

Effect of Water Absorption on Mechanical Properties of Thermoplastics Nanoclay Composites

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Abstract— Recently many researchers tried to improve mechanical properties of polymers using Nano clay inclusions. In the present study polypropylene (PP), Acrylonitrile butadiene styrene (ABS) and high density polyethylene (HDPE) thermoplastics polymers are considered. Nano clay included polymer composites are fabricated with an intention to enhance their mechanical properties. Often these materials are subjected to moisture hence the effect of water absorption on mechanical properties of these composites are to be studied. Hence, in the present work PP, ABS and HDPE Nano clay composites are fabricated using twin screw extruder for blending Nano clay in different percentage to study the effect of Nano clay weight fraction and water absorption on these properties. Samples fabricated using injection moulding process. Often these materials are exposed to certain temperature and immersed in constant temperature water bath for 150days. More after the water absorption is measured the effect of weight fraction of Nano clay on water absorption is studied. It is also exposed to the effect of water absorption on mechanical properties of PP, ABS and HDPE Nano clay polymer composites.

Key words: Mechanical Properties, Nanoclay, Water Absorption, Twin Screw Extruder and Injection Moulding Process

I. INTRODUCTION

Polymer nanocomposites are polymers that have been reinforced with small quantities of nano-sized particles (nanofillers). These materials represent a radical alternative to conventional filled polymers or polymer blends. In contrast to conventional composites, where the reinforcement is on the order of micrometres, polymer nanocomposites are exemplified by discrete constituents on the order of a few nanometres. An important class of nanofillers involves nanoclays belonging to the kaolin group, such as montmorillonite. Kaolin ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) is a 1:1 phyllosilicate containing a gibbsite octahedral layer and a silicon oxide tetrahedral sheet and there is a certain degree of Van der Waals attraction and hydrogen bonding between the hydroxyl groups of the gibbsite layer and the oxygen atoms of the adjoining silica layer, providing a large cohesive energy. To produce nanocomposite materials with optimum properties and performance, these nanoclays must be intercalated with the polymer matrix and also completely Exfoliated. However, because these nanoclays are hydrophilic by nature, it is not always easy to accomplish their exfoliation in a hydrophobic polymer matrix like polypropylene (PP), high density polyethylene (HDPE) and acrylonitrile butadiene styrene (ABS). The process, however, can be facilitated if the clay is treated with an organic intercalant, which replaces the metal cations located between the layers and increases the interlayer spacing. This aids further separation and eventual exfoliation when the treated

clay is mixed with molten polymer in a melt processing procedure.

It is known that nanocomposite materials can be processed by traditional melt-processing methods. The processing of these materials is important in determining their final morphological properties. Mixing facilitates nanoscale dispersion and can lead to clay and/or polymer alignment. The degree of shear during moulding determines not only the degree of clay alignment, but also the degree of polymer orientation. In the case of injection moulding, the clay platelets can also enhance the alignment of the polymer chains. The addition of nanoparticles in crystalline polymers was found, in general, not to affect considerably the crystallinity of the resulting nanocomposite materials, even though there may be some changes in particular nanocomposite systems. It has been proposed, however, that these particles produce a much larger number of nucleating sites and in turn greatly reduce the size. The physical and morphological characteristics can have a great influence on the mechanical properties of nanocomposite products. However, their exact effects on the water absorption behaviour of this class of materials have not been widely discussed in the literature. In the present study, extensive work is undertaken to further understand the mechanism of moisture transport in both neat polypropylene (PP), high density polyethylene (HDPE) and Acrylonitrile Butadiene Styrene (ABS) and its nanocomposites containing different amounts of nanoclay, as well as to characterize its effect on the tensile and flexural properties of materials.

II. EXPERIMENTAL PROCEDURE

A. Raw Materials

Polypropylene (PP), High Density Polyethylene (HDPE) and Acrylonitrile Butadiene Styrene (ABS). Kaolin Clay is a naturally occurring material composed of fine-grained size was used as a nanoparticle. All materials were dried at 55 °C for 10 hours in vacuum.

B. Nanocomposites Preparation

PP, ABS, HDPE and Nano clay blends were prepared via melt intercalation method by twin screw extruder. The process undergo at different temperature ranges from 180 °C to 215 °C 170 °C to 212 °C and 135 °C to 170 °C. Nano clay is used as a filler with PP, ABS and HDPE at different weight ratios 1Wt%, 3Wt%, 5Wt% in extrusion process. The material enters through the feed throat from hopper. The twin screws in extrusion machine forces the material and the material will be out from the die in the form of wires. The composite material wires obtained from extrusion process will be cooled in water bath.

