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Natural Inorganic Nano Particles to Reduce Water Absorption of Nylon-Jute Composite

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Abstract— *For the development of polymer based green composites, the role of natural fibres is growing at an increasing rate in the field of engineering and technology. The inherent moisture absorption of nylon is also higher compared to other polymeric materials. At the same time, jute fibre is hydrophilic in nature that also increases the moisture absorption of the nylon-jute natural fibre reinforced polymer composites. This is a serious concern, especially for their outdoor applications. This article reports the experimental results on the effect of locally produced river based nano silica sand and natural clay particles to control the water absorption of nylon-jute composite. At first, 90% nylon and 10% untreated chopped jute fibre reinforced composite was developed. In the next stage, 1% locally produced natural inorganic nano particles (either silica or clay) were added separately in the nylon-jute composite to make nano particle reinforced composites. Then following standard procedure water absorption tests were conducted by immersing pure polyester and its various composite specimens into distilled water. After detail experimental study, the produced nano silica sand and clay particles have been revealed to be very effective for reducing water absorption tendency of the nylon-jute composites.*

Keywords— *Nylon, Jute fibre, Polymer composite, Nano silica sand, Nano clay, Water absorption*.

I. INTRODUCTION

For several decades polymer composites have been competing with various conventional materials such as steel, aluminum, concrete, etc in cars, aircraft, buildings, bridges, bicycles and everyday sports goods. The increase in the dependency on petroleum-based materials and increasing environmental concerns are stimulating research to investigate more environment friendly, sustainable materials to replace the existing glass and carbon fibres for the development of new materials [1,2]. In this regard, interest in natural plant fibres like flax, hemp, jute, kenaf, etc as reinforcements in polymer matrix is growing rapidly [3-5]. Several advantages in comparison with synthetic fibres as low cost, low density, high specific strength and modulus, easy availability, easy processing, non-toxicity, acoustic insulation and much lower energy requirement for processing, etc can explain it [6,7]. Today, nearly 50% of vehicle internal parts are made of polymeric materials. In developed countries, the average use of plastic in a vehicle is 120 kg and the global average is around 105 kg, which accounts for 10-12% of the total vehicle weight [8]. According to the estimation of the Corporate Average Fuel Economy, a 10% reduction in weight of a car can decrease fuel usage by 6-8% [1]. In this regard, consumption of higher volume fraction of lower density natural fibres in plastic composites can reduce the weight of the final component significantly. Because of the latest developments and trends in the automobile industry, including government regulations requiring increases in fuel economy and the need to reduce component costs and minimize overall vehicle weight, worldwide automotive industry demand for natural fibres is expected to grow.

Nylon composites are playing a growing role in under-the-hood components for automobiles, where they are competing with incumbent metallic materials and thermoset plastics, because of their good combination of mechanical (strength and stiffness), chemical (resistance to oils and corrosive chemicals) and physical (light weight with attractive surface finish) properties [9]. Compared to other polymers, nylon matrix also has a great compatibility with natural fibres that eliminates the need to use a compatibilizer or coupling agent [1]. Another advantage is the possibility of recycling of nylon. However, in general, the cost of nylon compared with commodity plastics is very high [1,9,10]. Use of relatively low cost natural fibres significantly balances costing of the nylon based final products. However, one of the insidious disadvantages of nylon is its tendency to absorb moisture from ambient air. The moisture is known to affect a range of polymer properties, which in turn impact dimensional stability, mechanical, acoustic, electrical, optical, chemical properties and, ultimately, the performance of the products. Furthermore, another concern is related to the hydrophilic behaviour of the jute fibre. It has been revealed that the water absorption rate of the lignocellulosic fibre based composites could be reduced by filling with various nano particles in the polymer-natural fibre composites [11-13]. However, in general, nano particles like silica sand or clay are expensive materials. In this report, initiative will be taken to explain the possibility of use of locally produced low cost nano silica sand and clay particles of local resources to suppress the water absorption of nylon-jute composites.

II. Materials and Experimental

Nylon is widely used in manufacturing various components used for load bearing as well as consumer commodities. This thermoplastic polymer was selected as matrix material and chopped jute fibre was used for natural fibre. For convenience of proper mixing and distribution of reinforcement in the polymer matrix, the jute fibres were chopped to around 20mm length. Here it is to be mentioned that nano clay and silica particles were made at MME Department by top down method using locally available natural raw materials. The nano silica sand and clay particles and chopped jute fibres are shown in Figs.1-3.

