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Novel Coir/Chitosan Composites for Packaging Applications

Bharathi. V[a], Anilchandra A.R[a*], Siddesh B Shankar[b], Shantanu Sanjay Sangam[b], Shreyas. S[b]

[a]*Faculty, Dept.of Mechanical Engineering, B.M.S. College of Engineering, Bengaluru 019. E-mail: anilchandraar.mech@bmsce.ac.in*
[b]*Final year student, Dept. of Mechanical Engineering, B.M.S. College of Engineering, Bengaluru,-019*

Abstract

Composites are a popular choice in the current industrial scenario for a number of reasons and their extensive use poses serious environmental issues. This prompts us to explore the possibilities of completely natural composites that can strike a balance between performance and ease of disposal. In this regard, a novel "Green" composite material constituting Chitosan as a natural matrix material in conjunction with other natural reinforcements (Coir) is explored. Preliminary experimentation on composite fabrication was carried out to obtain laminated coupons. Physical characteristics such as density and finish quality were analyzed and used to optimise process parameters. Test coupons were prepared and evaluated for tensile properties. Further various food packages were produced and tested for their feasibility. This article presents an early investigation into the viability and effectiveness of chitosan as a natural matrix for the production of entirely natural composites and their appropriateness in packaging applications.

Keywords: *Biomaterials, Composite materials, Organic, Laminates*

1.0 Introduction

Demand for eco-friendly materials is rapidly increasing in the packaging industry and interior applications where multiple reasons favor application of such materials those studied by Prochon M. et al., 2021 [1]. In this pursuit, most of the work has been towards the partially natural/hybrid composites. Majeed K. et al., 2013 [2] trying to meet the global need for sustainable and environmentally friendly processes. However, such hybrid materials too pose serious environmental issues. This indicates that a keen focus needs to be laid upon fully natural (both reinforcement and matrix are natural) composites that can strike a balance between performance and eco-friendliness. In this regard, the present work explores Chitosan and Coir as natural matrix material and reinforcement respectively. Chitosan, a deacetylate form of Chitin, is a copolymer of 2glucosamine and N-acetyl-2-glucosamine units. It is a promising biomaterial with desirable attributes such as haemostatic fungicidal, regenerative effect and hence desirable for food packaging applications. Paiva et al., 2018 [3] studied the effect of crosslinking Starch-Chitosan micro-particles with glutaraldehyde and it showed a better behaviour in terms of tensile properties than neat SCM blend (30% fraction) showing the importance of cross-linking. Rai et al., 2017 [4] incorporated chitosan into lignin films to determine its viability in food packaging applications and it showed significant antimicrobial activity. Yang et al., 2016 [5] studied the effect of combining Polyvinyl Alcohol and Chitosan (CH) and Lignin nanoparticles. It was seen that addition of CH to this

