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Influence of $CaCO_3$ Filler on Physico-Mechanical Properties of Jute Fabric Reinforced Polyester Composites

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ABSTRACT

The waste chicken eggshells was synthetized to fabricate bio-based $CaCO_3$ powder via size reduction. Jute fabric polyester composites were fabricated using compression molding by mixing unsaturated polyester resin with (0, 5, 10, 15, 20, 25) wt% of $CaCO_3$. Effects of different proportions of prepared chicken eggshell and commercial $CaCO_3$ filler on the polyester resin compositeswere compared by means of mechanical and physical test. It was found that the addition of $CaCO_3$ filler to the polyester jute fabric composite leads to improve the mechanical properties. The mechanical properties of $CaCO_3$-jute fabric polyester composites were measured in terms of tensile strength, elongation-at-break, flexural strength, Young's modulus and impact strength. For eggshell $CaCO_3$-jute fabric polyester composites, the maximum values of the aforementioned mechanical properties were 65.9 MPa, 7.1%, 124.3 MPa, 1905 MPa and 15.88 kJ/m^2, respectively, whereas for commercial $CaCO_3$-polyester composites those values were 64.53 MPa, 6.9%, 125.1 MPa, 1842 MPa and 15.79 kJ/m^2, respectively. Water absorption of the composites as a function of time has also been investigated, and it increases by increasing the wt% of $CaCO_3$ filler content.

Key words: Composites, Jute, Polyester, Filler, $CaCO_3$, Eggshell

1. INTRODUCTION

Composites are materials consisting of two or moreidentifiable constituents of different natures. One or more discontinuous phasesembedded in a continuous phase to form a composite.The continuous phase is termed as the matrix, whereas, the discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement [1]. Over the past few decades, it is found that polymer matrix composites (PMC) have replaced many of the conventional materials in various applications. This is possible due to the advantages such as ease of processing, productivity, cost reduction etc. offered by polymers over conventional materials. In most of these applications, the properties of polymers are modified by using fibers or fillers to suit the high strength/high modulus requirement [2, 3].
However, due to the high cost of the petroleum-derived products or to environmental hazard, a growing effort has emerged in recent years on the research, development, and application of biocomposites. A composite containing at least one constitute (e.g. matrix or reinforcement) that is derived readily from renewable resources may be considered a biocomposite. Renewable resources, such as avian feathers or cellulose fibers from kenaf, ramie, flax, sisal, coir, rice-husk and jute [4]. Natural fibers are undergoing a high-tech revolution that could see them substitute synthetic materials in different applications such as boat hulls, bathtubs, and archery bows. Natural fibers have low abrasion multi-functionality, low density, low cost, high availability, high toughness, acceptable specific strength properties, good thermal properties, enhanced energy recovery, and biodegradability. Because of its excellent mechanical properties, low cost, renewable nature and much lower energy requirement for processing, jute is an attractive natural fiber for use as reinforcement in composite [5, 6].

Unsaturated polyester resins (UPR) are the most important thermosetting resins. It is widely used as the polymeric composites for their relatively low cost, high strength and ease processing. Unfortunately, the cross-linking degree of UPR makes them with inherently larger brittleness and lower impact strength, which limit their application in some fields. The methods of toughness modification for UPR include adding fillers is one of the most convenient way [7].

The past decades have witnessed increasing interest in the use of fillers in the polymer industryto improve the mechanical properties polymeric composites. Filler used in composite can be either fiber and/or particulate form. Fillers greatly enhance the dimensional stability, impact resistance, tensile and compressive strength, abrasion resistance and thermal stability when incorporated into polymers. Fillers which merely raise the bulk volume, and therefore, reduce price, are known as extender fillers while those which improve the mechanical properties specifically tensile strength are termed as reinforcing fillers.Calcium carbonate chalk, talc, marble dust or limestone sand, sawdust, chopped glass fiber, powdered slate and ground olive stonesare the typical fillers for polyester resins [8, 9].

