Thermo-mechanical properties of coconut shell powder reinforced plastic composites

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Abstract: The coconut shell powder reinforced polypropylene (CS-PP) composite was prepared. The thermogravimetric analysis of the coconut shell powder (CS), polypropylene (PP) and CS-PP composites was carried out. The mechanical properties of coconut shell reinforced polypropylene composite have been investigated to establish the feasibility of using it as a new potential raw material for various engineering related applications. CS-PP composite was prepared by compounding polypropylene matrix with 20% - 60 % volume fraction of coconut shell powder. The effect of the CS powder loading on thermal and mechanical properties of the obtained CS-PP plastic composite was also investigated. The 20% weight ratio of CS powder reinforced CS-PP plastic composite shows the superior mechanical properties.

Keywords: Biocomposites; Coconut Shell; Mechanical property.

1. Introduction

In recent years, composite materials have gained much importance due to its numerous distinctive features that benefit the society. The composite material can be prepared by mixing two or more materials which often have very different properties. The composite materials have the potential to use in many different industries. Composites are exceptionally lightweight and extremely strong, especially per unit of weight [1-10]. Among the existing composites, the natural fiber reinforced biocomposites have attracted much interest due to its advantages such as light as well as strong. Agricultural wastes such as oil palm empty fruit bunch, coconut fiber, sugarcane bagasse, rice husk and straw have attracted much attention in the past several years due to its large abundance and their applications in polymer based biocomposites [11–22]. Agricultural based plant fiber biocomposites have variety of attractive properties over the existing conventional composites. The plant fiber reinforced biocomposites have very good mechanical behaviors, cheap, low density, considerable processing advantages and outstanding resistance to chemicals. Among the agricultural based fibers, coconut shell (CS) is considered to be one of the potential smart lignocellulosic materials because of their availability and low production cost [21, 22]. It is interesting that the coconut shell powder has great potential as reinforcement in plastic composites. The oily nature of coconut shell powder provided a strong interfacial bonding between the fiber and polymer matrix [23, 24]. We made an attempt to use the agro-based coconut shell particles as reinforcement with polypropylene matrix. In this work, coconut shell powder and polypropylene were used to fabricate the plastic composites with the aim of exploring coconut shell as potential reinforcement filler for polypropylene matrix. We prepared the CS-PP plastic composites and also investigated the effects of various amount of CS powder filler loading on thermal and mechanical properties of CS-PP composite.

2. Experimental

2.1 Materials

All the chemicals were purchased from commercial sources and were the highest purity available. The coconut shell was collected from Coimbatore, Tamilnadu, India. The collected coconut shell was crushed into powder. The milled CS powder was sieved into size distributions in the range of 75-150μm. The sieved powder was dried in oven at 70°C before using for further process.

2.2 Preparation of CS-PP Plastic Composites

The composites were prepared by the melt blending of CS powder and polypropylene (PP) in a Brabender internal mixer at 180°C with a rotor speed of 100 rpm. The ratio of CS/PP was fixed at four different ratios such as 20/80, 40/60, 50/50 and 60/40. Briefly, PP pellets were first melted in the Brabender mixing chamber for 2 min and then the CS powder was added slowly into the mixing chamber and mixed for another 13 min. The compounded materials were compressed into sheets with thickness of 1 and 3 mm by hydraulic hot-press at temperature of 180 °C for 5 min followed by cold pressing at 30 °C for 5 min.

2.3 Characterization

The crystallinity of the CS powder was measured using Wide-angle X-ray diffraction (WAXD) (Rigaku Corporation, Japan) with Cu Kα radiation source. Thermogravimetric analysis (TGA) was carried out using TG analyzer model EXSTAR6000 TG/DTA6200 (Hitachi, Japan) in order to confirm the change in the composition of the CS powder and CS-PP biocomposites. The CS powder sample was placed on an aluminum pan and then the sample was heated from 50–550 °C at a heating rate of 10 °C/min under nitrogen flow of 100 mL/min. The corresponding weight loss (μg) and its derivative DTG (μg/min) were recorded. Tensile testing was carried out on the CS-PP biocomposites according to ASTM D638-V using Instron 4302 Universal Testing Machine. Flexural tests were conducted using IMC-18E0 Model Machine (Imoto Machinery Co., Ltd, Japan). Flexural properties were measured in accordance with the procedure in JIS K 7171 at a cross head speed of 5 mm/min with a span of 20 mm. Tests were carried out for at least five specimens to obtain a consistent average and standard deviations. Flexural and tensile tests were performed at room temperature.

