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Fabrication and Characterization of Jute Fiber Reinforced PP-Clay-based Nanocomposites

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Abstract

Nanocomposite is a new concept in the field of plastic-based composites. Jute fabric (hessian cloth)-reinforced polypropylene (PP) composites with different nanoclays were prepared by compression molding. Jute fiber content in the composites was approximately 50%. Mechanical properties of PP-clay blend and PP-clay/jute fiber composites were characterized. It was found that 5% clay containing PP-clay/jute composites showed the best results. Tensile strength (TS), elongation at break (EB) and tensile modulus (TM) of PP-clay/jute composites that contain 5% clay were found to be 59.85 MPa, 20.42% and 711 MPa respectively. Composites were soaked in water for a certain period, and it was observed that there is very little effect of water aging on the mechanical properties of composites.

Keywords: *Polypropylene, jute fabric, nanocomposite, clay, blend*

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INTRODUCTION

In the modern world, composite materials play a vital role in the fabrication of construction materials, automobiles, naval parts, and many more. Early work on composites chiefly emphasized the synthetic matrix and reinforcement [1–9]. The synthetic materials are undoubtedly good in mechanical properties and durability. But they are not biodegradable and cause environmental pollution. Therefore, great attention is being given to invent environment-friendly composite materials to replace synthetic composites [10–15]. For this reason, natural fiber composite is of great demand in the whole world for environmental and ecological concern [16–22]. Interest in using natural fibers as reinforcement in polymer matrices as partial replacement of synthetic fibers has grown significantly during the last decade because of its low cost, low abrasive nature and low density, biodegradability and recyclable nature [23–25]. The natural fibers used to reinforce thermoplastics mainly include wood, cotton, flax, hemp, jute, sisal and sugarcane fibers [26]. Among all natural fibers, jute appears to be a promising material due to it being relatively inexpensive, nonabrasive, low density, high strength and modulus than plastic and commercially available in tropical countries [27]. It has three principal constituents, namely, a-cellulose, hemi-cellulose, and lignin. In addition, it contains minor constituents such as fats and waxes, inorganic and nitrogenous matters, and traces of pigments like b–carotene and xanthophylls. Thermoplastic matrix materials are the most important part of a composite. Polypropylene (PP) is an amorphous thermoplastic polymer, made by chemical industry and used in a wide variety of applications, including packaging, textiles (e.g., ropes, thermal underwear, and carpets), stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes. As a matrix material, PP is used in the current study because it has some excellent characteristics for composite fabrication. It has good resistance to fatigue and has a melting point of

170 °C. Most commercial PP is isotactic and has an intermediate level of crystallinity between that of low-density polyethylene (LDPE) and high-density polyethylene (HDPE). PP is normally tough and flexible, especially when copolymerized with ethylene. Since it possesses several vital and useful properties such as dimensional stability, fire retardance, transparency, high heat-distortion temperature, high mechanical strength, high impact strength, low moisture pickup and good dielectric properties, it is being used as an engineering material. In addition, polymers made from the monomer propylene are rugged and unusually resistant to many chemical solvents, bases, and acids. They also are used for filling, reinforcing, and blending purposes. PP with fibrous natural polymers of biomass origin is one of the most significant routes to create natural-synthetic polymer composites [28–33]. Incorporation of inorganic particulate fillers has been proved to be an effective way of improving the mechanical properties and in particular the toughness of polypropylene [34]. Smectite clays such as montmorillonite, hectorite, saponite and surface-modified montmorillonite, are valuable minerals and are widely used in many industrial applications because of their high aspect ratio, plate morphology, natural abundance and low cost. They are expandable layered silicate and can be intercalated/exfoliated into nanocomposites. Due to nanoclay platelet-like structure, high aspect ratio and propensity to accelerate polymer crystallization, nanocomposites show enhanced mechanical properties, reduced gas permeability, improved solvent resistance and high thermal stability [35, 36]. The objective of this work is to study the mechanical properties of PP-clay-based jute fiber-reinforced nanocomposites.

MATERIALS AND METHODS

Materials

Hessian cloth (unbleached commercial grade, Tossa jute) was collected from Bangladesh Jute Research Institute (BJRI), Dhaka, and clay from Mymansingh, Bangladesh. Polypropylene beads were purchased from Polyolefin Company Ltd., Singapore.

Fabrication of Composites

At first, the clay lumps were crushed, grinded and screened to obtain fine clay particle (90 nm in size). Then certain amount of clay powder and polypropylene beads were taken in a beaker. The PP-clay blend was prepared in a single screw extruder. Then the blend was converted to sheet of PP-clay by using a hydraulic cold press. The polymer matrix sheets (PP-clay) were cut into small pieces (15 × 12 cm) and kept in a desiccator until composite fabrication. To remove moisture, jute fabric was dried in an oven at 105 ºC for 1 h and then cut into small pieces of dimension 15 × 12 cm. Composites were prepared by sandwiching layers of jute fabrics alternately between pre-weighted polymer matrix (PP-clay) layers and pressed at 190 °C for 5 min between two steel plates by using Carver Laboratory (USA Model 3856) press under a pressure of 5 t. Then composite containing steel sheets were cooled to room temperature using another press (Carver, USA) and then cut to the desired size.

