

# Coconut shell powder improves the mechanical performance of polypropylene biocomposites

Sarat Kumar Swain, Niladri Sarkar, and Gyanaranjan Sahoo

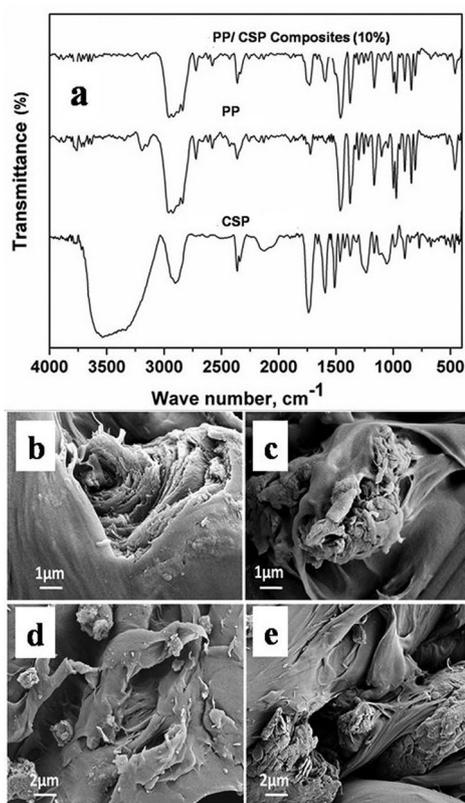
*Acrylic-modified coconut shell powder reinforces a hydrophobic polypropylene matrix and leads to a semi-ductile nature that may make the biocomposite suitable for use in construction.*

The increasing demand for greener and more biodegradable materials has compelled researchers to fabricate biomass-based lightweight construction materials with improved mechanical strength.<sup>1-3</sup> Of these biomaterials, natural fibers are a popular choice due to their renewability, low density, thermal insulation, and biodegradability. They also achieve comparable strength and stiffness to synthetic fibers. Indeed, some natural fibers (e.g., jute<sup>4</sup> and date palm leaf fibers<sup>5</sup>) achieve better results than their synthetic counterparts when used as fillers in polymer-based composites.

However, certain limitations of these fibers (e.g., the polar nature,<sup>6</sup> poor moisture resistance, low processing temperature, and low dimensional stability<sup>7</sup>) persist. These limitations can be overcome, however, through chemical modification, which in turn improves the fiber-matrix interfacial adhesion within the fabricated biocomposite. Due to its low cost and high availability, coconut shell powder (CSP) can be employed as an inexpensive natural fiber.<sup>8-10</sup>

In our work,<sup>11</sup> we aimed to improve the properties of a polypropylene (PP)/CSP biocomposite by modifying CSP through an acrylic acid treatment to enable better compatibility between CSP and the hydrophobic PP. We incorporated the acrylic-modified CSP (at different wt%) into PP via the hand lay-up fabrication technique, and investigated the properties of the resultant biocomposites using Fourier transform IR (FTIR) spectroscopy and field-emission scanning electron micrographs.

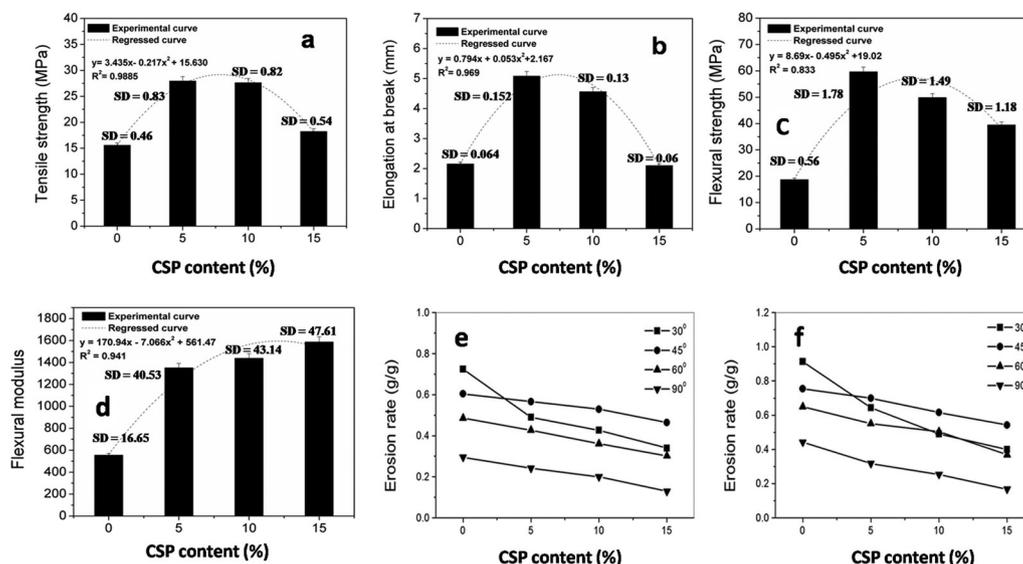
To obtain modified CSP, we subjected the alkaline natural fibers (pretreated with 5wt% sodium hydroxide, NaOH) to reactions with acrylic acid solutions at 50°C for a period of 1 hour. We then washed the modified fibers with an alkaline solution (1g/L NaOH and 6g/L sodium chloride) for 15 minutes, and finally washed them with distilled water. We dried the modified fibers in an oven at 80°C. The modified CSP was