*Corresponding Author

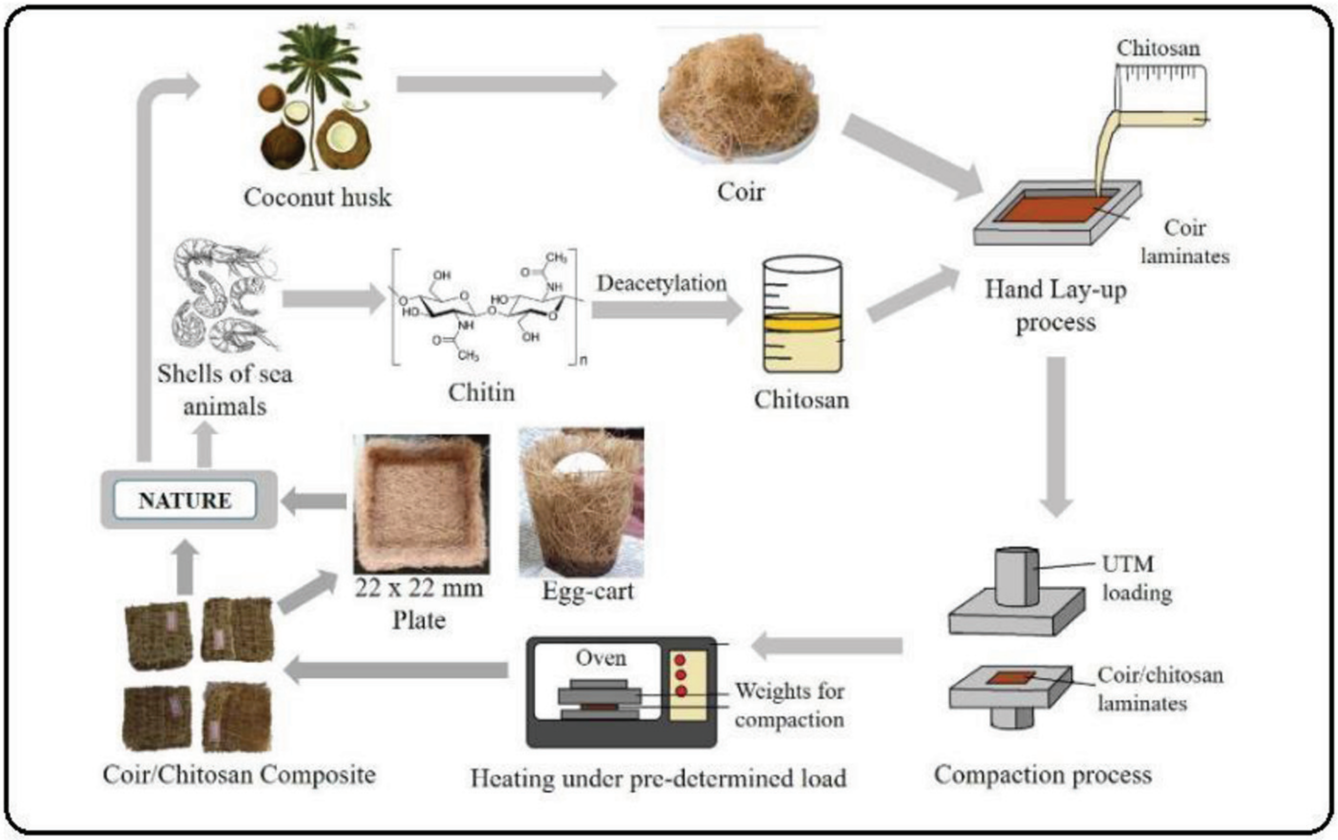

Figure 1: Coir/chitosan composite fabrication and potential products: the life cycle starts from nature and goes back to nature

combination caused a decrease in tensile performance. Chen et al., 2009 [6] studied the SEM micrographs of lignin-chitosan and observed a very good interfacial adhesion between lignin and chitosan. Coir is a lingo-cellulosic fibre obtained from the husk of coconut (Cocos nucifera). Harish et al., 2009 [7] observed that coir-epoxy composite had a lower tensile strength compared to GFRP due to poor interfacial bonding which led to instantaneous crack propagation. Monteiro et al., 2008 [8] studied the effects of variation of coir reinforcement percentage in a coir-polyester composite and observed that coir composition plays a crucial role in stiffness and rigidity of the composite. Romli et al. [9] studied the effect of fibre volume fraction, curing time and compression load during the fabrication on the tensile strength of Coir-Epoxy composite. He observed that coir fibre volume fraction is the most dominant factor influencing the tensile strength of the composite. From this literature review it is evident that there lies abundant scope to explore chitosan as matrix material in natural fibre reinforced "green" composites.

2.0 Materials and Methods

2.1 Composite Fabrication

Processed Chitosan along with randomly oriented Coir fibre mats (supplied by Swaket Biotech Ltd., Bangalore) were used as the matrix and reinforcement material respectively. To fabricate the composite laminates, double Coir fibre mats (placed one on the other) of 80x80 mm and Chitosan were hand laid with a 90:10 volume fraction following the studies of Romli et al., 2012 [9]. A 150x100x2 mm aluminium mould was used to cast the composite laminate. The composite was manufactured in a three step process. Firstly the hand layup process, UTM compaction lasting for 2 mins, followed by curing the laminates in an industrial oven with external loading.

2.2 Density Studies

Individual steps in the composite preparation process were optimized in terms of best density obtainable. The density was calculated by measuring the laminated composite's dimensions (using a Vernier) and the mass, which were plugged into the below equation:

$$\rho = \frac{m}{v} \quad \text{... (1)}$$

Where, ρ – density; m – Mass (g); V – Volume (cc)

The effect of load applied during heating was studied and from Fig 2, it is clear that the density of the laminated composite increases steadily up to ~0.2097g/cc at (90N, 90°C), and the density values decrease steadily for load values above 90N. The peak value of density observed at 90N could be explained as – for low loads during heating in oven (<< 90N), the load does not provide enough quasi-compaction for the escape of moisture from the composite, due to which it was observed that such composites were partly damp. However, for higher loads (>> 90N), the quasi compaction effect of the load may be high enough that it does not allow escape of air bubbles from the composite matrix, leading to a decrease in density. Thus, from the results, it was concluded that the optimized parametric value for load under heating in the oven was ~90N at 90°C (maintained constant). The UTM load applied during composite preparation was also varied and its effect is depicted in Fig. 3. It can be observed that the density improvement between 0kN (no UTM compaction) and 75kN compaction was only 10%. Considering the energy intensive nature of UTM compaction, it was observed that the compaction under UTM does not have a significant variation on the composite laminate density. Thus, it was concluded that the optimized parametric value for UTM compaction load was 0kN.

