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Original Research Article

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Inorganic natural nano particles to upgrade tensile properties of waste jute fibre reinforced nylon composite

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ABSTRACT

Composites are wonderful materials in the sense of a good combination of many useful engineering properties. In this regard, polymer composites have gained much more attention because of their light weight, low cost, ease of fabrication, corrosion and wear resistance, 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, where jute fibre is a potential candidate. Polymer based composites reinforced with waste natural fibre usually result poor to very moderate tensile strength that, naturally, restricts their uses only in some ordinary applications. This article reports the experimental results on the effect of locally produced river based nano silica sand and clay particles to enhance the tensile properties of nylon based composite reinforced with jute fibres of industrial waste. For doing this, at first, 90% nylon and 10% untreated 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 tensile tests. Experimental results revealed that nano silica sand or clay particles could be a very good source for low cost reinforcement material to increase the tensile properties of nylon.

KEYWORDS

Nylon; Waste jute fibre; Nylon-jute composite; Nano silica sand; Nano clay; Nano structured composites; Tensile properties.

INTRODUCTION

Polymeric materials are mostly oil based and they are not good for our environment. One of the options to lessen the environment related challenge is to reduce the oil based polymer dependence and replacing these polymers by bio-based or biodegradable ones[1-4]. This initiative can also promote waste reduction, diminishing its environmental impact[5]. Natural fiber reinforced polymeric composites are emerging as eco-friendly, green polymer composites and are offering commercial and engineering applications along with techno-economic advantages[6-9]. 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 manmade fibers like glass, carbon, aramid, etc because of their wide range of advantages as light weight, non toxic, cost effective, easily available and acceptable specific properties[6,8,10].

Agriculture is an important sector that contributes a lot in economic growth of many countries around the world. Bangladesh is such a country where jute is grown abundantly. Traditionally, the waste produced during industrial use of jute fibres is mainly thrown or burnt away. One of the possible prospects is to utilize them in polymer composites for technical applications[11]. In recent years, there have been studies to investigate the use of many industrial wastes for making biodegradable composites[12]. Waste jute fibres are very cheap; however, the resulted polymer composites are of poor to moderate strengths[13]. As a result, composites made from these are only suitable for some low performance applications, because of their relatively poor strengths[14,15]. If the strength is improved by any means as surface treating the fibres, improving the interface adhesion, addition of nano particles, etc, these biodegradable composites could be candidates for moderate to many high performance applications and replace manmade artificial fibres as well[15,16].

Nylon 6 is one of the most widely used engineering thermoplastics in a number of critical areas in automotives. As a result of increasing demand for environment friendly materials and the acceptable combination of many useful properties, there is growing interest to utilize natural fibers for polymer composite in many areas, particularly, in automotive industries for door panels, seat backs, headliners, package trays, dashboards trunk liners and interior parts[3,17]. The aim of this study is to investigate the effect of locally produced natural inorganic nano particles (nano silica sand and clay) additions on the tensile properties of waste jute fibre reinforced nylon based composite.

MATERIALS AND EXPERIMENTAL

Thermoplastic nylon polymer and waste jute fibre, respectively, were selected as matrix and initial 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 the used silica sand and nano clay particles were also made at MME Department, BUET, Dhaka, Bangladesh by combination of ball milling and hand grinding. The sizes of as received and ground clay particles are shown in Figures 1 and 2.

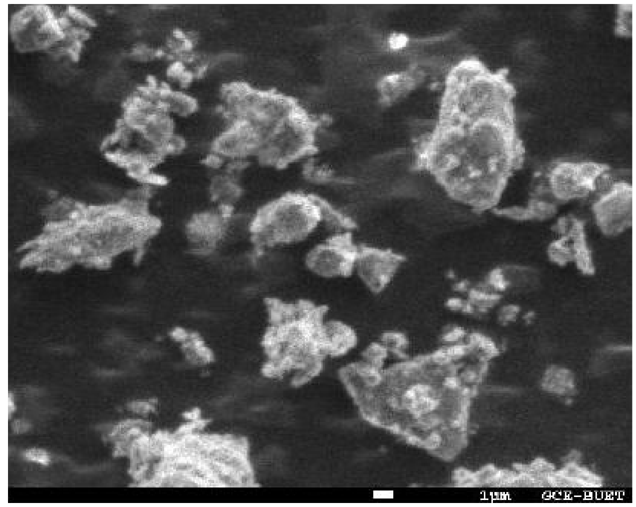

Figure 1: As received clay particles.

