EFFECT OF NANOPARTICLES ON TENSILE AND IMPACT PROPERTIES OF FRP AND SANDWICH FRP LAMINATES BY HAND – LAYUP TECHNIQUE

Anbusagar N.R.R.[1] **and Giridharan P.K.**[2]

[1]Research Scholar, Department of Mechanical Engineering, Sathyabama University, Chennai, India.
[2]Department of Mechanical Engineering, Shri USB College of Engineering & Management, Rajasthan, India.
Email: [1]asr2775@gmail.com

ABSTRACT

An advanced composite, like fibre-reinforced polymer (FRP), sandwich FRP composite has been favored for certain aerospace, military, marine and automotive applications. Polymer nanoscale composites containing layered silicates have attracted much attention. These nanoscale materials often exhibit mechanical, physical, thermal, ionic conductivity and chemical properties that are dramatically different from conventional microcomposites. In this research work we have developed ten different combinations of FRP and sandwich FRP composites with nanoclay (montmorillonite) by hand lay-up manufacturing techniques (HL). Composite samples were tested for tensile strength, impact strength, and moisture absorption. The measurement showed that the tensile strength and impact strength are greatly increased, over the range of nanoclay loading. A plausible explanation for high increase of properties has also been discussed.

Keywords: Nanocomposites, FRP, Sandwich FRP composite, Montmorillonite

I. INTRODUCTION

Glass fibre reinforced polymer is one of the fastest growing classes of thermosetplastics. This growth is attributed to its attractive combination of low cost, low density, and high heat distortion temperature (HDT). We are entering into the gateway of next generation “nanotechage”, where smaller and shorter things will play a big role. Nanotechnology will find its application in energy, medicine, electronics, computing, security and material sciences, etc. Nano clay is the most commonly used tool for the preparation of nanocomposites. Montmorillonite, hectorite, and saponite are the most commonly used Montmorillonite layered silicates. Layered silicates have two types of structure: tetrahedral-substituted and octahedral substituted. The main attraction of polymer (Polyester resin) is its high performance-to cost ratio. Polymers can also be easily modified to achieve greatly enhanced properties. With regard to reinforcement effects, considerable research can be found in recent literature [1] on improving mechanical properties of polymer using various kinds of fillers. It is now well recognized that the use of inorganic fillers is a useful tool for improving mechanical properties of polymer [2]. Polymer nano composites (PNC) are now prepared by different methods, namely, Brabender mixer and Hand mixing. PNCs are also made using a large variety of thermoplastic polymers [3]. Also considerable research can be found in recent literature [4] on improving mechanical properties of Polymer using various kinds of fibre fillers in various compositions. The nano composite fibre reinforced plastic has sufficiently high ultimate tensile strength and 23% improvement of ultimate tensile strength at 5 wt% increment of nano powder. Impact strength increases to 10 J/mm^2, an addition of 10 wt% of nanopowder [5].

The foams having high compressive strength and modulus can be fabricated by using high density micro balloons (350 – 460 kg/m^3). However, such foams suffer from disadvantages of high density and low fracture strain of about 8 - 10%. It is observed that syntactic foams using low density micro balloons (200 – 350 kg/m^3) have lower strength but their fracture strain is about 15 - 20% [6]. Hence, there is a need to modify the phase structure of syntactic foams in order to achieve a combination of high strength and high fracture strain to improve the toughness and damage tolerance of high density foams. Published studies have shown that the use of nanoclay particles increases the tensile strength, modulus, resistance to thermal failure, and impact resistance of polymers [7]. This improvement in performance has been attributed to the unique phase morphology and better interfacial properties in the nanocomposite [8,9]. In conventional composites, phase mixing occurs on a macroscopic scale, whereas nanocomposite materials are formed when phase mixing occurs on a nanometer length scale

[7]. A large number of interfaces are created in a nanocomposite upon dispersion of nanoparticles, resulting in an increase in strength of the composite matrix [10]. Desired result of increase in fracture strain of high density and high strength syntactic foams was achieved in the study through micro structural modification. Nanoclay particles are incorporated in the matrix resin system of syntactic foams for this purpose [11].

