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Poly(vinyl chloride) Nanocomposites

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Poly(vinyl chloride) is one of the major thermoplastics beside other commodities polymers like polyethylene and polystyrene. However, some of its main characteristics such as plasticity, thermal and photo stability are inferior to other commodity polymers. Adding nano scale inorganic fillers to poly(vinyl chloride) or other polymers in view to obtain polymer nanocomposites with superior properties has drawn the attention of many researchers in the last decades. Poly(vinyl chloride) nanocomposites are obtained mainly by *in situ polymerization*, solution based or mixing techniques. The resulting products show improvement of most important properties of poly(vinyl chloride) such as thermal, mechanical, rheological, flammability, antibacterial, etc. This paper presents preparation ways of poly(vinyl chloride) nanocomposites using different nano fillers and the improved properties compared with those of virgin poly(vinyl chloride).

Keywords: PVC nanocomposites, nano fillers, preparation, properties

1 Introduction

Poly(vinyl chloride) (PVC) is one of the major thermoplastics with low production cost, as well as good insulation performance, chemical and fire resistance; it is widely used in different fields. It ranks second among the most used thermoplastics and is considered the most versatile macromolecular compound. Its versatility arises from its suitability to a variety of transformations. Its main drawback is the low thermal stability that leads to discoloration due to the formation of conjugated polyene sequences.

The addition of mineral nano fillers to organic macromolecular compounds including PVC, has resulted in polymer nanocomposites characterized by light weight and low cost due to low amount of filler necessary and improved properties (1–5).

Generally the following nano fillers are often used:

- montmorillonite (MMT) both in its natural form as sodium montmorillonite (Na^+MMT) and as organo modified named also organofilic (oMMT)
- other mineral clays like laponite, bentonite, hectorite, kaolinite, halloysite (6–8)
- calcium carbonate, $CaCO_3$
- silica, talc
- layered double hydroxides (LDHs)
- carbon nanotubes (CNT)
- mica, vermiculite (mineral similar to mica)
- combination of different fillers (9–11)

A low amount of nano filler dispersed in the polymer matrix can lead to a very high surface of interaction. So, depending on it, we are able to obtain different nano structures of polymer-nano filler composites:

- Intercalated nanocomposites which are obtained by the insertion of polymer macromolecules between the filler layers.
- Exfoliated nanocomposites; in this case the individual layers of the filler are totally delaminated and dispersed in a continuous polymer matrix.
- Intermediate polymer nanocomposites. These are partially intercalated and partially exfoliated.

To produce polymer nanocomposites intercalated or exfoliated, many techniques are available, such as: *in situ polymerization*, solution dispersion and melt mixing.

The kind and the amount of nano filler and the preparation technique affect the main properties of polymer nanocomposites through the delamination and exfoliation levels.

2 Preparation of PVC Nanocomposites

2.1 *In Situ* Polymerization

In the presence of layered double hydroxide intercalated with sulfate anions (LDH-DS), the vinyl chloride (VC) suspension polymerization was conducted. The study

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based on transmission electron microscopy (TEM) showed that these nano filler particles were partially intercalated and partially exfoliated and well distributed in PVC (12). Hydrotalcite (HT) nano particles were also used by the same authors in the suspension polymerization of VC. The surface of this nano filler was modified with alkyl phosphate (AP). The properties of the obtained PVC nanocomposites were investigated (13).

Other researchers have used in the VC suspension polymerization oMMT (14.) or nano $CaCO_3$ (15).

VC was also used in copolymerization processes in view to obtain copolymer nanocomposites. Poly(VC-co-vinyl acetate VAc-co-maleic anhydride MA) nanocomposites were prepared by suspension radical copolymerization in the presence of fumed silica premodified with y-methylacryloxypropyl trimethoxy silane. The study proved that the main copolymer properties were significantly enhanced (16).

To obtain via *in situ polymerization* PVC/oMMT nanocomposites with average particle size of 150 μm 0.2–7.5 mass fraction (%) oMMT was used (17).

2.2 Solution Technique

Organic solvents such as tetrahydrofuran (THF), dimethylformamide (DMF), dioctylphthalate (DOP) and other are often used to prepare PVC nanocomposites.

