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Thermal Stability Enhancement of Nylon-Jute Composite by Additions of Nano Particles Made from Natural Sources

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ABSTRACT:
Composites are wonderful materials in the sense of good combination of very useful engineering properties. In this regard, polymer composites have gained much more attention because of their light weight, low cost, ease of fabrication, corrosion resistance, good wear property, etc. 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. In this regard, jute fibre is a pioneer source of natural fibres. It is well known that thermal resistance of polymeric materials is very poor and that addition of jute fibre in nylon further degrades this property, which is a serious concern for the natural fibre reinforced polymer composites. This article reports the experimental results on the effect of locally produced river based nano silica sand and clay particles to enhance the thermal degradation temperature of the 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 structured composites. All composites were then characterized by thermo-gravimetric analysis (TGA). Experimental results revealed that nano silica sand or clay particles could be a very good source for low cost reinforcement material to increase the thermal stability of polymeric materials.

Keywords: Nylon-jute composite, Nano silica sand, Nano clay,
Nano structured composites, Thermal degradation.

1. Introduction

Polymeric materials are generally oil based and they are not good for our environment. One of the solutions to reduce the environment related challenge is to reduce the usages of oil-based polymer and replacing these polymers by bio-based or biodegradable ones [1-4]. This initiative can also help to reduce environmental waste, diminish its environmental impact [5]. Natural fiber reinforced polymeric composites are known as eco-friendly, green polymer composites and also are offering some commercial and engineering applications along with economic advantages [6-8].

These natural fiber polymer composites also provide some environmental advantages such as low cost, availability, biodegradable resources; reduced dependence on oil-based sources, reduced pollutant and greenhouse gas emissions and enhanced energy recovery [9]. So, in recent years, natural plant based fibers, for example; jute, coconut, hemp, sisal, coir etc, are being used as reinforcing materials for polymeric composites in place of conventional synthetic fibers like glass, carbon, aramid, etc. Because these natural fibers have wide range of advantages as light weight, non toxic, cost effective, easily available and acceptable specific properties [6,8,10].

Nylon 6 is one of the most widely popular engineering thermoplastics polymer that is used in a number of critical areas in automotive parts such as engine, transmission, cooling systems and fuel system components, where mechanical and thermal stability are commonly required at temperatures of 150°C or above [11]. In automotive applications, usages of natural fibers as reinforcement material in nylon based light weight sustainable polymer composites might reduce the dependence on petroleum resources as well as artificial fillers like

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glass or carbon fibers. For jute fibre, in processing, one additional benefit is its wonderful compatibility with the nylon matrix because of their hydrophilic nature. So, it is possible to eliminate the use of coupling agents and surface modification of natural fibers for making their composite, which are time consuming and increase the cost of the final composite materials [12]. Despite all the advantages have been mentioned earlier, cellulosic fibers reduce the thermal degradation temperatures that eventually limit their usages as reinforcement for polymer-based composites [13]. Although there is considerable interest in nylon-based composites, available literatures are limited and that most of them focused mainly on mechanical and morphological properties of the composites. There is a lack of information about the thermal properties of the nylon based natural fibre composites. The aim of this study is to investigate the effect of jute fibre reinforcement on thermal degradation temperature of nylon and also to know the impact of locally produced nano silica sand and clay particles additions in the nylon-jute composite on its thermal behaviour.

2. Materials and Experimental

Nylon is widely used in manufacturing various components for load bearing as well as consumer commodities. This thermoplastic polymer and jute fibre, respectively, have been selected as matrix and reinforcing materials. 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 produced 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 fiber

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 in the nylon matrix were done in a polymer melting and blending unit developed in MME Department, Fig.4.

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°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°C, the material inside the chamber was blended for about 5 minutes isothermally.Then required amount of clay/sand partcles were gradually added into the pasty mass of nylon during the process of blending. Afterward, the pasty well mixed stock was transferred to the mould of hot press. 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 of its composites. For all cases, rectangular (150mm X 150mm X 2.5mm) sheets were made, Fig.5. The overall steps for making the cast sample in the hot press is shown in Fig.6.