The nano-FRP has sufficiently high ultimate tensile strength and 50% improvement of UTS at 5 wt. % increment of nanopowder. Elongation increases with the addition of nanopowder 0.5 wt. %; improvement in elongation was observed with the addition of 5% NP. Moreover, 3.9% improvement in elongation was observed with the addition of 10% NP. Yield strength increases into 7.24 N/mm^2 with the addition of 5% NP. Poisson ratio moderately increases with an addition of nanopowder wt. %. A 50% improvement in Poisson ratio was observed at 5 wt. % increment of nanopowder [12]. In another study the preparation and characterization of PU nanocomposite foams were also described and Clay dispersion is affected by foaming process [13].

The present study is to investigate the mechanical behavior of a FRP and sandwich FRP conceived as a lightweight material for naval engineering applications by means of incorporation of nanoclay particles.

II. MATERIALS AND METHODS

A. Materials

The plain weave glass fabric 360 g/m^2 are supplied by binani industries limited, Mumbai, India. Polyester was used as resin. Methyl ethyl ketone peroxide and cobalt naphthanate were used as catalyst and accelerator respectively. GEN-M-01-03002R04 Medium density foam sheet in squares 10 mm were used as a core material for sandwich structure. Cloisite1 Na is a natural, untreated montmorillonite type of clay, supplied by Southern Clay Products Inc. (Gonzales, TX). The specific gravity and mean particle size of Cloisite1 Na is reported as 2.86 and 6 lm, respectively, by the supplier. According to the x-ray diffraction results provided by the supplier, the gallery spacing of Cloisite1 Na is 11.7 Å and having CEC 2.6 meq/100 g clay

B. Preparation of Nanocomposites

Prepare molding box with the required size and use wax polish and polyvinyl alcohol which acts as a releasing agent. Apply the mixture of nanopowder and polyester resin (2, 4, 6 and 8% wt of clay) over the fiber mat of 300 cm square for a setting period of 12 - 24 h. All specimens were prepared as per ASTM standards. The specimens were carefully cut from the panels using a diamond saw with sufficient allowance for finishing. Final dimensions were obtained by finishing the samples using medium grade emery paper. Table1 shows various combinations of polyester resin, fiber, foam and nanopowder (montmorillonite) in wt. %. Specimen S1 was prepared in the combination of PR, and FR only. Specimens S2, S3, S4 and S5 were prepared by changing the wt.% of nanopowder. Specimen S6 was prepared in the combination of PR, FR and foam and Specimens S7, S8, S9 and S10 were prepared by changing the wt. % of nanopowder

Table 1. Combination of polyester resin, fibre, foam and nanopowder.

Specimen	Combinations	%	Weight (g)
S1	PR/FR	66.6/33.3	400/200
S2	PR/FR/NP	66.6/33.3/2	400/200/8
S3	PR/FR/NP	66.6/33.3/4	400/200/16
S4	PR/FR/NP	66.6/33.3/6	400/200/24
S5	PR/FR/NP	66.6/33.3/8	400/200/32
S6	PR/FR/F	64/32/4	400/200/20
S7	PR/FR/F/NP	64/32/4/2	400/200/20/8
S8	PR/FR/F/NP	64/32/4/4	400/200/20/16
S9	PR/FR/F/NP	64/32/4/6	400/200/20/24
S10	PR/FR/F/NP	64/32/4/8	400/200/20/32

PR-Polyester resin, FR-Fibre, F-Foam, NP-Nanopowder

C. Characterization

a. Mechanical characterization

Specimens of FRP composite and sandwich FRP nanocomposites of dimensions 250 $\times$ 25 mm were subjected to tensile test as per ASTM D-638 using universal testing machine (UTM) LR-100K (Lloyd Instrument Ltd U.K). A cross head speed of 50 mm/min and gauge length of 25 mm was used for carrying out the test. Impact tests are designed to simulate the response of a material to a high rate of loading and involve a test piece being struck a sudden blow. There are two main forms of tests, the Izod and Charpy tests. The Chapy impact strength was determined from the specimens having dimensions 127 × 10 mm accordance with ASTM D6110. Five replicate specimens were used for each test and the data reported are the average of five tests. Corresponding standard deviations along with measurement uncertainty values for the experimental data showing the maximum standard deviation is also included.

b. Scanning electron microscopy

Scanning electron microscopy is utilized to analyze the tensile fractured surfaces of FRP composite and sandwich FRP nanocomposites. Through-the-thickness surfaces of the samples are polished using a series of aluminum oxide lapping films down to 1 lm grit size. The samples were then coated with gold-palladium to render the surface conductive and prevent charging. All specimens were examined with EO MA15 high resolution microscope in secondary electron imaging mode at magnifications of 1000x.In addition to the polished surfaces, the fracture surfaces of the mechanically tested samples are also studied under SEM to identify any change in adhesion between epoxy matrix and glass fibers because of nanoclay

III. RESULTS AND DISCUSSION

A. Mechanical Properties

The mechanical properties of FRP composite and sandwich FRP nanocomposites are summarized in Table 2.