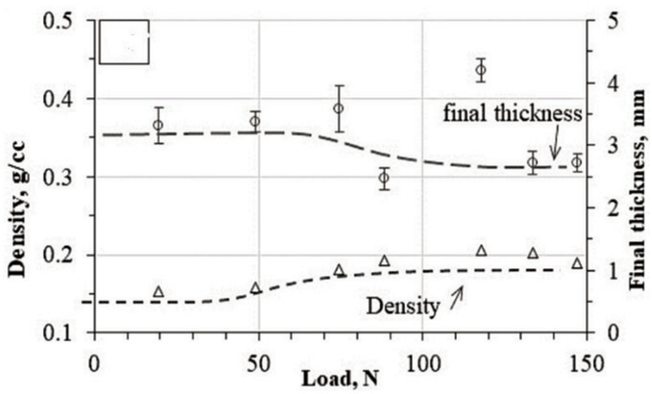

Figure 2: Without compaction, heating at 90°C under varying dead loads

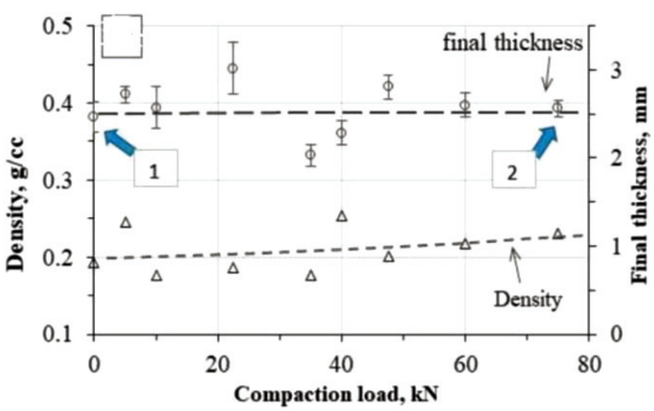

Figure 3: UTM compaction and heating at 90°C under a dead load of 90N

The holding time is defined as the time period for which the sample is placed in the oven under a predefined load. As an arbitrary practice, the sample was placed in the oven for a period of ~18 hours (4pm to 11am next day) due to logistical constraints. In order to determine the effect of varying the holding time, a sample specimen was kept under a load of ~90 N at 90°C for a period of 7 hours (10am to 5pm on the same day). It was observed that the composite obtained was damp with no clear indications of matrix formation. It further became clear that there was no point in reducing the holding time to a lower value to check the effect of reduced holding time. It was thus concluded that the optimized parametric value for holding time was 18 hours.

Considering the above given process parameters, the density of the specimen can be expressed as a function of all the parameters as:

$$\rho = f\,(L_C, L_H, T_H)$$

Where, ρ = composite density (g/cc); L_C = Compaction load under UTM (kN); LH = Load under heating (N); T_H = Holding time under heating (Hrs)

Having expressed the density of the composite laminate as a function of the said process parameters, the set of optimized parameters can be represented as:

$$\rho_{optimized} = f(L_C = 0\text{kN},\ L_H = 90\text{N},\ T_H = 18\text{ hrs})$$

The specimen prepared using the optimized parameter showed no signs of moisture content, had a fairly well cross-linked choir-chitosan matrix and seemed to show signs of better strength.

2.3 Fabrication for packaging

Literature review showed that Chitosan has enormous potential as a biopolymer with abundant opportunities. Studies by Cazón P. et al., 2019 [11] showed that Chitosan exhibits antimicrobial properties against a wide array of foodborne filamentous fungi, yeast, and bacteria. This coupled with the film-forming capabilities, Chitosan is sought after for manufacturing active food packages. Alongside this, studies performed by da Costa Castro et al., 2015 [12] on coir fibres revealed that there is enormous scope for the use of coir fibres in developing cheap alternatives for packaging applications. These findings proved that effective alternatives for food packaging solutions can be developed. Keeping egg packaging applications at the core of interest, efforts were made to develop egg carts. Small coir-chitosan composite containers were developed, this was accomplished by using coffee cups as makeshift molds. Coir and Chitosan were hand-laid and a small amount of load was applied on top of this set up and later placed in an oven to cure for about 18 hours. Two such specimens were placed one above the other to form a complete enclosure (Egg carts). When the egg cart containing an egg was dropped vertically from three feet height, the egg stayed intact whereas when it was dropped sideways from the same height the egg cracked (refer to supplementary). After clear observation, it was noted that the eggs stayed intact because of a higher concentration of chitosan at the bottom of the container which absorbed the impact very effectively. This shows that by proper engineering of these containers, effective solutions can be produced. Similar procedures were followed to produce Coir-chitosan plates, which were found to have good mechanical properties.

