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Preparation, Characterization and Abrasion Resistance Property of Melamine Formaldehyde/Montmorillonite Nanocomposite Coatings

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ABSTRACT

This study investigates preparation of melamine formaldehyde/montmorillonite nanocomposite coatings and evaluates its abrasion resistance property as a new material for wood based panel products. The ultrasonicated MF resin/clay blends with different clay loadings were applied in the form of coatings to the saturated decorative paper to prepare thermoset prepregs. Morphology and structure of nanocomposite coatings were characterized using X-ray diffraction and field emission scanning electron microscopy (FE-SEM). Then viscoelastic properties of resultant prepregs were investigated using DMTA method. Tensile test was also employed to determine tensile modulus and toughness of different prepregs. To evaluate abrasion resistance property of cured nanocomposite coatings, Taber abrasion test was performed on panels laminated with prepregs. The results showed that although modulus of storage (stiffness) and tensile strength of intercalated nanocomposite containing 4 % clay was lower than those of exfoliated nanocomposite at 1% clay, its toughness and abrasion resistance property was amazingly better. The results of Taber abrasion test suggest the contribution of nanocomposite morphology rather than stiffness and strength in improving the abrasion resistance property in MF/montmorillonite nanocomposites. It was also found that there must be a relation between clay intercalated morphology in the nanocomposite structure and improvement of its toughness property. However, further research is needed to gain an in-depth understanding on its affecting mechanism. Prog. Color Colorants Coat. 8 (2015), 267-281 © Institute for Color Science and Technology.

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1. Introduction

Among thermosetting polymeric matrix, MF resin is one of the hardest and stiffest existing polymers, which provides outstanding scratch resistance property. For example, MF resin is impregnated into cellulose paper to fabricate decorative or protective laminates on the surface of wood-based composite products. These laminate papers (prepreg composite) are hot-pressed on composite wood products to provide a hard surface finish [1].

During the last decade, interest in polymer layered silicate nanocomposites has rapidly been increasing at an unprecedented level, both in industry and in academia, due to their potential for enhanced physical, chemical, and mechanical properties compared to conventionally filled composites [2]. Polymer clay nanocomposites have also been increasingly used in many engineering applications in which abrasion resistance behavior is crucial. However, there are no or very few studies, if any, dedicated to this tribological aspect [3] of polymer clay nanocomposites particularly with thermosetting polymeric matrix. Laminate flooring is one of the engineering composites in which abrasion resistance of flooring surface is an important and crucial surface quality. Due to the significance of abrasion resistance property in laminate flooring products as an engineering composite, extensive application of MF resin in furniture and laminate flooring industry and because of very few researches done on abrasion resistance property of polymer clay nanocomposites with thermosetting polymeric matrix such as MF rein, this study was conducted to investigate preparation of MF clay nanocomposite, application of resulting nanocomposite in the form of coatings on decorative cellulose paper and preparation of prepregs and finally evaluation of abrasion resistance of MF/clay nanocomposite coatings for application in laminate flooring.

2. Experimental

2.1. Materials

UF and MF resins used in this study were low viscosity resins with the specifications suitable for impregnation of decor paper for lamination and were provided from a local supplier of these resins in Iran. Detailed specifications of UF and MF resins used in this research have been shown in Tables 1 and 2. Given the qualitative issues of laminate surface, it is necessary to have a specified amount of MF resin fixed on the top and bottom surfaces of prepregs. This will be obtained as a result of transferring determined amounts of MF resin during gravure coating stage onto the surfaces of already UF saturated decorative paper.

The level of UF resin treatment also strongly influences the surface quality of the MF coatings in laminates. If the decorative paper is not properly saturated with UF resin prior to coating stage, then MF resin applied as coatings will penetrate inside the unfilled voids by UF resin and will cause surface defects during hot press lamination [1].

In this study, the UF saturated decorative paper samples were Chinese printed decorative paper with basis weight and volatile content of around 140-145 GSM and 8.0 %, respectively. These samples were taken from production line of a running two stage impregnation line, just ahead of the MF coating station. It should be noted that the basis weight of printed decorative paper before UF saturation stage was 70 GSM.

Table 1: Specification of UF resin used for saturation of decorative paper.

color	Solubility in water	pH	Density (g/cm^3)	Solid Content (%)	Viscosity (second) (Ford Cup 4 mm)
transparent	> 10	7.7	1.210	50	14.5-15

Table 2: Specification of MF resin used for preparation of nanocomposites.

color	Solubility in water	pH	Density (g/cm^3)	Solid Content (%)	Viscosity (second) (Ford Cup 4 mm)
transparent	> 2	9.7	1.224	52	15-15.5

Nanoclay particles used in this study were Na^{+}-MMT from Southern Clay Products Inc., TX, USA, which is a hydrophilic pristine nanoclay. Since MF prepolymer used for impregnation of decorative paper is water soluble to an extent, this type of nanoclay can have good dispersion behavior in it. Thus hydrophilic nanoclay was investigated in this study. Table 3 shows the specifications of unmodified pristine nanoclay used for preparation of the nanocomposite. Additives such as anti-blocking agent, surface smoothing (anti-dusting) and releasing agent, plasticizers and catalyst were the products of Deurowood Company, Austria. Unfortunately, the technical information about chemical composition and other detailed properties of these additives are patented by Deurowood Company.

