

Nanoclay Reinforced Fibers and Nonwovens

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ABSTRACT

In this research, polypropylene fibers and nonwoven samples were produced with the commercial samples of nanoclay additives in semi-commercial processing machinery. Influence of two different types of nanoclay additives, at different add on levels on processing, structure and morphology of nonwovens is studied. The WAXD and DSC data showed some change in crystallinity and melting behavior indicating changes in the fiber morphology towards improved mechanical properties. Presence and extent of exfoliation of nanoclay in the polymer was verified using transmission electron microscopy (TEM). TEM image reveals intercalated and exfoliated morphology of nanocomposites. About 10 to 20 % increase in tensile strength and modulus in both machine and cross directions is observed. This increase in strength is not accompanied by a decrease in breaking elongation as is the case for most of the fibers. Similarly 10 to 25 % increase in web stiffness and 20 to 80 % increase in web burst strength was observed. Furthermore there is improvement in other performance properties of the spunbond nonwovens. SEM images showed improved thermal bonding in the presence of nanoclay additives. The main advantage of this process is that these fabrics can be produced without any need for change in the processing equipment. This study has shown that by using a suitable compounding method, nanoparticle reinforced fibers and fibrous products with improved performance properties can be produced using conventional production machinery.

INTRODUCTION

The history and growth in synthesis, characterization, and understanding of microscopic structures has given rise to a new chapter, the nanoscience and nanotechnology [1]. There is a continuing effort to take advantage of recent advances in nanotechnology, in the polymer and fiber industry. In its most basic form, nanotechnology refers to the manipulation of materials at the atomic or molecular level. The name derives from the nanometer, a scientific measurement

unit representing one billionth of a meter. With various manufacturing techniques such as vapor deposition, sputtering, scanning tunneling microscopy, and supersonic molecular beams, it is now possible to produce materials of nanometer size. Nanotechnology gives scientists the ability to create new materials containing fine layered atomic clusters, quantum dots, etc. that exhibit mechanical, electrical and optical properties different from the same materials in the bulk form. This difference is attributed to the observed increase in reactivity level due to the large surface to volume ratio that depends on size, shape, and lattice structure etc. studied extensively by X-ray diffraction methods [2]. Advances in microscopy: scanning tunneling microscopy, scanning electron microscopy and transmission electron microscopy has further facilitated the studies. With these powerful tools, scientists are able to better comprehend and account surface topology, structure and morphology up to atomic scale [3].

Nanoclay is one of the most affordable materials that have shown promising results in polymers. Nanoclay is made from montmorillonite mineral deposits known to have “platelet” structure with average dimension of 1 nm thick and 70 to 150nm wide. Nanoclays are known to enhance properties of many polymers such as nylon 6, EVA, epoxy, PET, PE and PP leading to better clarity, stiffness, thermal stability, barrier properties to moisture, solvents, vapors, gases and flavors; reduced static cling and UV transmission in film and bottles; improved chemical, flame, scratch resistance, and dimensional stability in injection molded products [4]. Plastic molded parts exhibit higher heat distortion temperatures, and better appearance when painted. Nanomer® and Cloisite® are the popular nanoclays available in the market. Nanomer® is a nanoclay [5] product developed by Nanacor/AMCOL International Corporation, and Cloisite® nanoclays are produced by Southern Clay Products, Inc., of Texas, USA.

Cloisite additives have been used in injection-molded parts, films, bottles, trays, blister packs, and wire and cable coatings. Cloisite® Na⁺ is a natural montmorillonite well known additive used to improve various plastic physical properties, such as reinforcement, heat deflection temperature (HDT), coefficient of linear thermal expansion (CLTE) and barrier properties. Cloisite15A is a natural montmorillonite modified with quaternary ammonium salt containing organic modifier, dimethyl dehydrogenated tallow [2M2HT], where HT is hydrogenated tallow with approximate composition 65% C₁₈, 30% C₁₆, 5% C₁₄ [6]. Specific gravity of Cloisite 15A is 1.66 and bulk density 172.84 kg/m³. Particle size distribution is such that 90 % are less than 13 micron and 50 % are less than 6 micron and 10% less than 2 micron. Average particle diameter as determined by x-ray diffraction is 31.5Å [7].

According to a US Patent [8] by Nanocor, the know-how of uniform dispersion of nanoclay (0.5 to 10% level) in polyolefins to produce concentrates that can be used in nanocomposites is claimed. The nanoclay dispersion is used to improve modulus and tensile strength, barrier properties, flame resistance, and thermal and structural properties of many plastics to extend their reach into areas dominated by metal, glass and wood.

Three different types of morphology in case of polymer-nanoclay composites are shown in *Figure 1*. When there is partial intercalation of extended chain in between the sheets intercalated (*Figure 1, A*) structure is obtained. When clay layers are completely dispersed in the polymer matrix gives exfoliated (*Figure 1, B*) morphology and when polymer is unable to intercalate between the clay sheets, phase separated nanocomposites (*Figure 1, C*) is obtained. Exfoliated structure has proved to incur better properties for the final product compared to intercalated structure [9].

Recent studies are focused towards modification of clay, altering processing conditions to achieve better exfoliation [10], change in rheological behavior with percentage and clay exfoliation etc [11-15]. Polykemi [16] claims that the nanoclay-reinforced polypropylene can be made scratch resistant, low density, higher stiffness compared to alternative to the mineral reinforced and virgin polypropylene. Nanocor claims that the nanocomposite with 6% nanoclays by weight that also contains 10%-12% glass fibers will deliver a property equivalent to 30 % straight glass-filled composite material with added advantage of lower specific gravity and lower part

weight [17]. Influence of clay loading on properties of polypropylene-clay nanocomposites has been studied by X. Liu et al, where they observed increase in tensile strength and modulus with increase in clay content from 0 to 5 wt %, considerable increase in storage modulus and decrease in tan (δ) and T_g were seen [18].