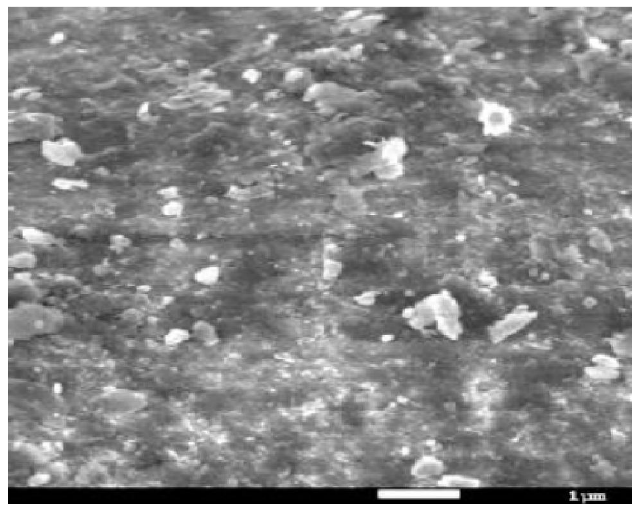

Figure 2: Clay particles after grinding.

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. At first, pure nylon granules and jute fibres were put into the chamber of the constructed melting and blending unit. Then the temperature of the melting unit was gradually increased to about 225°C with continued blending action. During the melting and blending period the chamber was kept closed to restrict air contact with polymer. 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 (1% by wt) 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. The cast sample was then allowed to solidify inside the mould by passing water through the hot press plate 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, Figure 3. The overall steps for making the cast sample in the hot press is shown in Figure 4.

For mechanical tests, tensile samples were made from all cast blocks having dimensions shown in Figure 5. Then tensile tests were conducted using an Instron UTM machine of 50kN capacity following ASTM Standard[18]. For each case, at least, three samples were tested.

RESULTS AND DISCUSSION

Tensile samples were prepared from cast blocks of pure nylon (sample N-100), nylon-jute composites (N-90:J-10), nylon-jute-nano sand particle composite (N-90:J-9:NS-1) and nylon-jute-nano clay particle composite (N-90:J-9:NC-1). Here, for each group, three samples were tested and the average values have been considered as the representative values of the developed composites. Typical stress-strain curves of each group are presented in Figure 6 and the average

Figure 3: As cast sample of pure nylon.

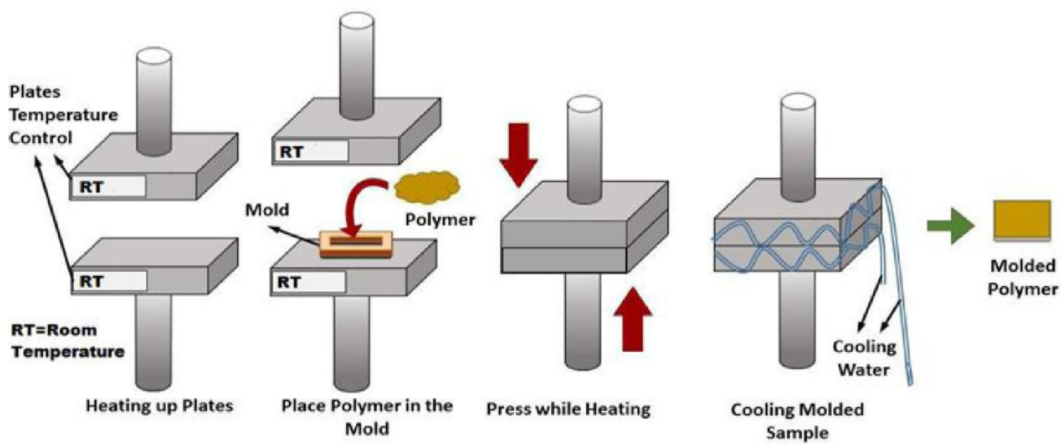

Figure 4: Schematics of sample preparation of compression molding in hot press.