So recent investigation given importance for uses of bio-based filler in polymer composites. Bio-filler was introduced in the jutepolyester composites as a re-useable material that enhances cost effectiveness to the processing ability and eventually to the overall performance of the composite itself. Calcium carbonate is one of the most common bio-filler in polymer composites [10]. Chicken eggshell (ES) which is a major source of calcium carbonate is an aviculture byproduct that has been listed worldwide as one of the worst environmental problems, especially in those countries where the egg product industry is well. About 150,000 tons of this material is disposed in landfillsin the U.S. alon [11].

Chicken eggshell (Es) contains about 95% calcium carbonate in the form of calcite and 5% of organic and inorganic materials.Calcium (Ca), magnesium (Mg), and sodium (Na) are major inorganic constituents of the Es.Compared to mineral and commercial calcium carbonate, Es has relatively lower density and low cost. Es filler gives slightly higher crystallinity value as compared to mineral $CaCO_3$. It has also been foundthat eggshell/ polymer matrix composite gives higher tensile modulus and Es $CaCO_3$ shows better reinforcement than composites with traditional $CaCO_3$ filler. Bio-based calcium carbonate can be synthesizedvia size reduction of waste eggshells. Extraction of calcium carbonate from waste eggshell by mechanical attrition process is an easy and economical way and proper use of waste material can occur. Study has been conducted shows that the natural $CaCO_3$ in seashell, hen's eggshell and other natural shell has significantly high modulus and mechanical properties than synthetic $CaCO_3$ that derived from quarried source [12-14]. Recycling of ES as filler will be an attractive alternative to traditional filler materials and a potential solution to the environmental hazards posed by ES solid waste.

In the present study focuses on the filler properties of Es in the particulate form on jutepolyester composites and the interaction between filler with fiber and its polymer matrix. The common modification in applying filler and fiber into polymer composite is to modified the mechanical properties and produce a better, cost effective, easy and abundance wastes bio-based filler to substitute synthetic and conventional filler.

2. EXPERIMENTAL

2.1. Materials

Jute fabric (Tossajute) andeggshells were collected from the local market of Rajshahi, Bangladesh. Unsaturated polyester resin used as polymeric matrix was obtainedfrom Singapore Highpolymer Chemical products (SHCP), Singapore. Methyl ethyl ketone peroxide (MEKP) used as catalystwas alsopurchased from SHCP, Singapore. Calcium carbonate ($CaCO_3$) used as filler was obtained from Merck company, Germany.

2.2. Synthesis of $CaCO_3$ Powderfrom Eggshells

Eggshells were washed with hot water and sun dried to remove the membranes. Then, washed it again. Samples of the eggshells were dried in an oven at 50° C for 2 days, and the shells were then crushed and blended through an electric blender into powder. Then it was grounded through a mortar pestle into fine powder, which was sieved through a laboratory stainless steel sieve. The calcium carbonate powders were finally packed into a polyethylene plastic bag for further analyses [15].

2.3 Fabrication of Composites

Both types of $CaCO_3$ (egg shells extracted and commercial) jute polyester composites were prepared using compression molding. At first, polyester-$CaCO_3$ sheet was prepared by hand lay-up technique according to our previous laboratory work [16]. In thisprocess, unsaturated polyester resin and $CaCO_3$mixed thoroughly to form a homogeneous gel like solution.