Mechanical Properties of Composites

The mechanical properties such as tensile strength (TS), elongation at break (EB), and tensile modulus (TM) were determined for the composites according to DIN 53455 and DIN 53452 standard methods by a universal testing machine (INSTRON 1011) with a gauze length of 20 mm. The impact strength (IS) was measured using impact tester (MT-3016) according to DIN EN IS0 179 standard in the flat wise, un-notched mode. All the results were taken as the average values of 10 samples.

Water Aging

Composite samples were immersed in a de-ionized water bath at 25 °C for different time durations and mechanical properties were studied. Change in mechanical properties with soaking time was determined for various compositions of composites.

RESULTS AND DISCUSSION

Comparative Studies of Mechanical Properties of Composites

PP-clay blend and PP-clay/jute fiber composites with different weight percentages of clay (0, 3, 5, 7, 10, 15, 20, 30 and 35%) were prepared and various mechanical properties were determined. The mechanical properties such as TS, EB, TS and IM of the PP sheet were evaluated and the values are represented in Table 1.

Table 1: *Tensile Strength, Elongation at Break, Tensile Modulus and Impact Strength of PP.*

Materials	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)	Impact strength (J/m)
PP	28.64	25.4	484	28.94

TS, EB, TM and IS of the PP sheet are found to be 28.64 MPa, 25.4%, 484 MPa and 28.94 J/m respectively. The TS and EB of the PP-clay blend gradually decreased whereas TM progressively increased with the increase of clay (wt %) in the blend. The results are shown in Figures 1, 2 and 3 respectively.

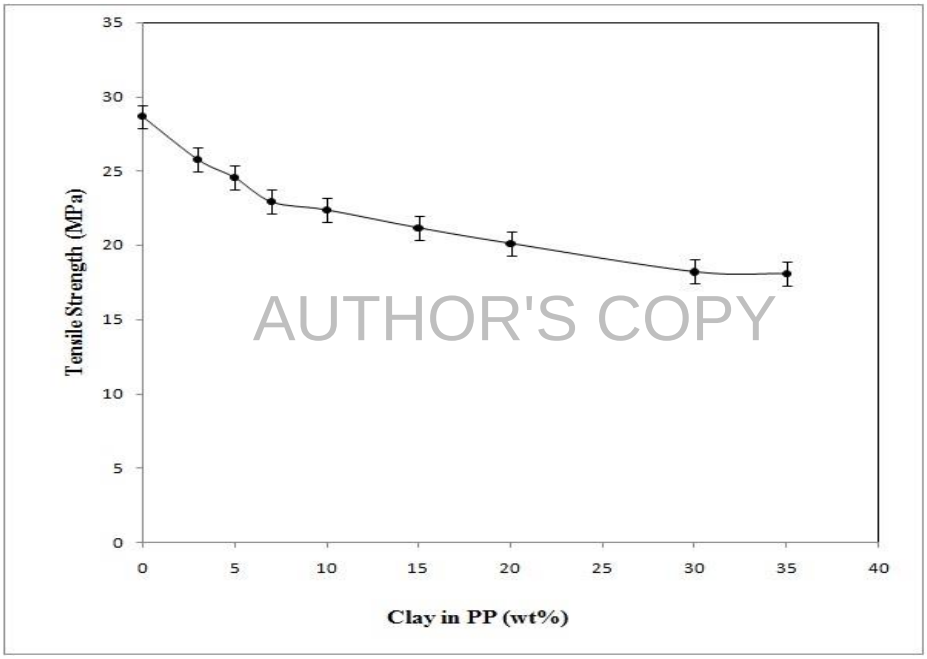

Fig. 1: *Tensile Strength of PP-Clay Blend against Clay Content (wt %) in Blend.*