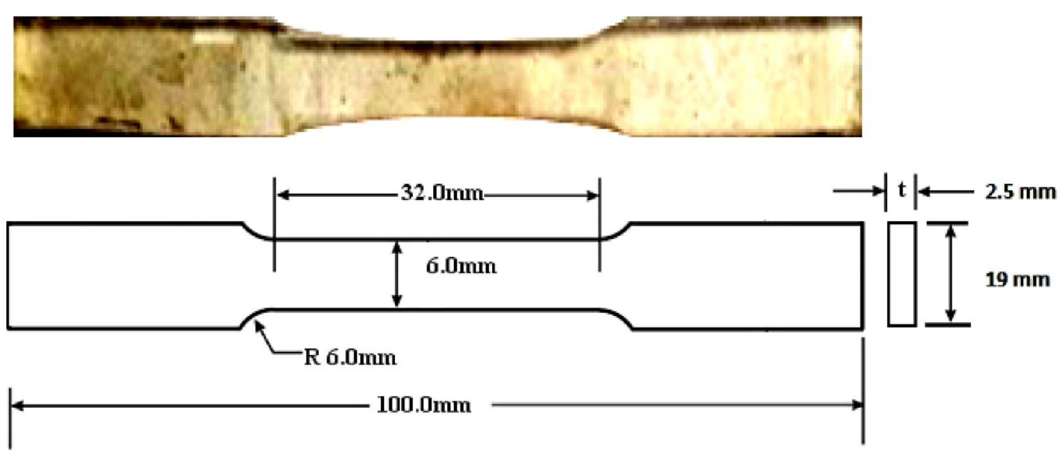

Figure 5: Tensile test sample and its dimensions.

0.2% proof strength, ultimate tensile strength (UTS), elongation at fracture and Young's modulus data thus obtained from the stress-strain curves are shown in TABLE 1.

From the stress-strain curves presented in Figure 6 and tensile data given in TABLE 1, some differences in the tensile behaviours of the pure nylon, nylon-jute composite and nylon-jute nano composites are clearly visible. The basic differences are summarized below:

i) Additions of chopped waste jute fibres increased the proof strength of the nylon, however, drastically decreased its elongation. Addition of jute fibre also decreased the UTS.

ii) Nano silica sand or nano clay particle additions, in general, improved all tensile properties including ductility of the nylon-jute composite.

iii) In improving the tensile properties of nylon-jute composite, the performances of both nano particles have been found to be very similar.

Now, why has the ductility of the nylon been decreased with the additions of jute fibres? It is well established that nylon is a linear type thermoplastic polymer[19]. In the as cast condition, its chains remain in random distribution, Figure 7.

When tensile load is applied on the sample pure nylon having randomly oriented linear chains, the curly morphology of the chains starts to straighten, Figure 8. With increased load, the curly chains try to be unidirectional as much as they can by overcoming the weak Van der Waals forces among them. As the chains have the opportunity to move freely, pure nylon shows a very high level of ductility. From TABLE 1, it is revealed that additions of 10% chopped jute fibre in nylon drastically decreased the elongation from 115% to only 13%, which is more than 8 times lower. Jute fibre is very brittle compared to the nylon matrix. Thus, addition of jute fibres restricted the free movement of nylon chain. On the other hand, additions of jute fibres caused several changes in the nylon matrix. It created gas pockets (Figure 9), poor nylon-jute fibre cohesion, creation of weak zones in chopped jute fibre

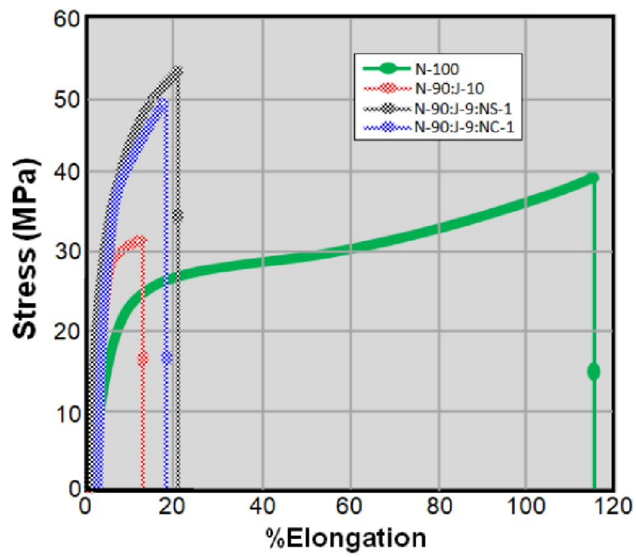

Figure 6: Typical stress-strain curves of the test samples in each group.