2.4 Testing for tensile properties

Two specimens (specimen 1- prepared without any UTM loading and loaded with 120N during heating; specimen 2-UTM loaded at 75kN and loaded with 90N during heating). Three test coupons were cut from individual specimens to check for the repeatability of the results from the tests. These test coupons were prepared as per the ASTM D3039 standards for tensile testing. Each specimen had a total length of 80mm, width of 10mm and end tabs of 30mm each, for better specimen gripping. The testing was carried out using an MTS UTM with a max capacity of 10kN.

3.0 Results and Discussions

Fig. 4 depicts the tensile behaviour of both the test specimens. It was clear that specimen 2 had a lower strength compared to specimen 1 by about 22%. However, both the specimens had low tensile strengths of about 1.4 MPa and 1.8 MPa respectively.

These results are similar to values of tensile strength of coir-epoxy composites with a 3% volume

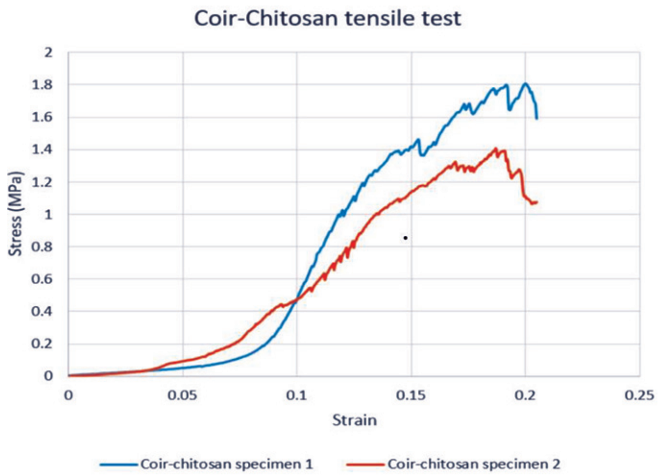

Figure 4: Stress v/s Strain response for test specimens 1 and 2.

fraction as studied by Romli et al., 2012 [9]. The tensile strength of the composite is low due to the presence of an irregular outer layer consisting of pectin and lignin, which prevents interfacial adhesion between coir and chitosan studied by Karthikeyan et al. [10]. It was also evident that these composites can undergo large deformations before failure (Tensile failure strain of 18%-20%) when compared to conventional packaging materials like EPS (Tensile failure strain of 5.1%) and molded pulp (Tensile failure strain of 3.5-4%) as stated by Chen et al., 2015 [12] and Gurav et al., 2003 [13] respectively. Further, from the stress-strain curves, the tensile energy absorption was evaluated and found to be 0.475 joules/g and 0.725 joules/g for specimens 1 and 2 respectively. These findings together prompt us to investigate further the applicability of these composites in various packaging applications. Preliminary egg drop tests were also performed using the manufactured egg carts. It was seen that effective egg packages can be engineered from these composites. Further characterization of these composite samples for various applications should be performed. The composite material's mechanical properties such as compressive strength and flexural strength are to be studied by performing specific tests, and care must be taken while analyzing these composites as there are enormous variations in their properties. The effect of strain rate on the mechanical properties is also a very significant factor and needs to be studied. The impact absorption capacity of the coconut fiber was evaluated by da Costa Castro et al., 2012 [14] and found satisfactory results. Similar tests are to be performed on these composites to analyze their properties. Vibration damping and sound-absorbing properties are also to be analyzed as these natural fibers can serve as a cheap and effective alternative for the existing materials as stated by M Rahman et al., 2016 [15] and Kaamin M. et al., 2018 [16] respectively. The studies by Salazar et al., 2011 [17] revealed that Coir fibers do not degrade easily, similar tests can provide better information with regard to their biodegradability, which is important for their applications where greater product life is expected. The results gathered by performing the above analysis will provide a pathway for the development of these composites for specific applications.

4.0 Conclusions

A novel completely natural coir-chitosan composite laminates were successfully fabricated. The process parameters that affect the final quality of the composite during the two phases of preparation were studied thoroughly and optimized for the best results. It was observed that the load applied to the composite during heating in the oven is a crucial parameter that affects the density of the composite significantly. Food packages were produced and found to be a viable material option. Also, the variation of strength as a function of the density of the composite might be a viable correlation, which shall be confirmed upon completion of further testing. These materials could serve as a sustainable alternative for a variety of packaging and interior applications. Further work on the same would provide a better understanding.

Conflicts of interest

The authors declare no conflict of interest.

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