Figure 4: Melting and blending unit.

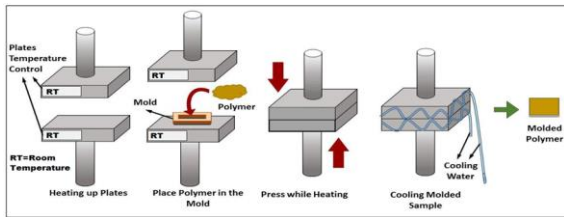Figure 5: As cast sample made by hot press.

Figure 6: Schematic of sample preparation of compression molding in hot press.

3. Results and Discussion

In general, polymers have poor thermal stability. So, in most cases, their applications are restricted within 200℃. Addition of natural fibres might also change the thermal stability. To understand the effects of jute fibre and nano particle additions on the thermal stability of nylon and its various types of composites thermo-gravimetric analysis were performed. In this study, following other, temperature corresponding 5% weight loss level has been considered as the thermal stability (onset of thermal degradation) levels of the composites [14]. The TGA curves for pure nylon (sample N-100), nylon-jute composites (N-90:J-10) and nylon-jute nano composites (N-90:J-9:NS-1, N-90:J-9:NC-1) are presented in Figs.7-10.
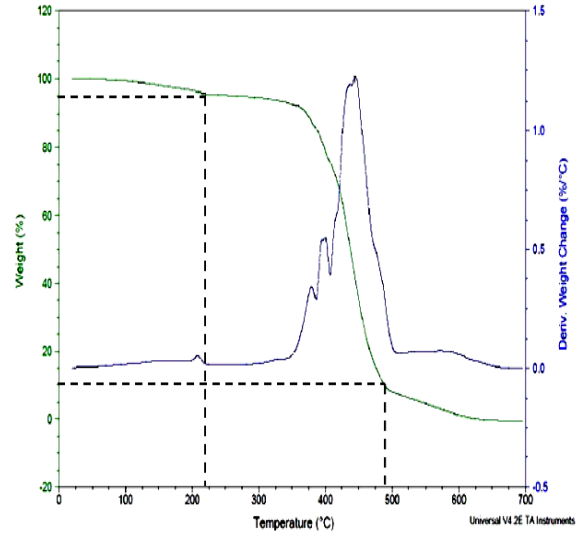

Figure 7: Thermal degradation behaviour of sample N-100.
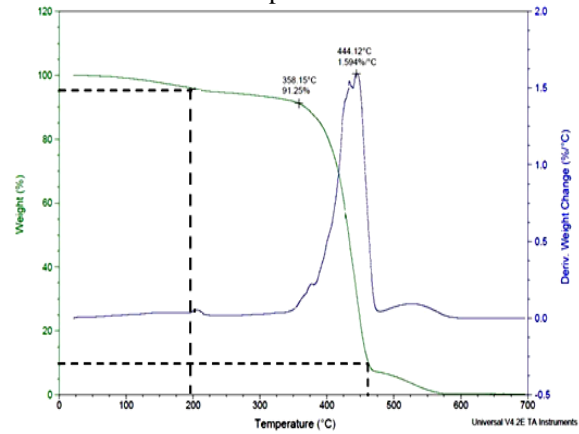

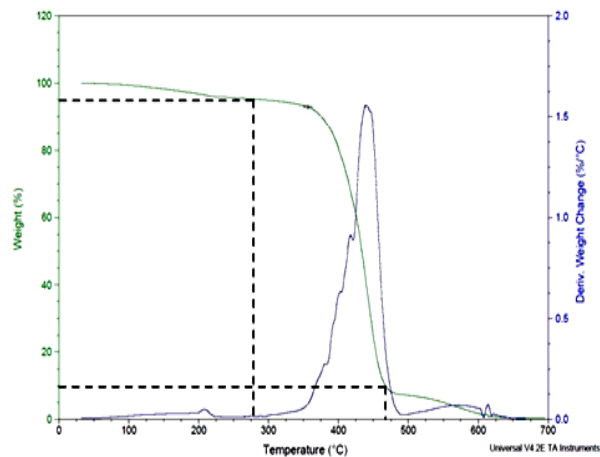Figure 8: Thermal degradation behaviour of sample N-90:J-10.