TABLE 1: Tensile properties of pure nylon and its various composites.

Serial	Group Identification	Average Proof Stress (0.2%), MPa	Average UTS, MPa	%Elongation (GL: 32mm)	Young's Modulus (MPa)
1	N-100	24	38	115	812
2	N-90:J-10	30	33	13	900
3	N-90:J-9:NS-1	48	53	22	1045
4	N-90:J-9:NC-1	47	51	17	1110

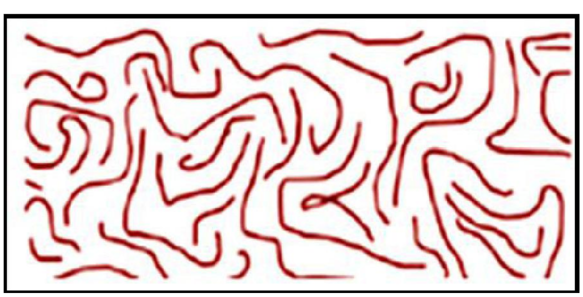

Figure 7: Random distribution of nylon chains in as cast sample.

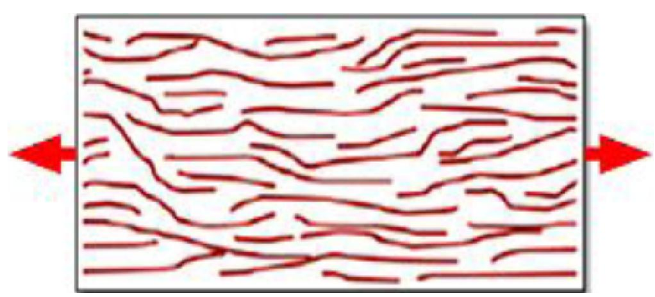

Figure 8: Straightened chains in nylon sample under tensile loading.

agglomerated or entangled areas (Figure 10), etc. Due to the presence of several varieties of defects, there was a premature of the sample of nylon-jute composite. This is the reason for drastically lower ductility of the nylon-jute composite.

Although, addition of jute fibre decreased the ductility drastically, there is a noticeable increase in the proof strength and modulus level of the nylon-jute fibre composite. Jute fibre is not as ductile as nylon, but significantly stronger than it[20,21]. So, under tensile load, stronger jute fibres in the composite naturally can take more stress when relatively ductile nylon matrix starts to deform. In this case, for higher strength of the resulted composite as per the rule of random mixing[19], jute fibres must not be debonded from each other and also from jute fibre-nylon matrix interfaces easily. In this case, reinforced fibres must be broken and/or crushed under tensile loading. However, because of presence of defects and inhomogeneous distribution of the jute fibre in the nylon matrix (Figures 9 and 10), the benefit of high strength jute fibre additions could not be incorporated properly into the developed composite. Moreover, in the case of untreated jute fibres poor cohesion with polymer is the reality[22]. So, altogether, addition of untreated jute fibre caused some potentially easy crack initiation sites that accelerated fibre to fibre debonding, especially in the agglomerated jute fibre areas (Figure 11), fibre-nylon interface debonding, fibre pull out, etc (Figure 12).

When the possibility of potent crack initiation sites increases, for any developed materials, expected mechanical properties cannot be achieved. This is the reason why reinforcement of significantly high strength jute fibre could not ensure expected high strength of