The solution was used to prepareseveral formulations varying weight ratios of $CaCO_3$ content of 0, 5, 10, 15, 20 and 25wt%. About 2.5 wt% MEKP catalyst was added to the mixture solutions. The mixed solution was then poured into an aluminum frame with a dimension of 15 cm×12 cm×1 cm. The frame was positioned in a mold holding two parts with a melot paper at the end. The mold was closed or another part of the stainless steel plate kept on the melot paper. Then, the mold was placed in the hot press machine to heat at 70°C for about 10 min. After passing 10 min the mold was removed and placed in the cold press machine again. Finally, the polyester-$CaCO_3$ sheet was separated by removing of two steel plates. The composites were prepared by sandwiching three layers of jute fabric (JF) between four layers of polyester-$CaCO_3$ sheet. Composite were made by pressing this sandwich at 90°C for 10 min under a pressure of 5 tons using a

Carver Laboratory Press (model 2518). Thencomposites were cooledto roomtemperature using another press, then cut to the desired size and kept in the desiccators. The schematic representation of the fabrication process of jute fabric polyester composite with $CaCO_3$ fillers is shown in Figure 1.

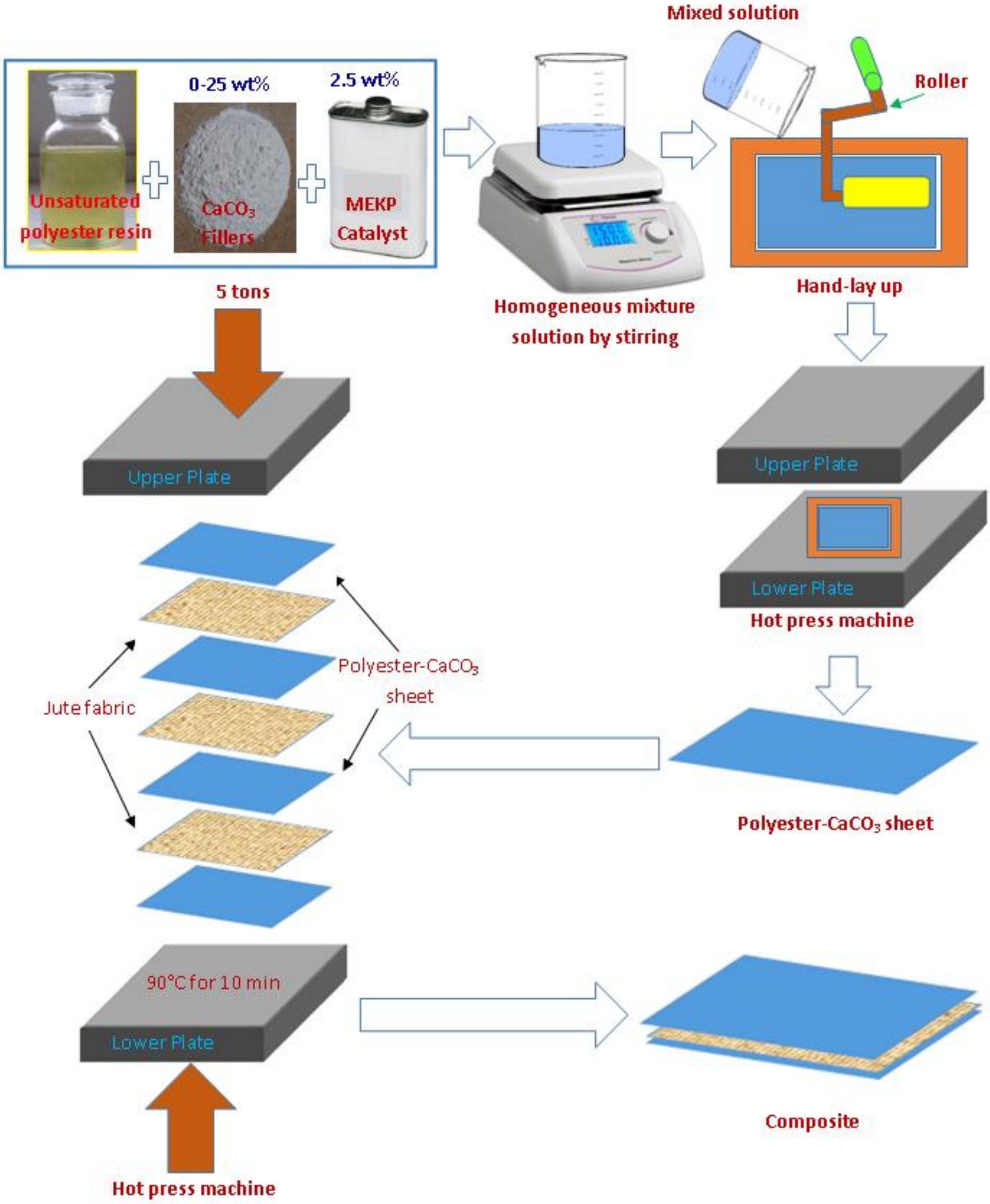

Fig. 1 Schematic representation of the fabrication process of jute fabric polyester composite with $CaCO_3$ fillers

2.4. Mechanical Tests

The tensile properties of the composites were determined using a Universal Testing Machine (Model: 1011, UK). Tensile strength measurements and flexural strength tests were carried out following ASTM D638 and ASTM D790 standards, respectively. Dynamic Izod impact tests were conducted using a Universal Impact Tester (Hung Ta Instrument Co. Ltd., Taiwan). For the impact test, all the samples were notched on the center of one longitudinal side according to the ASTM D256 standards. All the results were taken average values of five samples.

2.5. Water Absorption