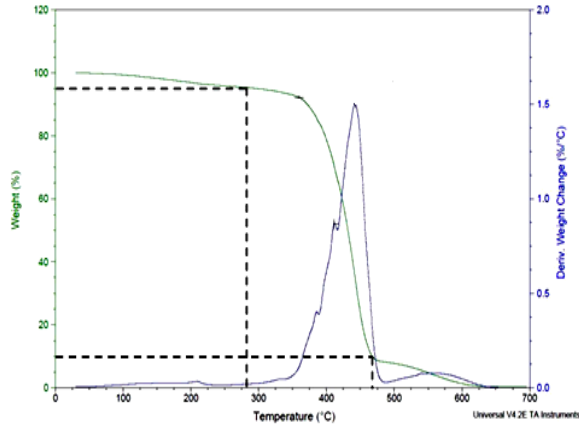Figure 9: Thermal degradation behaviour of sample N-90:J-9:NS-1.

Figure 10: Thermal degradation behaviour of
sample N-90:J-9:NC-1.

In Bangladesh, both the atmospheric temperature and humidity levels are very high. This type of environmental situation enables the samples of the polymer and its composites to absorb moisture from the atmosphere. As a result, the initial weight loss associated with the evaporation of moisture at around 100°C is a common feature of any polymer and its composite samples. For polymeric materials, this feature has been mentioned by many researchers [14-16]. After removal of moisture, the base materials start to decompose gradually. As per research results of Ahmad et al, at ordinary atmospheric conditions (23°C/75%RH), the equilibrium water absorption is around 2.0% for nylon 6 [17]. At 5% weight loss level, thus, plausibly all moisture was removed along with start of decomposition of the nylon matrix. Now, from TGA curves presented in Figs.7-10 for pure nylon and its various composites the following information is revealed.

i)   Addition of jute fibres reduces the onset of degradation (5% weight loss level) temperature of the pure nylon
ii)   Addition of nano particles (both sand and clay) revived and further enhanced the thermal degradation temperature of the nylon-jute composites
iii) In enhancing the thermal degradation temperatures of the nylon-jute composites both the nano silica sand and clay particles showed almost similar performances.

From Figs.7 and 8, it is observed that addition of jute fibres in the polyester matrix the 5% weight loss has been observed at earlier level, i.e., relatively at lower temperature. This means addition of jute fibres degraded the thermal stability of the nylon composite. In earlier research work, Manfredi et al mentioned that the thermal degradation start temperature of jute fibre is about 180°C [14]. On the other hand, pure nylon starts to decompose at around 220°C [18]. In this present study, very similar decomposition temperature of pure nylon has also been found. So, the decrease in the degradation temperature of the nylon-jute composite to 195°C is due to the lower thermal stability of the jute fibre. The details of thermal analysis results are presented in Table 1.

Table 1: 5% and 90% decomposition temperatures of polyester and its

Serial	Group Identification	5% Wt Loss Temp. (°C)	90% Wt. Loss Temp. (°C)
1	N-100	220	490
2	N-90:J-10	195	460
3	N-90:J-9:NS-1	280	470
4	N-90:J-9:NC-1	285	470

The temperatures corresponding to 90% decomposition level of pure nylon and its composites are also given in Table 1, although, polymeric products do not possess any usability at this level. This data is just for comparison of the experimental data. From Table 1, it is clear that pure nylon has the highest, nylon-jute composite has the lowest and nylon-jute nano composite medium temperatures for their decomposition to 90% wt loss level. This means nano particle addition did not improve the 90% decomposition, i.e. wt. loss of the nylon-jute composites.