2.2. Preparation of MF/montmorillonite nanocomposites

In this study, nanoclay was introduced to the MF resin at two levels, i.e. 1 wt % and 4 wt % based on the weight of liquid MF resin. It is generally accepted that the overall properties of polymer clay nanocomposite are affected by morphology of dispersed nanoclay in the nanocomposite structure. Hence, two levels of clay particles loading, i.e. 1% and 4%, were considered due to the fact that under certain mixing conditions and with a similar mixing technique, there would be a strong probability to attain a better dispersed (exfoliated) morphology of silicate nanolayers in the resin matrix at around 1% level as reported in the previous literatures [1, 4] and an intercalated morphology in 4% clay loading level. Moreover, the improvements in nanoparticles reinforced polymeric nanocomposites seem to plateau at levels of about 4 wt % clay loading [2, 5-8].

The weighed amounts of Cloisite Na^{+} nanoclay particles were added to the MF resin at room temperature and mixed with hand for 20 minutes and then ultrasonicated using Hielscher UP400S (400W, 24kHz) for 30 minutes to disperse the clay particles. The ultrasonicated blends were kept at room temperature and in lidded bottles for 24 hours. Then all additives were added to the resin mixture based on wt % of liquid MF resin basically according to the procedures recommended by Deurowood Company for the impregnation of decorative paper and with some minor modification as well. A detailed formulation of the coating is illustrated in Table 4. The prepared nanocomposite mixture was coated on a 10 × 15 cm^2 UF saturated decorative paper surface.

2.3. Preparation of nanocomposite prepregs

In an industrial two stage impregnation line, decorative paper saturated with UF resin in the first stage is coated with MF resin simultaneously on top and bottom sides by means of two gravure roll coaters in second stage and then is dried to a controlled b-stage level through hot air floatation ovens. A schematic representation of a two stage impregnation line with gravure roll coater is illustrated in Figure 1 [9].

Table 3: Properties of pristine Montmorillonite used for nanocomposite preparation.

Purity (%)	Density (g/cm^3)	d_{001} (Å)	Ave. particle size (µ)	Modifier	Commercial code	C.E.C
None	8	11.7	2.86	92	Cloisite Na+	90-95 meq/100g

Table 4: Composition of coatings.

Resin system	Weight percent of different additives added to the MF resin			
	Antiblocking (FA)	Antidusting (GMEcp)	Plasticizers (THP +DEG)	Catalyst (KS)
0.4	2.0 + 2.0	0.4	0.4	MF

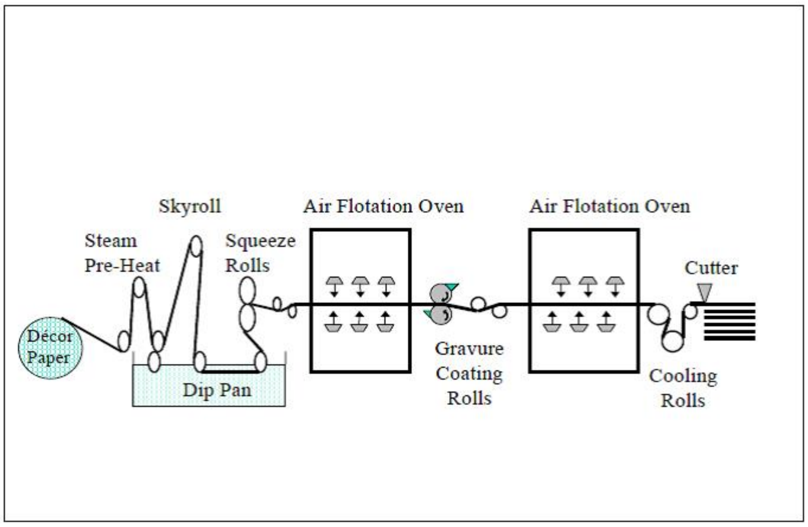


Figure 1: Schematic representation of a two stage impregnation line with gravure roll coater (Reproduced by Permission from TAPPI).

Figure 2: Prepregs coated with MF/montmorillonite nanocomposite.

Due to the lack of such a laboratory gravure roll coater, a flat painting brush with very thin bristle head was utilized for coating practice in this study. In this method, the amount of each coating substance (i.e. nanocomposite) for coating the top surface and formulated MF resin mixture without nanoclay for coating the bottom surface were calculated for each level of nanoclay loading. First, the bottom surface was coated. After a partial drying for 2 hr (not to be sticky), the top surface was coated. Based on the concentration of MF resin (i.e. 52 wt %) used in this study and considering the area of 10 × 15 cm^2 of the paper sample, the total amount of ~ 50-55 g dry MF resin (30-35 g on top side and about 20 g on the bottom side) per square meter of the prepreg samples was achieved. The final basis weight of prepreg in this method reached about 195-200 GSM which reasonably corresponds to the tolerance of impregnated paper basis weight in the industry.After coating, the impregnated paper prepregs as shown in Figure 2, were kept at room temperature for another two hours and then procured to the final volatile content of 6.5-7 % using two drying ovens. The impregnated paper samples were put in first oven at 90 ^{o}C for 3 minutes and then in the second oven at 125 ^{o}C for 2.5 minutes. The prepreg samples were kept in closed plastic bags to prevent from exchanging moisture with the environment and to be used for characterization and evaluation tests.