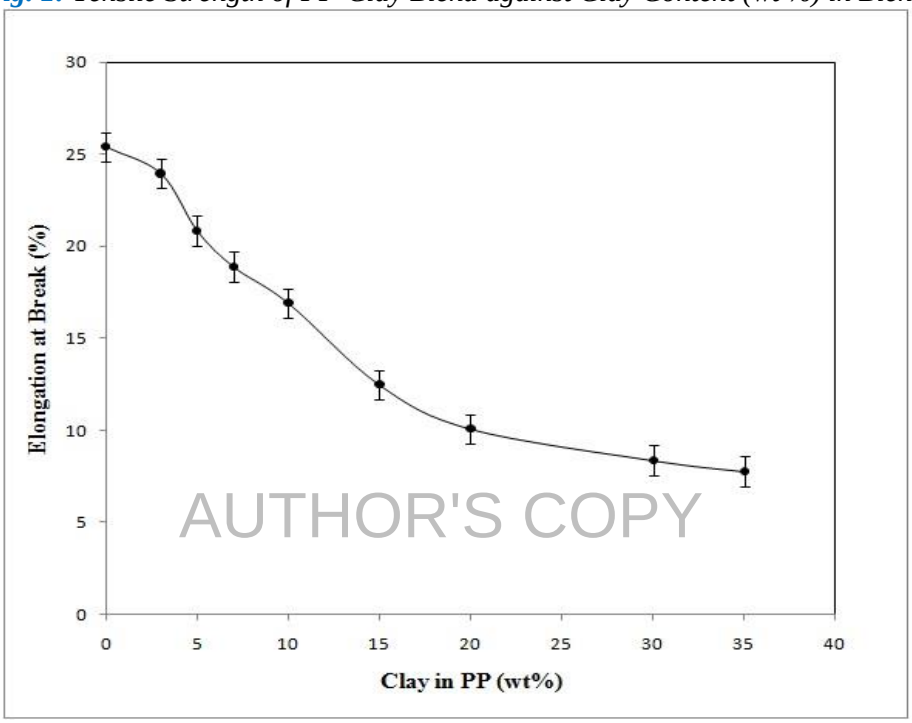

Fig. 2: *Elongation at break of PP-Clay Blend against Clay Content (wt %) in Blend.*

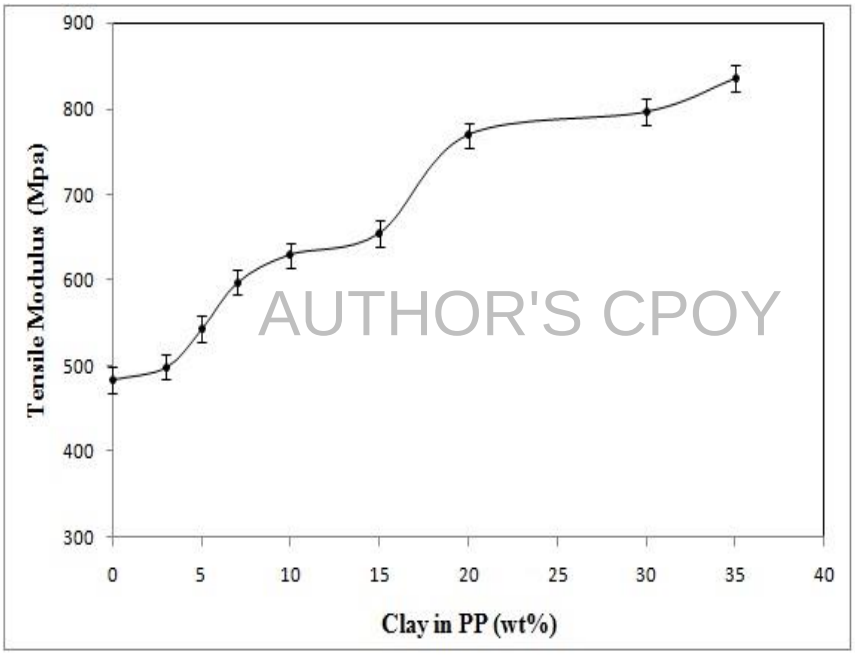

Fig. 3: *Tensile Modulus of PP-Clay Blend against Clay Content (wt %) in Blend.*

Mechanical properties of the PP-clay/jute composites as a function of clay content (wt %) were measured. TS, EB, TM and IS of the composites with regards to percentages (wt %) of clay content in the PP-clay/jute composites are shown in Figures 4, 5, 6 and 7 respectively. It is observed that the TS, EB, TM and IS of composites increased linearly with the increase in clay content up to 5%. It may be for the high interaction among the matrix, jute fabrics and clay that cause the improvement of mechanical properties.