Pallets from extrusion and cutting process will be dried in oven at 55 °C for removal of moisture content. Granulated or pallets is fed from a hopper into the Injection Moulding machine. The Injection Moulding machine consists

of a hollow steel barrel, containing a rotating screw. The screw carries the plastic along the barrel to the mould. The screw is forced back as the melted plastic collects at the end of the barrel. Once enough plastic has collected a hydraulic ram pushes the screw forward injecting the plastic through a sprue into a mould cavity. The mould is warmed before injecting and the plastic is injected quickly to prevent it from hardening before the mould is full. Pressure is maintained for a short time (dwell time) to prevent the material creeping back during setting (hardening). This prevents shrinkage and hollows, therefore giving a better quality product. The moulding is left to cool before removing (ejected) from the mould. Finally, the specimen will be out from the injection moulding machine.

C. Water Absorption Experiment

The water absorption amount of the kaolin-Nano clay treated and untreated PP, ABS, and HDPE with 1, 3 and 5 Wt% of Nano clay were tested by submerging the preconditioned composites completely in distilled water at 65 °C and maximum immersion time was 150days. Before taking measurements, samples were washed with distilled water and wiped dry, and then put in an oven set at 55°C to remove moisture. At predetermined time intervals, samples were taken out of water for weight measurement. Prior to weight measurement, surface water was carefully removed from the samples. The water absorption of the composites was expressed as percentage of weight gain and was calculated using equation.

$$\text{Weight gain\%} = 100 \left(\frac{W_t - W_0}{W_0} \right)$$

Where, W_0 is the initial weight of the oven dried PP, ABS and HDPE (with or without Nano clay), while W_t is the weight of the PP, ABS and HDPE at a given time t .



Fig. 1: Constant Temperature water bath at 65°C

D. Tensile and Flexure Test of PP, ABS and HDPE Composites

The specimens of PP,ABS and HDPE will be removed from constant water bath and dried up, and cooled to room temperature in order to determine the mechanical properties such as tensile strength and Young's modulus from machine called INSTRON servo hydraulic machine with a cross-head speed of 3.0 mm/min.



Fig. 2: Tensile Test of composite Material



Fig. 3: Flexural test of composite material



Fig. 4: Images of the specimens before and after loading (PP, ABS and HDPE).

III. RESULTS AND DISCUSSION

A. Moisture Absorption

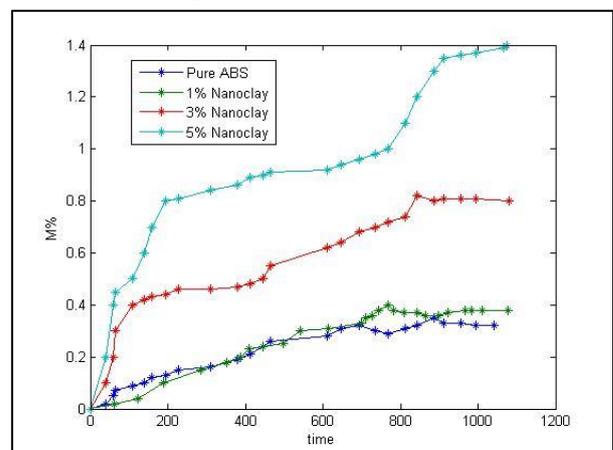


Fig. 5: Weight gain percentage and time for ABS nanocomposite at T=65°C

Fig.5 shows the water absorption results of Nano clay filled and unfilled ABS composites. The weight gain of the samples is plotted as a function of time. It is observed from Fig.5 that the water uptake continuously increased with the increase in time of immersion for all specimens. Water uptake rate is linear and very rapid in the beginning of the exposure, after that, it slows down and reaches the saturation level. It is observed that the weight gain and maximum moisture content both increase as the amount of Nano clay increases when compared to PP and HDPE.

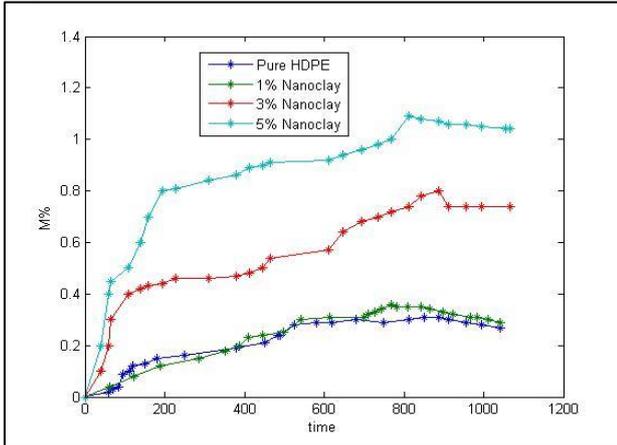


Fig. 6: Weight gain percentage and time for HDPE nanocomposite at T=65°C

Fig.6 shows the water absorption results of Nano clay filled and unfilled HDPE composites. The weight gain of the samples is plotted as a function of time. It is observed from Fig.6 that the water uptake continuously increased with the increase in time of immersion for all specimens. Water uptake rate is linear and very rapid in the beginning of the exposure, after that, it slows down and reaches the saturation level. It is observed that the weight gain and maximum moisture content both increase as the amount of Nano clay increases when compared to ABS and HDPE.