**Figure 1.** (a) Fourier transform IR spectroscopy spectra of coconut shell powder (CSP), polypropylene (PP), and PP/CSP (10wt%) composites. Field-emission scanning-electron-microscope (FESEM) images of (b, c) PP/CSP biocomposite with untreated CSP and (d, e) PP/CSP biocomposite with acrylic-modified CSP.<sup>11</sup>

then integrated with PP via the hand lay-up technique, i.e., the simplest open-molding technique for low-volume production of composite materials.

*Continued on next page*



**Figure 2.** Results of mechanical tests on the PP/CSP composites. (a) Tensile strength, (b) elongation at break, (c) flexural strength, and (d) flexural modulus of PP/CSP biocomposites with acrylic-modified CSP at a variety of weights. Results of an erosion study of PP/CSP biocomposites with different acrylic-modified CSP contents at impact velocities of (e) 82 and (f) 109m/s.<sup>11</sup>

To examine the chemical interaction between the functional groups of modified CSP and PP, we employed FTIR spectroscopy. The FTIR spectrum of our PP/CSP (10wt%) composite (see Figure 1) shows a shifting in the carbonyl absorption band of chemically treated CSP (from 1750 to 1710cm<sup>-1</sup>). This shift can be attributed to the strong chemical interaction between PP and chemically modified CSP in the biocomposite. Untreated CSP contains polar hydroxyl groups on its surface (because it is a lignocellulosic material) and therefore has a tendency to agglomerate through the formation of hydrogen bonds. Due to this phenomenon, fibers form a discontinuous phase within the matrix rather than a continuous one. This discontinuity leads to the formation of a stress concentration point in the composites at high CSP loading. The FTIR band at 3600cm<sup>-1</sup> arises due to the hydroxyl functionality of CSP. In the pure PP and the PP/CSP biocomposite, the FTIR bands at 3000cm<sup>-1</sup> correspond to the ethylene stretching vibration.

To further investigate the effect of chemical modification on the dispersion of CSP within the PP matrix, we obtained field-emission scanning-electron-microscope (FESEM) micrographs of the samples under different magnifications: see Figure 1(b–e). Untreated CSP is a lignocellulosic material and primarily consists of cellulose, hemicellulose, lignin, and pectin. Due to this composition, it is highly hydrophilic and shows poor fiber-matrix interfacial adhesion in PP/CSP biocomposites. This poor interfacial adhesion between untreated CSP and PP is reflected in the FESEM images—see Figure 1(b) and (c)—where CSPs appear bundled. With acrylic modification, however, the hydrophobicity of the CSP is increased, and it undergoes a strong interfacial

adhesion with the hydrophobic PP matrix, resulting in the uniform distribution of modified CSP fibers within PP/CSP biocomposites: see Figure 1(d) and (e). This uniformity may occur due to the removal of lignin through the acrylic-acid treatment.

We investigated the mechanical strength of our samples and found the tensile strength of the PP/CSP biocomposite to increase considerably with modified-CSP loadings of up to 10wt%: see Figure 2(a). This enhancement arises because the chemical esterification of the CSP causes the plasticization of cellulosic fiber, which increases the surface roughness and enables the development of better fiber-matrix adhesion. The effect of acrylic modification of CSP on the value of elongation at break is shown in Figure 2(b). With an increase in the fiber loading, a greater number of weak interfacial regions are formed between the CSP and PP matrix. This means that cracks propagate easily through weak interfacial regions and result in decreased elongation at break. Additionally, we found that elongation at break is decreased not only at higher fiber contents but also at lower contents. We attribute this to unfavorable load transfer from the fiber phase to the matrix phase. However, the increase in elongation at break for the composites containing chemically modified CSP is a clear indication of improvement in the interfacial adhesion between CSP and PP. The flexural strength is also increased up to a certain CSP content (5wt%), and then reduces with a further rise: see Figure 2(c). The decrease in flexural strength for the composites with higher CSP contents can be explained by the

increase in the hardness of the biocomposites. Finally, we found that the flexural modulus increases with an increase in CSP content: see Figure 2(d). This can be attributed to the capacity of CSP to strengthen the PP/CSP biocomposites.