Figure 1: Nano sand particles.

Figure 2: Nano clay particles.

Figure 3: Chopped jute fibres

For any thermoplastic polymer, uniform mixing of the reinforcing materials in the matrix is a great challenge. In this situation, melting of nylon and mixing of the chopped jute fibres along with sand or clay particles were done in a polymer melting and blending unit developed in MME Department, Fig.4.

Figure 4: Melting and blending unit.

At first, pure nylon granules and jute fibres were put into the chamber of the constructed melting and blending unit, Fig.4. Then the temperature of the melting unit was gradually increased to about 225^{o}C with continued blending action by means of blender propellar attached with the motor. During the melting and blending period the chamber was kept closed to limit air contact. When the temperature was reached to 225^{o}C, the material inside the chamber was blended for about 5 minutes isothermally. At this stage, required amount of clay/sand partcles were gradually added into the pasty mass of nylon during the process of blending, Fig.5.

Figure 5: Addition of nano particles in melting and blending unit with nylon-jute fibre paste

Then the pasty well mixed stock was transferred to the mould of hot press, Fig.6.

Figure 6: Nylon-jute-nano particle pasty mass

After placing the mould with lump of the molten nylon or composite mixture in hot compression press, a pressure of approximately 30kN was applied for 10 minutes at 230°C. The cast sample was then allowed to solidify inside the mould by passing water through the hot press plate at the same pressure and after cooling the resulting composite was taken out from the mould. This process was continued for pure nylon and all

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of its composites. For all cases, rectangular (150mm X 150mm X 2.5mm) sheets were made. The overall steps for making the cast sample in the hot press is shown in Fig.3.7 and macro photographs of the as cast samples are shown in Figs.8-10.

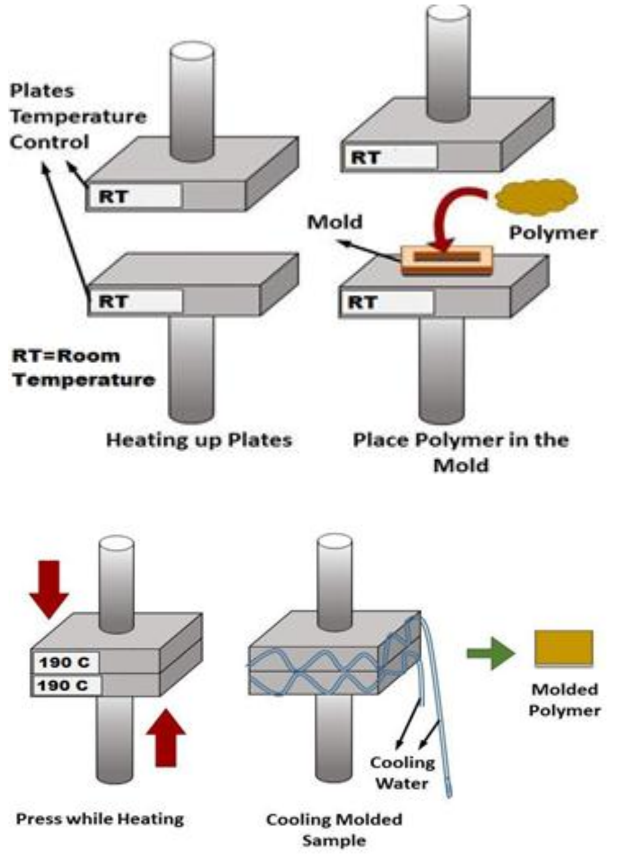

Figure 7: Schematic of sample preparation of compression molding in hot press.

Figure 8: As cast pure nylon sample.

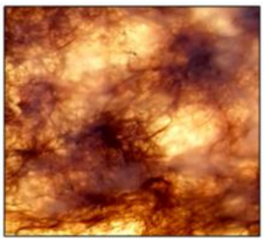

Figure 9: As cast nylon-jute composite sample.