3. Results and discussion

3.1 X-ray Diffraction Analysis

The XRD pattern of CS powder is shown in Fig.1. The noticeable strong crystalline peak of CS powder was observed at around $2\theta = 22.5°$. The observed peak could be assigned to the crystallographic plane of cellulose materials of CS Powder.
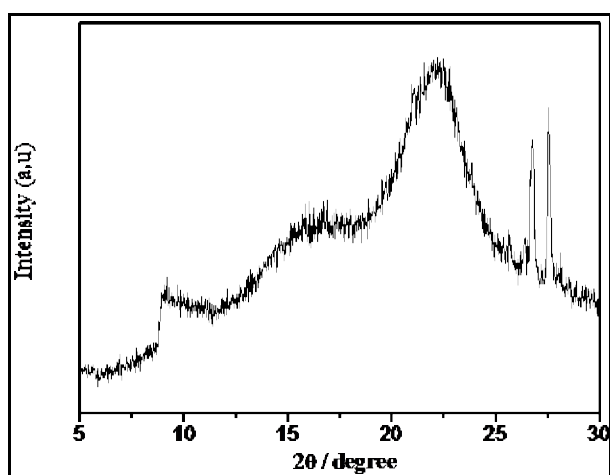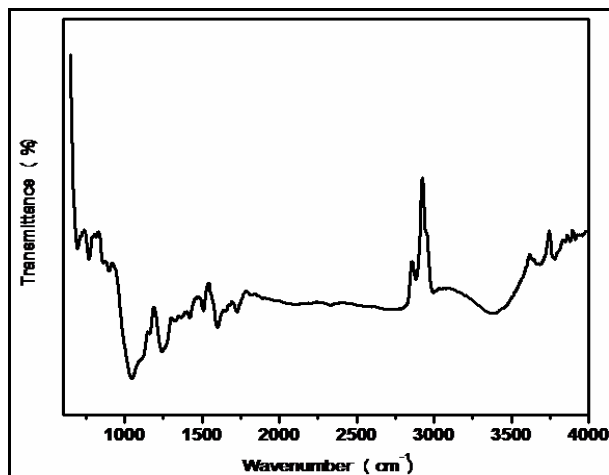

Fig.1. XRD patterns of CS powder   **Fig. 2. FT-IR spectra of CS powder**

3.2 FTIR Analysis

Fourier transform infrared (FTIR) spectroscopy is one of the important techniques used to determine the molecular structure of biological samples and recently it has been applied to detect and identify the tree species (cellulosic materials) and microbial strains [25]. Figure 2, illustrates the FTIR spectrum of CS powder. The FTIR spectrum was recorded as the transmittance (%) versus frequency in the range of $4000 – 400$ cm^{-1} (Fig. 2). The spectrum demonstrates many number of absorption peaks representing the presence of various groups in the samples. The FTIR spectrum of CS powder show bands at around 1730 and 1248 cm^{-1}, which corresponds to the stretching vibration of >C=O and > C-O groups, respectively [26]. These groups are exist in lignin and hemicelluloses structure of natural lignocellulosic fibers due to >C=O peak (1739 cm^{-1} and the FTIR study indicates that the simple physical treatment (grinding) does not eliminate the lignin or hemicelluloses from the coconut shell powder.