In a typical synthesis chlorotrimethylsilane (TMCS), functionalized SiO_2 nanoparticles and PVC were ultrasonically dispersed in THF followed by the addition of mercaptopropyl trimetoxy silane and stirred magnetically. The coating obtained after the evaporation of THF shows stability in a wide pH range and can be applied to different metal surfaces to prevent corrosion (18). In the same solvent, by using titanosilicate nano filler, a transparent film of PVC nanocomposite was obtained (19). In another research, casting films based on PVC/multi-wall carbon nano tube (MWCNT), using the nano filler in different concentrations (0.05, 0.005 and 0.0005 wt%) were produced (20).

Cadmium doped zinc oxide ($Cd_{0.5}Zn_{0.5}O$) nano powder with uniform particle size of around 10 nm dispersed in methanol was mixed with PVC solution in THF. The nanocomposites PVC/$Cd_{0.5}Zn_{0.5}O$) films are highly transparent and show high UV shielding efficiency (21).

A PVC in THF solution was added to MgAl layered double hydroxide lauryl ether phosphate (LDH-PK) suspension. The mixture was poured in ethanol for rapid precipitation in order to avoid aggregation of LDH platelets. It is considered a novel exfoliation re-staking technique using the LDH-PK (22).

PVC- DOP (a plastisol technique at 150°C), with MWCNT (20–80 nm in diameter), heat expanded graphite and diamond nano powder in amounts of 0.01 up to 0.08 wt% PVC were used in another study. It was found that such small amounts of nano fillers are able to increase the strength and elasticity of PVC (23).

The influence of adding nano clay (Na^+MMT and oMMT) on the plastisol micro suspension PVC/diisononyl phthalate was the object of another study (24). Polyaniline modified TiO_2 (PANI-TiO_2) nano particles (1-5 wt%) were used for obtaining PVC nanocomposites via solution blending. Due to filler particles good dispersion they are able to improve the interfacial adhesion between the nanocomposite components (25).

Plastisol technique was applied also in a research where epoxidized Ceylon iron wood (*Mesua ferrera L.*) seed oil was used as a plasticizer for PVC. Nanocomposites were obtained through *ex-situ* technique using epoxidized oil-swelled oMMT (5 wt%) and PVC. Important improvement in thermal and processing characteristics of the nanocomposites was established over those of virgin PVC as studied by thermogravimetric analysis (TGA). Isothermal tests at different temperatures reveal sufficient stability of the new nanocomposites as confirmed by TGA and Fourier transform infra red analysis (FTIR) (26).

Nanocomposites made of PVC plastisol and carbamide organo clays show high physical mechanical properties, as well as reduced toxic smoke emission while burning (27).

In a study graphene oxide (Go) was dissolved in dimethyl formamide (DMF) and PVC was added to the obtained solution. The nanocomposite (with 5 wt% Go) was coagulated and abundantly washed with methanol and dried. It presented improved thermal and mechanical properties compared to PVC (11).

A PVC suspension in DOP was mixed with 5–10 wt% Na^+cloisite and two other organo modified cloisite. The modifiers contribute to lower the surface energy of the silicate layers and enhanced the miscibility between PVC and the filler (28).

2.3 Mixing Technique

Haake torque rheometer, mono screw extruder, twin screw extruder, microcompounder and other equipments are used for the preparation of PVC nanocomposites with different nano fillers by mixing technique.

The effect of SiO_2 particle size on the fusion and rheological behavior of PVC composites prepared in a Haak torque rheometer were investigated. Scanning electron microscopy (SEM) micrographs showed that some aggregates were formed when the filler particles were 25 nm. But the thermal degradation onset temperature was shifted to lower temperature with decreasing the SiO_2 particle size (29).

By using the melt mixing process, nano SiO_2 into the plasticized PVC is able to increase mechanical properties. Nanoparticles (SiO_2, TiO_2) filled anti-static PVC was prepared by mixing with di-butyl phthalate and an

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antistatic plasticizer containing bis(2(-methoxyethoxy)-ethyl) phthalate doped with sodium perchlorate. The obtained PVC nanocomposites showed good thermal stability and processibility and a decrease of the surface resistivity (30). SiO_2 having particles of different dimensions was used for PVC micro and nanocomposites prepared in a Haake torque rheometer. It was found that the fusion time and fusion temperature of the composites decreased with the decreasing of SiO_2 particle size (31).

PVC nanocomposites with $CaCO_3$ nano filler were obtained by *in situ* coupling with titanate using a twin-screw extruder (32).