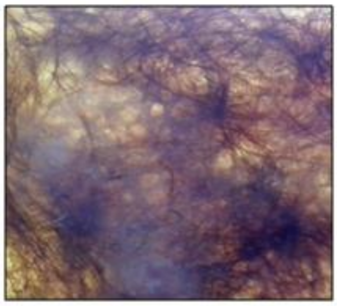

Figure 10: As cast nylon-jute-nano clay composite sample.

Finally, water absorption tests were conducted for the pure nylon and its various composites as per ASTM D570 standard. The results thus obtained are presented in Table 1 and Fig.11.

Table 1: Water absorption test results of pure nylon and its composites.

Serial	Group Identification	% Water Absorption
1	N-100	2.22
2	N-90:J-10	7.23
3	N-90:J-9:NS-1	3.91
4	N-90:J-9:NC-1	3.82

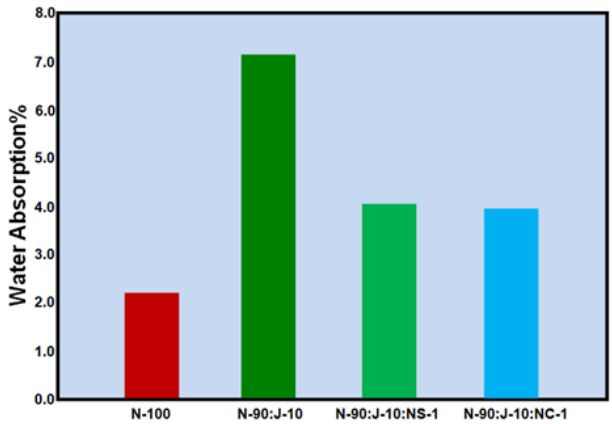

Figure 11: Water absorption test results of pure nylon and its composites.

III. RESULTS AND DISCUSSION

From Table 1 and Fig.11, it is observed that addition of jute fibre increased the water absorption level of the nylon composite from the base water absorption level from the base value 2.22% to 7.23%, which is more than three times higher. This type of significant amount of water absorption for natural fibre reinforced polymer composites has been mentioned by many researchers [10,14-17]. However, detail reasons for the underlying mechanisms have been remained unexplained. In this paper, initiative will be taken to discuss the technical reasons for this significantly higher level of water absorption in the case of jute fibre reinforced nylon composite.

In general, polymeric materials such as polyethylene, polypropylene, nylon, unsaturated polyester, etc resist water. However, no one is fully waterproof, unless it is coated with special materials. In this respect, water resistance of nylon is relatively poor [18]. The water absorption characteristics of polymeric materials depend largely on the basic type and final composition of the polymer. For example, thermoplastic

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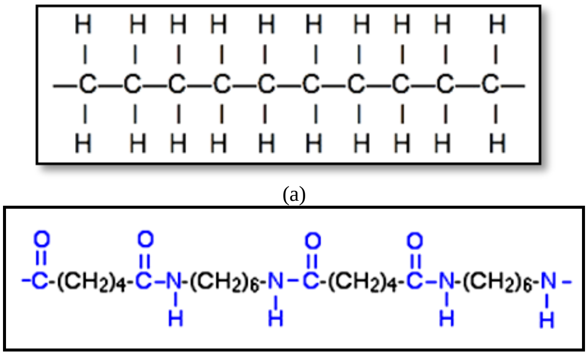
polymers containing only hydrogen and carbon, such as polyethylene and polystyrene, are extremely water resistant, whereas plastic materials, such as nylon, that contain oxygen groups, are susceptible to water absorption, Fig.12.



(a)

(b)

Figure 12: Molecular structures of polyethylene (a) and nylon (b).

As a result, all nylon polymer is hygroscopic by nature, because they contain hydrophilic amide groups that absorb moisture from the atmosphere. Absorption of moisture from the atmosphere occurs slowly in nylon polymers and continues until an equilibrium results between the moisture content of the nylon and the moisture in the atmosphere. Assuming ordinary atmospheric conditions (23°C/75%RH), the equilibrium water absorption is around 2.0% for nylon 6 [19]. Addition of 10% jute fibres increased the water absorption of the nylon from 2.22% to 7.23%. For natural fibres, increase in water absorption has also been mentioned by other [20]. However, detail explanation concerning this too much water absorption due to addition of jute fibres in nylon is not so available.