2.4. Characterization Methods

2.4.1. Structure and morphological characterization of the nanocomposites

The structure of the nanoclay and the morphology of the nanocomposites were characterized by wide angle X-ray diffraction (WAXD) and Field Emission Scanning Electron Microscopy (FESEM).

The degree of interlayer distance of the clay nanolayers in the fully cured nanocomposite samples was determined by WAXD. The ultrasonicated blends of MF resin/clay at 1 and 4 % clay loading levels were held at room temperature and in lidded bottles for about nine months to be fully cured and be analyzed by X-ray diffraction. The diffraction patterns were obtained using a Philips analyzer model PW 1800 with $Cu_{k\alpha}$ radiation (wavelength = 1.542 Aº) at a step size of 0.04° and a scan rate of 2.4° /min from 4° to 60° for nanocomposites and from 4° to 25° for pristine Na^+MMT. The $Cu_{k\alpha}$ radiation was filtered with a thin Ni filter. The Na^+MMT clay and cured nanocomposite powders were analyzed by WAXD.

To prepare the FE-SEM samples, prepregs were fractured, and the fractured surfaces were gold coated using Emitech K450 gold coater. FE-SEM micrographs were obtained using the MIRA 3-XMU TESCAN electron microscope (10 kV and 15 kV) from the cross section of the nanocomposite coatings at different magnifications.

2.4.2. Dynamical Mechanical Thermal Analysis

The neat MF prepreg and nanocomposite prepregs samples were analyzed using DMTA Analysis Instrument. Analysis was done using a temperature ramp method from 25 ºC to 200 ºC at a ramp rate of 3 º C /min and in the tensile geometry at 1Hz and 0.02 % strain. In each DMTA graph, three curves as Modulus of Storage curve, Modulus of Loss curve and Tan δ curve were obtained.

2.4.3. Tensile Properties

The tensile test was performed according to ASTM 5035 Standard Test Method for Textile Tensile Strength with some modification in sample preparation. The impregnated paper prepregs samples were cut into rectangular strips in the paper machine direction (MD), having dimensions of 25 mm width and 60 mm length. The test was conducted at room temperature using an INSTRON Model 5566 testing machine and at a loading speed of 5 mm/min. The Young's modulus, tensile strength, toughness and tensile strain of different prepreg samples were obtained.

2.4.4. Abrasion Resistance Property

The nanocomposite prepregs were short cycled hot pressed on HDF boards with dimensions of 10 cm × 10 cm × 8 mm, by a Burkle laboratory press and then these cured laminates were used for abrasion resistance test. Table 5 shows the conditions of Burkle laboratory hot press for preparing different laminate samples. The abrasion tests were done using a Rotary Platform 5135 Model Taber Abraser. The Calibrase CS -17 was selected as Abrasive Wheels for performing this test.

3. Results and Discussion

3.1. X-ray diffraction

XRD is used to evaluate the degree of clay platelets dispersion in polymer matrixes [10]. Figure 3 represents the X-ray diffraction patterns of pristine Na^+MMT and fully cured MF/montmorillonite nanocomposites containing 1% and 4% nanoclay. The strong peak at 2θ ~ 7.6° corresponds to Na^+MMT and a d-spacing of 11.7 Aº according to the Bragg's equation. The XRD pattern of MF mixed with 4% Na^+MMT shows a downward shift in 2θ angle from 7.5° to 5.6° with a very low intensity peak. The calculated d-spacing of pristine Na^+MMT increased from 11.7 Aº to about 15.6 Aº in the nanocomposite

Table 5: Laboratory press conditions for preparing different laminate samples.

Press time (second)	Specific Pressure (kg/cm^2)	Temperature (° C)
185	35	25

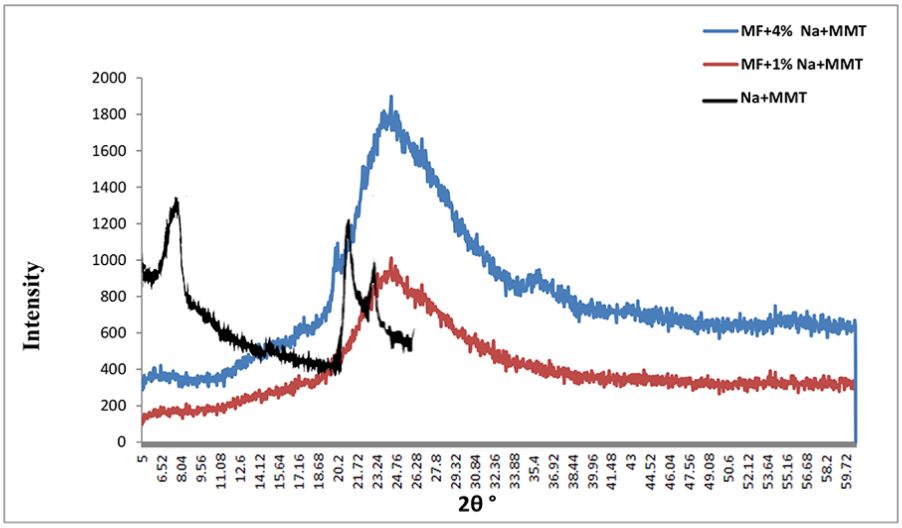


Figure 3: X-ray diffraction spectra of pristine Na^+ MMT and cured nanocomposites.

containing 4% nanoclay. The increment observed in the basal spacing of pristine nanoclay indicates a degree of derangement (intercalation) of clay crystalline structure in the nanocomposite containing 4% nanoclay prepared using ultrasonic mixing technique. The intercalation of pristine nanoclay in the MF resin used for manufacturing of particleboard was reported in previous literatures [11], while there was no report about the intercalation of 4% Na^+MMT nanoclay in the MF resin suitable for impregnation of décor paper using ultrasonication mixing technique.