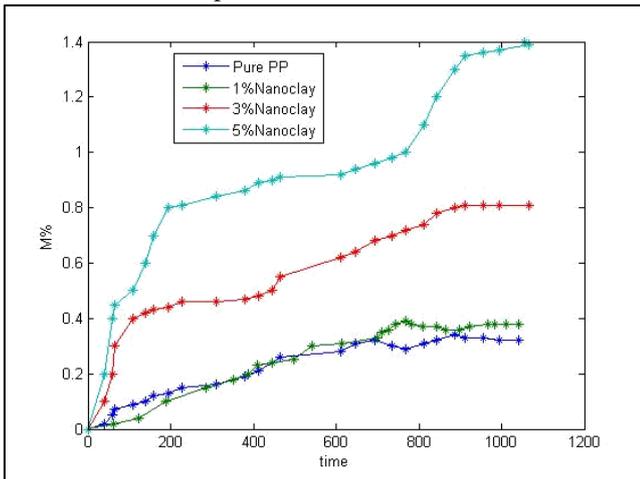


Fig. 7: Weight gain percentage and time for Polypropylene nanocomposite at T=65°C

Fig.7 shows the water absorption results of Nano clay filled and unfilled polypropylene composites. The weight gain of the samples is plotted as a function of time. It is observed from Fig.7 that the water uptake continuously increased with the increase in time of immersion for all specimens. Water uptake rate is linear and very rapid in the

beginning of the exposure, after that, it slows down and reaches the saturation level. It is observed that the weight gain and maximum moisture content both increase as the amount of Nano clay increases when compared to ABS and HDPE.

IV. EVALUATION OF MECHANICAL PROPERTIES OF NANOCOMPOSITES

A. Tensile Strength of ABS, HDPE and PP

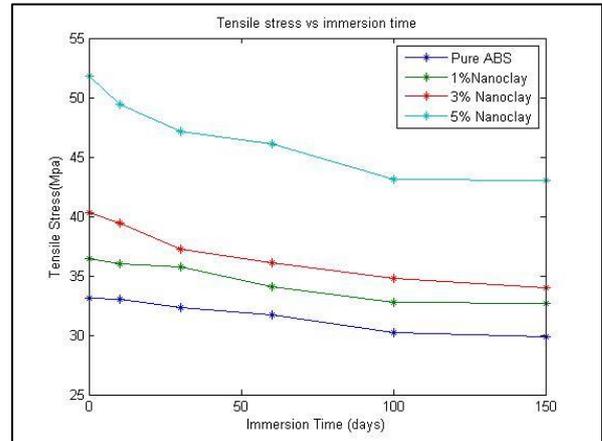


Fig. 8: Tensile stress and immersion time for ABS Nanocomposite at T=65°C

From the Fig.8 shows the effect of both Temperature (T=65°C) and immersion time in distilled water on the tensile properties of neat ABS and ABS Nanocomposites. It is observed that there is a gradual decrease in tensile stress with increase of days and the amount of moisture absorbed. Finally the material will be saturated. But this degrowth condition of tensile stress in ABS Nanocomposites will be low when compared to other materials polypropylene and high density polyethylene.

IMMERSION TIME	TENSILE STRESS (MPa)			
TIME	PURE ABS	1% NANOCLAY	3% NANOCLAY	5% NANOCLAY
0	33.133	10.12%	21.75%	56.44%
10	33.01	9.10%	19.41%	49.71%
30	32.29	10.68%	15.23%	45.92%
60	31.69	7.66%	13.97%	45.53%
100	30.2	8.54%	15.03%	42.78%
150	29.88	9.43%	13.82%	43.87%

Table 1: Improvement of ABS Nanocomposite in percentages.

The enhancement of immersion time with inclusion of Nano clay in ABS at different soaking temperatures is reported in table.1. It is observed at 5% inclusions and 150days soaking time the improvement in immersion time is 43.87%. The maximum immersion time is observed at 5% Nano clay inclusions.