Structure and properties of polypropylene/montmorillonite hybrid composite and melt spun fibers have also been studied and found that good intercalation of clay in PP matrix improves the spinnability. At same draw ratio, fiber with clay had higher crystallinity and lower orientation. Improved moisture absorption and dye affinity was observed for fibers with clay [19]. In our previous studies influence of nanoclay on crystallization kinetics of nylon 6, polypropylene and PET fibers were investigated [20]. Though extensive research has been done to study the influence of nanoclay additive on the processing, structure and morphology of polymer products [21-25], influence of nanoclay additive on the spunbond processing, web properties and thermal bonding has not been studied. This research was conducted to investigate the development of structure and properties during spunbonding with nanoclay. Spunbond web reinforced with natural and organo modified nanoclay additive has been produced successfully. Influences of two different type of nanoclay additive at two different add on levels on structure, morphology and mechanical properties of resultant spunbond web has studied. Influence of nanoclay additive on processing and intricacies necessary for successful processing of nanoclay incorporated spunbond products has been revealed.

EXPERIMENTAL

Materials and Processing

Commercial spunbond grade 35MFR polypropylene (PP 3155) was obtained from Exxon-Mobil Company. Nanoclays were procured from Southern Clay Products and compounded into concentrates in a twin screw extruder by Techmer PM, Clinton, TN. Concentrate pellets provided by Techmer PM had 20 % natural nanoclay (Cloisite Na⁺) and organo modified (Cloisite 15A) in two different carrier resins (control PP and a high MFR PP). For sample designated CNO and CAO, maleated polypropylene (m-PP) was used at same percentage as that of nanoclay during compounding. These combinations were used to achieve good dispersion of nanoclay in master batch. Concentrates were dry-blended with polypropylene (PP) pellets in a concrete mixer at different percentage and fed to the extruder to get the

different final spunbond sample with 1 and 2 wt % on clay additive. Different sample combinations produced are listed in *Table I*.

TABLE I. DESCRIPTION OF THE SAMPLES PRODUCED.

Sample	Sample composition
Control	35 MFR PP (PP 3155)
2CN	2% Cloisite Na+ 1 % high MFR PP+ compounded in PP3155
2CA	2% Cloisite15A+ 1 % high MFR PP + compounded in PP3155
2CNO	2% Cloisite Na+ 1 % high MFR PP + 2 % m-PP compounded in PP3150
1CNO	1% Cloisite Na+ 1 % high MFR PP + 1 % m-PP compounded in PP3150
2CAO	2% Cloisite15A+ 1 % high MFR PP + 2 % m-PP compounded in PP3150
1CAO	1% Cloisite15A + 1 % high MFR PP + 1 % m-PP compounded in PP3150

Spunbonding

Spunbond fabrics with additives (*Figure 1*) were produced using the Reicofil II[®] spunbonding machine. Processing conditions used are included in *Table II*. Extruder and spinning conditions were maintained same for all the samples with the target fabric weight of 50 grams per square meter (GSM). All the fiber and fabric samples produced in the experiments were conditioned for 24 hours under standard textile laboratory conditions before testing and characterization.

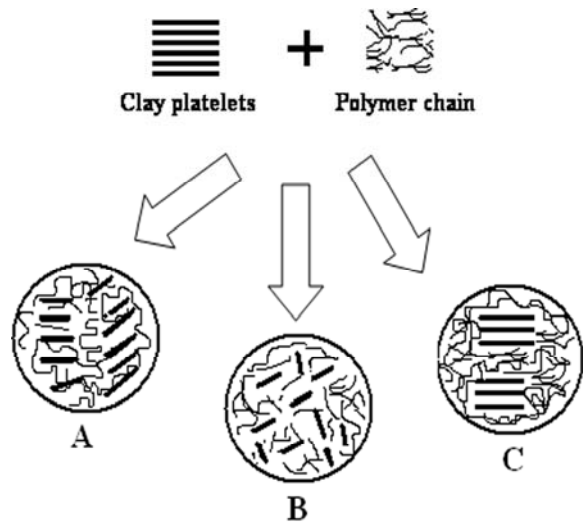


FIGURE 1. Schematic of the (A) intercalated, (B) exfoliated structure and (C) phase separated polymer-nanoclay composite morphology.

TABLE II. SPUNBOND TRIAL PROCESSING CONDITIONS.

Melt temperature	240 (°C)
Extruder speed	125 (rpm)
Through put	0.4 (gms/hole/min)
Air suction (blower speed)	1490 (rpm)
Cooling blower speed in	1671 (rpm)
Belt speed	25 (mts/min)
Calendering temperature	140 (°C)
Bond area	14.5 (%)
Calender speed	25 (mts/min)

Testing and Characterization

The web basis weight is calculated as per IST 130.1. The web thickness was determined using the TMI thickness tester as per ASTM D5729-97 [26]. Wide angle X-ray Diffraction (WAXD) of samples was carried out using Phillips XPert Pro X-ray diffraction system in continuous scan mode to evaluate crystallinity and crystal size. Equatorial scans were obtained from $2\theta = 2^\circ$ to 30° in steps of 0.01° and a dwell time of 4 seconds, operated at 45 kV and 40 mA. Crystal size (t) was calculated using the Scherrer equation as shown in *Eq. (1)*, from the measured full width half maximum (FWHM) intensity of reflection peaks in the equatorial scans.

$$\text{Scherrer equation is: } t = \frac{0.9\lambda}{B \cos \theta_B} \quad (1)$$

Where λ is the wavelength in \AA and B the measured FWHM intensity of (110) reflection peaks. Hot pressed films were prepared from PP containing 2 wt % natural nanoclay and organo modified nanoclay additive. Sections of thickness less than 60nm were cut on a Reichert OMU3 ultra microtome using a diamond knife. Transmission electron microscopy (TEM) images were taken using a Hitachi H-800 microscope operated at 200 kV. SEM images of cross-sections were taken using the Leo 1525 Field emission gun. Fibers were dipped in liquid nitrogen and chopped with a sharp razor blade. In order to avoid charging problems, fibers were coated with gold for 10 seconds in argon environment using a SPI sputter coater. Thermal analysis was carried out using the Mettler Toledo DSC/SDTA 822e differential scanning calorimeter. Samples were heated at a rate of 20°C per minute in the N_2 atmosphere.