3.3 Thermogravimetric analysis

The studies on thermal behaviour of CS powder is important in order to find out the filler's stability in reinforced-polymer composite processing because the processing temperature for many polymeric materials exceeds over 180 °C. The thermogram and DTA curve of CS powder, PP, CS powder reinforced PP composites are shown in Fig. 2 and 3. The TG curve of CS powder clearly indicates the weight loss at different temperature region. The first weight loss occurred at around 100ºC may be due to the evaporation of absorbed moisture. The occurrence of weight loss can be seen from 220 to 315°C. The degradation of CS powder at various temperature region clearly demonstrated that the continuous degradation of several components. The weight loss in the temperature range of 240 - 350 °C could be due to the degradation of hemicelluloses and cellulose [14]. The DTG curve of CS powder also confirms the degradation of hemicelluloses and lignin (Fig. 4). The TGA curve of polypropylene shows the degradation from at around 350°C. It is very interesting to note that the degradation temperature of CS-PP plastic composites enhanced depends upon the addition of CS powder loading on the composite as shown in Fig. 3 and 4.
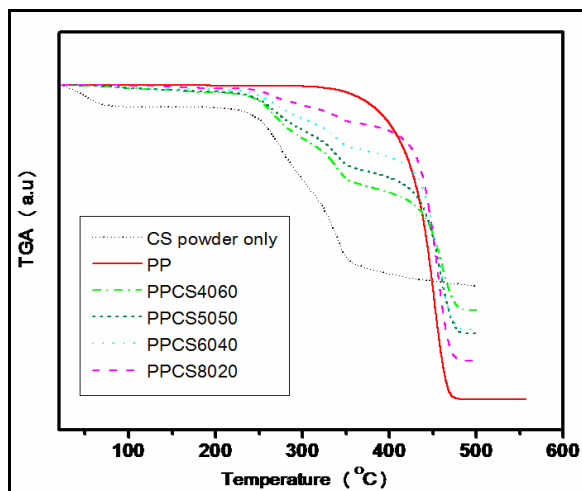

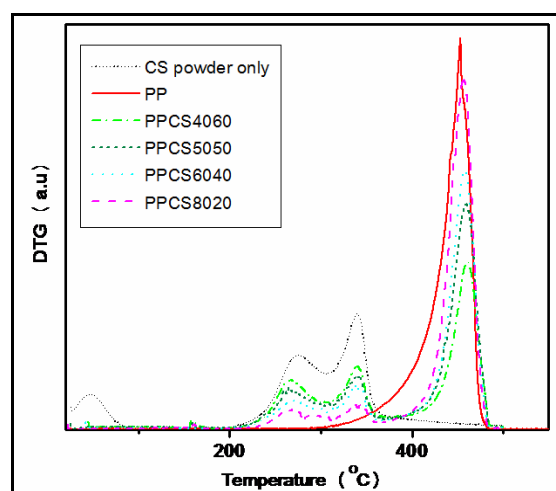**Fig. 3. TGA curves of CS powder, PP and CS-PP plastic composites**

Fig. 4. DTG curves of CS powder, PP and CS-PP plastic composites

3.4. Effect of CS powder loading on the mechanical properties of the composite

Recent research on natural fiber reinforced composites found that the loading of fillers plays a significant role in enhancing the mechanical properties of natural fiber reinforced plastic composites. CS-PP plastic composites were prepared using four different weight ratios of CS powder in combination with PP and investigated the effect of powder loading on the mechanical properties of the CS-PP plastic composites. We prepared the plastic composites using the CS powder in the weight ratio of such as 20%, 40% and 60% in combination with PP. Figure 5 and 6 shows the tensile strength and young's modulus of the tested composite materials, respectively. Tensile strength and modulus of the CS-PP plastic composites linearly decreases while increasing the weight of CS powder content in the composite. The tensile strength of the CS powder reinforced

PP plastic composite has dramatically decreased when the loading of CS powder has increased more than 40% as compared to the bare PP. However, the tensile modulus of the composites does not decrease much compared to the bare PP. This decrease in tensile strength may suggest that there is no effective transfer of stress from the CS powder to the PP matrix. It has been reported that the addition of filler into the polymer matrix always reduces the tensile strength and that can be improved by the addition of some compatibilizers during the composite preparation [11].
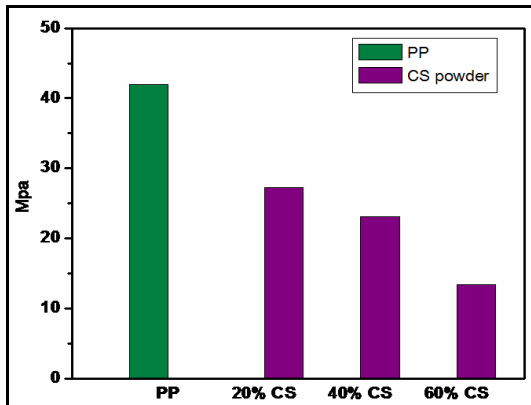