Table 2. Mechanical properties of FRP and sandwich FRP nanocomposites

S No	Specimen	Tensile strength (Mpa)	Tensile modulus (Gpa)	Impact strength (kJ/m^2)
1	S1	80.52	7.93	20.35
2	S2	79.20	7.29	25.45
3	S3	85.20	8.42	19.30
4	S4	78.23	7.70	27.72
5	S5	55.70	4.49	32.63
6	S6	79.18	2.19	24.32
7	S7	72.50	1.99	25.68
8	S8	82.50	2.32	23.83
9	S9	69.83	2.13	26.59
10	S10	57.73	1.17	36.21

Fig. 1 illustrates the plots of tensile strength in MPa versus specimens of FRP composite in various clay combinations. It has been seen that the specimen S1 yielded 80.52 MPa for 33% of fibre. Specimen S2, yielded 79.20 MPa for the increment of 2% nanopowder. Tensile strength increced by 5.8% due to addition of nanopowder which yielded 85.20 MPa (S3) for the increment of 4% nanopowder due to better bonding between fibre and polyester resin. Specimens S4 and S5 yielded 78.23 MPa and 55.70 MPa respectively. Tensile strength has been reduced to 2.8% and 30% due to further addition of nanopowder at 6% and 8% respectively; addition of nanopowder has been reducing the bonding strength. A similar trend for the tensile modulus of the nanocomposites is shown in Fig. 2.

Fig. 3 illustrates the plots of tensile strength in MPa versus specimens of sandwich FRP composite in various clay combinations. The tensile strength displayed considerable increase over the range of nanoclay loading. The tensile strength for the sandwich FRP composite sample without nanoclay is measured as 79.18 MPa. The tensile strength decreased to 72.50 MPa at 2 wt% and increced to 82.50 MPa at 4 wt% nanoclay loading. A sharp decrease subsequently occurs with 6 and 8 wt. % specimens dropping to 69.83 MPa and 57.73 MPa for the strength respectively. A similar trend for the tensile modulus of the sandwich FRP nanocomposites is shown in Fig. 4. Mechanical property improvements due to nanoclay loading are reported more frequently for weak polymers such as polyester resin and rubbery epoxies. For instance, the tensile modulus of 3 MPa for the epoxy matrix without nanoclay increased to 35 MPa at 23.2 wt% loading as reported by Lan and Pinnavaia [15]. Similarly, Boukerrou et al. [16] was reported that tensile modulus for neat epoxy to change from 0.56 MPa to 0.76 MPa at 5 wt% nanoclay loading. Considering that the values of elastic moduli of nanoclay platelet are reported to be ranging between 20 and 400 GPa [17], such improvements are not surprising [18]. However, even after such improvements, the effectiveness of these polymers is superseded by composites comprising conventional fiber reinforcements [1,5 and 12].

The increase in impact strength for a nanoclay loading at 8 wt. % is by the formation of exfoliated nanoclay structures shown in the SEM analysis. Figure 5 and figure 6 shows an increase in impact strength at 8 wt. % loading in both FRP composite and sandwich FRP composite