For determining the crystallization behavior during cooling, a higher cooling rate of 50°C per minute was

used for all the samples. Before cooling, the samples were heated to 200°C at the rate of 20°C /min and then held at that temperature for five minutes to ensure complete melting of all the crystals.

Percentage of crystallinities X_c %, of samples were calculated from enthalpies of crystallization using Eq. (2),

$$X_c \% = \frac{\Delta H}{(1-\phi)\Delta H_{100\%}} \times 100 \quad (2)$$

Where, ΔH is the measured heat of fusion of the sample, $\Delta H_{100\%}$ is the heat of fusion of the 100 % crystalline polypropylene which is taken as 190 J/g for this study [27] and ϕ is the weight fraction of nanoclay additive [28]. Thermo gravimetric analysis of the samples was carried out using the Mettler Toledo TGA/SDTA 851. Samples were heated at the rate of 20°C per minute from 50 to 800°C. The purpose of TGA was to determine the ash content and to reconfirm the presence of additive in the final product. Effect of nanoclay additives on the complex rheological properties such as viscoelasticity, storage and loss modulus at different temperatures is analyzed using Advanced Rheometric Expansion System (ARES) rheometer. Samples in circular disc form of 20 mm radius and approximate thickness of 2mm were prepared using a Wabash Hydraulic hot press. Samples with different percentage of nanoclay additives were placed between the two parallel plates of rheometer. The dynamic sweep test was carried out at angular velocity in the range of 1 to 120 radians /sec at four different temperatures in the vicinity of processing temperatures used during spunbonding.

Tensile properties were determined using the United Tensile Tester as per ASTM D5035-95. Sample dimension of 25mm wide and 75mm gage length were used for tensile test, stretched to break at a uniform strain rate of 0.34mts/min. For fiber samples, a bundle of 20 filaments was tested using 25mm gauge length. Fabric stiffness was estimated by measuring the bending length using the cantilever bending test method as per ASTM D5732-95. Tear strength was conducted using the Elmendorf tear tester as per ASTM D5734-95. Burst strength was tested using the B F Perkins, Mullen burst tester as per ASTM D3786-87 [29].

RESULTS AND DISCUSSIONS

Rheology and Processability

Variation in complex viscosity of different compounded polymers as a function of angular velocity, for different samples at 230°C is shown in Figure 2.

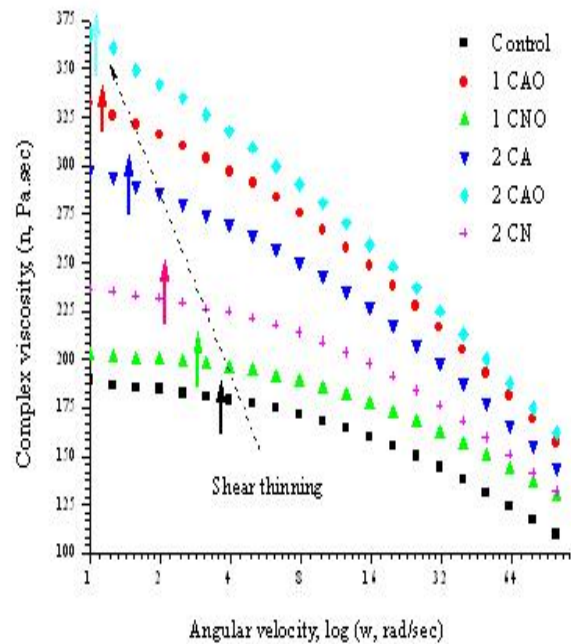


FIGURE 2. Complex viscosity of the polymer measured at 230°C using ares rheometer.

For all the samples with nanoclay additive, the viscosity was higher than that of the control. Higher viscosity at lower angular velocity is due to the hindrance to motions caused by added nanoparticles. Nano additives entangle with the polymer chain and resist the free motion of chains. The sample with 2 wt% has higher viscosity compared to 1 wt% nanoclay additives might be due to confinement of chains within clay galleries [30]. Viscosity decreases with the increase in angular velocity because of the disentanglement of nanoclay additives and the polymer chain [31]. However this decrease in viscosity is higher for sample with nanoclay since they had higher viscosity to start with. Also at higher angular velocities, nanoclay particles disperse with and are likely to separate from the surrounding PP chains. Sample with clay additive shows shear thinning at lower shear rate than that of control. In other words sample with clay additive enters non-

newtonian region earlier than the control polypropylene. Similar results of change in viscosity with clay addition have been reported by Hatzikiriakos et. al. who claimed that the addition of lower concentration of 0.1 wt % clay slightly reduced the viscoelasticity due to disruption of chain entanglement by high aspect ratio of clay platelets [32]. Due to shear mixing, if the dispersion of clay leads to structure as shown in *Figure 1, A or B*, it will lead to reduction in viscosity.

Processing Observations

As evident from rheological measurements, viscosity of samples with the nano additives is higher than that of the control. The main effect of these viscosity differences on the processability is that the pressure in the spin pack increases with increase in viscosity, and may require the use of higher melt temperature. However, in this study, the melt temperatures were kept same. Processing was without any major problem with 1% clay samples. Also, it was observed that processability under these conditions was not very good with 2% clay additives. With higher level (2% in this case) of clay, there was increase in back pressure and polymer flow problem in the die. Since the run was only carried out for short duration, we did not observe any possible buildup on spinnerette face. However there was drip formation after a while and good quality fabrics could not be collected especially 2% nanoclay samples (2CAO). Observation is consistent with Rheology data, since sample 2CAO showed the highest viscosity.