Fig. 5. Tensile strength value of biocomposites made of CS powder/PP (20:80 v/v), (40:60 v/v) and (60:40 v/v) in comparison with PP
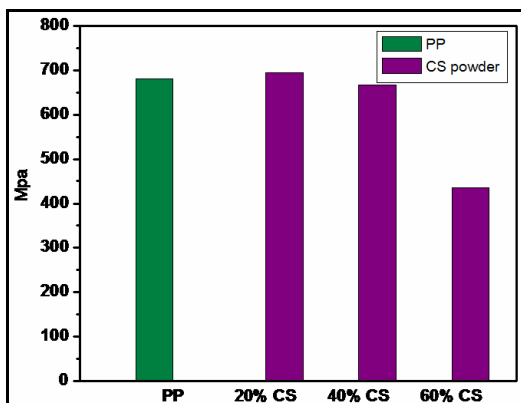

Fig. 6. Young's Modulus value of biocomposites made of CS powder/PP (20:80 v/v), (40:60 v/v) and (60:40 v/v) in comparison with PP

Figure 7 and 8 shows the flexural test results of the fabricated CS-PP plastic biocomposites. The results show the higher flexural strength and flexural modulus values for CS-PP composites compared to bare polypropylene. Further, the flexural test was carried out on the obtained CS -PP biocomposites to understand the effect of filler loading on the mechanical properties. The flexural strength and flexural modulus of CS-PP biocomposites are higher when the CS powder loading is 20% compared to the higher weight ratio of CS powder loading. This may be attributed to the increase of interfacial bonding strength between the CS filler and polypropylene matrix at optimum loading (20%). Further optimization of the size of the CS powder and addition of compatibilizer are expected to improve the mechanical properties of this green composite. The tensile and flexural test results clearly indicate that the increase of interfacial bond strength between the CS powder and polypropylene matrix at the optimum CS powder loading with PP composites. This study indicates that the CS powder is a potential replacement for the natural fiber to use as filler in the polymer composites.
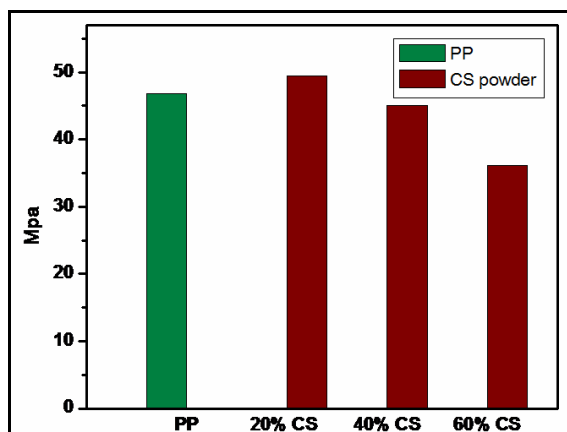
Fig. 7. Flexural Modulus value of biocomposites made of CS powder/PP (20:80 v/v), (40:60 v/v) and (60:40 v/v) in comparison with PP
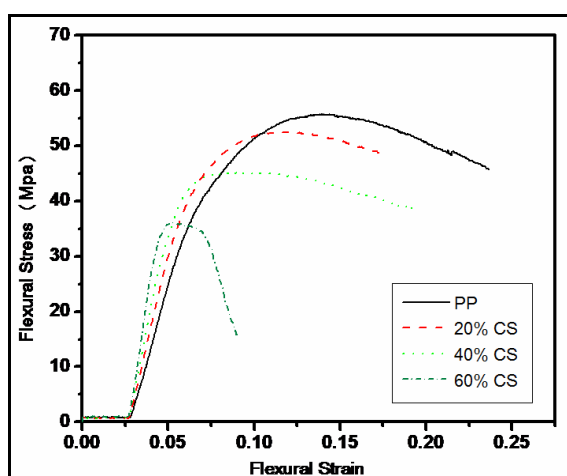

Fig. 8. Flexural strength value of biocomposites made of CS powder/PP (20:80 v/v), (40:60 v/v) and (60:40 v/v) in comparison with PP

4. Conclusions

The CS powder has been used to blend with polypropylene to achieve CS-Polypropylene plastic composites. Various weight contents (20 - 60%) of the CS powder were reinforced in the polypropylene matrix. The effect of the fiber weight contents on thermal and mechanical properties of the obtained CS-PP plastic composite was investigated. The young's modulus, flexural strength and flexural modulus values of the CS powder reinforced CS-PP composites were the highest compared to the bare PP composites at optimum loading of the CS filler.

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