A conducting mixture of graphite nano sheets and Ni particles in 80/20 wt% ratio was added to PVC powder and mixed for 30 min to obtain a dry blend. The linear behavior of the electrical resistivity of pressed nanocomposite as a function of the applied pressure demonstrates the potential of PVC/graphite-Ni composites as pressure sensitive products (33).

PVC, additives and various amounts of oMMT were first dry mixed and then melt blended in a Haake rheometer. The study found that the oMMT layers were basically exfoliated or exhibited intercalation morphology depending on the organic modifier. Compared to that of pristine PVC, the stiffness and impact strength of the nanocomposites were improved when the amount of oMMT was in the range of 0.5–3 wt%. Even the introduction of a small amount of oMMT led to an improvement of thermal stability and a slight increase of glass transition temperature (Tg) (34). PVC nanocomposites with Na^+MMT and oMMT have also been prepared by melt processing using mixing of the components and extrusion. The differential scanning calorimetry (DSC) with stochastic temperature modulation results shows that Tg of PVC is higher than the Tg of PVC/Na^+MMT and PVC/oMMT. Such data indicate that MMT plays the role of an internal plasticizer able to increase the distance between PVC macromolecules (35). Na^+MMT intercalated with different alkyl-amines was melt mixed in a KO-Kneader with PVC in view to determine the applicability of these modifiers with different chain length on the properties of PVC nanocomposites (36).

oMMT obtained after treatment with different chelating agents such as poly(ethylene glycol), propylene glycol, monooctadecanoate and palm oil was added to PVC during mixing in a microcompounder. The master batch concept turned out to be promising in terms of dispersion and delamination of clay (37). PVC nanocomposites with 5 wt% MMT were prepared on a two-roll mill or in a microcompounder. MMT was treated with non-ionic surfactants. The research has used for analyzing the nanocomposites, SEM, TEM and equipment for some mechanical tests. The dispersion of the nano filler was found to be the best in the roll milled composites prepared via the masterbatch; some mechanical properties like elongation at break and impact strength were also better, but Young's modulus and tensile strength were much better for the microcompounded nanocomposites (38, 39).

Ammonium cations have a great influence on the hybrid prepared by melting, while they have no obvious effect on the nanostructures of the composites produced via *in situ polymerization* due to its distinctive mechanism (40).

Applying DSC to a PVC/bentonite nanocomposite prepared by mixing the components showed the existence of a single higher Tg in comparison with that of pristine PVC. The dispersion and interfacial compatibility of PVC-bentonite was characterized by SEM (4l).

Some oxide nano fillers such as Al_2O_3, TiO_2, CuO and $CaCO_3$ are also used in some nanocomposites studies. Nano Al_2O_3 modified with a silane coupling agent was melt blended with PVC. The SEM data demonstrated that the nano filler was dispersed uniformly in the PVC matrix. Some essential mechanical properties were improved (42). TiO_2 nano rods and nano powder were melt blended with PVC powder to produce PVC nanocomposites. The interfacial adhesion between TiO_2 nano rods and PVC matrix was investigated. The nano rods presence improved the photo stability and mechanical properties of PVC (43).

Nano $CaCO_3$ was modified with poly (acrylic acid) (PAA) and the terpolymer poly (butadiene-co-acrylonitrile -co-acrylic acid) (PBAA).In a first step stabilizer/lubricant was added to PVC powder. This compound was mixed to prepare the dry blend. In a second step the dry blend was processed in an internal mixture. The influence of $CaCO_3$ nano filler and of the surface modifiers on the thermal and mechanical properties were studied (44).

To produce nanocomposite according to a patent, PVC powder is mixed with an impact modifier, a stabilizer and a nano filler selected from CNT, CuO and Al_2O_3 (45).

3 Properties

The addition of nano fillers to PVC is able to improve many of these polymer properties like thermal, mechanical, electrical, rheological, antibacterial, flammability, barrier, photo stability, etc.