The 5% weight loss temperature of pure nylon is around 220°C, where addition of nano clay particles (around 5%) Lim et al mentioned this degradation temperature to around 350°C [18]. In this research project only 1% nano sand or clay was used, which increased the degradation onset temperature to around 280°C. Some other researchers also

mentioned similar findings [19,20]. Considering all, the experimental results of this research project seemed to be consistent. Incorporation of nano particles into the nylon matrix results in the increase of the thermal stability of the nano composites. But the question is why? Thermal degradation of the polymer starts with formation of free radicals from its free surfaces, which further proceeds through chain fragmentation processes [21]. Because of nano level size, the added sand or clay particles filled the intermolecular and/or gas pockets and reduced the effective free surface of the polymer and/or jute fibre surfaces from where oxidation or decomposition usually starts. These nano particles (sand or clay) are ceramic materials with high level of melting as well as evaporation temperature (fig 11).
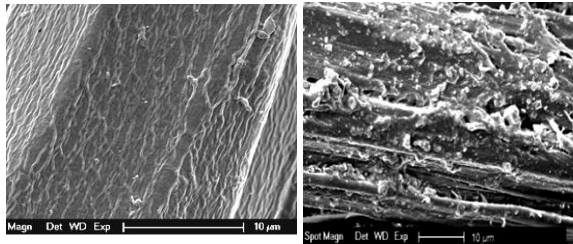

Figure 11: SEM micrograph showing clean (left) and sand particle attached jute fibres (right)

So, the added particles could build potential barriers around the matrix polymeric materials as well as jute fibres and protect them from early thermal decomposition by means of oxidation at least at the lower range of temperature. These nano particles thus restricted the mobility of the polymer chains and reduced the normal oxidation rate of the nylon matrix as well as the natural jute fibres. The degree of the fragmentation, obviously, also depend on the transfer of the radicals from one chain to another and the restricted segmental motions due to the presence of the nano particles that substantially slowed down these effects. As a result, the formation of the volatile oligomers (responsible for the mass loss) is partially prevented and the whole degradation process is shifted towards a higher temperature.

But the 90% wt. loss for N-90:J-9:NS-1 or N-90:J-9:NC-1 occurred at lower temperature than the 90% wt. loss occurred for N-100 (Table 1). This is because of the presence of cellulose material in nano composite system. At higher temperature, the composite becomes almost perforated because of extremely higher level of decomposition and jute fibers have been burnt out at higher temperature. Thus, lower temperature was needed for N-90:J-9:NS-1 or N-90:J-9:NC-1 than N-100 for 90% wt. loss.

4. Conclusions

In the present research, nylon polymer-based jute fibre reinforced composites along with nano structured nylon-jute composites have been developed by using nano silica sand and clay particles produced locally. The stability of the developed composites was characterized by thermogravimetric analysis (TGA). The main concern of this study is to find out whether nano silica sand and nano clay particles produced in MME Department, BUET are capable of enhancing the thermal stability of the nylon-jute composites. After detail experimental works, the following final conclusions have been made.
Additions of jute fibers decreased the thermal stabilities (onset of thermal degradation, 5% wt loss) of the polymer. Significantly enhanced thermal stabilities of nylon-jute composites have been observed due to addition of nano particles. The used nano particles (sand or clay) are ceramic materials with high level of melting as well as evaporation temperature. So, coverage of the nano particles on the nylon matrix or jute fibres reduces the effective free surface areas and built potential barriers around the matrix polymeric materials as well as jute fibres and protected them from early thermal decomposition and chain fragmentation. In final remarks, it can be said that locally produced nano silica sand and clay particles are capable to enhance the onset of thermal degradation temperature of nylon-jute composites.

5. Acknowledgement

6. References

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