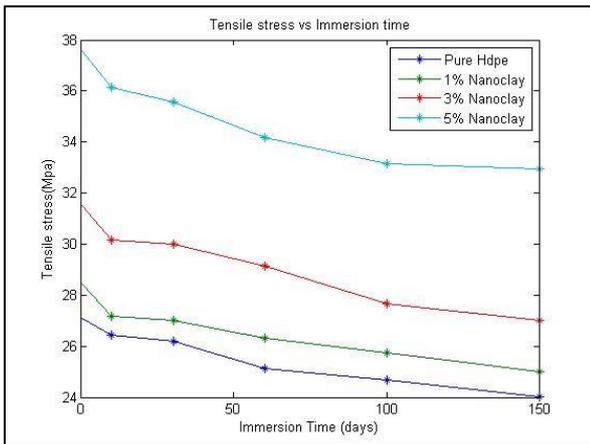


Fig. 9: Tensile stress and immersion time for HDPE Nanocomposite at T=65°C

From the Fig.9 shows the effect of both Temperature (T=65°C) and immersion time in distilled water on the tensile properties of neat HDPE and HDPE Nanocomposites. It is observed that there is a gradual decrease in tensile stress with increase of days and the amount of moisture absorbed. Finally the material will be saturated. But this degrowth condition of tensile stress in HDPE Nanocomposites will be low when compared to other materials polypropylene and ABS.

IMMER SION TIME	TENSILE STRESS (MPa)			
	PURE HDPE	1% NANOC LAY	3% NANOC LAY	5% NANOC LAY
0	27.123	4.96%	16.21%	38.67%
10	26.423	2.83%	14.11%	36.70%
30	26.2	3.06%	14.5%	35.68%
60	25.12	4.77%	16.05%	35.99%
100	24.67	4.25%	12.16%	34.41%
150	24.01	4.16%	12.41%	37.27%

Table 2: Improvement of HDPE in percentages.

The improvement of immersion time with inclusion of Nano clay in HDPE at different soaking temperatures is reported in table.2. It is observed at 5% inclusions and 150days soaking time the improvement in immersion time is 37.27%. The maximum immersion time is observed at 5% Nano clay inclusions.

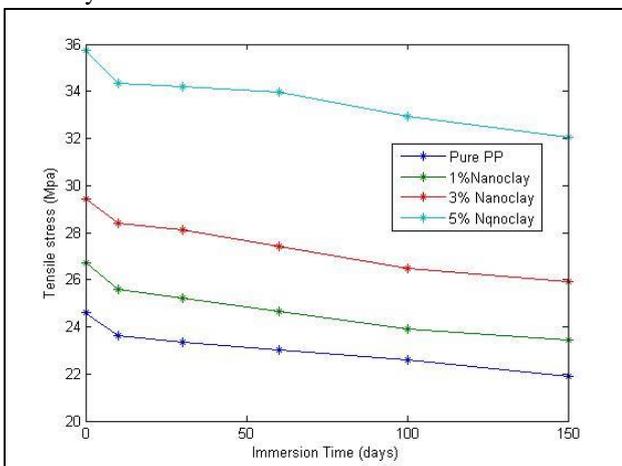


Fig. 10: Tensile strength and immersion time for PP Nanocomposite at T=65°C

From the Fig.10 shows the effect of both Temperature (T=65°C) and immersion time in distilled water on the tensile properties of neat PP and PP Nanocomposites. It is observed that there is a gradual decrease in tensile stress with increase of days and the amount of moisture absorbed. Finally the material will be saturated. But the degrowth condition in tensile stress of polypropylene Nanocomposites will be low when compared to other materials HDPE and ABS as it is subjected to water environment.

IMMER SION TIME	TENSILE STRESS (MPa)			
	PUR E PP	1% NANOCL AY	3% NANOCL AY	5% NANOCL AY
0	24.601	8.5%	18.16%	45.20%
10	23.64	8.34%	20.22%	45.17%
30	23.35	8.05%	20.42%	46.50%
60	23.01	7.049%	19.16%	47.54%
100	22.61	5.74%	17.07%	45.73%
150	21.9	6.53%	18.35%	46.34%

Table 3: Enhancement of Polypropylene in percentages

The improvement of immersion time with inclusion of Nano clay in PP at different soaking temperatures is reported in table.3. It is observed at 5% inclusions and 150days soaking time the improvement in immersion time is 46.34%. The maximum immersion time is observed at 5% Nano clay inclusions.