Concerning the moisture absorption or damping resistance of the composite, function of the matrix is to seal the reinforcement materials and protect them from the environment. In the real sense, complete sealing of the filler materials by the matrix is not so easy. It was also not exceptional for this present case. As a result, some of the exposed jute fibre to surfaces directly absorbed moisture from the environment. Besides, casting or manufacturing defects like crack and gas pockets might also be incorporated in the composites, which ultimately facilitate the entry of moisture inside the composites. This penetrated moisture finally gets socked by the jute fibres because of its hydrophilic nature. Moreover, in the microscopic level, interfacial gaps between individual jute fibres due to fibre entanglement in the polymer matrix is frequently created because of improper distribution of added fibre. Pasty and viscous mass of the polymer some time cannot reach to the free space of the gap making the jute fibres in the entangled area to remain loosely bonded with each other. Under load, they separate from each other very easily without breaking or tearing, which is clear from the fracture surface of nylon-jute composite, Fig.13.

The entanglement among jute fibres due to inhomogeneous distribution of jute fibres in the nylon matrix is also clear from macrograph of nylon-jute composites (Fig.9). In this research work, untreated jute fibres have used that contained lignin. Lignin the polysaccharide component of plant cell walls is highly water permeable and more hydrophilic in nature [14,15]. The presence of more water permeable lignin is another reason responsible for a very high level of water absorption.

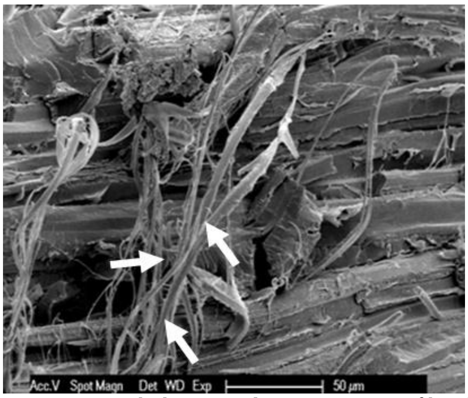


Figure 13: SEM micrograph showing polyester matrix-jute fibre (marked by arrows) interfacial gap

Besides, the hydrophilic nature, let us discuss some other hidden physical properties of jute fibre. Apparently, individual jute fibre seems to be solid and internal pore free. However, in reality, it is not true anyway. Every single jute fibre have several hollow pores (lumens, Fig.14), which are, more or less, longitudinally extended from one end to another. This type hollow passage is called “hollow lumen”. When polymer-jute composite is kept in moist environment, moisture enters through various passages and fills the longitudinal gap of the hollow lumen increasing the tendency of the water intake.

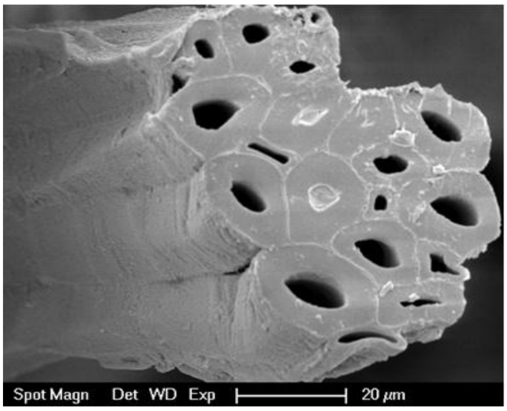


Figure 14: SEM micrograph showing the hollow lumen in jute fibres.

Now, initiative will be taken to discuss the scenario after addition of the nano sand and clay particles into the polymer-jute composites. Table 1 revealed that addition of nano sand and clay particles in the nylon-jute composite reduced the water absorption from 7.23% to, respectively, 3.93 and 3.82%. This means, more or less, nearly 50% water absorption has been reduced and that both types of nano particles showed almost similar effect in reducing the water absorption of the nylon-jute composites.

Every bunch of jute fibre has many single fibres that have interstitial or inter-fibre gap. Similarly, poorly bonded areas of polymer-jute fibre composite might remain unfilled by polymer material because of its high viscosity. Nano particles are very tiny, which is many times smaller than micron size particles. When nano particle is added in the polyester-jute composites, in one side it got chance to fill various micron size defects caused by incorporation of jute fibres in polymer and seal possible water entry passages in much better way. On the other hand, there is good coverage of the nano particles on the jute fibre surfaces that also fill the surface pores of the jute fibre and limit the water entry towards the hollow lumen. The evidence of sand particle distribution over jute fibre surfaces is clear from Fig.15.