Water absorptions of the composites were performed according to ASTM Designation: C 67-91 [17]. Composites samples were immersed in a static water bath at 25 °C for interval of a 4 hr (up to 24 hr). After certain periods of time, samples were taken out from the bath and wiped using tissue paper, then weighed. Water intake was determined by the subtraction from final weight to initial weight.

3. RESULTS AND DISCUSSION

3.1. Mechanical Properties

3.1.1. Tensile Strength

Figure 2 shows the effect of both types (eggshell and commercial $CaCO_3$) of the filler contents, on the tensile strengths of unfilled and filled jute polyester composites. From the above figure, it is observed that increasing the filler content, results in increase tensile strength. The maximum tensile strength obtained for 10 wt% filler content composites in both eggshell and commercial $CaCO_3$. This is merely due to good interface and strong bonding between the $CaCO_3$ filler particles and resin matrix. But the maximum tensile strength is obtained 65.90 MPa for eggshell $CaCO_3$ filler reinforced jute polyester composites when compared with commercial $CaCO_3$ reinforced jute polyester composite and pure jute polyester composites. However, further increase of filler content, a decrease in tensile strength is found in both cases. The strength decrease is only due to increase in void content and imbalance of filler and matrix weight percentage [18-20].

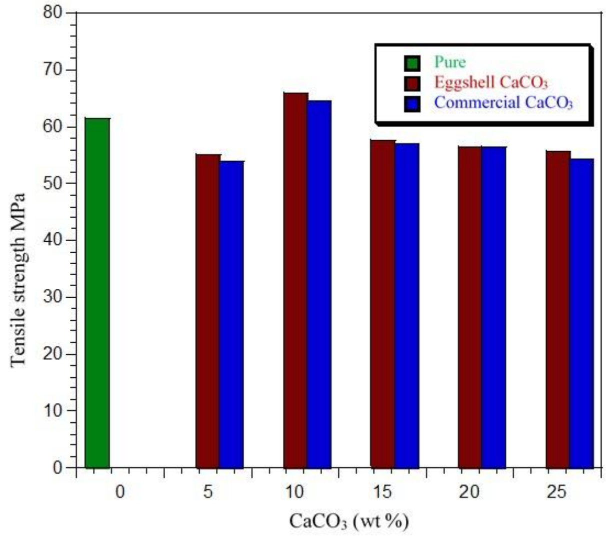

Fig. 2 Effect of $CaCO_3$ filler content on tensile strength of jute polyester composites

3.1.2. Elongation-at-break

The effect of $CaCO_3$ filler on the elongation at break of jute polyester composites is shown in Fig. 3. From the above figure, it can be seen that the elongation at the break for the composites increasing with increasing $CaCO_3$ filler content because the addition of $CaCO_3$ powder causes an increase in the elasticity which leads to reduce the strength of the material. Increase of the elongation at break with the increasing filler loading indicates the capability of the filler to support the stress transfer from filler to polymer matrix or filler to fiber [8]. The maximum elongation found at 20% filler content for both samples. Further increase of $CaCO_3$ filler content the elongation decreases due to increasing the rigidity of the composites [21, 22].