Spun Fiber Structure and Properties

As-spun fibers were collected from the belt, before thermal bonding. The results from tensile testing of the fiber samples are summarized in *Figure 3* and *Table III*. There is a substantial increase in tensile strength when nanoclay additives are present in the polymer. It can be seen that blending of nanoclay increases the tensile strength and modulus. This increase in strength is not accompanied by a decrease in breaking elongation, which is very unique. In most of the cases, when one tries to increase the tensile strength of the fiber, there is a simultaneous decrease in the elongation due to drawing effect. Here nanoclay has a true reinforcing effect. This is a promising situation as one can expect improved tensile properties without any decline in elongation in the fibers and fibrous products containing nanoclay. Also from the data it is clear that having small percent of maleated polypropylene (m-PP) results in better property of the fibers.

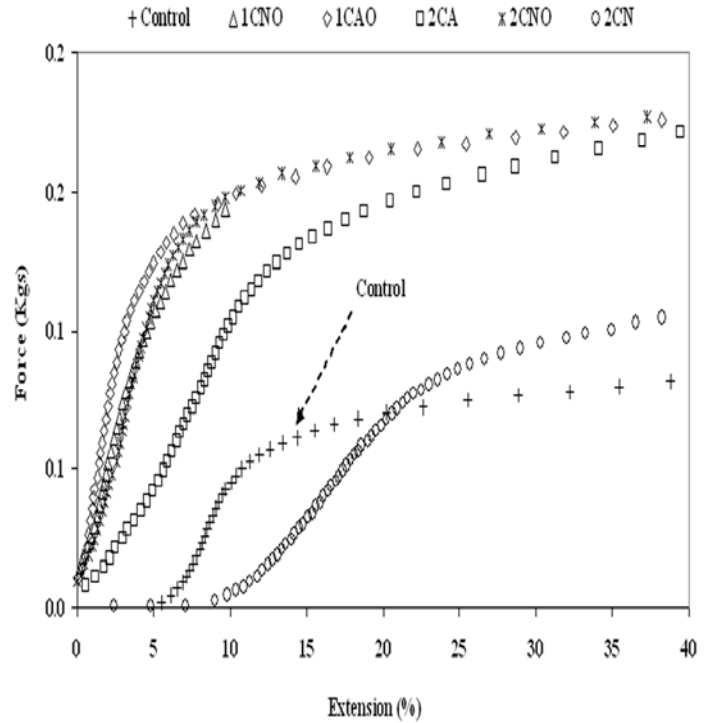


FIGURE 3. Load-elongation response of spun fibers (20 filaments)

TABLE III. FIBER TENSILE PROPERTIES.

Sample	Peak force (Kgs)	Std Dev	Elongation (%)
Control	0.24	0.06	249.8
1CNO	0.39	0.1	264.6
1CAO	0.37	0.1	249.5
2CA	0.36	0.09	222.5
2CNO	0.31	0.08	241.6
2CN	0.19	0.05	169.3

WAXD patterns of fiber samples are shown in *Figures 4 (a) and (b)*. Peak corresponding to γ -form has been observed for sample with 2 wt% clay additives in *Figure 4 (a)*. γ -crystalline form was first reported in the 1960s and it is well known that γ -crystalline form is formed when crystallized at elevated pressure due to interruptions to chain diffusion [33-36]. Similar results of increased γ -crystalline phase were formed in polypropylene nanocomposites due to restriction to chain movement [37]. At lower 2θ scans, peak corresponding to Cloisite Na⁺ at $2\theta = 6.07^\circ$, $d = 11.7 \text{ \AA}$ is only observed for sample 2CA with 2 wt% natural

nanoclay. For other samples, WAXD scans do not show any prominent peak corresponding to (100) of clay which might be due to good dispersion and possible delamination of clay additives. From the results of fiber crystallinity (%) and crystal sizes (*Figure 5*), it is evident that the fiber crystallinity increases with percentage of nanoclay added. Results are further confirmed by the thermal analysis (DSC) results as shown in *Figure 6*. Crystallinity % for

sample with nanoclay additive was about 15 to 20 higher than that of control polypropylene. Typically spunbond fabrics have lower crystallinity than spun drawn fibers due to lower level of drawing and orientation. It is possible that nanoclay acts as a nucleating agent and accelerates the crystallization process, leading to higher crystallinity.