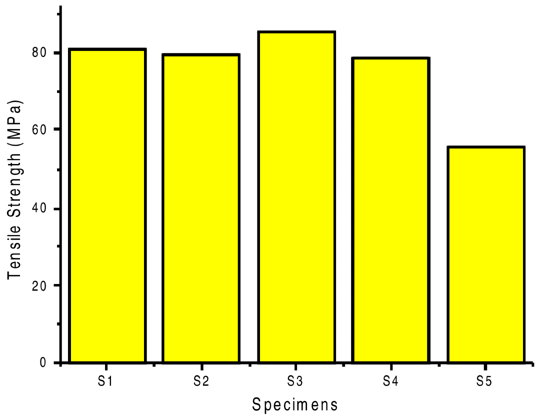

Fig. 1. Tensile strength Vs FRP Specimens

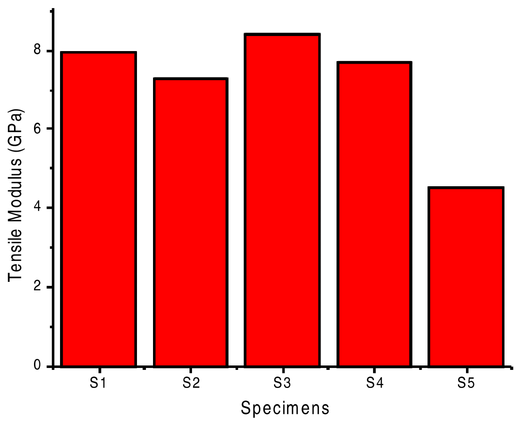

Fig. 2. Tensile modulus Vs FRP Specimens

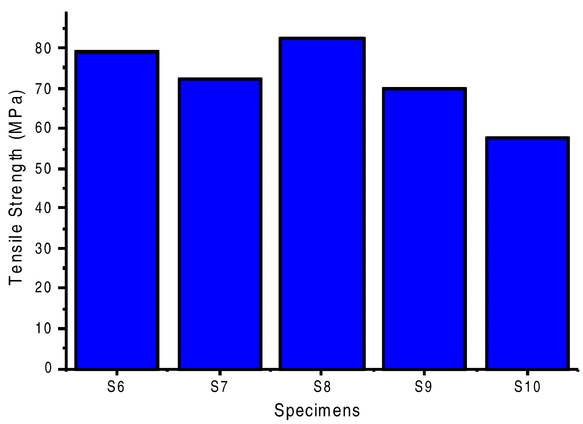

Fig. 3. Tensile strength Vs Sandwich FRP Specimens

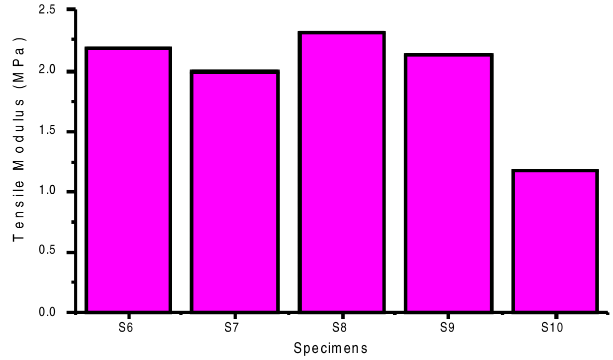

Fig. 4. Tensile modulus Vs Sandwich FRP Specimens

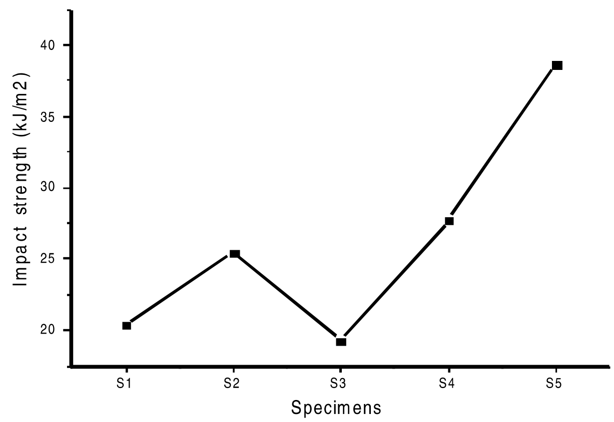

Fig. 5. Impact strength Vs FRP Specimens.

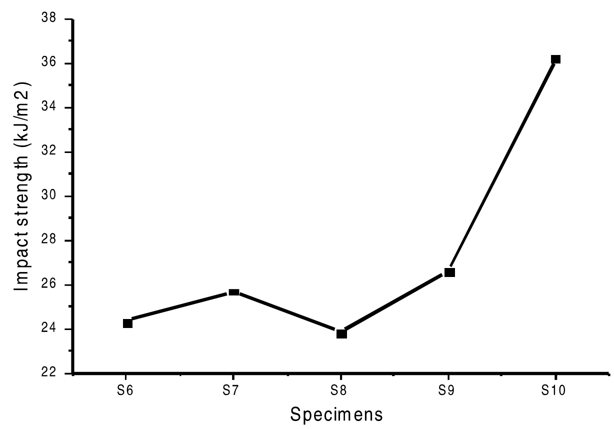

Fig. 6. Impact strength Vs Sandwich FRP Specimens.