3.1 Thermal Properties

PVC nanocomposites have been prepared using both hectorite and bentonite based organically modified clays. The modification was done with tallow-triethanol ammonium ion. TGA, DSC and DMA were used for this research. Thermal stability of the PVC nanocomposite was assessed using a standard thermal process evaluating the evolution of HCl and by color development through the yellowness index (46). Organophilic MMT contributes to the shifting of thermal degradation towards higher temperatures

compared to chemically untreated clay (47).The heat distortion temperature (HDT) and the Vicat softening temperature (VST) of PVC/halloysite nanotubes (HNT) increase with increasing HNTs content. The PVC/HNTs nanocomposites are also characterized by a reduction in smoke production rate, the total smoke production and the peak heat release rate (PHRR) (7).

The loading of PVC by single-walled carbon nanotubes (SWCNTs) increases the Tg demonstrating the interaction between macromolecular chains and nano filler (48). PVC nanocomposites with different tacticity with alkyl-modified multiwalled nanotubes (eMWNTs) were studied. The authors found that the improvements in the thermal stability of nanocomposites of more isotactic PVC samples arises from the formation of halogen bonding between carboxylic groups in eMWNTs with chlorine atoms at isotactic conformations that inhibits the initiation stage of the degradation (49).

Effects of Ag nano particles on thermal properties of dodecylbenzenesulfonic acid -doped polyaniline (PAND)/PVC blends have been investigated by TGA and heat flow micro calorimetry methods. It has been established that the thermal stability increased in such nanocomposites by increasing the amount of PAND (50).

Many other studies found the increase of PVC thermal stability by adding different nano fillers (14, 38, 51–56). PVC nanocomposites were prepared also by melt blending of the polymer with an organically modified clay, both in the presence and absence of DOP. Thermal properties were evaluated by using TGA and the thermal stability was determined to be variable depending upon the amount of DOP and nanofiller. The fraction of PVC nanocomposites that remained at 600°C was significantly reduced, indicating that the filler had an effect on the course of the polymer degradation process (57).

3.2 Mechanical Properties

PVC is mostly amorphous due to its atactic configuration. Its hard form can withstand a tensile stress in the order of 46–52 MPa before yielding, while the soft form can elongate up to 60% before breaking. These and other characteristics make this polymer a very suitable matrix for producing nanocomposites with improved mechanical properties.

Such properties and morphology of PVC/polyhedral oligomeric silsesquioxanes containing octyl groups (o-POSS) nanocomposites were studied. Their impact strength can increase 8 kJ/m^2 when o-POSS amount is 1.5 wt%. This nano filler at low amount can be used as an impact additive for PVC (58). It was found that the addition of nano silica in a certain quantity to the plasticized PVC by melt mixing technique results in the increase in the Young's modulus and tear strength, and the decrease in the tensile strength and elongation at break (59).

The notched impact, tensile, flexural strength and flexural modulus of PVC/halloysite nanotubes (HNTs) nanocomposites were remarkably increased compared with those of PVC (60). The tensile mechanical properties of PVC/Al_2O_3 were studied, mainly the stress-strain curves at different temperatures. The Young's modulus was calculated and found to decrease with increasing both filler loading and temperature. The complex viscosity as well as the storage modulus were found to decrease with increasing the nano filler loadings at different frequencies. The relaxation time was found to be independent on the concentration of the nano filler loadings at different frequencies (61). PVC/MMT nanocomposites with varying clay contents have been studied for their morphology and tensile properties. Young's modulus and stress at yield point initially increase with the amount of clay but later start decreasing with further clay loading. The maximum increase of these mechanical characteristics has been observed in PVC nanocomposites with 2.5% clay content (62). The influence of *Eurycoma longifolia* (EL)/MMT hybrid fillers loading on the mechanical properties of PVC has been investigated. The incorporation of EL fibre only into PVC improved its flexural modulus and tensile strength of PVC, whereas the tensile strength and impact strength decreased with increasing EL content. The addition of MMT significantly increased the flexural modulus and tensile modulus of PVC hybrid composite compared with PVC, but has decreased the flexural and impact strength (63).

TiO_2 nano rods and nano powder proved to improve the mechanical properties of PVC (64, 65).

3.3 Other Properties

Some composites generally have a wide absorption bandwidth and low reflection loss. In a research La $(NO_3)_3$ – doped MWCNTs was used as absorber and PVC as matrix. The nano component broadened the absorption bandwidth and decreased the reflexion loss of the nanocomposites. Due to the insertion of diamagnetic La^{3+} the microwave absorption was enhanced (66, 67).