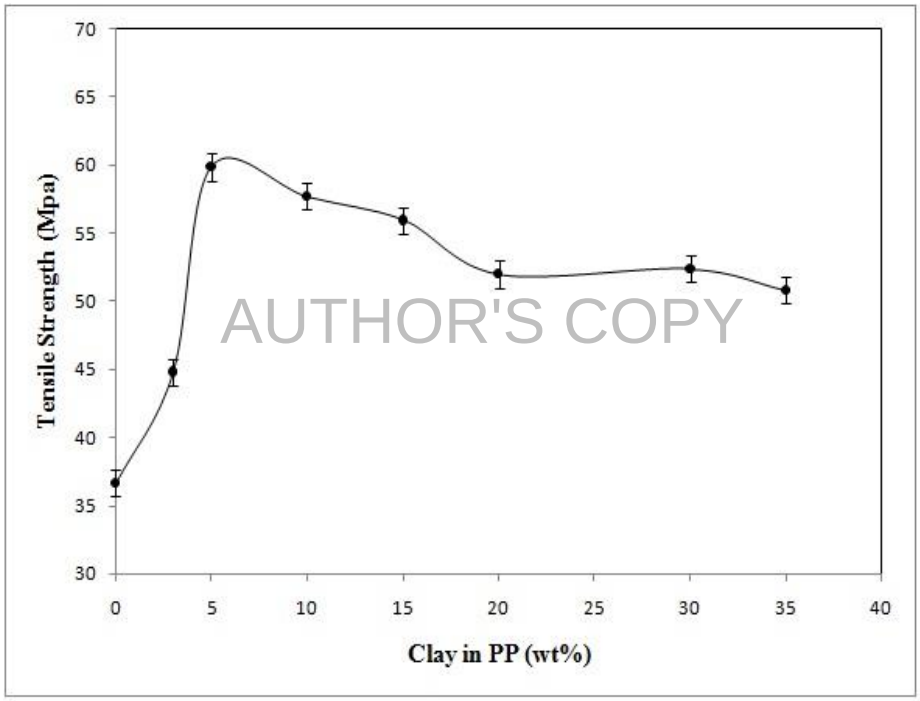

Fig. 4: *Tensile Strength of PP-Clay/Jute Composites against Clay Content (wt %) in Composites.*

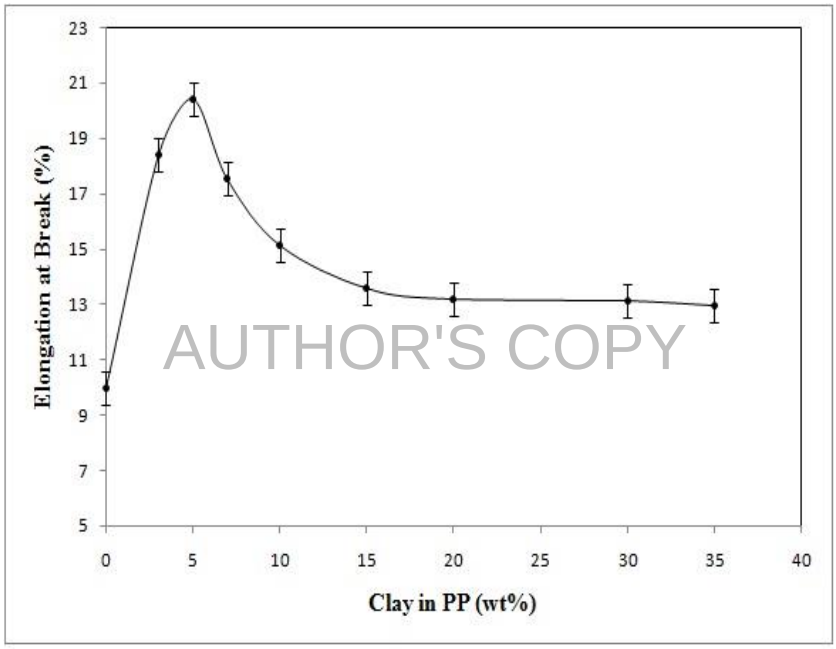

Fig. 5: *Elongation at Break of PP-Clay/Jute Composites against Clay Content (wt %) in Composites.*

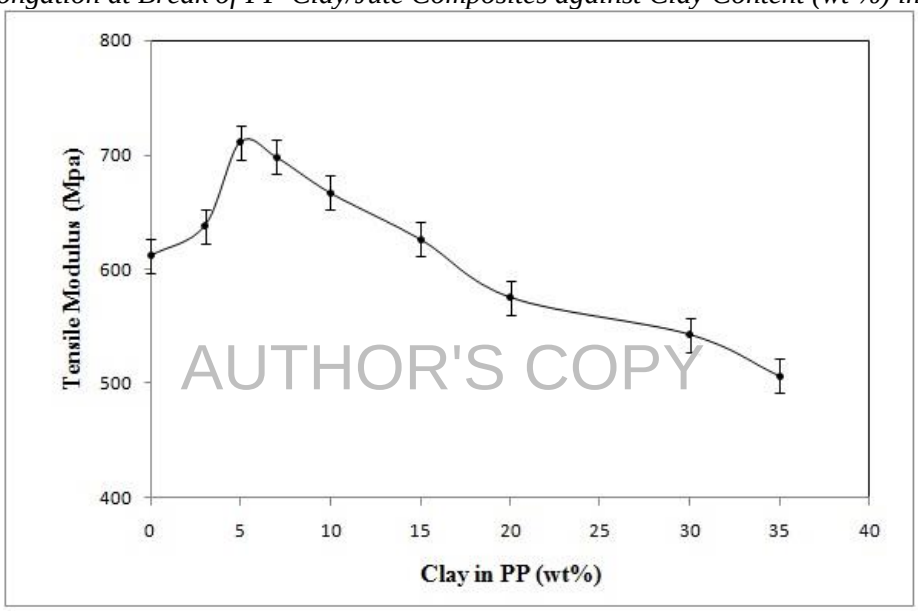

Fig. 6: *Tensile Modulus of PP-Clay/Jute Composites against Clay Content (wt %) in Composites.*