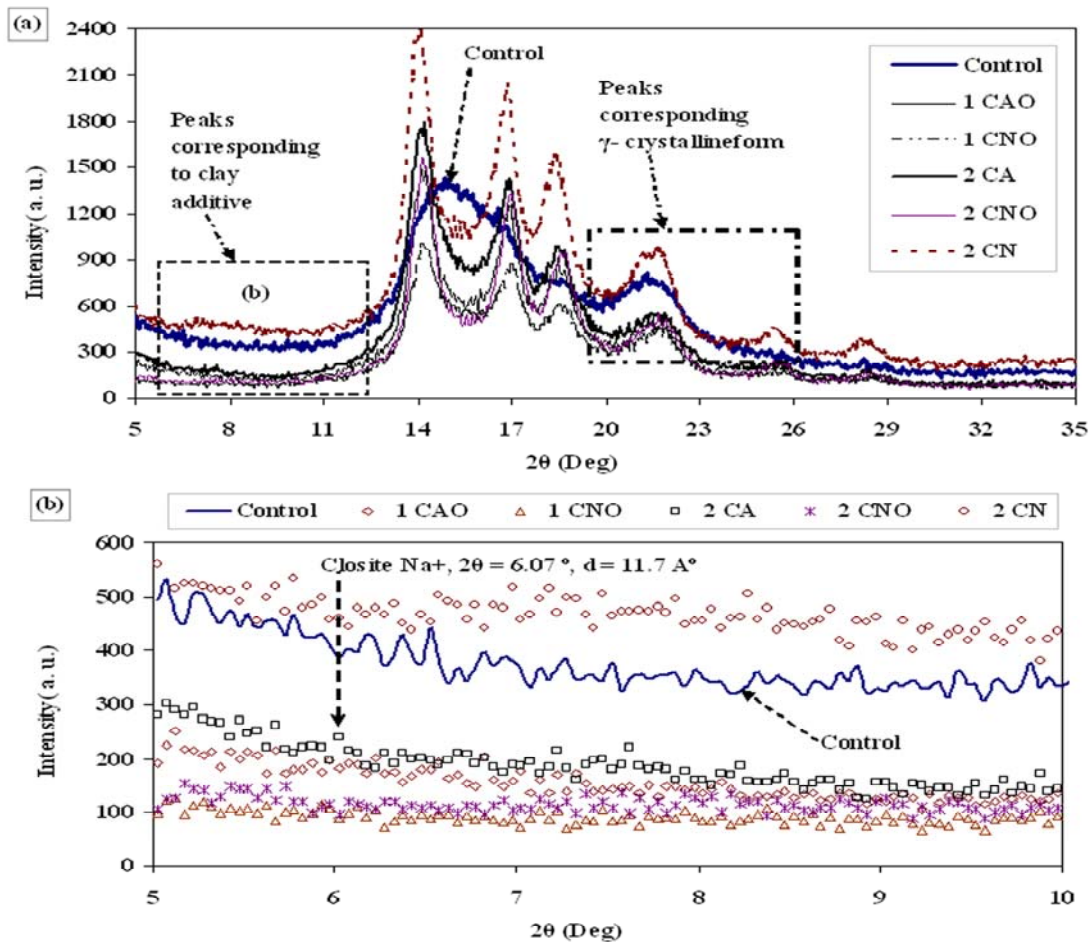


FIGURE 4. Schematic of (a) waxd scans of fiber samples (b) waxd peaks corresponding to clay at lower 2-theta angle.

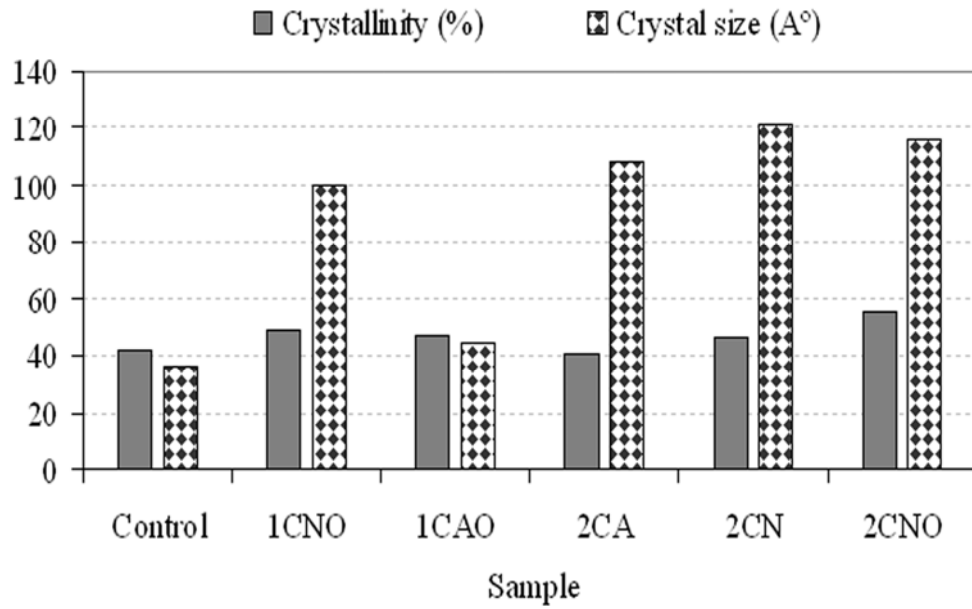


FIGURE 5. Crystallinity and crystal size data for different fiber samples.

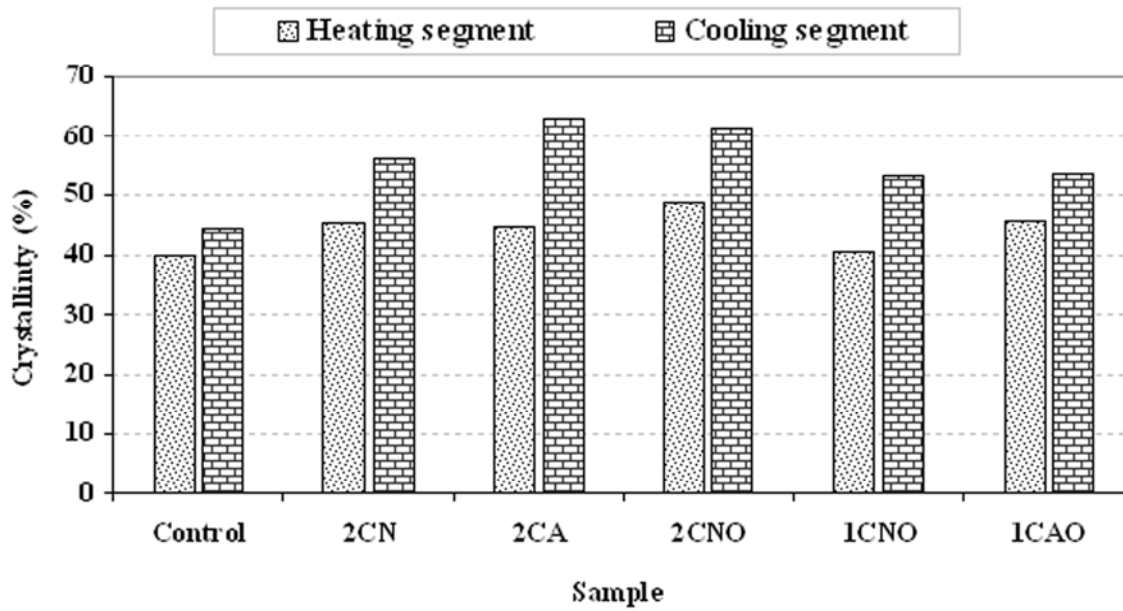


FIGURE 6. Percent crystallinity of fibers [determined from DSC].