We also found that the erosion-resistance property was increased in the biocomposite based on modified CSP (due to the reinforcement effect offered by acrylic-modified CSP). Graphs of the results of the solid-particle erosion tests that we carried out—see Figure 2(e) and (f)—show that the erosion rate decreased with an increase in the loading of chemically modified CSP at different impact velocities (i.e., 82 and 109m/s). This increase may be due to the CSP filling up microvoids within the PP. Moreover, strong interfacial bonding between PP and CSP plays another important role in the erosion resistance of the biocomposite, and leads to semi-ductile behavior.

In summary, we have developed PP biocomposites reinforced with modified CSP via the hand lay-out method. Improved interfacial adhesion between the CSP and PP is reflected in the FESEM micrographs of PP/CSP (5wt%). We found that tensile strength and elongation at break were improved in biocomposites based on modified CSP (compared with untreated CSP). This improvement arises due to increased surface roughness and improved fiber-matrix adhesion. The tensile strength of the biocomposite increases for loadings of up to 10wt%, and elongation at break achieves its highest value at a loading of 5wt%. The flexural modulus of biocomposites increases with higher CSP contents, whereas the flexural strength decreases (because of increased hardness). Finally, erosion tests demonstrate the semi-ductile nature of our biocomposites. This property gives rise to enhanced mechanical strength and may make PP/acrylic-modified-CSP biocomposites suitable for application in civil construction. We will next investigate the influence of acrylic modification of other natural fibers (e.g., kenaf and sisal fibers) on the thermal and mechanical properties of PP biocomposites.

## Author Information

**Sarat Kumar Swain, Niladri Sarkar, and Gyanaranjan Sahoo**

Department of Chemistry  
Veer Surendra Sai University of Technology  
Sambalpur, India

Sarat Kumar Swain is a professor of chemistry and a dean of post-graduate studies and research. He completed his post-doctoral training at the University of Akron, OH. His research focuses on polymer-based nanocomposites.

Niladri Sarkar is currently working toward his PhD. His research interests include polymer-based nanocomposites and carbon dots.

Gyanaranjan Sahoo is currently working as a PhD student. His research interests include graphene-reinforced polymer nanocomposites.

## References

1. A. K. Mohanty, M. Misra, and G. Hinrichsen, *Biofibres, biodegradable polymers, and biocomposites: an overview*, **Macromol. Mater. Eng.** **276–277**, pp. 1–24, 2000.
2. P. Bordes, E. Pollet, and L. Avérous, *Nano-biocomposites: biodegradable polyester/nanoclay systems*, **Prog. Polym. Sci.** **34**, pp. 125–155, 2009.
3. L. Averous and N. Boquillon, *Biocomposites based on plasticized starch: thermal and mechanical behaviours*, **Carbohydr. Polym.** **56**, pp. 111–122, 2004.
4. A. K. Rana, A. Mandal, B. C. Mitra, R. Jacobson, R. Rowell, and A. N. Banerjee, *Short jute fiber-reinforced polypropylene composites: effect of compatibilizer*, **J. Appl. Polym. Sci.** **69**, pp. 329–338, 1998.
5. J. R. Mohanty, S. N. Das, H. C. Das, and S. K. Swain, *Effective mechanical properties of polyvinylalcohol biocomposites with reinforcement of date palm leaf fibers*, **Polym. Compos.** **34**, pp. 959–966, 2013.
6. J. George, M. S. Sreekala, and S. Thomas, *A review on interface modification and characterization of natural fiber reinforced plastic composites*, **Polym. Eng. Sci.** **41**, pp. 1471–1485, 2001.
7. X. Li, L. G. Tabil, and S. Panigrahi, *Chemical treatments of natural fiber for use in natural fiber-reinforced composites: a review*, **J. Polym. Environ.** **15**, pp. 25–33, 2007.
8. A. K. Mohanty, M. Misra, and L. T. Drzal, *Surface modifications of natural fibers and performance of the resulting biocomposites: an overview*, **Compos. Interface.** **8**, pp. 313–343, 2001.
9. M. Rafatullah, O. Sulaiman, R. Hashim, and A. Ahmad, *Adsorption of methylene blue on low-cost adsorbents: a review*, **J. Hazard. Mater.** **177**, pp. 70–80, 2010.
10. Z. H. T. Faisal, F. Amri, H. Salmah, and I. Tahir, *The effect of acetic acid on properties of coconut shell filled low density polyethylene composites*, **Indo. J. Chem.** **10**, pp. 334–340, 2010.
11. N. Sarkar, G. Sahoo, T. Khuntia, P. Priyadarsini, J. R. Mohanty, and S. K. Swain, *Fabrication of acrylic modified coconut fiber reinforced polypropylene biocomposites: study of mechanical, thermal, and erosion properties*, **Polym. Comp.**, 2015. doi:10.1002/pc.23887