The XRD pattern of the cured nanocomposite containing 1% nanoclay is also illustrated in Figure 3. The strong peak at 7.6° for Na^+MMT disappeared in the XRD pattern of the MF resin mixed with 1% Na^+MMT indicating a complete disordering of the nanoclay crystalline structure. The lack of XRD peak suggests either an exfoliated or an intercalated disordered nanocomposite [12]. Therefore, an effective dispersion of pristine clay platelets in the MF resin matrix occurred at 1% clay loading using ultrasonication dispersion method in this study. The exfoliated morphology of Na^+MMT nanoclay in the UF and MF resin matrixes was also reported in previous studies [1, 4, 11, 13, 14].

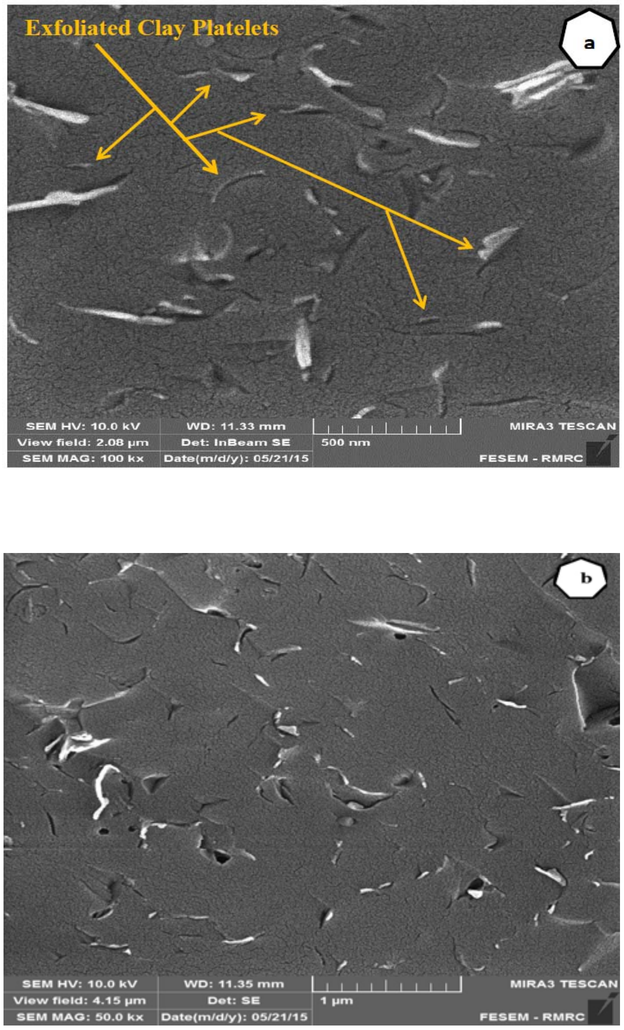
3.2. Field Emission Scanning Electron Microscopy

The FESEM micrographs of the clay morphology in the MF/clay nanocomposite structure are shown in Figures 4 and 5. As can be seen from Figures 4a and 4b, the clay nanolayers with exfoliated morphology exist in the ultrasonically prepared MF/clay nanocomposite coatings structure at 1% clay loading. Moreover, a mixed morphology of exfoliated platelets and stacked layer structures as clay intercalated tactoids is also observed in the micrograph of the nanocomposite coatings containing 4% clay in Figure 5.

The characterization of nanoclay morphologies in the structure of nanocomposites obtained by FE-SEM micrographs are in complete agreement with the results of XRD analysis suggesting that the FE-SEM technique can be a useful tool to a great extent for further analysis of the intercalated and exfoliated nanocomposites inferred from XRD patterns particularly for characterization of the polymer clay nanocomposites with thermosetting brittle polymeric matrix like melamine formaldehyde.

3.3. Viscoelastic Properties of MF/clay/cellulose nanocomposite prepregs

Under the exposure of heat and force in DMTA test, in addition to gelation and vitrification transformations, the impregnated paper has shown a softening area which is the onset of MF resin flow. In fact, the thermoset prepreg shows a thermoplastic behavior in the softening area. This area which is characterized as first peak in Tan δ curve lasts longer and to higher temperature when nanoclay introduces into the MF resin matrix.



Figures 4: (a, b) FESEM micrographs of exfoliated platelets at 1% clay loading.