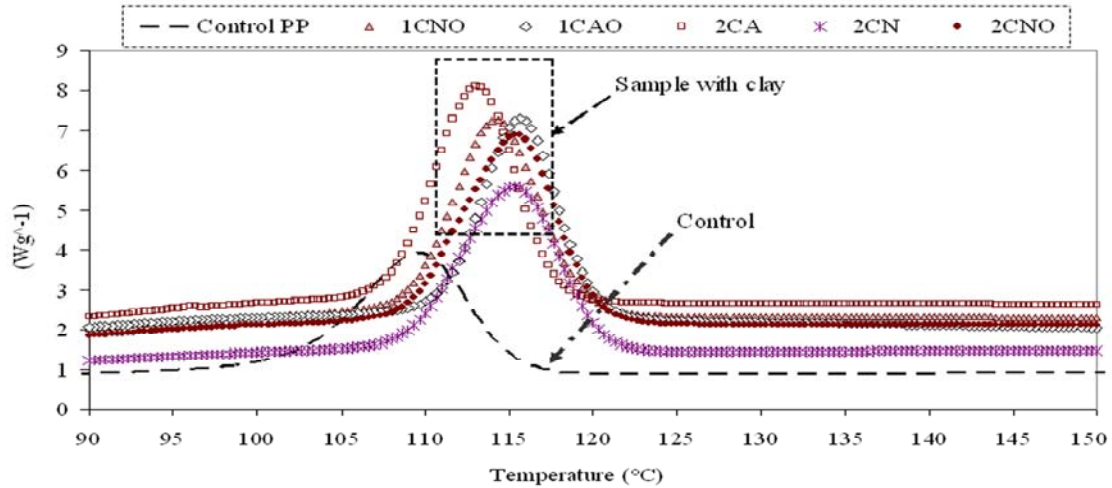


FIGURE 7. DSC cooling scans of as-spun fibers.

Also fibers with nano additives show difference in crystallinity and melting behavior to that of control. In the DSC cooling segment all the fibers with nanoclay additives show higher crystallization temperatures than that of control (*Figure 7*), indicating the nucleating effect of nanoclay additive. The samples with these additives do show some shift in peak melting temperature and change in the shape of the melting peak, indicating differences in crystallinity or crystal size distribution. Results from DSC and WAXD are consistent and both demonstrate that there is difference in crystalline structure of the sample with and without clay.

Figures 8 (a) and (b) show the TEM images obtained from sections of film sample 2CN-with 2 wt % natural nanoclay and 2CAO- with 2 wt % Cloisite 15A compounded in PP respectively. The shady lines in the figure represent cross-sections of layered clay platelets with polymer chain intercalation. Images show the exfoliated and intercalated morphology. Degree of exfoliation, orientation and distribution within the matrix play a significant role in extent of property improvement. Exfoliated morphology gives better mechanical properties [38].

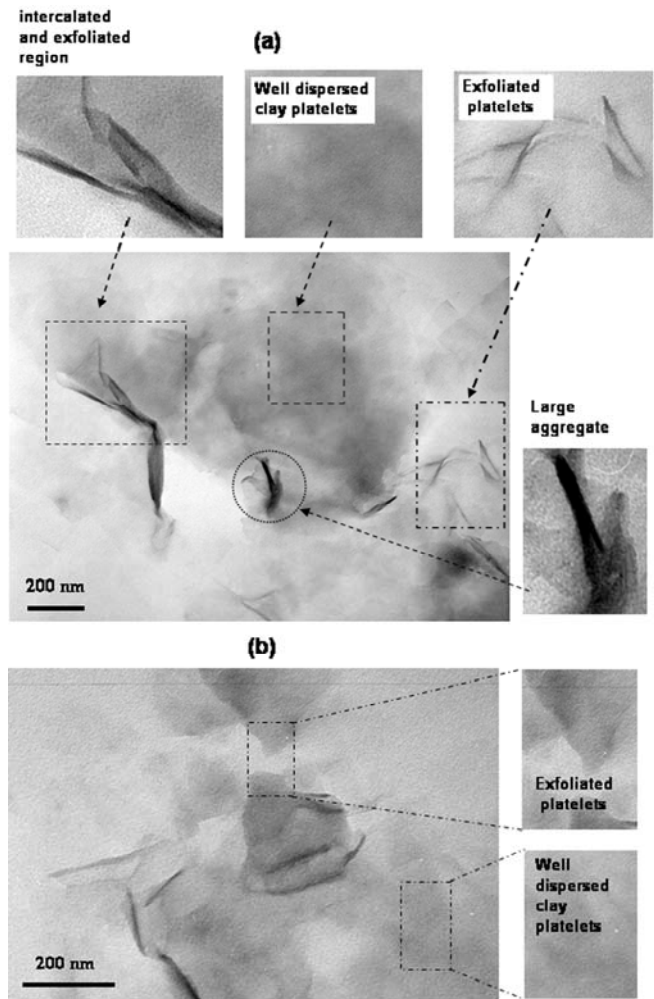


FIGURE 8. TEM image of pp film (a) 2cn-with 2 wt % natural nanoclay (b) 2cao- with 2 wt % cloisite 15a compounded in PP.