However, beyond 5% clay content, the mechanical properties decrease because nanoparticles might migrate into the interface of jute-PP and be agglomerated. It is also found from Figures 4–7 that the TS, EB, TM and IS for PP-jute composite (0% clay content) are 36.66 MPa, 9.99%, 612 MPa and 39.57 J/m respectively. The values of TS, EB, TM and IS of 5% clay-containing composites are found to be 59.85 MPa, 20.42%, 711 MPa and 46.89J/m respectively. The TS, TM and IS of composites gain 108.97, 46.90 and 62.02% increase than those of PP matrix and also 63.25, 16.17 and 18.49% higher than that of PP-jute composites. The incorporation of jute into PP-clay matrix has resulted in reduction of the elongation at break than PP matrix. The percentage of EB of the composites was decreased due to low elongation at break of the jute fiber compared to PP.

Water aging of PP-clay blend and PP-clay/jute composites was performed in water for up to 6 days. Figures 8, 9 and 10 for PP-clay blend and 11, 12 and 13 for PP-clay/jute composites show the effect of aging time on TS, EB and

TM respectively. It is found that the effect of soaking time on mechanical properties is very little. Although jute and clay are hydrophilic in nature but PP is strongly hydrophobic in nature. Since the adhesion between PP, clay and jute in composites is very strong, so the water uptake is very little. Therefore, mechanical properties do not change significantly.

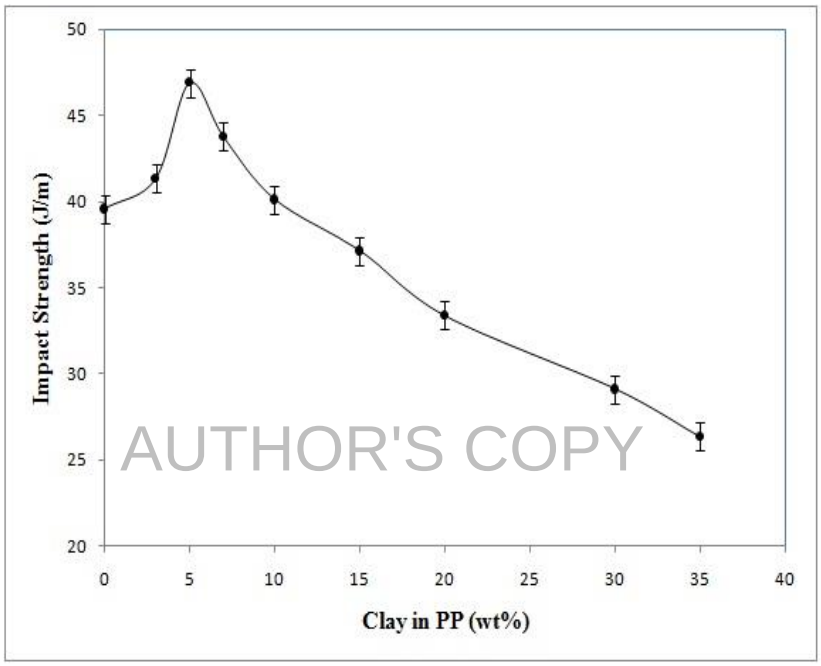

Fig. 7: *Impact Strength of PP-Clay/Jute Composites against Clay Content (wt %) in Composites.*