Rheological data of PVC/oMMT like torque, fusion time, viscosity and shear rate were recorded on Brabender plasticorder. The improvement in properties with an increased amount of oMMT loading was evidenced from reduction in shear viscosity and torque. Due to the soft nature of oMMT and improvement in d-spacing the processing of PVC becomes easier (68). The fusion and rheological behaviors of PVC/SiO_2 composites were evaluated by means of torque data to investigate the influence of the SiO_2 particle size on these characteristics. It was found that the fusion time and temperature decreased with the reduction of clay particle size, whereas the fusion torque increased with reduced particle size. The PVC/SiO_2 25 nm nanocomposites showed the highest apparent viscosity (29).

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In the case of PVC/SWCNTs nanocomposites the rheological loss factor indicates two relaxation peaks at frequencies of 0.11 and 12.8 Hz due to the interaction SWCNT–PVC (69).

The PVC/graphite nanoplates (nano-Gs) nanocomposites exhibit low volume resistivity of 104 Ω.cm when the mass fraction of nano-Gs goes beyond 10 wt% and the percolation threshold of the nanocomposite is as low as 6 wt% (70). Electrical conductivity anomalies were also studied in case of PVC nanocomposites (71).

Films of PVC/Cu nanocomposites obtained by casting technique exhibit bacterial adhesion (72). It was also confirmed that the TiO2@Ag nanostructure could increase the antibacterial efficiency of a PVC film (73). Some PVC nanocomposites could be used as antimicrobial food packaging materials (74).

Cone calorimetry technique have been used in the case of PVC nanocomposites obtained with organofilic bentonite and hectorite in view to evaluate the smoke evolution. The addition of the modified clays led to both a reduction of the total smoke and an increase in the length of time over which smoke evolved. A reduction of PHRR was obtained. It is likely that the presence of the clay, in some way, interferes with the cyclization of the conjugated system produced upon HCl release (46).

4 Polyblends Nanocomposites Based on PVC

The adding to PVC beside the nano filler another thermoplastic polymer, an elastomer, or even wood flour can contribute significantly to the improvement of PVC properties. In some cases, a second polymer may cover the surface of the nano filler particles enhancing the interaction PVC-nano filler.

The effect of chlorinated polyethylene (CPE) content and test temperature on the notched Izod impact strength and brittle-ductile transition behaviors of PVC/CPE/nano $CaCO_3$ composite was studied. The CPE loading and the test temperature were from 0–50 phr and 243–363 °K, respectively. It was found that the optimum nano $CaCO_3$ amount was 15 phr. The impact strength was improved significantly when CPE content or test temperature are higher than the critical values of brittle-ductile transition content (C_{BD}) or brittle-ductile transition temperature (T_{BD}) (75).

The nanocomposites PVC/acrylonitrile-chlorinated polyethylene – styrene terpolymer (ACS)/ methylacrylopropyl- containing polyhedral oligomeric silsesquioxane (MAP-POSS) were prepared by mixing technique. Plasticizing behavior, dynamic rheology and mechanical properties of the obtained nanocomposites were studied. The results of the research showed that the plastic time decreased with increasing MAP-POSS content, the dynamic storage modulus G', loss modulus G'' and complex viscosity (η^*) of the nanocomposites all exhibit a monotonic change with increasing frequency; all have maximum value at 4 wt% MAP-POSS at the same frequency (76). The impact strength of these nanocomposites increases with increasing of the nano filler content and has the best value at 10 wt% MAP-POSS, which is 5.38 kJ/m^2 higher than that of the polyblend without this nano filler (77).

In order to improve PVC thermal stability, poly (vinyl butiral) (PVB) and nano $CaCO_3$ were introduced in plasticized PVC. The two additives acted as HCl scavengers and afforded an important delay of both onset thermal degradation temperature and HCl release. By the addition of 10 wt% PVB and 8 wt% $CaCO_3$ the release temperature of HCl was delayed of about 60°C (54).

In situ polymerization of methyl methacrylate in the presence of nano Sb_2O_3 led to the formation of nano particle covered with PMMA shell. These particles enhanced interactions with PVC macromolecules, breaking down filler agglomerates, improving its dispersion and increasing PVC-Sb_2O_3 interfacial adhesion. It was found that 2.5 wt% nano PMMA modified Sb_2O_3 provides optimum Young's modulus, tensile yield strength, elongation at break and Charpy notched impact (78).