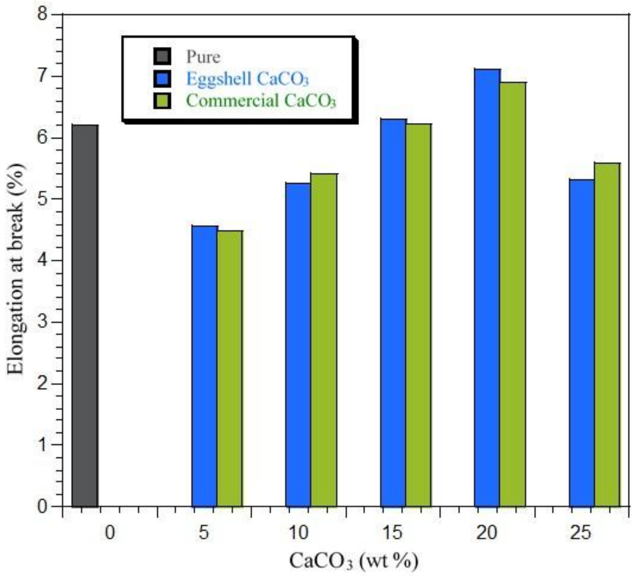

Fig. 3 Effect of $CaCO_3$ filler content on elongation at break of jute polyester composites

3.1.3. Tensile Modulus

Figure 4 shows the tensile modulus as a function of filler content. The tensile modulus values for eggshell $CaCO_3$ jute polyester composites and commercial $CaCO_3$ jute polyester composites are the maximum at 10 wt% $CaCO_3$ content, having the values of 1905 and 1842 MPa, respectively. This decrement in tensile modulus can refer to increase the resistance of material to deformation [12]. The modulus of composites increased with increases in filler content. This observation highlights the fact that the incorporation of fillers into polymer matrix improves the stiffness of the composites [22]. This is because at a high filler loading, the composite will be able to withstand greater loads [23-24].

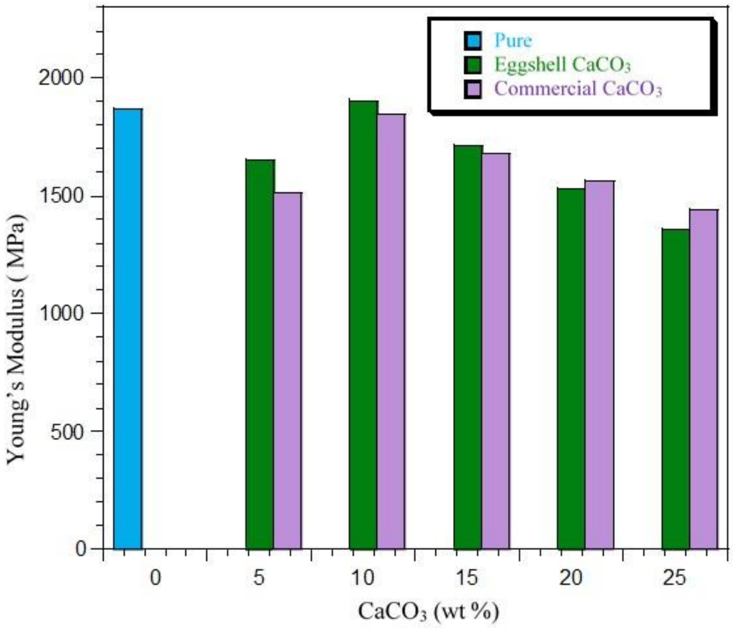

Fig. 4 Effect of $CaCO_3$ filler content on tensile modulus of jute polyester composite

3.1.4. Flexural Strength

The flexural test experiment of eggshell $CaCO_3$ and commercial $CaCO_3$ jute polyester composites as shown in Figure 5.