B. Flexural Modulus of ABS, HDPE and PP

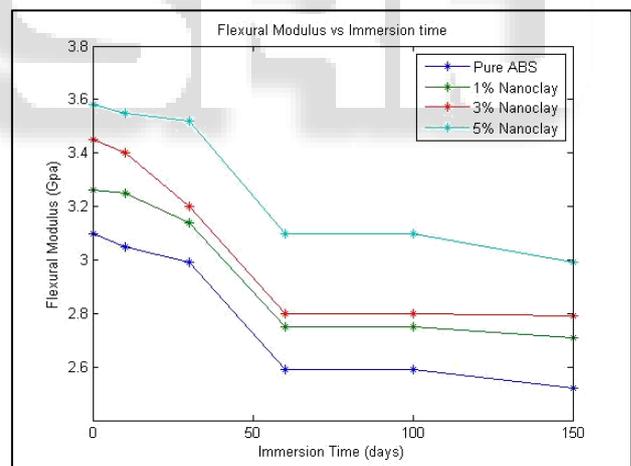


Fig. 11: Flexural modulus and Immersion time of ABS nanocomposite at T=65°C

From the Fig.11 shows the effect of both Temperature (T=65°C) and immersion time in distilled water on the flexural modulus of neat ABS and ABS Nanocomposites. It is observed that there is a gradual decrease in flexural modulus with increase of days and the amount of moisture absorbed. Finally the material will be saturated. But this degrowth condition of flexural modulus in ABS Nanocomposites will be low when compared to other materials polypropylene and HDPE.

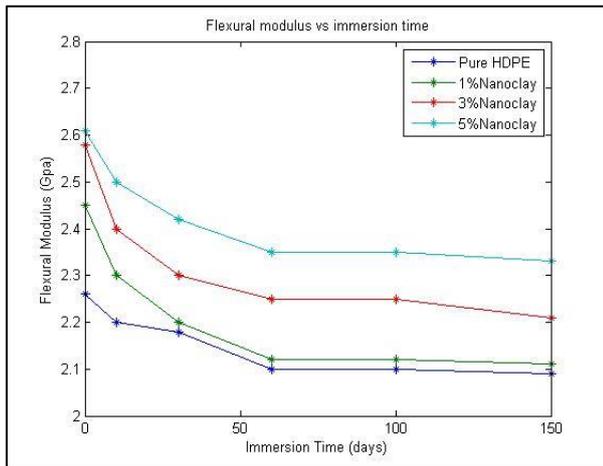


Fig. 12: Flexural modulus and Immersion time of HDPE nanocomposite at T=65°C

From the Fig.12 shows the effect of both Temperature (T=65°C) and immersion time in distilled water on the flexural stress of neat HDPE and HDPE Nanocomposites. It is observed that there is a gradual decrease in flexural stress with increase of days and the amount of moisture absorbed. Finally the material will be saturated. But this degrowth condition of tensile stress in HDPE Nanocomposites will be low when compared to other materials polypropylene and ABS.

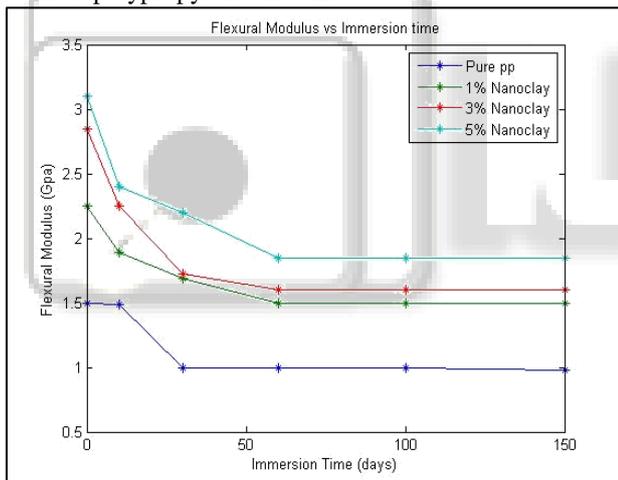


Fig. 13: Flexural modulus and Immersion time of PP nanocomposite at T=65°C

From the Fig.13 shows the effect of both Temperature (T=65°C) and immersion time in distilled water on the flexural properties of neat PP and PP Nanocomposites. It is observed that there is a gradual decrease in flexural modulus with increase of days and the amount of moisture absorbed. Finally the material will be saturated. But the degrowth condition in flexural modulus of polypropylene Nanocomposites will be low when compared to other materials HDPE and ABS as it is subjected to water environment.