Two quaternary ammonium products with polymerizable vinyl groups were synthesized for use as MMT modifiers. Copolymers of such modified MMT platelets with methyl methacrylate were introduced to produce a series of PVC/MMT nanocomposites by melt mixing. The platelet fillers with better organic coverage represented much more useful functional fillers than the conventional ammonium treated fillers due to the potential to exfoliate to a greater extent when melt mixed with the PVC matrix. The obtained products show better performance in increasing the thermal stability of PVC/MMT nanocomposites (79).

A graft copolymer of PVC-g-poly (ethylene methacrylate) PVC-g-POEM was synthesized *via* atom transfer radical polymerization, and fumed silica nano particles were solution blended to prepare PVC-g-POEM/SiO_2-POEM nanocomposite membranes. These membranes show high permeation and good mechanical properties (80).

For the preparation of water resistant and thermally stable nonlinear optical elements containing SWCNTs, an original technique based on formation of layered structures made of alternating layers of PVC and water soluble carboxymethyl cellulose (CMC) with dispersed SWCNTs was proposed (81, 82).

In the case of PVC/ABS/oMMT nanocomposites, the morphology and the effects of Na^+oMMT and Fe^{++}oMMT on thermal, flammability and smoke suppressant properties have been determined. XRD, TEM, TGA, limiting oxygen index (LOI), UL-94 vertical burning test, and smoke density tests have been used. The nanocomposites containing Fe^{++}oMMT exhibited better flame retardancy, smoke suppressant characteristics and

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lower degradation degree than those of pure PVC/ABS blends and PVC/ABS/Na^+oMMT nanocomposites (83).

During the preparation by melt mixing of PVC/acrylonitrile-butadiene rubber (NBR)/clay nanocomposite, a self-cross-linking process occurs which affects its properties. FTIR, XRD,SEM, and tensile test were done to establish the effect of self-cross linking on the properties of such polyblend nanocomposites. It was found that they became stronger with high Young's modulus and tensile strength (84). The same authors showed that with a small amount of nano filler the same mechanical properties of PVC/NBR/cloisite can significantly be improved (85). Studying the morphology and viscoelastic properties of PVC/NBR/cloisite, the experimental results have been compared with data obtained by using Taguchi theoretical method. The data confirmed that this method is useful to find some properties of the PVC/NBR nanocomposites (86).

The addition of SiC increased the permitivity of PVC/NBR/MWCNTs, and this may have led to an impedance mismatch at the air-material interface that not favored the microwave absorbing performance. The tensile strength and stress at 100% extension of the PVC/NBR nanocomposites increased with the addition of MWCNTs and SiC, whereas the elongation at break decreased (87).

The influence of different amounts of nano graphite and Cu on the properties of PVC/NBR polyblends obtained by the solution technique was studied recently. Besides the mechanical properties, the research investigated also the dielectric ones by means of broad band ac-relaxation spectroscopy in the frequency range between 0.01 Hz to 10 MHz at 25°C. According to the results, the nanocomposites of PVC/NBR (50/50) filled with 5% Cu are considered that they belong to semiconductor materials (88).

PVC/epoxidized natural rubber (ENR) nanocomposites have been prepared by solution technique with tetraethoxy silane (TEOS) as a silica precursor. Tensile test, SEM and TEM have been applied in this study. The tensile test indicated that the highest mechanical strength was at 30% TEOS added to the PVC/ENR blend prepared at pH = 2.0 (89).

Interesting research have been done on PVC/methyl methacrylate-butadiene-styrene (MBS)/halloysite nanotubes (HNTs) (90).

It is well known that most physical properties of PVC/wood composites are lower than those of pure PVC because of poor interfacial adhesion between the hydrophilic wood flour (WF) and hydrophobic PVC macromolecules. The effects of treating WF with aminosilanes and adding a nano clay on the mechanical properties of the composites were investigated by using universal testing machine (UTM), izod impact tester, DMA and TMA. The performance of PVC/wood was considerably improved by using the aminosilane -treated WF and the nano clay (91).

The effects of nano $CaCO_3$ on the mechanical properties and flame retardancy of PVC/WF/$CaCO_3$ composites were investigated by cone calorimetry. After applying a surface coupling agent the composite properties were improved due to the improvement of interface adhesion between PVC and WF. The flame resistance was also improved (92).

