21088	114.52	23.69	34

3-2- Mechanical Properties

Mechanical properties such as impact and tensile as a function of clay concentration are studied at both RT and HT. Impact and tensile tests carried out according to ASTM standards. A poor compatibility between the PP matrix and the nanoclay was modified by adding of poly propylene-

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graft-maleic anhydride (PP-g-MA). In order to determine their mechanical properties, tensile and impact tests at both room temperature (25°C) and high temperature (120°C) were performed on composites with various nanoclay contents (1, 3 and 5 wt.%).

3-2-1- Notched Impact Test

Notched impact properties of PP and PP/nanoclay composites are given in Table 2. Codes for the prepared nanocomposites specimens with different clay contents are described beneath the Table 2. Figure 2, also shows the plot of notched impact strength of the PP composites at RT and HT as a function of nanoclay content.

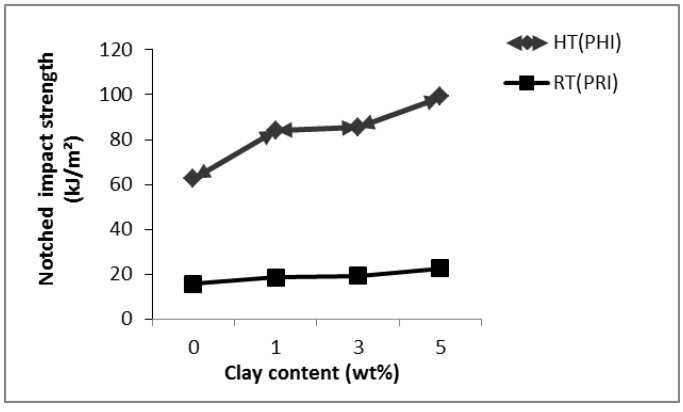

Figure 2- Notched impact strength of the PP composites at RT and HT.

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Table 2- Impact properties of PP and PP/nanoclay composites

Properties	Room temperature				High temperature			
	P0RI	**P1RI**	**P3RI**	**P5RI**	**P0HI**	**P1HI**	**P3HI**	**P5HI**
Notched impact strength (KJ/m^2)	15.63	18.48	19.32	22.68	47.05	65.54	66.38	76.47
Density (g/cm^3)	0.91	0.915	0.92	0.925	0.91	0.915	0.92	0.925
Specific notched impact strength ($(KJ/m^2)/(g/cm^3)$)	17.17	20.19	21	24.51	51.71	71.62	72.15	82.67
Specific notched impact strength increases in comparison to P0RI (%)	-	17.58	22.31	42.74	201.16	317.12	320.21	381.47
Specific notched impact strength increases in comparison to P0HI (%)	-66.81	-60.95	-59.38	-52.61	-	38.51	39.52	59.87

Difinition of codes are P= polypropylene, 0, 1, 3 and 5= weight percentage of nanoclay, R and H= room and high temperature, I= impact test.

The notched impact strength at RT is increased from 15.63 to 22.68, when increasing clay content from 0 to 5 wt.%. The presence of clay at suitable contents into PP matrix can effectively enhance the notched impact strength when compared to the neat PP. Addition of 5% nanoclay by weight, could increase the impact strength by 45%. It is possible that the clay layer orientation as well as molecular orientation contributes to the observed reinforcement effects. Toughness improvement of nanocomposites can be attained, when the clay in PP matrix can withstand the propagation of cracks with increasing the clay content at RT as indicated by the increase in notched impact strength. The more rough surfaces of the nanocomposites in Figures 3b and 3c and better dispersion and distribution of clay particles in PP matrix as compared to those of neat PP matrix in Figure 3a, are indicative of the improvement in the toughness. The notched impact strength at HT (120°C) is shown to be higher than that at RT (25°C). This is mainly because of the higher constrains of the molecular mobility of the PP matrix at the temperature of 120°C due to nanoclay