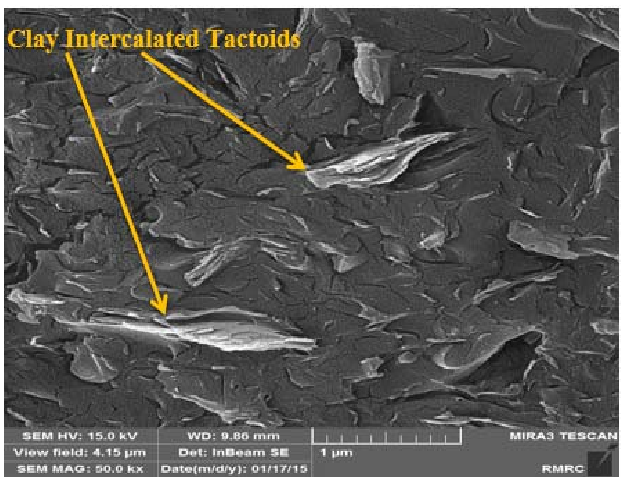


Figure 5: FESEM micrograph of intercalated tactoids at 4% clay loading.

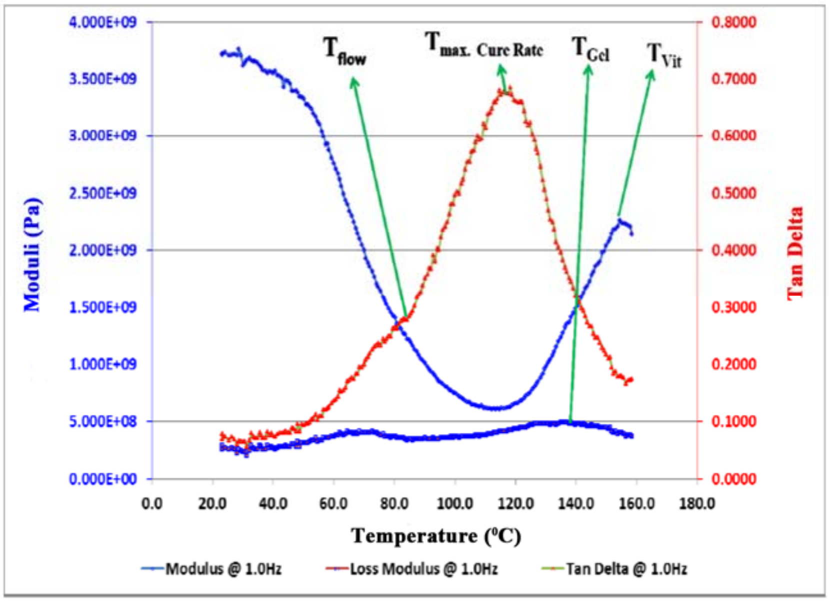


Figure 6: DMTA curves of neat melamine formaldehyde prepreg.

As illustrated in Figures 6, 7 and 8, the MF resin starts to flow at around 84 ºC in the impregnated paper without nanoclay particles, at 94 ºC in the prepreg coated with nanocomposite containing 1% nanoclay and 105 ºC in the sample containing 4% nanoclay. This is because nanoclay platelets with high aspect ratio and very high specific surface area can bond chemically (ionic and intermolecular hydrogen bonds) and entangle physically with MF molecules in the resin matrix and hinder their mobility to flow. This hindering effect of silicate nanolayers on MF molecules mobility restricts resin flow. Thus MF resin incorporated with nanoclay particles has lesser tendency to flow. Resin flow is an important parameter in utilizing these melamine impregnated film particularly for parameter optimization in hot press machines operating with shorter cycle time.

The second tan δ peak transition can be used to characterize the peak reaction temperature at which the curing reaction reaches at maximum rate. It was found that changes of the peak reaction temperature depend on the morphology of dispersed clay in the nanocomposite structure. The results suggest that the peak reaction temperature of MF resin in the nanocomposites decreased at 1% clay loading level and then slightly increased at 4% clay loading compared to the neat MF resin. A decrease in peak reaction temperature indicates a higher curing rate. It was observed that the peak curing reaction temperature decreased from around 115 °C in the neat MF resin (Figure 6) to around 106 °C in the nanocomposite containing 1% clay (Figure 7) and then increased to around 117 °C in the nanocomposite containing 4% clay (Figure 8). These results could be due to the formation of exfoliated morphology of dispersed clay platelets in the nanocomposite structure containing 1% clay and intercalated morphology of clay platelets in the nanocomposite structure containing 4% clay as confirmed by XRD and FE-SEM. While the results of previous studies [1, 4] showed that the exfoliated clay platelets in the MF/montmorillonite nanocomposite structure have a decelerating effect on curing rate of MF resin, the findings of present study indicated higher curing rate of MF resin in the presence of exfoliated platelets. This could be attributed to the effect of the presence of catalyst in the exfoliated nanocomposites which was not investigated in the mentioned previous literatures. However, further research is needed to achieve better understanding on the exact mechanism of how exfoliated nanoclay platelets accelerates curing rate of the catalyzed MF resin.