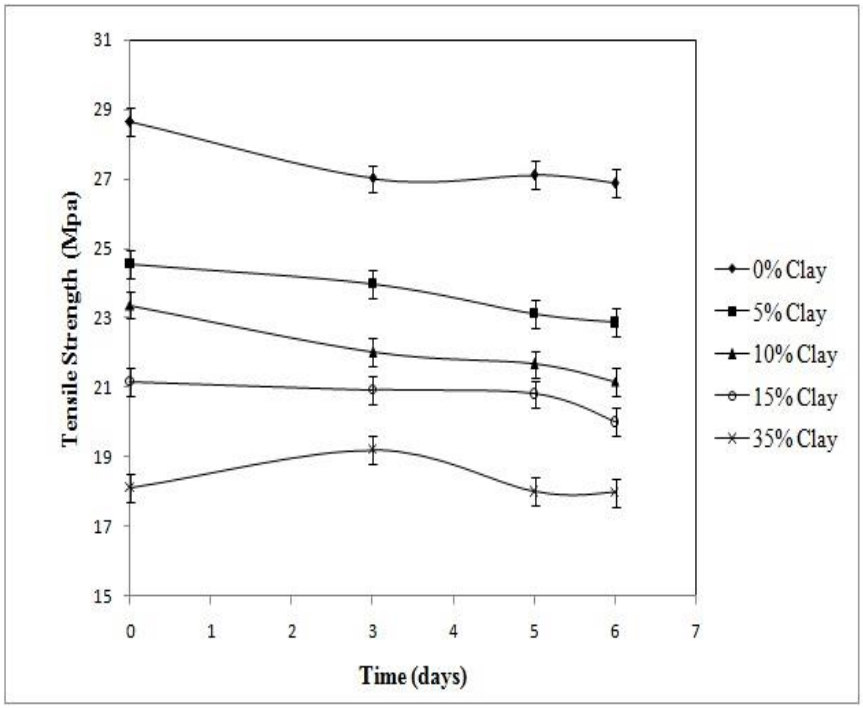

Fig. 8: *Variation of Tensile Strength of Different PP-Clay Blends against Soaking Time (days).*

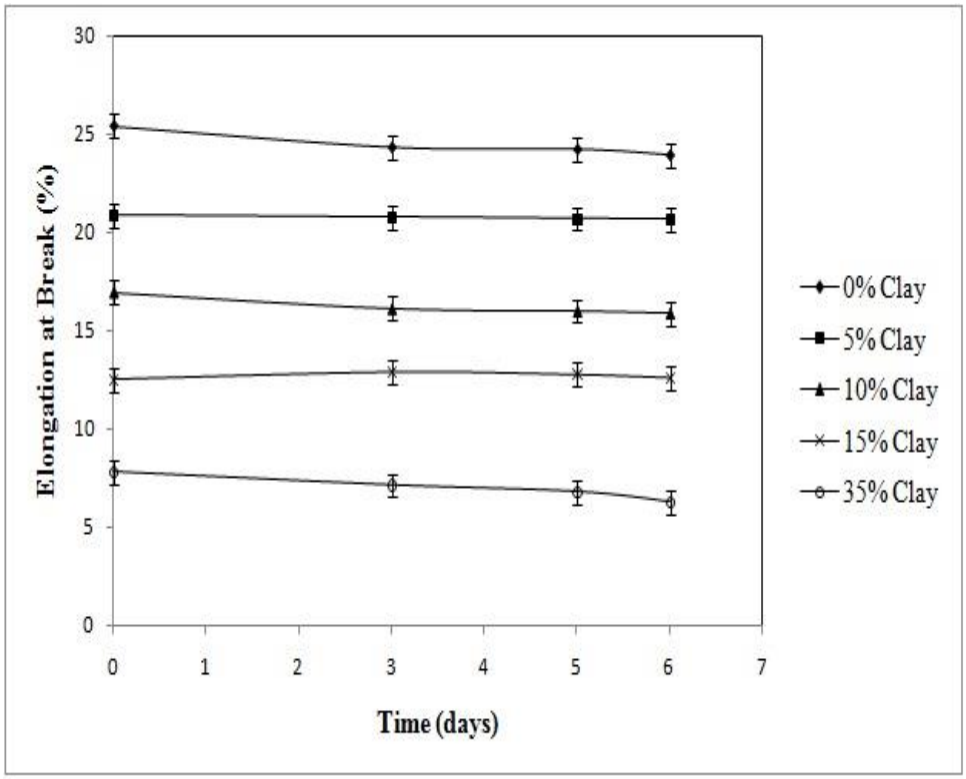

Fig. 9: *Variation of Elongation at Break of Different PP-Clay Blends against Soaking Time (days).*