B. Scanning Electron Microscopy (SEM) Analysis

The scanning electron micrographs of the polished surfaces of the specimens with 0, 2, 4, 6 and 8 wt % nanoclay are shown in Fig. 7. It is often not possible to see individual nanoclay platelets embedded in a polymer matrix using scanning electron microscopy. However, the surface properties observed in polished nanocomposite specimens is an indication of the uniformity of the nanoclay dispersion. Compared with the specimen without nanoclay, specimen containing 2, 4, 6 and 8 wt % nanoclay display a granular surface topology with geometric features at smaller length scales. In addition, the surface roughness is observed to increase with increasing nanoclay content. These differences in surface topologies are most likely due to the presence of nanoclay clusters. The homogeneity of the surface characteristics of the specimens as observed in low magnification SEM images shown in Fig. 7 (c) and 7 (d) indicates that nanoclay dispersed uniformly within the polyester matrix. Matrix residues that are observed on the fiber surfaces and between fibers are unequivocal signs of good fiber-matrix adhesion. It is interesting to note that the fiber matrix interface contains more matrix material compared to the specimen without nanoclay. Especially the buildup of matrix material around the fibers is notable. Existence of matrix material around the fibers after fracture indicates that effective fiber-matrix adhesion is maintained after the addition of nanoclay.

IV. CONCLUSION

In this study, the tensile strength, modulus, and impact strength, experimentally produced FRP and sandwich FRP nanocomposite in various combinations of nanopowder were investigated at room temperature. The results are summarized as follows. The nanocomposite FRP and sandwich FRP has sufficiently high tensile strength and 7% improvement of tensile strength in FRP composite at 4 wt% increment of nanopowder and 4% improvement of tensile strength in sandwich FRP composite at 4% increment of nanopowder.The modulus of the nanocomposites increases with addition of 4 wt% of nanoclay and impact strength of the nanocomposites increases with addition of 8 wt% of nanoclay. The study of above parameters which can predict the influence of nanoparticle in FRP and sandwich FRP greatly increase tensile strength and, impact strength. Scanning micrographs also revealed improved adhesion of fibers to the matrix material with increasing nanoclay content.

ACKNOWLEDGEMENT

The author would like to thank the Central Instiute of Plastics Engineering and Technology, Chennai, India for testing and Puma Boat yard, Puducherry for manufacturing the nanocomposites.The author also would like to thank Sathyabama University, Chennai-119 and Mechanical engineering Department, SMK FOMRA Institute of technology, Chennai-103 for their facility and support.