C. Maximum Flexural Stress of ABS, HDPE and PP

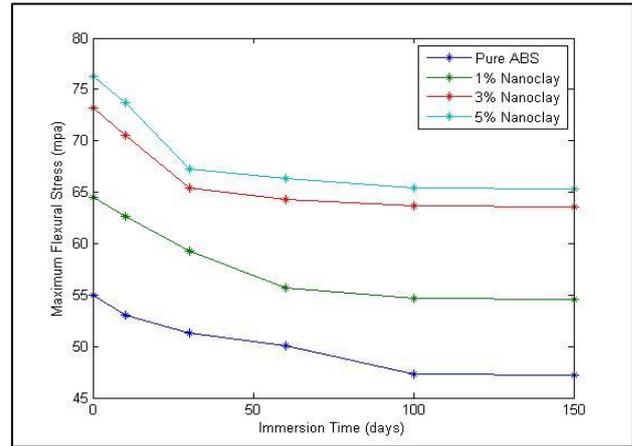


Fig. 14: Maximum Flexural Stress and Immersion time of ABS Nano composite at T=65°C

From the Fig.14 shows the effect of both Temperature (T=65°C) and immersion time in distilled water on the flexural properties of neat ABS and ABS Nanocomposites. It is observed that there is a gradual decrease in maximum flexural stress with increase of days and the amount of moisture absorbed. Finally the material will be saturated. But this degrowth condition of maximum flexural stress in ABS Nanocomposites will be low when compared to other materials polypropylene and HDPE.

IMMER SION TIME	MAXIMUM FLEXURAL STRESS (MPa)			
	PURE ABS	1% NANOCL AY	3% NANOCL AY	5% NANOCL AY
0	55	64.5	73.2	76.3
10	53	62.7	70.5	73.7
30	51.3	59.3	65.4	67.3
60	50.1	55.7	64.3	66.3
100	47.3	54.7	63.7	65.4
150	47.2	54.6	63.6	65.3

Table 4: Improvement of water absorption in ABS Nano composite

The improvement of immersion time with inclusion of Nano clay in PP at different soaking temperatures is reported in table.4. It is observed at 5% inclusions and 150days soaking time the improvement in immersion time is 65.3%. The maximum immersion time is observed at 5% Nano clay inclusions.

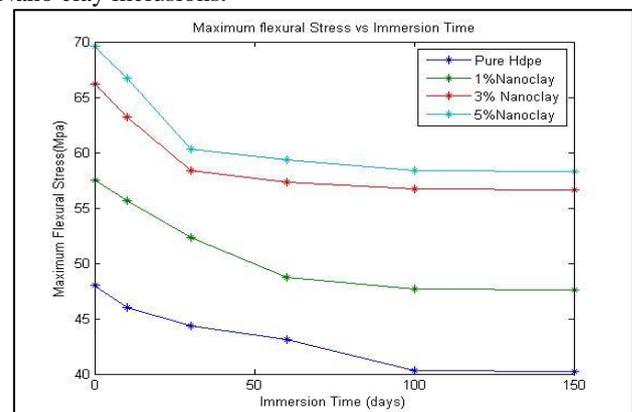


Fig. 15: Maximum Flexural Stress and Immersion time of HDPE Nano composite at T=65°C

From the Fig.15 shows the effect of both Temperature (T=65°C) and immersion time in distilled water on the flexural properties of neat HDPE and HDPE Nanocomposites. It is observed that there is a gradual decrease in maximum flexural stress with increase of days and the amount of moisture absorbed. Finally the material will be saturated .But this degrowth condition of tensile stress in HDPE Nanocomposites will be low when compared to other materials polypropylene and ABS.

IMMERSION	MAXIMUM FLEXURAL STRESS (MPa)			
TIME	PURE HDPE	1% NANOC LAY	3% NANOC LAY	5% NANOC LAY
0	48	19.79%	37.91%	45.0%
10	46	21.08%	37.39%	45.0%
30	44.3	18.05%	31.8%	36.11%
60	43.1	12.99%	32.94%	37.58%
100	40.3	18.3%	40.69%	44.91%
150	40.2	18.4%	4079%	45.02%

Table 5: Improvement of HDPE Nanocomposite in percentages

The enhancement of immersion time with inclusion of Nano clay in HDPE at different soaking temperatures is reported in table.5. It is observed at 5% inclusions and 150days soaking time the improvement in immersion time is 45.02%. The maximum immersion time is observed at 5% Nano clay inclusions.

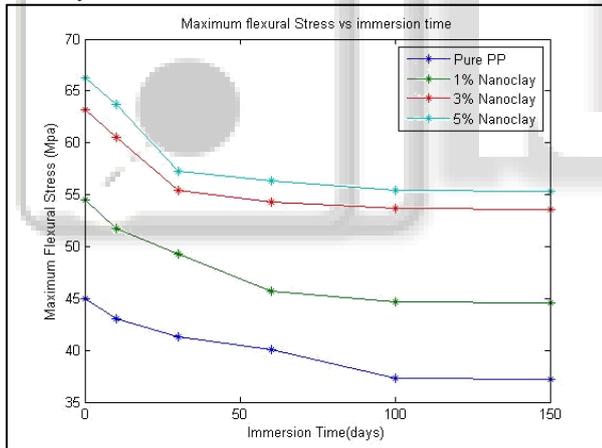


Fig. 16: Maximum Flexural Stress and Immersion time of PP Nano composite at T=65°C

From the Fig.16 shows the effect of both Temperature (T=65°C) and immersion time in distilled water on the flexural properties of neat PP and PP Nanocomposites. It is observed that there is a gradual decrease in maximum flexural stress with increase of days and the amount of moisture absorbed. Finally the material will be saturated .But the degrowth condition in maximum flexural stress of polypropylene Nanocomposites will be low when compared to other materials HDPE and ABS as it is subjected to water environment.