In case of 2CN larger tactoids were observed. Though the clay additive forms aggregates at some points, close observations reveal that there is sufficient intercalation of polypropylene molecules. Compared to 2CN (2 wt % natural nanoclay-Cloisite Na⁺), sample 2CAO (with 2 wt % organo modified clay-Cloisite 15A and 2 % maleated PP compounded in PP) had better dispersion and exfoliation. The observed improvements are due to the presence of maleated PP in these samples. One has to remember that these TEM images were obtained from a very small section (less than 60 nm) from film and it is not a guarantee that there is complete exfoliation or intercalation throughout the fiber or fabric sample. However they are the true representation of nanocomposite morphology with respect percentage of clay additive in selected matrix polymer (polypropylene). In addition when viewed with WAXD results that are obtained from drawn larger samples, one can draw the conclusion that the clay is exfoliated in these samples. Results of thermo gravimetric measurements are shown in *Figure 9*. Ash content was slightly higher for samples with nano-additives, as expected due to the presence of stable nanoclay in the material.

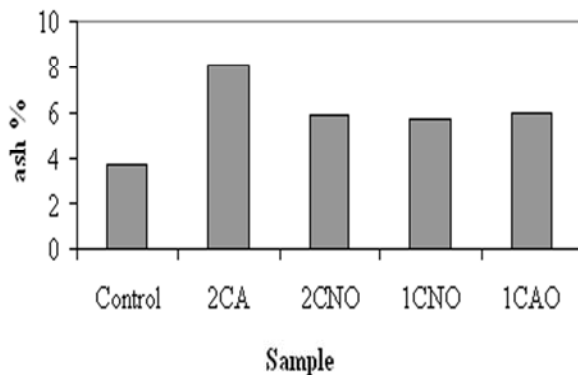


FIGURE 9. Ash content of the spunbond by TGA.

Spunbond Fabric Properties

From the machine direction (MD) tensile strength data (*Table IV* and *Figure 10*) it is evident that the nanoclay additives help improve the tensile strength of spunbond fabrics. Most of the samples had a similar basis weight of 48 to 52 grams/square meter, and the web thickness was in the range of 450-600 microns. Further, it can be noticed that there is no substantial increase in strength by raising the level of additive from 1% to 2%. As is typically observed with spunbond products, there is substantial

variability in the samples and interpretations have to be done carefully. Tensile properties of the fabric with Cloisite15A are slightly better than with natural nanoclay. Compared to the fiber tensile data, the improvement in fabric properties are minimal, which may be due to changes taking place during web bonding. Optimization of bonding conditions may yield better tensile properties in the webs since it has been shown that optimum bonding conditions are different for fibers with different morphology [39]. This needs to be explored further in future studies.

TABLE IV. FABRIC STRENGTH IN MACHINE DIRECTION.

Sample ID	Max Force (Kgs)	Std Dev	Elongation (%)
Control	5.66	1.8	141.5
1CNO	5.23	1.7	105.6
1CAO	5.85	1.9	123.3
2CNO	5.41	1.7	94.0
2CA	5.44	1.7	89.0

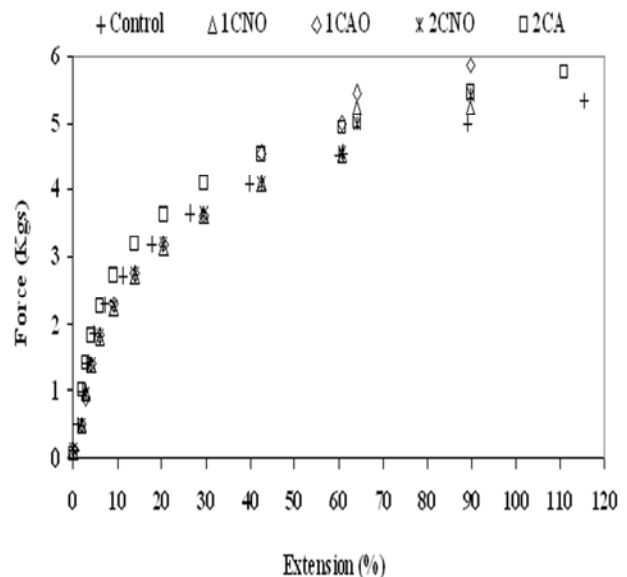


FIGURE 10. Spunbond fabric tensile properties in Machine Direction.

Nanoclay addition increases the stiffness of the fabrics, which can be seen from the observed increase in bending length (*Figure 11*). This increase in stiffness is incurred from non-homogeneous distribution of clay platelets along the length of sample and high modulus of clay itself [40].

Similarly, increase in burst strength due to nanoclay can be seen from the data with the highest strength evident for 2CA (Figure 12). The improvement in burst strength is due to the increased toughness of fibers and sufficiently well bonded structures for samples with nanoclay. The effect of nanoclay additive on the spunbond fabric properties is the combination of the improvement in fiber properties due to additive and the influence of clay on thermal bonding. Overall the improvement in fiber properties with nanoclay additive has an effect on the fabric properties, though not to the similar degree. This is probably due to the bonding effect as seen in our earlier studies with other PP fibers having different morphology [41, 42].