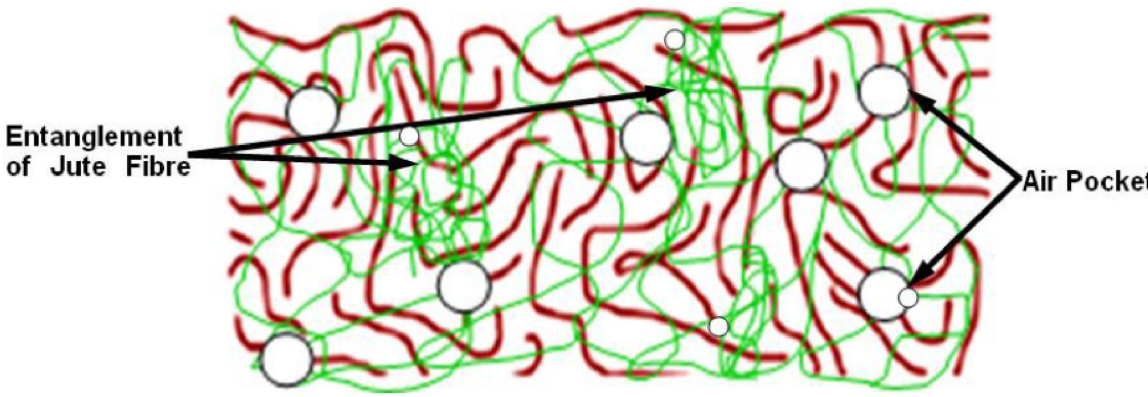

Figure 9: Schematics showing various defects in nylon-jute composites before nano particle addition.

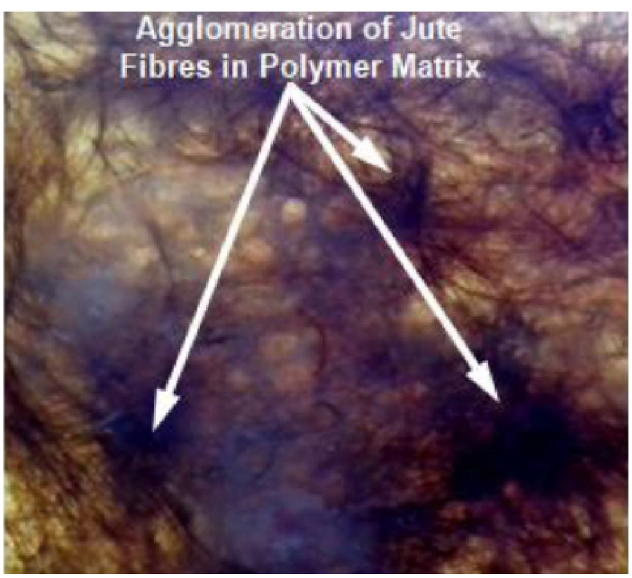

Figure 10: Photograph showing jute fibre agglomerated zones.

Figure 11: Inter-fibre separation in jute fibre agglomerated areas.

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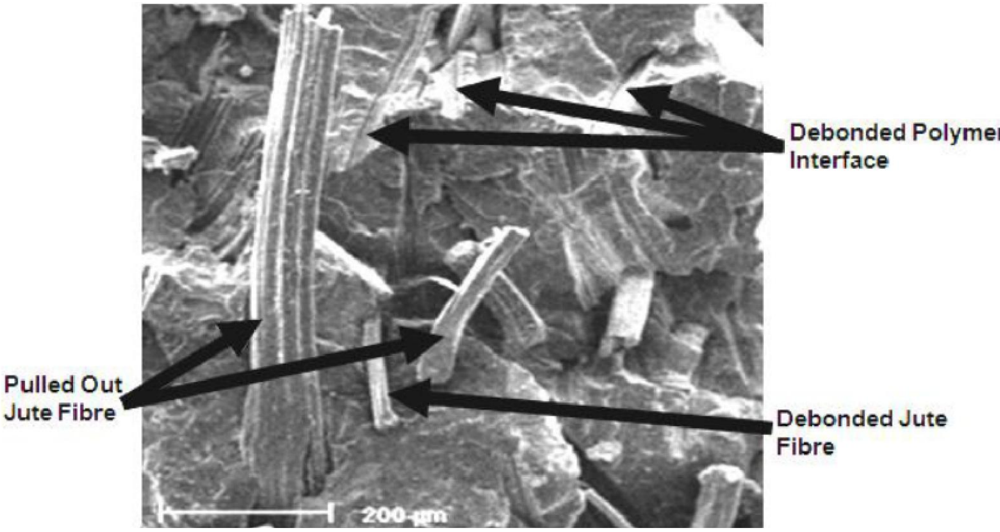

Figure 12: Jute fibre pull out/debonding in jute-nylon composite

nylon-jute composite. Similar observation has also been made by other for wood particle reinforced polymer composites[23].