IMMERSION	MAXIMUM FLEXURAL STRESS(MPa)			
TIME	PUR E PP	1% NANOCL AY	3% NANOCL AY	5% NANOCL AY

0	45	21.11%	40.44%	47.3%
10	43	20.23%	40.69%	48.13%
30	41.3	19.3%	34.14%	38.74%
60	40.1	13.96%	35.41%	40.39%
100	37.3	16.55%	43.96%	48.52%
150	37.2	19.89%	44.08%	48.65%

Table 6: Increment of PP Nano composite in percentages.

The enhancement of immersion time with inclusion of Nano clay in PP at different soaking temperatures is reported in table.6. It is observed at 5% inclusions and 150days soaking time the improvement in immersion time is 48.65%. The maximum immersion time is observed at 5% Nano clay inclusions.

V. FESEM IMAGES OF NANOCOMPOSITES

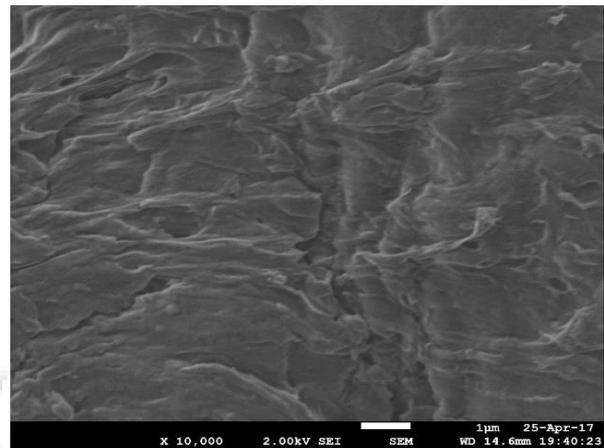


Fig. 17: FESEM image of 3% Nano clay treated with ABS material

From the above image Fig.17 it is observed that the reinforcement of Nano clay 3Wt% in ABS material are clearly visible within the plastic matrix. But the ABS Nanocomposite material immersed in distilled water upon exposed to larger time water absorption severely damaged the matrix interface. This causes a poor adhesion between the plastic matrixes. Due to poorer adhesion of ABS Nanocomposite material tends to decrease the mechanical properties of ABS nanocomposite.

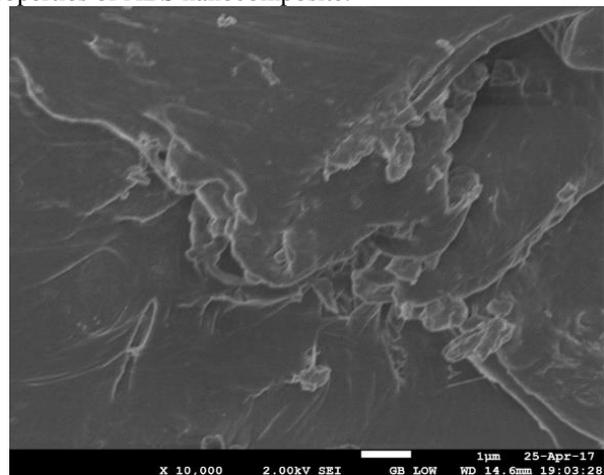


Fig. 18: FESEM image of 3% Nano clay treated with HDPE material

From the above image Fig.18 it is observed that the reinforcement of Nano clay 3Wt% in HDPE material are clearly visible within the plastic matrix. But the HDPE Nanocomposite material immersed in distilled water upon exposed to larger time water absorption severely damaged the matrix interface. This causes a poor adhesion between the plastic matrixes. Due to poorer adhesion of HDPE Nanocomposite material tends to decrease the mechanical properties of HDPE nanocomposite.