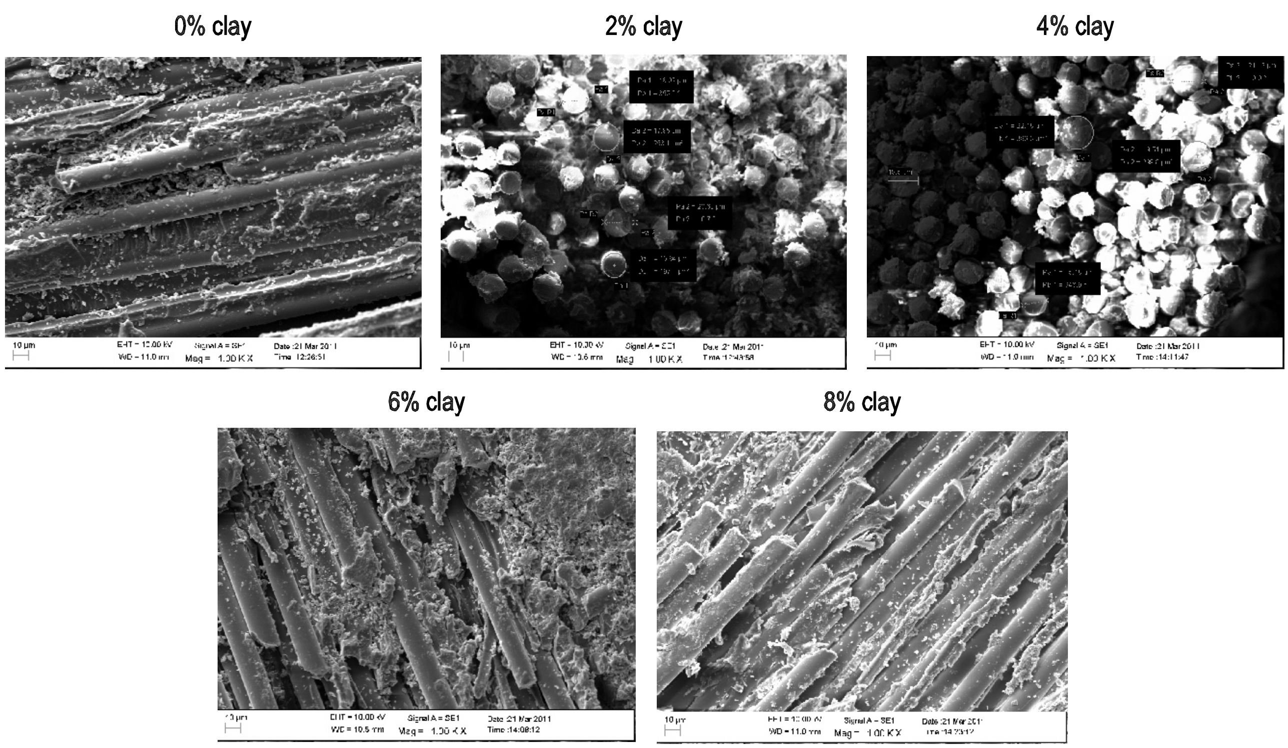

Fig. 7. Scanning electron micrographs of sandwich FRP composite samples with 0, 2, 4, 6 and 8 wt% nanoclay

REFERENCES

[1] Levent Aktas, Cengiz Altan M., 2009, "Characterization of Nanocomposite Laminates Fabricated from Aqueous Dispersion of Nanoclay", Society of Plastics Engineers.

[2] Davallo. M, Pasdar. H, Mohseni. M, 2010, "Mechanical Properties of Unsaturated Polyester Resin", International Journal of chemTechResearch, 2,pp. 2113-2117.

[3] Selvakumar. V, Palanikumar.K, Palanivelu.K, 2010, "Studies on Mechanical Characterization of Polypropylene/Na+-MMTNanocomposites", Journal of Minerals & Materials Characterization & Engineering, 9, pp.671-681

[4] Velmurugan.R, Manikandan.V, 2005, "Mechanical properties of glass/plamyara fiber waste sandwich composites", Indian journal of engg. & Material science,12, pp.563-570.

[5] Nagalingam.R, Sundaram.S and stanly jones retnam.B, 2010, "Effect of nanoparticles on tensile, impact and fatigue properties of fibre reinforced plastics", bull. mater. sci. vol. 33, no. 5

[6] Gupta, N. and Woldesenbet.E, 2004, Composites Part A: Applied Science and Manufacturing 35(1),pp.103–111

[7] Pinnavia, T. J. and Beall, G. W., 2000, "*Polymer-Clay Nanocomposites*", Wiley Series in Polymer Science,

[8] Messersmith, P. B. and Stupp, S. I., 1992, 'Synthesis of Nanocomposites – Organoceramics', Journal of Materials Research, 2599–2611.

[9] Giannelis, E.P., 1996, 'Polymer Layered Silicate Nanocomposites', *Advanced Materials* 8(1), ,29–35

[10] Yasmin, A., Luo, J. J., Abot, J. L. and Daniel, I. M. 2008, Proceedings of ASC, 18^{th} Annual Technical Conference,

[11] Nikhil Gupta, Rahul Maharsia, 2005, "Enhancement of Energy Absorption in SyntacticFoams by Nanoclay Incorporation for Sandwich Core Applications", Applied Composite Materials, 2,pp.247– 261

[12] Sundaram.S , Nagalingam R, Satheesh Raja, 2008, "Experimental analysis on tensile Roperties of FRPwith nano clay",Int J Adv Manuf Technol DOI 10.1007/s00170-008-1868-8

[13] Xia Caoa, James Leea L., Tomy Widyab, Christopher Macosko,2005, "Polyurethane/clay nanocomposites foams: processing,structure and properties",Polymer, 46, pp.775–783

[14] Olivero K.A., Hamidi Y.K., Aktas L., and Altan M.C., 2004, J. Compos. Mater., 38, 937

[15] Lan T. and Pinnavaia T.J., 1994, Chem. Mater., 6, 2216.

[16] Boukerrou A., Duchet J., Fellahi S., Kaci M., and Sautereau H., 2007, J. Appl. Polym. Sci., 103, 3547.

[17] B.Q. Chen and J.R.G. Evans, 2006, Scripta Materialia, 54, 158.

[18] Ngo T.D., Ton-That M.T., Hoa S.V., and Cole K.C., 2006, "Rubbery and Glassy Epoxy-Clay Nanocomposites," in Proceedings of the Sixth Joint Canada-Japan Workshop on Composites. Design, Manufacturing and Applications of Composites, Toronto, ON, Canada, 112