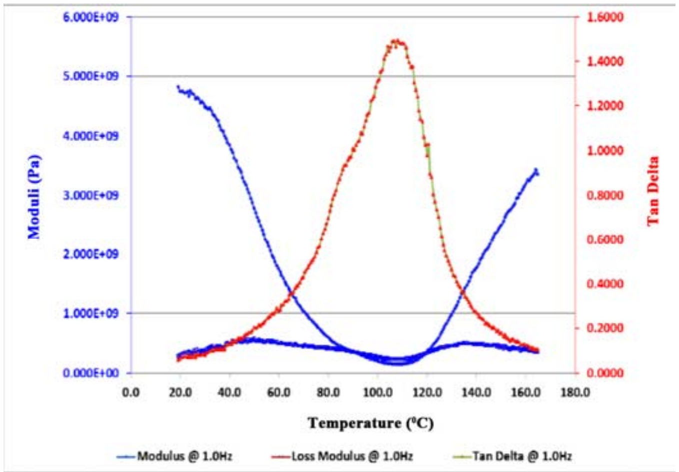


Figure 7: DMTA curves of nanocomposite prepreg containing 1 % nanoclay.

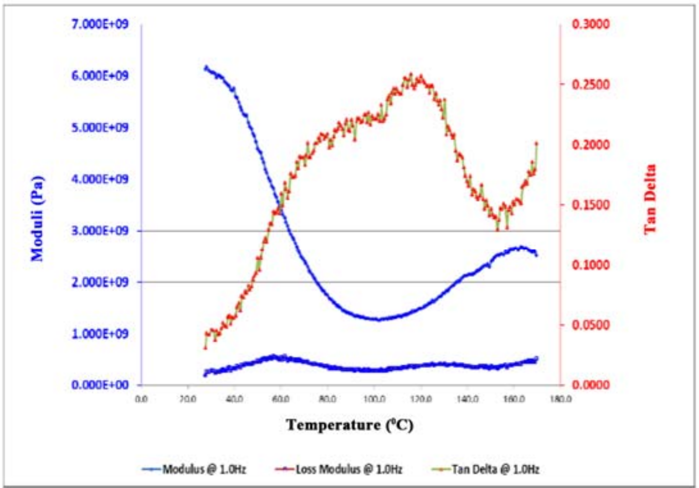


Figure 8: DMTA curves of nanocomposite prepreg containing 4% nanoclay.

Moreover, the peak transition temperature in the modulus of loss curve is characterized as a function of temperature at which gelation occurs [15]. It was observed that gelation point of melamine resin containing 4% nanoclay occurs at lower temperature (130.5 ^{o}C) or in a shorter time compared to MF resin containing 1% nanoclay (134.8 ^{o}C) and neat MF resin without nanoclay particles (136.4 ^{o}C). At 4% nanoclay loading level, due to the large amount of clay and the presence of the intercalated tactoids in the resin matrix as confirmed by FE-SEM, viscosity increases significantly and gelation occurs in advance.

Vitrification is that phase transformation of a curing thermosetting resin corresponding to the formation of a glass solid. The polymerization becomes diffusion-controlled and may continue very slowly. Knowledge of vitrification time may also be useful to optimize cure cycle times [16]. Vitrification is also characterized as maximum point in the modulus of storage curve in the DMTA analysis [15]. It was observed that the vitrification point increased from around 154 ^{o}C in the regular melamine film containing no nanoclay to 164 ^{o}C in the nanocomposite prepregs containing 1% and 4% nanoclay. The increase in the vitrification point could be attributed to the diffusion- controlled nature of the MF resin polymerization reaction at this stage and further hampering effect of dispersed clay nanolayers on MF resin molecules mobility in the matrix. Due to the better dispersion of clay nanolayers, the storage modulus of the nanocomposite containing 1% nanoclay, was found to be higher (3.425 GPa) than that of nanocomposite containing 4% nanoclay (2.677 GPa) and pristine MF polymer (2.265 GPa). This means that in comparison with pristine polymer, around 51% and 18 % increments in storage modulus or stiffness of nanocomposites containing 1% and 4% nanoclay were achieved, respectively. Almost all studies on polymer/clay nanocomposites have reported large improvements in stiffness (modulus of elasticity) and strength compared to their corresponding pristine polymers, particularly when the clay is in the exfoliated morphology. This was commonly attributed to the high aspect ratio of rigid clay nanolayers and huge interfacial contact area between clay and polymer matrix. The extent of improvement in a polymer matrix, however, is dependent on many factors like the extent of exfoliation, type of clay, spatial distribution/orientation of clay layers [17-23].

3.4. Tensile test

The tensile properties of different impregnated paper prepregs are summarized in Table 6 and Figure 9. The results show that the incorporation of nanoclay into the MF matrix improved both Young's modulus and tensile strength. But the amount of this enhancement noticeably depends on the morphology of dispersed clay in the nanocomposite structure at each clay loading level [23]. According to Table 5, the nanocomposite prepreg containing 1% clay was found to have higher Young's modulus (1.217 GPa) compared to prepreg containing 4% clay (0.627 GPa) due to the better dispersion and greater reinforcing effect of exfoliated clay platelets in the MF polymeric matrix containing 1% clay. In other words, this could be due to the formation of clay agglomerates in the nanocomposite structure at 4% clay loading as shown by FE-SEM in Figure 5. Aggregation of clay particles has been shown to reduce the amount of reinforcement that can be provided by the clays resulting in less enhancement of the Young's modulus [24]. The maximum Young's modulus obtained in the tensile test is completely consistent with the maximum modulus of storage (stiffness) observed in the DMTA test for the exfoliated nanocomposite prepreg containing 1% clay.