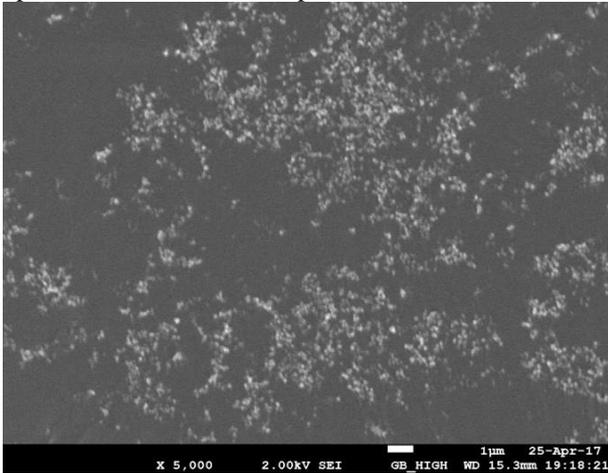


Fig. 19: FESEM image of 3% Nano clay treated with PP material

From the above image Fig.19 it is observed that the reinforcement of Nano clay 3Wt% in PP material are clearly visible within the plastic matrix. But the PP Nanocomposite material immersed in distilled water upon exposed to larger time water absorption severely damaged the matrix interface. This causes a poor adhesion between the plastic matrixes. Due to poorer adhesion of PP Nanocomposite material tends to decrease the mechanical properties of PP nanocomposite.

VI. CONCLUSIONS AND FUTURE SCOPE

The present study concerning the humidity absorption process and its effect on the mechanical properties of the clay-reinforced PP, ABS and HDPE has led to the following conclusions

The Mechanical properties of the as-moulded materials, i.e. the elastic modulus and the maximum stress, increase upon introduction of the Nano clay particles into the PP, ABS and HDPE matrix. This is attributed not only to the conventional reinforcing effect of the high-modulus clay, but also to the fact that the many Nano scale particles present restrict the mobility of the matrix polymer chains in the interfacial region, thus contributing further to the improvement in mechanical properties of the polymer clay hybrid composites.

The moisture absorption process occurring upon immersion in distilled water depends on the immersion temperature. In the case of distilled water, the deviation takes the form of a further weight gain. This was attributed to physical and/or chemical degradation of the exposed material.

The presence of the Nano clay particles in the PP, ABS and HDPE matrix promotes the water absorption process at all immersion temperatures used in this study. The clay particles can also promote the creation of micro pores in

the PP, ABS and HDPE matrix, accelerating therefore the diffusion of the water molecules in the nanocomposite materials. For a given material, the temperature dependence of the diffusion coefficients.

The absorbed moisture generally decreases both the elastic modulus and the maximum stress. Such reduction is due to both degradation of the Nano clay PP, ABS and HDPE interface area and plasticization of the matrix. Although the Nano composites absorb water faster and to a greater extent than the neat PP, ABS and HDPE their superior initial properties mean that even after prolonged exposure they can still show better performance than unexposed PP, ABS and HDPE.

Finally, the experiments and tests done on different percentages of Nano clay examined that there is reduction in stiffness and strength due water absorption. Actually in process there will be less decrease of strength and stiffness in ABS when compared to polypropylene and high density polyethylene. So ABS is better in water environment because the reduction strength is less when compared to polypropylene and high density polyethylene.

The production of Nano clays and their incorporation in Nano composites have an impact on the environment that may be compensated for if the weight reduction resulting from the use of Nano composites is large enough. When a nanocomposite material is used for agricultural film, for example, there are clear environmental benefits due to the high estimated weight reduction.

The use of a nanocomposite materials for packaging film and automotive panels, however, has no obvious environmental benefit. From an economic point of view, the use of a nanocomposite in packaging film is advantageous if the Nano clay price is not higher. Depending on which material and energy prices are assumed, the life cycle costs can be reduced by 26–39% when a nanocomposite material is used for agricultural film. We estimated the economic advantage of using Nano composites in automotive applications to be 3–6%.

Based on the results of this study, we can conclude that the use of nanocomposite material can have clear environmental advantages over conventional material in certain circumstances. These advantages are mainly caused by a reduction in the amount of material needed, which depends on material properties like the Young modulus and tensile strength. We found, for example, a high increase in these properties compared to those which have less properties of materials, which explains the large reduction in material. There were only small improvements (12% improvement in tensile strength) compared to neat thermoplastic materials like PP, ABS and HDPE compared to Nano clay reinforced PP, ABS and HDPE, the only improvement was reduced density. The use of polymer Nano composites, therefore, only has advantages when it replaces polymers with less favourable material properties. However, be stated that there are no disadvantages in using Nano composites. In general, the Nano composites do not have a higher environmental impact than conventional products.

Moreover, they show some economic benefits when used in agricultural film and automotive panels and definite environmental benefits in the case of agricultural film. One exception to the use of Nano composites may be the toxic

effects of free nanoparticles: more research is required on this topic. Provided the potential release of free nanoparticles from polymer Nano composites can be excluded as source of concern for human health and the environment, the outcomes of the required Nano clay price reduction to make nanocomposite cases clearly support further polymer research and technology development.

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