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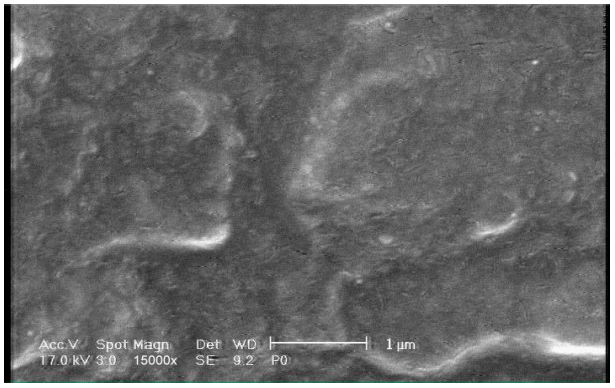
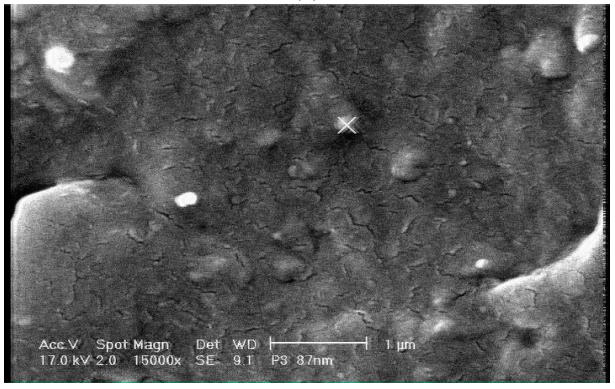
particles. Maximum and minimum notched impact strengths at HT related to P5HI and P0HI are 76.47 and 47.05 kJ/m², respectively, which shows an improvement of 62.5% as compared to P0HI. The effect of nanoclay at HT is higher as compared to RT.



(a)



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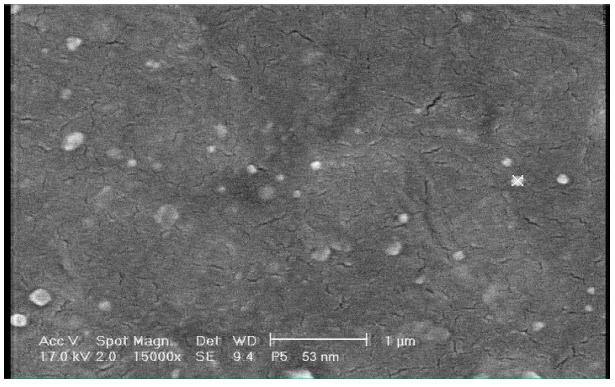

(c)

Figure 3- SEM micrographs of composite fracture surfaces for (a) neat PP, (b) PP with 3 wt.% nanoclay and (c) PP with 5 wt.% nanoclay.

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3-2-2- Tensile Test

Tensile properties such as ultimate tensile strength, yield strength, Young's modulus, displacement at break and energy absorption for PP and PP/nanoclay composites at RT and HT as a function of weight percentage of nanoclay are shown in Table 3.

Table 3- Tensile properties of PP and PP/nanoclay composites

Properties	Room temperature				High temperature			
	P0RT	**P1RT**	**P3RT**	**P5RT**	**P0HT**	**P1HT**	**P3HT**	**P5HT**
Displacement at break %	307.64	274.69	273.22	243.95	527.41	527.41	532.77	483.21
Yield strength (MPa)	24.4	23.16	23.76	24.12	11.04	10.21	10.27	10.61
Energy absorption (J)	156.68	151.89	131.99	118.23	297.66	291.62	257.41	234.07
Ultimate tensile strength (MPa)	19.76	18.06	16.68	15.53	17.77	16.53	16.94	17.69
Young's modulus (MPa)	523.42	588.17	612.33	714.22	134.05	150.6	258.92	345.84
Density (g/cm³)	0.91	0.915	0.92	0.925	0.91	0.915	0.92	0.925
Specific ultimate strength (MPa/g/(cm³))	21.71	19.73	18.13	16.78	19.52	18.06	18.41	19.12
Specific stiffness (MPa/g/(cm³))	575.18	642.8	665.57	772.12	147.3	164.59	281.43	373.88
Specific toughness	172.17	166	143.46	127.81	327.09	318.71	279.79	253.04
Energy absorption / P0RT energy absorption	_	0.96	0.84	0.75	1.89	1.86	1.64	1.49
Energy absorption / P0HT energy absorption	0.53	0.51	0.44	0.39	-	0.97	0.86	0.78
Specific ultimate tensile strength increases in comparison to P0RT (%)	_	-9.12	-16.5	-22.7	-10.08	-16.81	-15.21	-11.92
Specific ultimate tensile strength increases in comparison to P0HT (%)	11.21	1.07	-7.12	-14.03	-	-7.47	-5.68	-2.04
Specific stiffness increases in comparison to P0RT (%)	-	11.75	15.71	34.23	-74.39	-71.38	-51.07	-35
Specific stiffness increases in comparison to P0HT (%)	290.48	336.38	351.84	424.18	-	11.73	91.05	153.82

Specimen codes are P= polypropylene, 0, 1, 3 and 5= weight percentage of nanoclay, R and H= room and high temperature, T= Tensile test.

Young's modulus and yield strength at RT and HT are improved by increasing the amounts of nanoclay particles due to better dispersion of clay layers in PP matrix that restricts the mobility of polymer chains under loading. Although the Young's modulus is improved, nanoclay had no considerable influence on yield strength for nanocomposites. According to Chen et al. and Bahrami et al. [26,27], the improvement in strength was quite gentle at low clay content (below 10 wt.%). The increase in yield strength of P5RT and P5HT is 4% as compared to P1RT and P1HT, respectively. The effect of nanoclay at HT is more significant than RT for tensile strength. The value of ultimate tensile strength for neat PP at RT (P0RT) is 19.76 MPa and at HT (P0HT) is 17.77 MPa, which show a reduction of 10% at HT. However, by adding nanoclay particles of 5 wt.% (P5RT), ultimate tensile strength reduced as compared to P0RT by 28%, but P5HT shows a tensile strength of 17.69 MPa, which indicates a reduction approximately 0.5% as compared to P0HT. Therefore, the effect of nanoclay particles are higher at HT. Maximum and minimum Young's modulus related to P5RT, P5HT and P0RT, P0HT are 714.22, 345.84 and 523.42, 134.05 MPa, respectively. Young's modulus of P5RT and P5HT indicate the improvement of 36% and 157% as compared to P0RT and P0HT, respectively.

Figures 4 and 5 show the variation of Young's modulus and yield strength of the PP nanocomposites at RT and HT as a function of nanoclay content. The orientation of clay platelets and polymer chains with respect to the loading direction could be a reason to the reinforcement effect. Ultimate tensile strength, displacement at break and energy absorption at RT and displacement at break and energy absorption at HT are decreased when increasing clay content from 0 to 5 wt.%. These reductions are almost 21%, 20% and 24% for ultimate tensile strength,

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displacement at break and energy absorption at RT and also 17% and 21% for displacement at break and energy absorption at HT, respectively.

Ultimate tensile strength of PP nanocomposites at RT and HT as a function of nanoclay content is shown in Figure 6. The presence of clay layers in the PP matrix prevented PP chains from free motions, thus decreasing the toughness and increasing the brittleness and therefore the plastic deformation of polymer matrices is limited by an increase in clay contents. However, ultimate tensile strength at HT increased by increasing of the weight percentage of nanoclay, because the temperature effects caused the mobility of PP matrix and since there is a good interface between the nanoparticles and the matrix. Approximately 7% increase is observed in ultimate tensile strength at HT with addition of 5 wt.% clay content as compared to 1 wt.%. Displacement at break and energy absorption at HT are higher than those at RT, because PP/clay nanocomposites are exhibited relatively ductile behaviour at HT as compared to those at RT which shows higher toughness and hence causes later failure. The increase in the yield strength at both RT and HT and also ultimate tensile strength at HT for the neat PP may be attributed to the tight arrangement of PP molecules and no different contractive coefficients in the homogeneous phase.

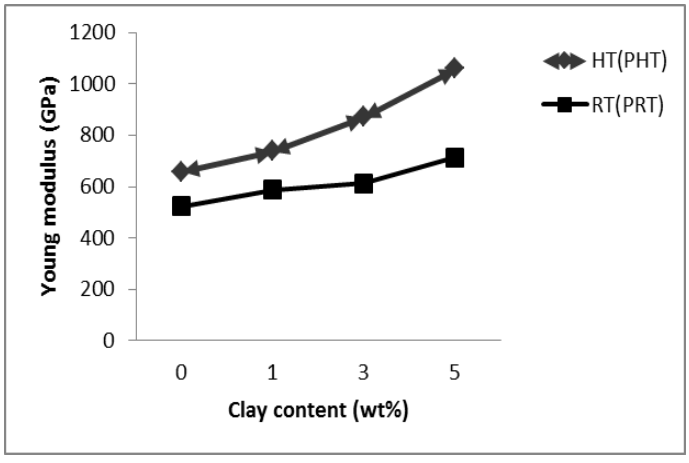

Figure 4- Young's modulus of the PP composites at RT and HT.

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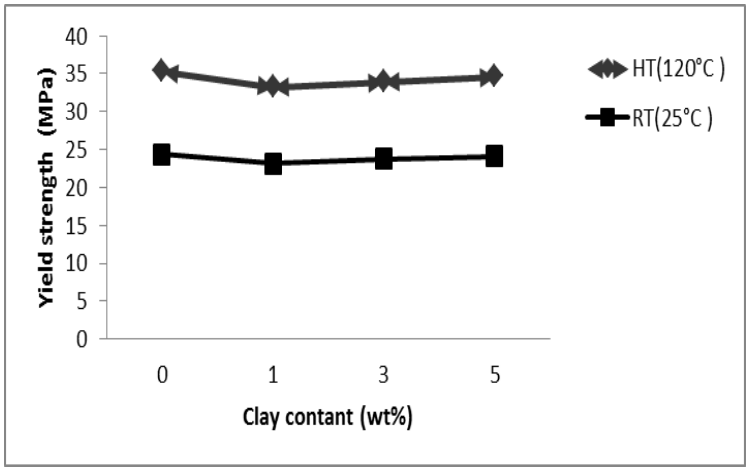

Figure 5- Yield strength of the PP composites at RT and HT.

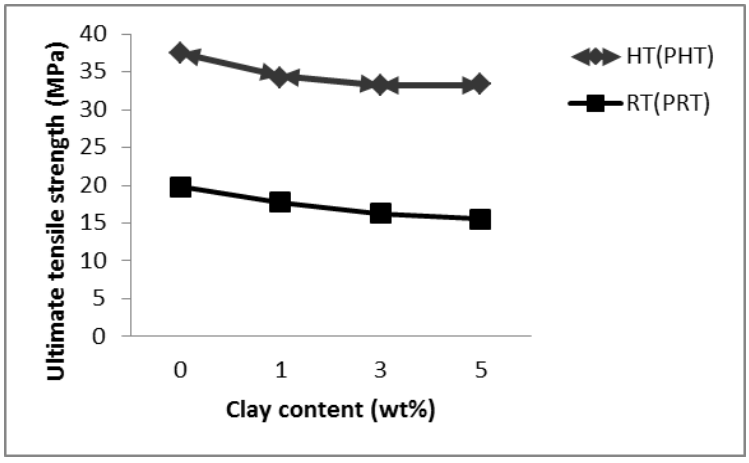

Figure 6- Ultimate tensile strength of the PP composites at RT and HT.

3-3- SEM

The phase morphology of the nanocomposites are observed using SEM. Figure 3a to 3c display some representative SEM images of the fracture surfaces of the notched impact specimens at RT. Figure 3(b) shows the SEM micrograph of PP/clay (3 wt.%) nanocomposite. This shows that the aggregates of nanoparticles are large as compared to PP/clay (5 wt.%) nanocomposite. With the addition of nanoclay, the aggregates are small and this confirms better dispersion of organoclay and

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PP matrix is achieved and it is shown in Figure 3 (c). Figure 3 (a) shows that the surfaces of the neat PP specimens are smooth and featureless, representing brittle failure of homogenous materials. As shown in the SEM images for the PP/clay nanocomposite specimens with the 3 and 5 wt.% nanoclay contents, the fracture surfaces obtained are significantly different from those of neat PP specimens. The fracture surfaces are broken into small and rough fracture pieces, contributing to improvement of the toughness of the nanocomposites.

At 3 wt.% of nanoclay particles added to PP matrix, the aggregates of particles are high and the size of the reinforcement particles are greater and distribution of the particles are uneven as can be seen in Figure 3b. Figure 3c shows the SEM photographs of 5 wt.% nanoclay PP composites, which shows an even distribution as well as smaller particles distribution in the matrix. This indicates higher properties in impact and more efficient in other mechanical properties.

4- Conclusions

The following conclusions are obtained.

1- Notched impact strength is increased at both RT and HT by increasing weight percentage of nanoclay because of reinforcement effect of nanoclay. Notched impact strength of P0HI and P5HI specimens is higher than P0RI and P5RI specimens for about 201% and 237%, respectively.

2- Young's modulus and yield strength at both RT and HT are improved by increasing amounts of nanoclay due to better dispersion of clay layers in PP matrix that contributes to restrict the mobility of polymer chains under increasing of clay contents. Young's modulus of P0RT and P5RT specimens is higher than P0HT and P5HT for about 290% and 106%, respectively. Yield

strength of P0RT and P5RT specimens is higher than P0HT and P5HT for about 121% and 127%, respectively.

3- Displacement at break and energy absorption at RT and HT and also ultimate tensile strength at RT are decreased due to limited plastic deformation of polymer matrices by increasing the nanoclay contents.

4- Displacement at break and energy absorption of PP and PP/nanoclay composites at HT are higher than those as compared the RT, because the PP specimens at HT have a great deal for ductile behaviour in which results in higher toughness and hence later failure.

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