Addition of nano particles changed the scenario. Now, they improved the tensile properties of the nylon-jute composites globally. Here it is to be mentioned that this type global tensile property enhancement of nylon-jute composites is the indirect actions of nano particles. In fracture mechanics, it is well established that poor interfacial bonding between any matrix and reinforcing materials, presence of gas pockets or other defects in the matrix, even they are in micron level, act as crack or nuclei of crack formation under loading condition[22,24-27]. In this respect, larger the size of the fibre agglomerated zones or other defects, more potent will be the crack initiation site because of higher stress concentration effects over there. It is well documented that the nano particles provide a high surface area that can provide a better cover up in the matrix[28,29]. Thus, addition of nano sand or clay particles thus had healing actions to repair the bad effects related to jute fibre additions because their higher degree of accessibility to any type of open defective zones and heal the areas. The evidence of partial or full filling of gas pockets in composite by nano particles is shown in Figure 13.

Similar to gas pockets, nano particles also fill any other empty spaces between nylon-jute fibres or in the agglomerated jute fibres, etc as shown schematically in Figure 14. As the defect size, i.e. the effective crack size decreases, the stress concentration action also decreases as per fracture mechanics relationship. So, the critical stress required to initiate the fracture also increases. The overall scenario caused the final fracture to delay leading to increase in the proof strength, UTS, modulus and elongation. Similar type of effects of nano particles on strength and ductility enhancement of polymer composite has been observed by other[30].

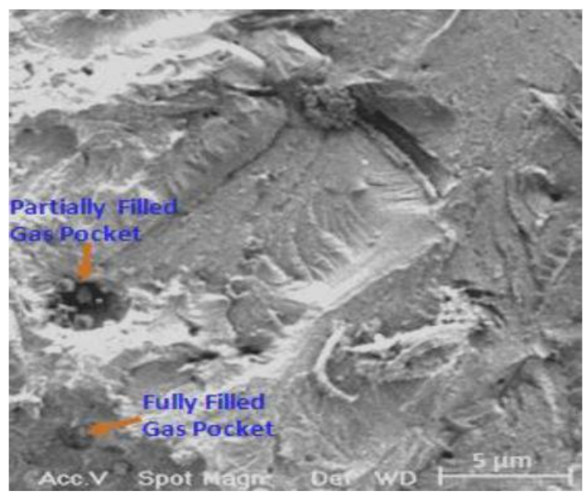

Figure 13: Filling gas pockets by nano particles.

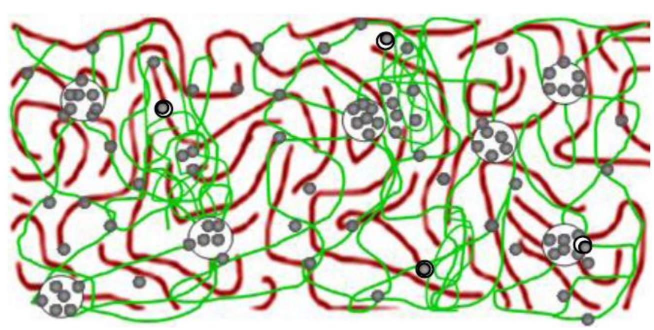

Figure 14: Healing of defects in nylon-jute composite by addition of nano particles.

CONCLUSIONS

In the present research, using local facilities and naturally available materials nano silica sand and clay particles were produced. Then nylon polymer based jute fibre reinforced composites were filled with 1% nano silica sand and clay particles separately to develop nano structured nylon-jute composites. Samples made from pure nylon, nylon-jute composites, nano silica and clay added nylon-jute composites were tested to characterize their various tensile properties following ASTM standard procedure. After detail experimental works, the following final conclusions have been made from this research work:

i) Pure nylon showed the lowest proof strength among all composites. Addition of waste chopped jute fibre in nylon caused a noticeable increase in the proof strength, however, a decrease in the UTS has been observed.

ii) For pure nylon, the highest level of elongation has been found. Addition of jute fibre drastically decreased the elongation from 115% to just 13%. Jute fibre is brittle material. At the same time, incorporation of brittle jute fibres in nylon for making composite restricts the movement of ductile nylon matrix leading to this drastic decrease in ductility.

iii) Addition of nano silica sand or nano clay particles enhanced the gross tensile properties, i.e. proof strength, UTS, modulus and elongation of the nylon-jute composite.

In final remarks, it could be said that the locally produced low cost nano sand or clay particles are good enough to reinforce the nylon-jute composite to enhance the tensile properties of nylon-jute composites.

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