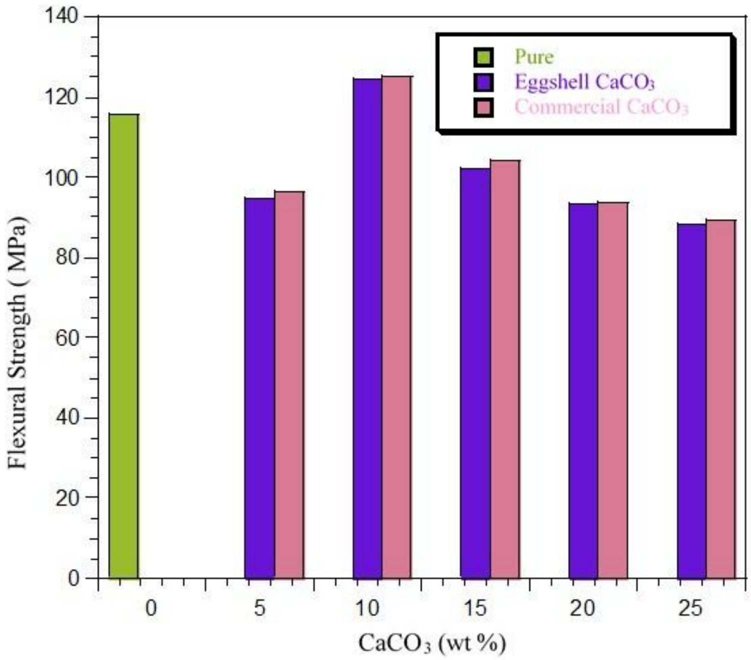

Fig. 5 Effect of $CaCO_3$ filler content on flexural strength of jute polyester composites

It is clear that flexural strength show a continuous increase as the filler loading increases in both cases, although there is a slight decrement in flexural strength from 15 to 25 wt% filler loaded composites, this may be happen due to crack formation, poor filler-matrix adhesion strength, and increase in void content in the matrix of composites [18]. The maximum flexural strength is obtained 124.3 MPa for eggshell $CaCO_3$ and 125.1 MPa for commercial $CaCO_3$ particulates filler reinforced jute polyester composite.

3.1.5. Impact Strength

Effect of both types of calcium carbonate content on jute polyester composites were studied and the obtained results are shown in Figure 6.

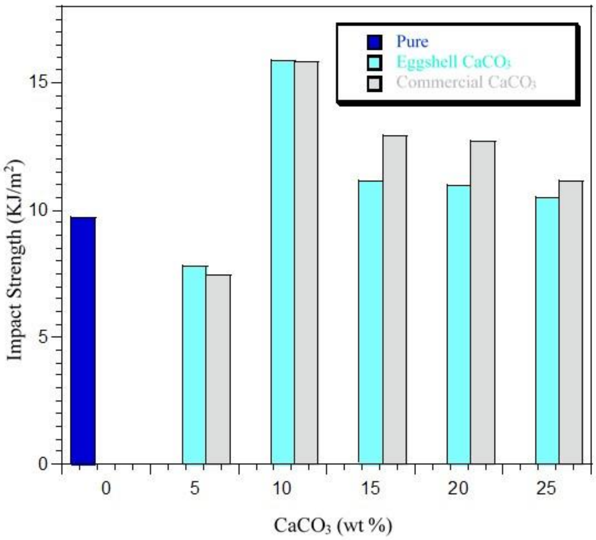

Fig. 6 Effect of $CaCO_3$ filler content on impact strength of jute polyester composites