Figure 9 shows the toughness of different prepregs as a function of clay content incorporated in the MF resin matrix. The toughness which has the unit of Joule is defined here as the amount of energy per unit volume that a prepreg can absorb before rupturing. It is determined by integrating the stress-strain curve obtained from the tensile test for each prepreg sample.

Table 6: Tensile properties of various prepreg samples.

Clay content (%)	Tensile strength (MPa)	Toughness (J)	Young's modulus (GPa)	Strain (%)
0	19.79	0.01	0.618	3.19
1	25.19	0.02	1.217	2.08
4	25.08	0.05	0.627	4.03

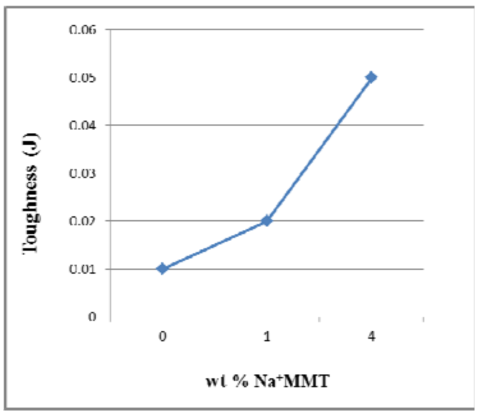


Figure 9: Toughness of various prepreg samples.

It is generally accepted that the major contribution to the toughness of polymers comes from plastic deformation mechanisms. In fact, toughness is a balance of strength and ductility. It can be conclude from table 5 that the nanocomposite prepreg containing 4% clay has the maximum toughness and tensile strain among the three prepregs analyzed. This result could be attributed to the formation of clay intercalated morphology as a toughening phase resulting in enhancement of both toughness and plastic deformation of prepreg containing 4% clay. It should be noted that the majority of the studies on binary polymer/clay nanocomposites have shown a drop in toughness. This is particularly true when clay is well exfoliated in the matrix. Because it is believed that the presence of a stiff nano-filler will hinder the mobility of the surrounding chains, and thus limit its ability to undergo plastic deformation [25-30]. Despite this, there are some studies pointing to a dramatic increase in fracture toughness of binary polymer/clay nanocomposites, particularly when clay is intercalated [31-38]. However, More research is needed to be done for understanding how and based on what exact mechanism the nanoclay morphology affects the toughness and plastic deformation of MF polymeric matrix in the nanocomposite structure.

3.5. Abrasion Resistance Evaluation of Cured MF/clay Nanocomposite coatings

As mentioned earlier, the MF/clay nanocomposite prepregs were laminated on 8 mm thick HDF board using a Burkle laboratory short cycle hot press in order to evaluate the abrasion resistance property. For having a logical comparison between different laminated samples, one sample of laminate flooring containing AC_3 class overlay layer and one sample of regular melamine laminated board was also prepared using Burkle press. Then, abrasion test was performed on laminated samples using Rotary Taber Abraser with CS-17 abrasive wheels. The results are reported as Wear Index per 1000 revolutions of abrasive wheels in Table 7 This test was done on pristine melamine laminate, nanocomposite laminates at different clay loading levels and for a sample of AC_3 class laminate flooring.

It can be concluded from the results of Taber abrasion test in Table 5 that around 48% and 61% improvements in abrasion resistance property of pristine melamine laminate were observed with incorporating of 1% and 4% nanoclay into the MF polymeric matrix, respectively. As can be seen from Figures 10 a and 10 b which illustrate the fracture surface and thickness of nanocomposite prepregs at 1% and 4% nanoclay loadings, thickness of the nanocomposite coatings for the two samples are approximately the same (36.5 and 38 microns, respectively), but the abraded appearance of the latter is remarkably different from the former.

Moreover, while the impregnated paper containing 4% nanoclay has lower modulus of storage (stiffness) compared to the film containing 1% nanoclay, it's Taber abrasion resistance property was found to be better which is attributed to the clay intercalated tactoids in the MF resin matrix at 4% clay loading. Figure 11 a, b, c, d show the abraded appearance of different laminates after Taber abrasion test at 1000 revolutions of CS-17 abrasive wheels. Although it was reported in literatures that the intercalated morphology of clay can improve plastic deformation and fracture toughness of some binary polymer clay nanocomposites [31, 38], the results of the study emphasize that clay intercalated morphology may contribute to the improvement of toughness and Taber abrasion resistance of such polymer/clay nanocomposite coatings with a brittle polymeric matrix like MF.

Table 7: Taber abrasion test results for different laminate samples.

Laminate sample	Abrasive Wear Index (mg /1000 revolutions)
neat melamine laminate (**a**)	106.5 mg
Nanocomposite laminate with 1 % nanoclay (**b**)	55.3 mg
Nanocomposite laminate with 4 % nanoclay (**c**)	41.3 mg
AC_3 class Laminate flooring (**d**)	5.5 mg