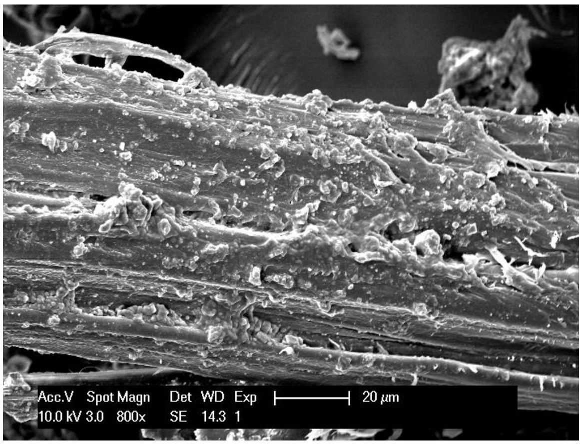


Figure 15: SEM micrograph showing sand particle coverage over the jute fibres.

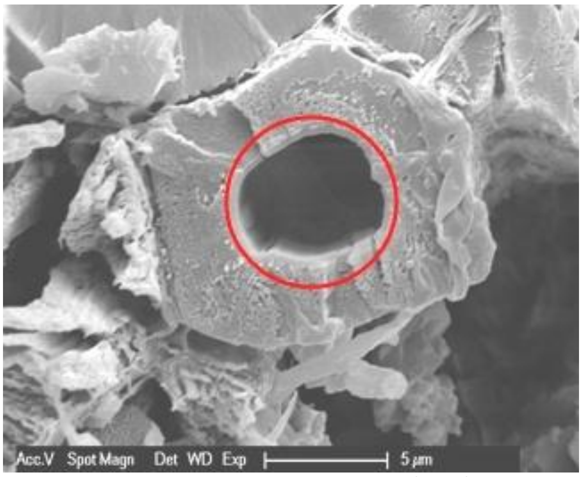


Figure 16: Empty hollow lumen (marked by circle) of jute fibre in nylon-jute-nano particle composites.

No doubt that addition of nano particles significantly reduced the water absorption level of nylon-jute composites. However, the water intake level is still very high compared to that of the pure nylon. Because, these particles just stopped the water entry by filling gap caused due to addition of jute fibres and by various casting defects. Another possible reason is that the surface pores were filled by nano particle coverage over it to some extent. However, the matrix material, i.e. nylon or nano particles could not reach in the hollow lumen and fill the gap, Fig.16. As a result, water entered through the unfilled or partially filled surface pores of the jute fibres. In this regards, addition of more nano particles might help further reduce water absorption. So, finally, it can be said that complete elimination of surface pores by 1% nano particle addition is not enough for complete nano particle coverage over the jute fibres to seal the entry passage towards hollow lumen.

Experimental based results of this research work arguably revealed that locally produced nano silica sand and clay particles are capable to reduce the water absorption level of the nylon-jute composite significantly.

IV. Conclusions

In the present research, using locally produced nano silica sand and clay particles nano structured nylon-jute composites were developed. These composites were characterized by water absorption tests following standard procedure. The main concern of this study is to know whether the locally produced nano particles are capable to reduce the inherent water absorption of nylon-jute composite. After detail experimental works, the following final conclusions have been made from this research work:

i) Addition of jute fibre in nylon polymer water absorption levels increased more than three times compared to that of the base nylon itself. This higher level of water absorption is revealed due to poor adhesion in jute-nylon interface, surface pores and hollow lumens of the jute fibres.
ii) Addition of nano silica sand or nano clay particles reduced the water absorption level of the nylon-jute composite to nearly 50%. The decrease in the water absorption of the composite by nano particle addition is thought due to coverage of the nano particles over the jute fibres and sealing the surface pores of jute fibres that actually act space for water accommodation as well as water entry passages towards hollow lumen.
iii) In final remarks, it could be said that the locally produced nano silica sand and clay particles are capable to the water absorption of the nylon-jute composite.

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