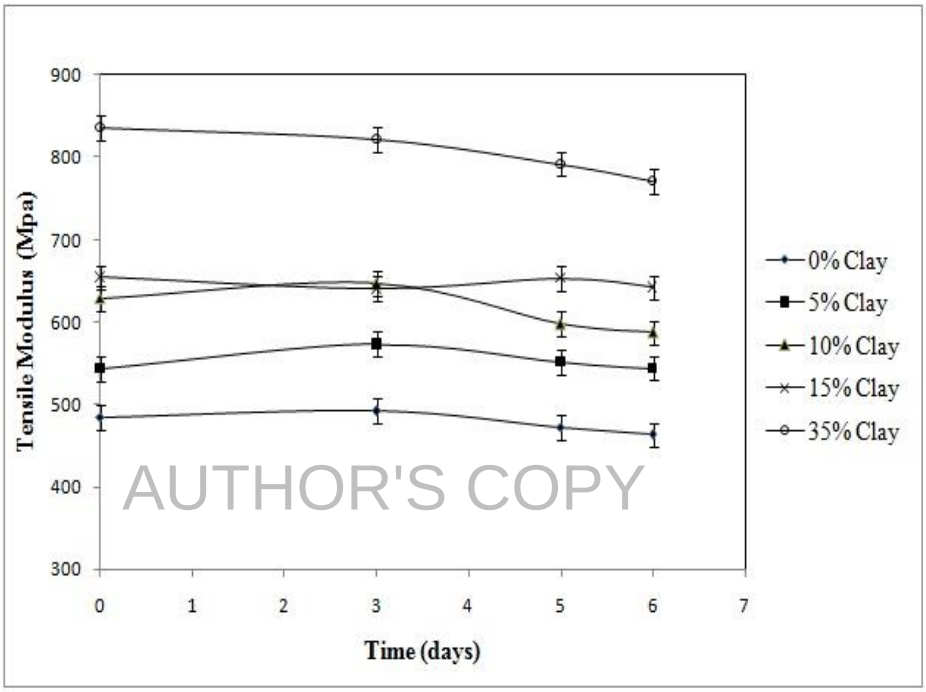

Fig. 10: *Variation of Tensile Modulus of Different PP-Clay Blends against Soaking Time (days).*

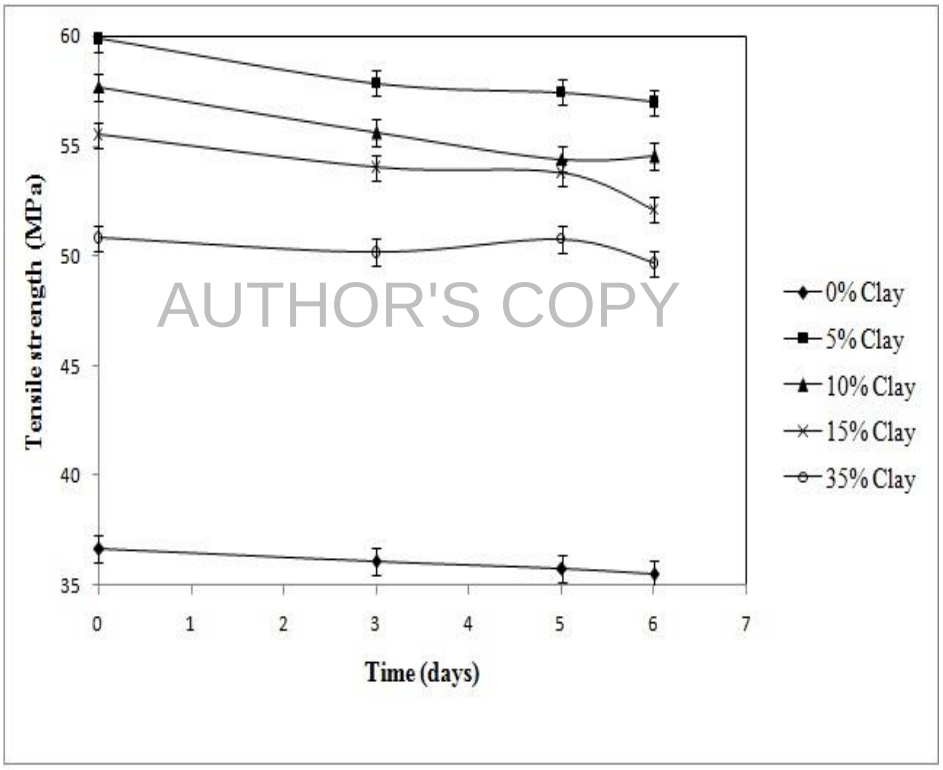

Fig. 11: *Variation of Tensile Strength of Different PP-Clay/Jute Composites against Soaking Time (days).*