Foaming PVC/WF nanocomposites have been recently considered by researchers. In a such study MWCNTs were compounded with PVC,WF and a foaming agent in an internal mixer. The experimental data indicated that, in the presence of MWCNT the cell density increased and the cell size decreased, but the density of the foam nanocomposites were not affected by the content of the foaming agent. The research results show that the addition of MWCNT to PVC/WF foams led to more density reduction, increase of the flexural strength and Young's modulus up to 16% and 13%, respectively (93). The influence of MWCNT functionalization on the morphology and mechanical properties of nanocomposite foams based on PVC/WF/MWCNT are presented also in an another research (94).

The effects of TiO_2 and nanoclay on one side and of SiO_2 and nanoclay on another side were recently studied in the case of polyblends of PVC with high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP) and polyethylene -co- glycidyl methacrylate (PE-co-GMA) with WF (*Phragmites karka*) (95, 96). The influence of nano fillers on flammability, UV resistance, biodegradability, chemical resistance of some polyblends that include PVC was also investigated (97, 98).

5 Conclusion

Based on the data obtained by different researchers we can draw the following conclusions:

-Nano fillers, mixture of nano fillers, and nano fillers with some polymers introduced in PVC matrix lead to the formation of PVC nanocomposites with better properties than those of virgin PVC.

-Some of such new additives act as HCl scavengers and afforded significant delay of both PVC degradation temperature and HCl release.

-Beside the thermal properties improvement PVC nanocomposites posed better mechanical, rheological, photo stability, barrier, antibacterial, flammability characteristics depending on the chosen nano filler, mixtures of nano fillers, mixtures of polymers and nano fillers and the technique used for their preparation.

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Abbreviations

ABS	-Acrylonitrile-butadiene-stytene terpolymer
ACS	-Acrylonitrile-chlorinated polyethylene-styrene terpolymer
AP	-Alkyl phosphate
C_{BD}	-Brittle-ductile tansition content
CNT	-Carbon nano tube
CMC	-Carboxymethyl cellulose
CPE	-Chlorinated polyethylene
DMF	-Dimethylformamide
DOP	-Dioctyl phthalate
DSC	-Differential scanning calorimetry
DMA	-Dynamic mechanic analysis
eMWCNT	-alkyl modified multi walled carbon nano tube
EL	-*Euricoma longifolia*
ENR	-Epoxidized natural rubber
FTIR	-Fourier transform infra red analysis
Go	-Graphene oxide
HDT	-Heat distortion temperaturers
HNT	-Halloysite nano tube
HT	-Hydrotalcite
LDH	-Layered double hydroxide
LDH-DS	-Layered double hydroxide intercalated with sulfate anions
LDH-PK	-Layered double hydroxide lauryl ether phosphate
LOI	-Limited oxygen index
MA	-Maleic anhydride
MAP-POSS	-Methylacrylopropyl containing polyhedral oligomeric silsequioxane
MBS	-Methyl methacrylate-butadiene-styrene terpolymer
MMT	-Montmorillonite
MWCNT	-Multi walled carbon nano tube
nano-G_s	-Graphite nano plates
NBR	-Acrylonitrile-butadiene rubber
oMMT	-Organo modified montmorillonite
oPOSS	-Polyhedral oligomeric silesquioxanes
PAA	-Poly (acrylic acid)
PAND	-Dodecylbenzene sulfonic acid doped aniline
PBAA	-Poly (butadiene-co-acrylic acid) copolymer
PANI-TiO_2	-Polyaniline modified TiO_2
PE-co-GMA	-Polyethylene-co-glycidil methacrylate
PHRR	-Peak heat release rate
PMMA	-Polymethylmethacrylate
PP	-Polypropylene
PVB	-Poly (vinyl butiral)
PVC	-Poly (vinyl chloride)
PVC-g-POEM	-PVC-g-poly(ethylene methacrylate)
SEM	-Scanning electron microscopy
SWCNT	-Single walled carbon nano tube
T_{BD}	-Brittle-ductile transition temperature
TEM	-Transmission electron microscopy
TGA	-Themogravimetric analysis
THF	-Tetrahidrofuran
TEOS	-Tetraetoxysilane
TMCS	-Chlorotrimethylsilane
UTM	-Universal testing machine
VAc	-Vinyl acetate
VC	-Vinyl chloride
VST	-Vicat softening temperature
WF	-Wood flour
XRD	-X-ray diffraction

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