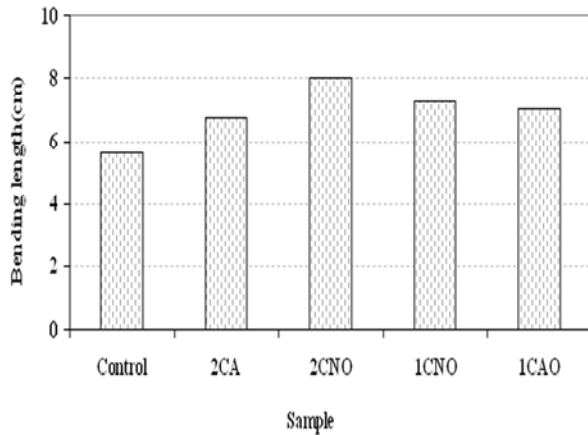


FIGURE 11. Spunbond fabric bending length in MD

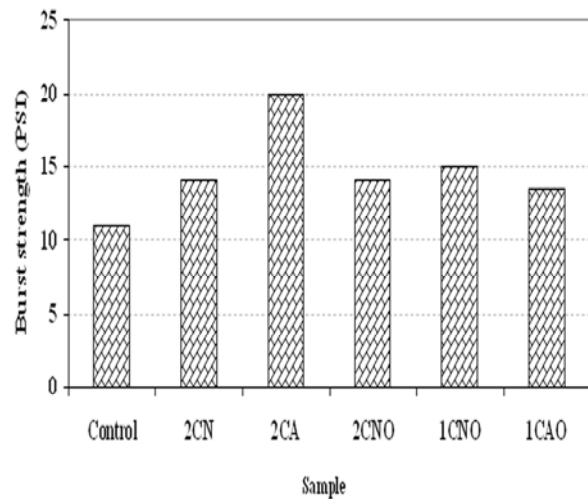


FIGURE 12. Spunbond fabric Burst strength.

SEM micrographs (Figure 13) show good bonding for sample with and without nanoclay. From the

comparison of SEM micrographs of bond points and cross-section between sample with additive and control, it is clearly evident that, presence of 1% of nanoclay leads to stronger and uniform fabrics by improving the properties of fibers and the quality of bonding. SEM micrographs indicate that the fibers with additive maintain better integrity during calendaring. As a result, the failure mechanism will be different, and this leads to higher modulus, strength and elongation of the bonded fabrics. Going to higher levels of nanoclay does not show further improvement, may be due to difficulties in getting better dispersions and exfoliation of clay in the polymer. As mentioned before, there were processing difficulties as well, suggesting that in such processing schemes, nanoclay additives should be kept at a level of less than two percent.

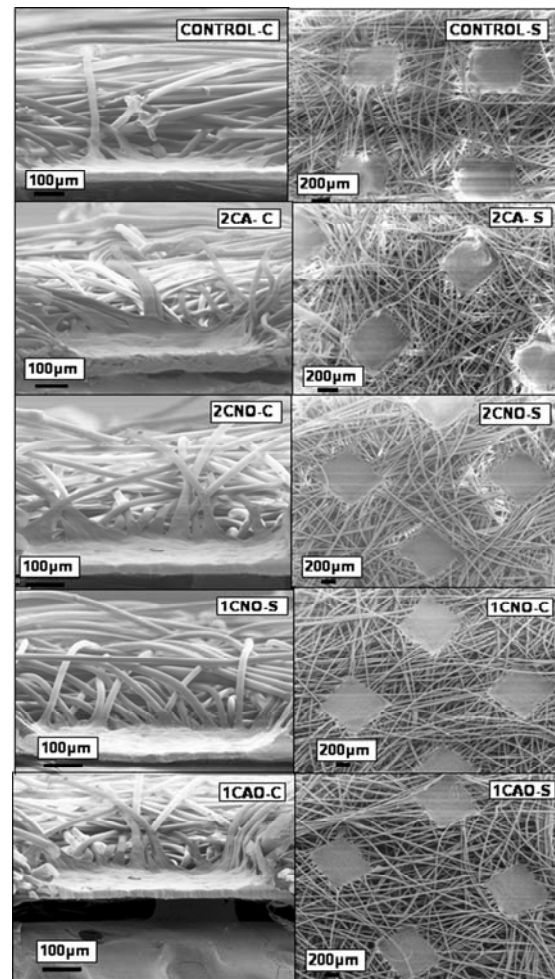


FIGURE 13. SEM micrograph of cross-section-c and surface-s of spunbond fabric samples.

CONCLUSIONS

It is clear from this study that the properties of polypropylene spunbond fabrics can be enhanced by inclusion of nanoclays at a level of 1%. Observed increase in tensile strength and modulus of the webs is 10 to 20%, both in the machine and cross directions. Similarly, bending length or stiffness of the fabric increased by 10 to 25%. Substantial increase is in burst strength, to the order of 20 to 80%, was observed. Improvements in fabric properties are supported by 15 to 75% increase in fiber properties. Improved fiber and fabric properties are derived from the change in polymer morphology as evident from DSC and WAXD results. TEM image shows intercalated and exfoliated morphology of nanocomposites. SEM images show improved bonding in the presence of nanoclay. It can be concluded that benefits are realized at the additive level of 1%, and further enhanced by compounding nanoclay in a PP. Moreover, property benefits are marginal when additive level is increased from 1% to 2%. Increasing nanoclay concentration to 2% level leads to increase in melt pressure, filter blockage, and problems in spinning that lead to poor processability. Performance with Cloisite 15A is slightly better than with natural nanoclay. Thus, modification of clay has its advantages in achieving good performance properties in polymers. Also using small amount of maleated PP helped in better dispersion and intercalation of nanoclay in these samples. These processing studies indicate that, by proper compounding techniques, it should be possible to prepare nanoparticle reinforced polymer products such as fibers, films and fabrics.

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ABBREVIATIONS

Control PP-Commercial spunbond grade 35MFR polypropylene-PP 3155
Cloisite Na+-natural nanoclay
Cloisite 15A-organo modified nanoclay
m-PP-Maleated polypropylene
PP-Polypropylene
PE-Polyethylene
EVA-Ethylene vinyl acetate
PET-poly(ethylene terephthalate)
GSM-Grams per square meter

MFR-Melt flow rate

TEM-Transmission electron microscopy

WAXD-Wide angle X-ray diffraction

SEM-Scanning electron microscopy

DSC-Differential scanning calorimetry

FWHM-full width half maximum

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