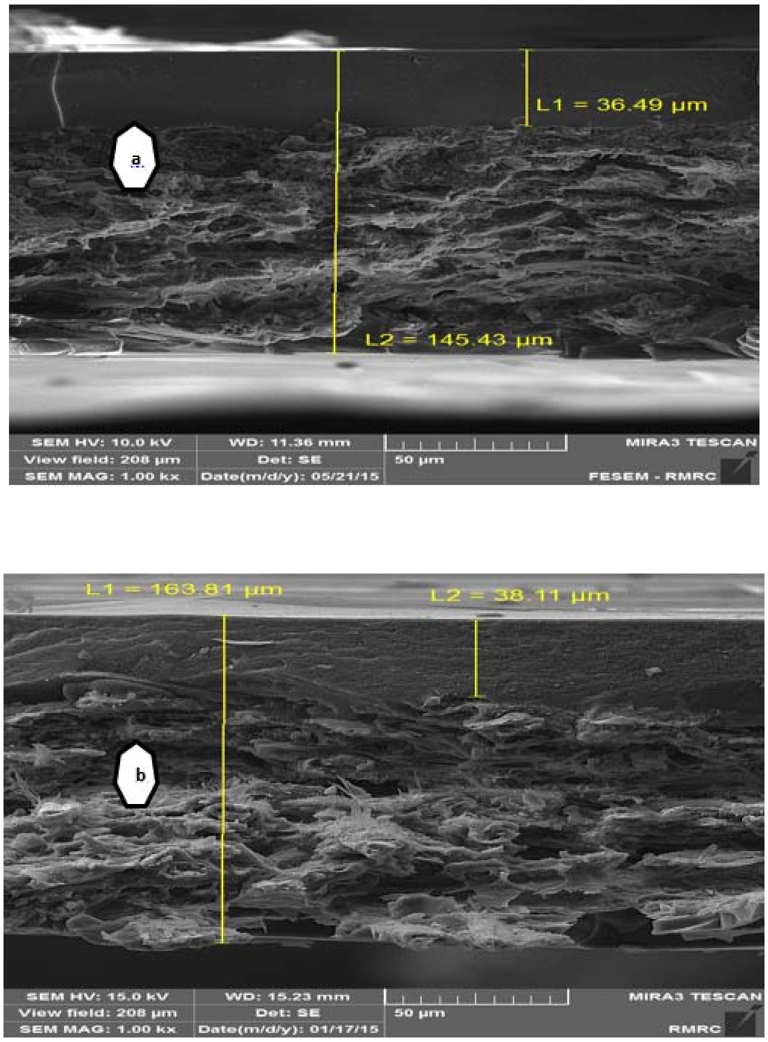


Figure 10: FE-SEM micrographs from thickness of nanocomposite prepregs at 1% (a) and 4% (b) nanoclay.

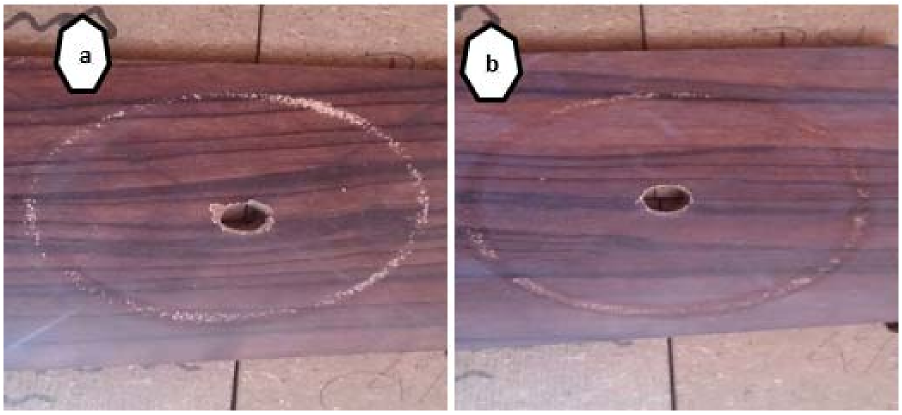


Figure 11: Abraded appearance of different laminate samples.

Figure 11: Continued.

4. Conclusions

In this study, preparation and abrasion resistance evaluation of melamine formaldehyde/montmorillonite nanocomposite coatings was carried out. The X-ray diffraction patterns and FE-SEM micrographs confirmed the exfoliation and the intercalation of clay platelets in the montmorillonite/MF nanocomposite structure containing 1 wt % and 4 wt % clay, respectively. The effect of pristine Na^{+}MMT on polymerization and viscoelastic behavior of MF resin in the impregnated paper prepregs was analyzed using DMTA method. The results showed that the pristine hydrophilic nanoclay speeds down the MF resin flow in the impregnated paper at both 1 wt % and 4 wt % clay loading levels. In addition, it was observed that the peak curing reaction temperature depends on the degree of nanoclay dispersion in the MF resin matrix. While previous studies reported the decelerating effect of exfoliated clay platelets on curing rate of the MF resin, the findings of present study suggest that the exfoliated morphology of nanoclay platelets decreased the peak reaction temperature of the catalyzed MF resin. This may be attributed to the presence of catalyst which was not the area of focus in previous literatures. It was also found that the storage modulus (Young's modulus) of the exfoliated nanocomposite containing 1% nanoclay was higher (3.425 GPa) than that of the intercalated nanocomposite containing 4% nanoclay (2.677 GPa) and pristine MF polymeric matrix (2.265 GPa). Finally, the results of the study suggest that clay intercalated morphology likely contributes to the improvement of toughness and Taber abrasion resistance of MF/montmorillonite nanocomposite coatings. However, more research should be done to understand the mechanistic effect of clay intercalated morphology on enhancing tribological properties of MF/montmorillonite nanocomposites.

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