

**ORIGINAL RESEARCH ARTICLE****Correlation of mechanical and optical properties of polypropylene plastic waste for application in composite panels**

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Abstract

Sustainable plastic waste management systems are needed to reduce environmental pollution impacts as they are non-biodegradable and emit greenhouse gases when burned. This study investigates the feasibility of using recycled polypropylene (PP) from commonly used plastics to process composite panels. The samples were obtained from household plastics with a Resin Identification Code (RIC) of 5. In addition, other common polymer samples were obtained from plastic coffee cups (W) and red basin tubs (R) and moulded using an injection moulding machine. The mechanical strengths of the resultant composites were plotted and compared with the theoretical value of the pure polymer. The ultimate tensile strength of the white cups and the red basin tubs was found to be 36 MPa and 14.55 MPa, while their yield points were 14.45 MPa and 4.55 MPa, respectively. Infrared spectra of the absorption of the samples were obtained using Fourier transform infrared (FTIR) spectroscopy. The band gaps were analysed from Tauc's plot and were found to be of white cups and the red bath tubs at 3.392 eV and 3.646 eV, respectively. These properties were found to be suitable for recycled plastics to be applied to process value-added panels with no significant adverse influence on material properties.

1.0 Introduction

Thermoplastic polymer composites have been demonstrated to be good substitute materials for conventional polymer composites. The polymers used are required to have a melting temperature that is typically lower than the thermal decomposition of wood for Wood Polymer Composite (WPC). The thermoplastics can be sourced from both recycled and virgin materials. Different technologies have been applied for the development of single polymer composites from some thermoplastic polymers, such as polyethylene (Jordan, Olley, Bassett, Hine, & Ward, 2002), polypropylene, polyethylene terephthalate (Rojanapitayakorn, Mather, