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Organoclay as a potential eco-friendly substitute of chalk in the manufacturing of the PVC based electric cable

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ABSTRACT

The aim of this work was to study the effects of an organoclay on the properties of a polyvinyl chloride polymer and to compare the obtained results to polyvinyl chloride/chalk counterpart in order to replace the no eco-friendly and no-economic chalk by the cheap and eco-friendly organoclay in the electric cable polyvinyl chloride manufacturing. The obtained nanocomposites were prepared by dry blending followed by extrusion. The x-ray diffraction analysis evidenced an intercalation of the polyvinyl chloride chains between organoclay platelets. The thermal stability (Beilstein test) of the nanocomposite was greatly improved and thermgravimetric analysis (TGA) showed that the formulation containing 1 wt % of organoclay is the more thermally stable up to 240 °C. Differential scanning analysis showed that the glass transition temperature of the nanocomposite is higher than the neat polyvinyl chloride. A rheological analysis revealed that the addition of organoclay had not damaged the processability of the nanocomposite. Scanning electronic microscopy analysis revealed a uniform dispersion of the organoclay particles in the polyvinyl chloride matrix. The PVC based organoclay exhibits properties better than PVC based chalk used in the industry. So, the eco-friendly organoclay can be a good alternative to the expensive and irritating chalk.

KEYWORDS

Organoclay,
Polyvinyl chloride,
Nanocomposite,
Mechanical properties

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1 Introduction

Polyvinyl chloride (PVC) is the major polymeric material used in medical devices, electric cable sheaths and packaging applications. Indeed, PVC resin offers a very broad range of physicochemical properties for a wide variety of applications, especially in the medical, health care industry and electric cable fabrication. PVC resin fulfills an extensive range of performance and processing requirements such as, transparency, chemical resistance, flexibility, and sterilizability by water steam [1]. On the other hand, PVC resin can be blended to other polymer in order to obtain a blend with satisfying properties [2].

The main objective of adding organically modified clay or organoclay (OMMT) to a thermoplastic polymer or to a polymer blend is to improve mainly the mechanical properties, chemical characteristics and thermal stability [3-5]. Indeed, numerous studies claim the positive influence of organoclay on the tensile modulus or stiffness of the PVC resin [6-9]. The adding of organoclay was found able to increase the thermal stability and reduce the toxic smoke emission during the thermal degradation of the PVC matrix [10]. It has also been reported that organoclay enhances the resistance to UV radiation [11] and influences the fusion characteristics of the resulting nanomaterial [12].

Furthermore, the organoclay can exhibit different morphologies in the resulting nanocomposite such as intercalated and exfoliated structures [13]. Besides that, the organoclay greatly influences and improves the rheological behaviour of the nanocomposite [14]. The dielectric properties of the material can also be modified by organoclay [15, 16]. The organoclay can affect the antistatic coating and electromagnetic shielding properties of the resulting nanocomposite [17]. As well, the organoclay is able to affect the antibacterial and gas (oxygen) barrier or permeability properties of a polymer matrix [18]. It is worth noticing that the organoclays are able to improve the properties of recycled polymers [19, 20] and the optical properties of the polymer matrix [21]. The organoclay particles can be combined with other organic fillers, such as wood flour, in order to improve the properties of the polymeric matrix [22]. The nature of raw clays and the organic modifier used to render them organophilic impact greatly the properties of the resulting nanocomposite [23]. On the other hand, chalk ($CaCO_3$) is a mineral filler which, after modified, is added to polyvinyl chloride in order to improve its mechanical and thermal properties [24]. Chalk is commonly used as reinforcement filler in order to improve the mechanical properties of electric cable and pipe used for irrigation and sewerage systems [25].

The main objective of this work is to check the possibility to use the cheap and eco-friendly organoclay instead of the expansive and irritant chalk commonly used in the manufacturing of PVC-based sheath of electric cable. The organoclay concentration in the PVC compound was 1, 3, 5 and 7 wt %.

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2 Experimental

2.1 Materials

A commercial grade of PVC (SHINTECH SE 1200 ITOCHU S 70, Japan) was used as the blend major constituent. It was in powder form with a 100 µm mean dry particle size and had a linear configuration. The plasticizer used was DIDP (Di-Iso-Decyl-Phtalate) (45 wt %) and the thermal stabilizer was Ca/Zn (BAEROPAN MC 9917 KA, BAERLOCHER, Germany). The organically modified Montmorillonite type clay (OMMT) used was BENTONE 38® (BENTONE SUD, France), it was used as received (Cationic Exchange Capacity = 120 mEq/100g). As mentioned by the manufacturer, the quaternary ammonium salt used for the clay organic treatment was: di-methyl di-hydrogenated tallow salt: 2M2HT (HT = $C_{18}H_{37}$). The OMMT was in powder form with a 20 µm mean dry particle size. The used chalk (ARMINIUS GOEBEL GmbH, Germany) for industrial application (cable insulators fabrication) of PVC was a commercial grade with a 32 µm mean dry particle size and a not packed density equal to 800 kg/m^3.

2.2 Preparation of the samples

Before blending, the organoclay and PVC were dried in an oven at 80 °C for 24 hours. The components were first dry blended, at 70 °C, in a dry blender (VEM MSH 25, Germany) operating at 3000 rpm. Afterward, the resulting blend was extruded in a single screw extruder. The extruder used was a conventional one (PLASTICORDER PLE 330, Germany); it had a ratio of length/diameter equal to 21, a diameter of 20 mm, a thread thickness of 5.4 mm. The barrel and screw speed were set at 140 °C and 35 rpm.

For PVC/Organoclay formulation (Table 1) five PVC compounds were prepared. Each PVC compound had 4 kg total weight. The proportion of the organoclay in the compound was 1, 3, 5, and 7 wt. %. In each compound formulation, the weight of the thermal stabilizer (Ca/Zn) was kept constant (2 wt. %) and the weight of the plasticizer was also kept constant (45 wt. %). Regarding the PVC/Chalk blend used in the fabrication of cable sheath, the weight proportion of the chalk was 20 wt %, and the weight proportion of the PVC compound was 80 wt %.

Table 1. Weight composition of the PVC/Organoclay and PVC/Chalk formulations.

Sample code	PVC	Thermal stabilizer (Ca/Zn)	Plasticizer (DIDP)	Organoclay (OMMT)	Chalk ($CaCO_3$)
PVC	2120g	80g	1800g	0g	0g
PVC/OMMT (99/1)	2080g	80g	1800g	40g	0g
PVC/OMMT (97/3)	2000g	80g	1800g	120g	0g
PVC/OMMT (95/5)	1920g	80g	1800g	200g	0g
PVC/OMMT (93/7)	1840g	80g	1800g	280g	0g
PVC/Chalk (80/20)	1320g	80g	1800g	0g	800g

2.3 Characterizations

Tensile tests were done at ambient temperature (25 ± 2°C) according to ASTM D-638 norm with a ZWICK ROELL Z100 (Zwick-Roell, Germany) testing machine. The dumb-bell shaped specimens were extended at 100 mm/min cross head speed. The reported values of the tensile strength and strain at break were averages of five runs. The standard deviations were 2 % and 5 % for the tensile strength and the strain at break respectively. The dumb-bell shaped samples were cut from 2 mm thick sheets that were obtained by compression moulding 35 g of each sample at 165 °C in a SCHWABENTHAN POLYSTAT 300S (Schwabenthan, Germany) press. Shore A hardness tests were carried out by Zwick Roell HPE (Zwick-Roell, Germany) apparatus according to the ISO 868 standard. Reported results are averages of six measurements on each side of a 6 mm thick plate obtained by compression moulding. The standard deviations for the Shore A hardness tests were 3 %.

X-ray diffraction measurements (WAXD) were conducted on an Xpert Philips (Philips, Netherland) diffractometer operating at 40 KV and 40 mA in a continuous mode. The Incident ray had a wavelength of 1.54 A˚ generated by a CuKα anode. The 2θ range varied from 1.5 to 8.5 ° with a scanning rate of 0.02°/min. The composite specimens analyzed by X-ray diffraction were strips of 0.5-mm thickness obtained by compression molding at 140 °C.

The thermal stability of the nanocomposites and neat PVC were investigated by a dehydrochlorination apparatus at 200 °C according to the well-known Beilstein test. The dehydrochlorination apparatus consists of an electric resistance system in which test tubes, containing samples, are placed vertically and then heated. The thermal stability was evaluated by measuring the exact time for the occurrence of the sample degradation caused by the dehydrochlorination monitored by the released HCl, which results in the red coloration of the pH paper which was placed with the sample at the top of the tube test. The obtained results were averaged for three successive measurements.

The thermogravimetric analysis (TGA) was carried out with a TA SDT Q600 (TA instruments, England) apparatus under N2 atmosphere (20 ml/min) at the rate of 10°C/ min with a sample weight of 10 mg.

The rheological analysis was done with a Brabender (Brabender, Germany) R100/4308 model Rheometer, in order to obtain the plots of the applied torque versus time. For each formulation, samples of 4.5 g weight were analyzed at 140 °C.

Scanning electron microscopy (SEM) was done with a TESCAN VEGA3 (Tescan, Czech Republic) microscope. The observed samples were PVC/organoclay fractured surface obtained at the end of the tensile tests.

DSC measurements were carried out under nitrogen on a TA DSC 2920 (TA instruments, England) apparatus. For each formulation, samples of 10-mg weight were analyzed. The measurements were done under nitrogen at a heating rate of 10 °C/ min.

3 Results and Discussion

3.1 Mechanical properties

It can be observed from Table 2 that the 1 wt % loading organoclay blend possesses balanced mechanical properties, i.e., the stiffness (expressed by the tensile strength and hardness) as well as the ductility (expressed by the elongation at break) are maximal. The maximal values of tensile strength, hardness, and elongation at break obtained for 1 wt % organoclay loading can be explained by the better interfacial interactions between the organoclay particles and the matrix polymeric chains, i.e. the occurrence of the intercalation and/or exfoliation of the PVC chains between organoclay platelets. The improvements (up to 1 wt % organoclay loading) of tensile strength and hardness showed that organoclay acts as a reinforcing filler. The increase of elongation at break (up to 1 wt % organoclay loading) can be explained by the improvement of the ductility [4] due to the compatibilizing effect of the organoclay [5]. The improvements in the mechanical properties, up to 1 wt % organoclay loading, can also be explained by the two step processes used in the present study (dry blending followed by extrusion) since it has been reported that such a two-step process can improve notably the properties of composites [6]. Therefore, in the present study, the inclusion of 1 wt % organoclay rigid filler leads to a better balance between strength and ductility. It can be noticed from Table 2 that nanocomposites can exhibited strain values greater than PVC/chalk one, especially for 1 wt % organoclay loading. The same observation is true for hardness. Concerning tensile strength, PVC/chalk composite exhibited the same value than 7 wt % organoclay loading nanocomposite one. Nevertheless, on the whole, the nanocomposite containing 1 wt % organoclay loading showed mechanical properties clearly improved relatively to PVC/chalk composite ones.

Table 2. Mechanical properties values of neat PVC, PVC/ Organoclay nanocomposites and PVC/Chalk.

Sample code	Organoclay (OMMT) (wt %)	Tensile strength (MPa)	Shore A hardness	Elongation at break (%)
PVC	0	7.12	65.35	150.77
PVC/OMMT (99/1)	1	8.97	65.80	133.50
PVC/OMMT (97/3)	3	5.40	60.10	161.89
PVC/OMMT (95/5)	5	4.62	57.20	139.87
PVC/OMMT (93/7)	7	4.62	57.20	139.87
PVC/Chalk (80/20)	0	4.62	57.10	135.65

3.2 XRD Analysis

From Fig. 1 it can be noticed that for neat organoclay, the (001) plane diffraction peak is located at 2θ = 2.75°. This last value, according to Bragg's law, corresponds to 3.2 nm interlayer spacing. For 1 wt % organoclay loading, the organoclay (001) plane diffraction peak is shifted toward low angles at 2θ = 2° (2θ = 2° is indicated by a vertical line in Fig. 1). The value 2θ = 2° according to Bragg's law, corresponds to 4.4 nm interlayer spacing. The shift toward lower angles of the (001) organoclay peak can be explained by an increase of the interlayer distance of the organoclay platelets due to intercalation of PVC chains inside organoclay galleries. The polarity of PVC macromolecular chains blended with polar organoclay platelets explains this intercalation. The shift toward 2θ = 2° of the (001) organoclay peak can be explained by an important increase of the interlayer distance of the organoclay platelets due to more intercalation of PVC chains. This observation can explain the important improvement of the mechanical properties of the 1 wt % organoclay containing formulation. Similar results, i.e., improvement of the mechanical properties of the 1 wt % organoclay containing formulation were reported in the scientific literature [7]. The occurrence of intercalation instead of exfoliation, can be explained in this study by the lack or no use of a compatibilizer such as PP-g-MAH, PE-g-MAH and maleic anhydride (MAH) [5]. For the formulation containing 3 wt % organoclay, it can be seen that the organoclay (001) plane diffraction peak is also shifted toward low angles at 2θ

= 2.5° (2θ = 2.5° is indicated by a vertical line in Fig. 1). This last value, according to Bragg's law, corresponds to 3.53 nm interlayer spacing. For formulations containing 5 and 7 wt % of organoclay, we can observe that the (001) organoclay diffraction peak remains unchanged at 2θ = 2.75°. This observation can explain the lack of improvement of the mechanical properties for these formulations relatively to other cases.

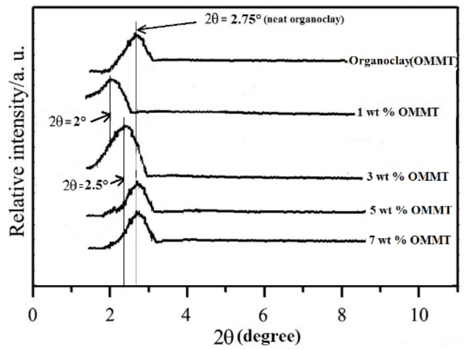

Fig.1. XRD patterns of neat organoclay (OMMT) and PVC/OMMT nanocomposites.

3.3 Thermal analysis (Beilstein test)

A method that seems to be important to characterize thermal stability is the dehydrochlorination test (Beilstein method). The dehydrochlorination time is measured by the dehydrochlorination duration of the tested samples. The obtained results for dehydrochlorination test are summarized in Table 3. One can see that for the formulation containing 1 wt % of organoclay, the time of degradation is maximal and equal to 73.55 minutes. The time of degradation increases as a function of the organoclay loading up to 73.55 min, corresponding to 1 wt % organoclay concentration, and then it decreases for 3, 5 and 7 wt %. The PVC/Chalk blend exhibits a dehydrochlorination time lower relatively to the PVC /OMMT (99/1) one. Table 2 shows clearly that the 1 wt % organoclay based blend is the more thermally stable since it presents the maximal dehydrochlorination duration; this is due to the high degradation resistance of the intercalated-confined PVC chains and also to the reduction of the diffusion rates of volatiles out of the material [22]. Therefore, the maximal dehydrochlorination duration for 1 wt % organoclay loading can be explained by the intercalation and partial exfoliation mixed nanostructure as revealed by previous XRD analysis.

Table 3. Dehydrochlorination duration values of neat PVC and PVC/Organoclay nanocomposites.

Sample code	Organoclay (OMMT) (wt %)	dehydrochlorination duration (min)
PVC	0	45.00
PVC/OMMT (99/1)	1	73.55
PVC/OMMT (99/3)	3	25.00
PVC/OMMT (99/5)	5	19.00
PVC/OMMT (99/7)	7	16.48
PVC/Chalk (80/20)	0	68.00

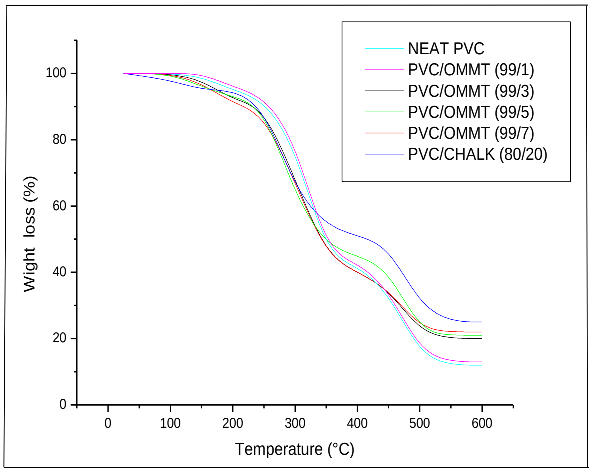

Fig.2. Thermograms of PVC, PVC nanocomposites and PVC/chalk blend.

3.4 Thermogravimetric analysis

Fig. 2 shows that the PVC/chalk, the PVC and its nanocomposites exhibit three steps of decomposition. The first weight loss may be attributed to the vaporization of residual water retained in the nanocomposites [23, 24]. The second step of decomposition may be assigned to PVC degradation and its additives. PVC degradation consists of sequential loss of hydrogen chloride accompanied by the generation of polyene sequences [23, 24]. In the third stage, the polyene sequences formed in the second stage give place to scission. At higher temperatures (600 °C), the residue of the PVC/OMMT nanocomposites and PVC/Chalk are higher than for the unfilled PVC. Furthermore, Fig. 2 shows that up to 350 °C, the PVC/OMMT (99/1) formulation exhibits the less weight loss and therefore it is more stable than the other nanocomposites and then PVC/Chalk blend. This last result is in accordance with the results obtained in the Beilstein tests. For higher temperatures (beyond 340 °C), Fig. 2 shows that the PVC/chalk is the more thermally stable, relatively to the other formulations, since it presents the less weight loss.

3.5 Rheological analysis

The Brabender torque –time curves can be used to analyse the processing characteristics and hence the processability of the resulting composite [3]. The equilibrium torque (stabilization torque) reached at the end of the melt mixing was used to assess the processability of the blend [3, 5]. Furthermore, the maximal torque (MH) can be considered as a measure of the blend stiffness or Young's modulus [3, 5], and the minimal torque (ML) is related to the melt viscosity of the blend [3, 5]. Fig. 2 shows the plastograms of pure PVC and PVC/Organoclay nanocomposites and their related results are summarized in Table 4. It can be deduced from Fig. 3 and Table 4 that, up to 1 wt % organoclay loading, the incorporation of organoclay increased the MH and MH-ML difference, whereas the ML remains constant on the whole (approximately 5 dN.m). So, the inclusion of organoclay particles in the PVC matrix increases the stiffness of the resulting composite as noticed in the previous mechanical characterisation. Also, the inclusion of 20 % wt of chalk in the PVC matrix increased notably the stiffness of the resulting blend. Furthermore, it can be noticed that, up to 1 wt % organoclay loading, the incorporation of organoclay increased the torque in the steady state (BT). Furthermore, the melt viscosity, expressed by ML and BT [3, 5], of organoclay-based formulations did not significantly increase relatively to the pure PVC formulation. Therefore, it can be concluded that the processability of the PVC/OMMT blend is not notably damaged by the addition of the organoclay. On the other hand, it can be noticed that the minimal torque (ML) and balanced torque (BT) of PVC/Organoclay nanocomposites are lower than the PVC/Chalk (80/20) formulation (Tab 4). Therefore, the processability of PVC/Organoclay nanocomposites is better than the PVC/Chalk (80/20) formulation. On the other hand, the maximal torque (MH) of the PVC /OMMT (99/1) nanocomposite is close to the PVC/Chalk (80/20) one (Tab 4). So, the stiffness of PVC /OMMT (99/1) nanocomposite is close to the PVC/Chalk (80/20) one.

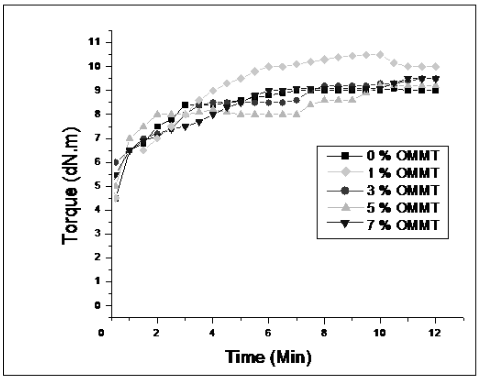

Fig.3. Torque versus time of neat PVC (0 % OMMT) and its nanocomposites.

The MH-ML value is a measure of the dynamic shear modulus, which is directly related to the filler crosslink network density in the nanocomposite matrix [26, 27]. The filler crosslink resembles a three-dimensional network in the composite [28]. Since the MH-ML values of the nanocomposites are constant (approximately 5 dN.m), thus, it can be assumed that a three-dimensional network is probably formed or has a tendency to be formed by organoclay platelets embedded in the PVC matrix. The formation of a reinforcing filler network is commonly reported in the filler reinforcement of matrix polymer [29, 30]. The formation of this filler network can explain the important improvement of the mechanical properties especially at 1 wt % organoclay loading. Furthermore, as the torque, expressed in N.m or Joule, represents the energy consumed during the fabrication of the composite (by melt mixing of the components blend), and as the steady state torque values of PVC/OMMT (99/1) is lesser than PVC/chalk (80/20) one (10.0 < 13.0), so the fabrication of the PVC/OMMT (99/1) composite did not consume an excess of energy relatively to the case of the fabrication of PVC/Chalk blend used in the industry.

Table 4. Torque maximum (MH), torque minimum (ML), torque difference (MH-ML) and balanced torque (BT) for neat PVC, PVC/Organoclay nanocomposites and PVC/Chalk.

Organoclay content (%)	MH (dN.m)	ML (dN.m)	MH-ML (dN.m)	BT (dN.m)
PVC	9.6	5.5	4.1	9.6
PVC/OMMT (99/1)	10.5	4.5	6.0	10.0
PVC/OMMT (97/3)	9.5	5.5	4.0	9.1
PVC/OMMT (95/5)	9.0	5.0	4.0	9.1
PVC/OMMT (93/7)	9.0	4.5	4.5	9.0
PVC/Chalk (80/20)	17.0	8.0	9.0	13.0

3.6 Morphological characterization (SEM analysis)

For PVC/OMMT (99/1) formulation, it can be seen from Fig. 4a that the organoclay particles are homogeneously dispersed, and these particles are not debonded from the PVC matrix. This fact can explain the improvement of the interfacial adhesion between the OMMT particles and the PVC matrix expressed by the good mechanical properties exhibited by the corresponding composite. Fig. 4b is related to PVC/OMMT (93/7) formulation, and it can be seen that the organoclay particles are more numerous, more debonded from the matrix and not homogeneously dispersed in the PVC matrix and these particles have a tendency to create voluminous agglomerates which explain the poor mechanical properties exhibited by this formulation. Indeed, it was reported that organoclay agglomerates constitute stress concentration points that can lead to material breaking under mechanical loading [31]. Furthermore, it can be seen from Fig. 5a and 5b, that as the organoclay concentration increases, its dispersion state becomes no uniform and the organoclay particles are more debonded from PVC matrix and constitute voluminous agglomerates due to the weak interfacial interactions between these particles and the PVC macromolecular chains leading thereby to poor mechanical properties, especially strain at break; since, it was reported that the strain at break is directly related to the adhesion or the compatibility between two immiscible phases in a binary macromolecular composite [31].

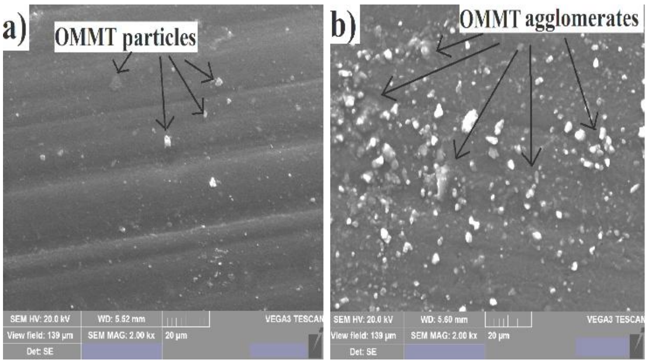

Fig.4. SEM micrographs showing (a) the PVC/OMMT (99/1) and (b) the PVC/OMMT (93/7) of fractured samples obtained at the end of the tensile tests.

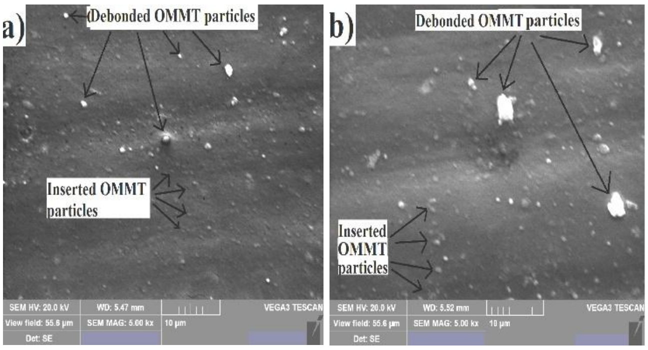

Fig.5. SEM micrographs showing (a) the PVC/OMMT (99/1) and (b) the PVC/OMMT (93/7) of fractured samples obtained at the end of the tensile tests.

3.7 DSC analysis

The DSC thermograms are represented in Fig. 6, and their related results are summarized in Table 5. Figure 5 shows the peak related to the glass transition temperature of the PVC phase. Only the glass transition peak (Tg) was detected under the used experimental conditions. It can be noticed from Fig. 6 that for formulations containing 0, 3, 5 and 7 wt %, of organoclay, the glass transition temperature of the PVC phase remains constant and is estimated to be equal to 76 °C. When the concentration of the added organoclay is 1 wt %, the glass transition temperature of the PVC phase increases and becomes equal to 78°C. An increase of the glass transition temperature of the matrix PVC was observed for PVC/Organoclay nanocomposites [32], and this increase was explained by the confined environment which restricts the mobility of the intercalated PVC polymer chains within the organoclay galleries.

It was reported [33] that for PVC/Organoclay, when the exfoliated structure dominates relatively to intercalated one, the interlayer of organoclay may take the role of a plasticizer, increasing the distance between PVC chains resulting in a decrease of the interaction forces between PVC macromolecules and lead to the lower glass transition temperature of PVC/OMMT nanocomposites. Since, in this study, it was found by DSC analysis that the glass transition temperature of 1 wt % loading nanocomposite was higher than neat PVC one, so, the intercalated structure is the main morphology obtained in this study as evidenced by the previous XRD analysis.

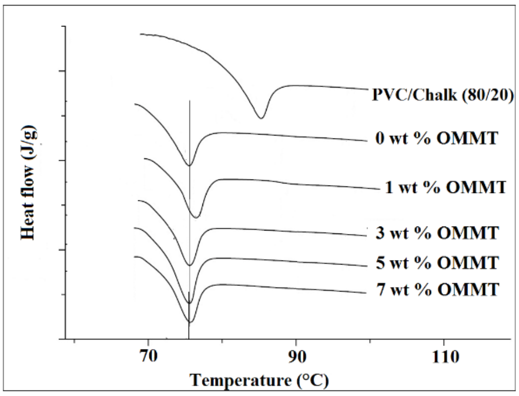

Fig.6. DSC thermograms of PVC nanocomposites and PVC/chalk (80/20) blend.

Table 5. Glass transition temperature (Tg) of PVC phase in PVC/Organoclay nanocomposites.

Sample code	Organoclay content (%)	T_g (°C)
PVC	0	76
PVC/OMMT (99/1)	1	78
PVC/OMMT (99/3)	3	76
PVC/OMMT (99/5)	5	76
PVC/OMMT (99/7)	7	76
PVC/Chalk (80/20)	0	87

4 Conclusion

In this study it was observed that the improvements in the mechanical properties of the prepared blend were realised for 1 wt % organoclay loading. The stiffness (expressed by the tensile strength and hardness) and ductility or toughness (expressed by the elongation at break) are well balanced for 1 wt % organoclay concentration, and the reinforcement effects of the organoclay are highest for the same concentration. The XRD analysis showed that for 1 wt % organoclay loading there was a shift toward low angles of the organoclay (001) plane diffraction peak indicating an intercalation of the PVC chains between organoclay platelets. The thermal stability measured by Beilstein test is maximal when the concentration of the organoclay was equal to 1 wt %. On the other hand, it was found by TGA that the PVC/organoclay (99/1) composite is, up to 225 °C, the most thermally stable relatively to other formulations and the PVC/Chalk blend. The rheological study revealed that the viscosity of the studied formulations does not increase with the addition of organoclay and the addition of organoclay to the PVC matrix did not damage the processability of the resulting composite relatively to the PVC/Chalk blend. The SEM microscopy examinations showed the uniform dispersion of organoclay particles inside the PVC matrix for 1 wt % organoclay loading nanocomposite. The DSC analysis revealed the increase of the glass transition temperature value for 1 wt % organoclay loading nanocomposite, relatively to neat PVC, suggesting a dominant intercalated structure for this organoclay concentration. The improvement of the properties of 1 wt % organoclay loading nanocomposite relatively to PVC/ Chalk industrial formulation suggests strongly that the organoclay can constitute a good alternative as a cheap, eco-friendly; non-irritant and renewable green filler for substituting the chalk in the fabrication of PVC based cable insulators destined for relatively low temperatures applications (less than 250 °C).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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