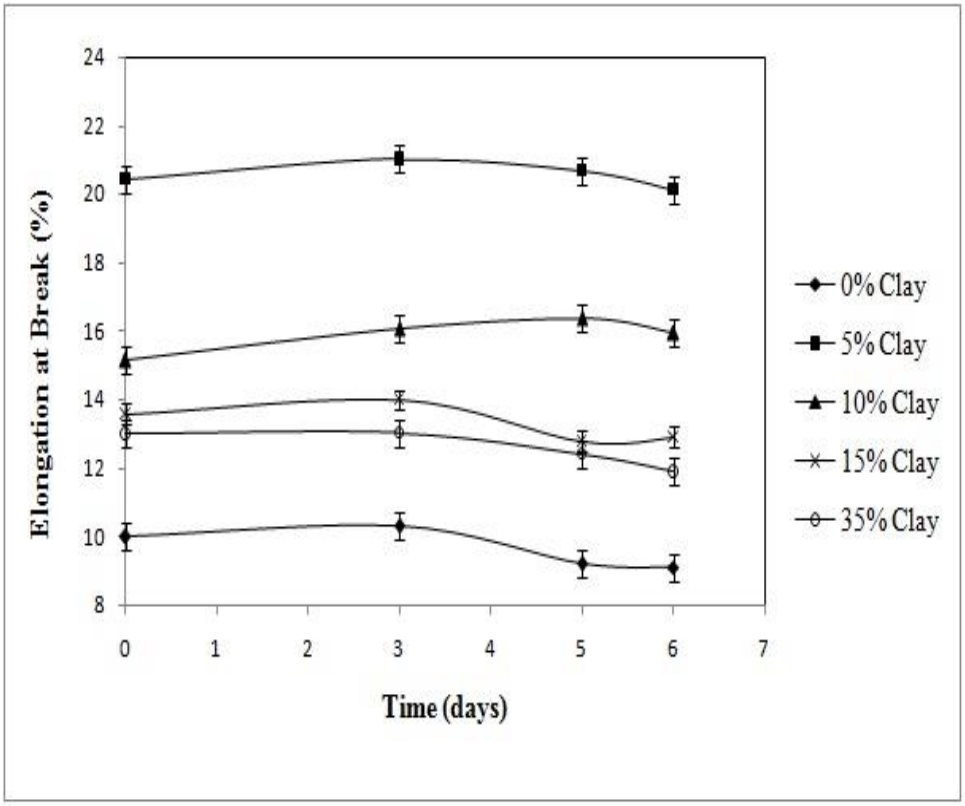

Fig. 12: *Variation of Elongation at Break of Different PP-Clay/Jute Composites against Soaking Time (days).*

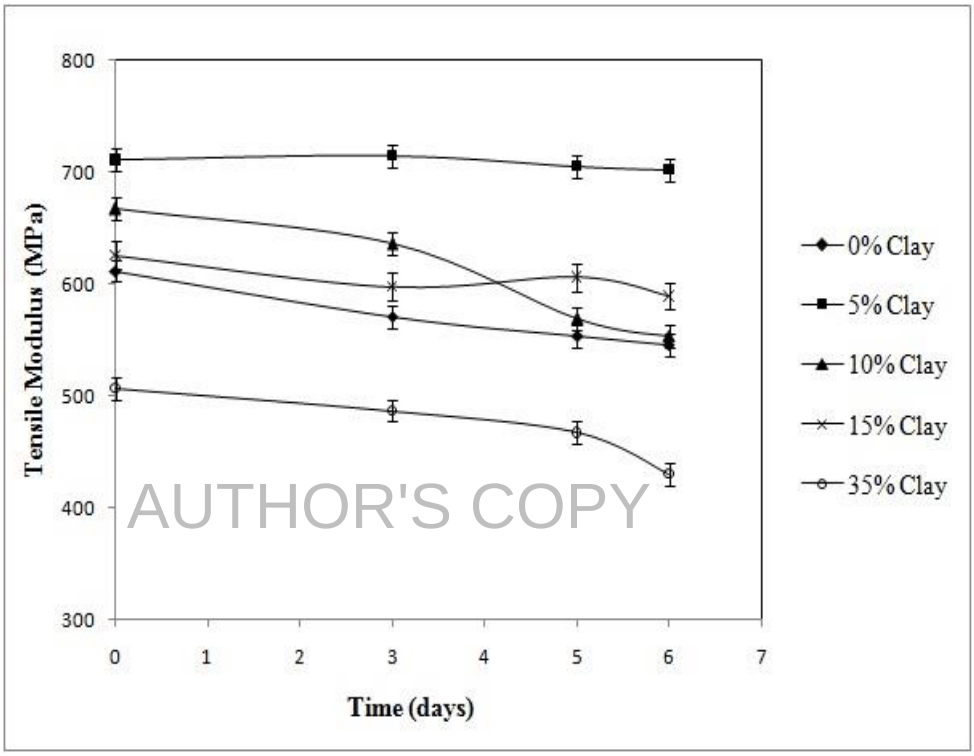

Fig. 13: *Variation of Tensile Modulus of Different PP-Clay/Jute Composites against Soaking Time (days).*

CONCLUSIONS

The study was aimed at preparing a bio-degradable composite material by using natural fiber, as a reinforcing agent and clay powder. Composites were prepared by extrusion and compression molding methods and mechanical properties were evaluated. Mechanical properties of composites increase with the addition of clay powder to a certain degree. It was found that addition up to 5% of clay in PP-clay/jute composite improves the mechanical properties. The TS, TM and IS of PP-clay/jute composites gain 108.97, 46.90 and 62.02% increase than those of PP matrix. There is very little effect of soaking in water on mechanical properties of composites.

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