For impact strength it was observed that, presence of 5 to10 wt% $CaCO_3$ filler increases the impact strength. This increase in impact strength may relate to the fact that when $CaCO_3$ filler is added to polymer it acts like a solid "Plasticizer", therefore the flexibility of the polymer increases and its ability to absorb and dissipate energy increases, so the polymer needs high impact energy to fracture [12]. The highest impact strength values for eggshell $CaCO_3$ jute polyester composites and commercial $CaCO_3$ jute polyester composites are 15.88 and 15.79 KJ/m². Further increase of calcium carbonate filler content impact strength decreases. This could be due to the effect of brittle calcium carbonate content, which resulted in a lower strength [25, 26].

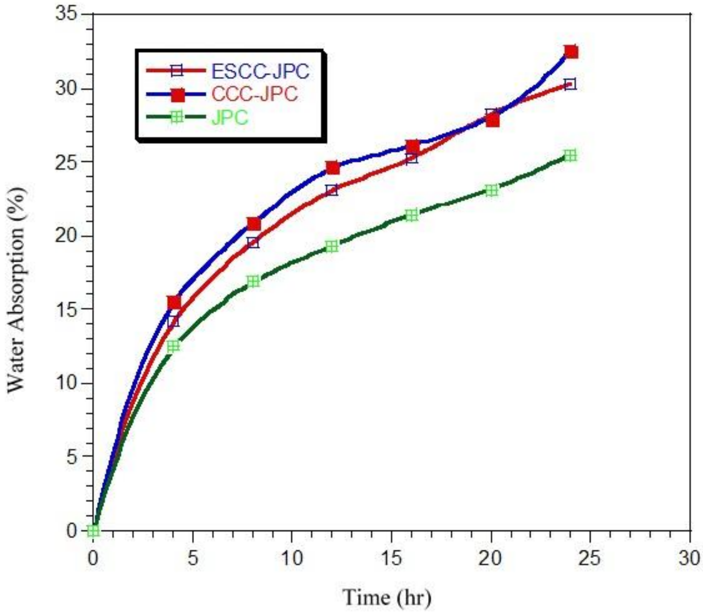

Fig. 7 Water absorption of different composites as a function of time. *JPC= jute polyester composites; CCC-JPC= commercial $CaCO_3$- jute polyester composites; ESCC-JPC= eggshell $CaCO_3$-jute polyester.

3.2. Water Absorption Characteristics of Composites

Figure 7 shows the variation of water absorption versus exposure time for composites. It can be seen that the composites with higher filler content show more water absorption. The pure jute polyester composites (JPC) absorb less water in comparison with eggshell $CaCO_3$-jute polyester (ESCC-JPC) and commercial $CaCO_3$- jute polyester composites (CCC-JPC). As the filler content increases, the formation of agglomerations increases due to the difficulties of achieving a homogeneous dispersion of filler at high filler content. The agglomeration of the filler increases the water absorption of the composites [12]. For calcium carbonate, which contain hydrophilic sites, an increase in water absorption can be expected [27-30].

4. CONCLUSIONS

An effective economical method established for disposing waste eggshells. Eggshell waste was used to extraction of $CaCO_3$ powder. The addition of $CaCO_3$ filler has resulted in some improvement in the mechanical properties of the jute polyester composites. It was found that 10 wt% $CaCO_3$ filler content in the composites performed the best mechanical properties. Eggshell $CaCO_3$- jute polyester composites show better tensile strength, elongation at break, tensile modulus, impact strength than commercial $CaCO_3$-jute polyester composites. On the other hand, commercial $CaCO_3$-jute polyester composites show better flexural strength in comparison with eggshell $CaCO_3$-jute polyester composites. Water absorption of the composite as function of time also investigated. $CaCO_3$-jute polyester composites show higher water absorption than pure jute polyester composites because of hydrophilic nature of $CaCO_3$.

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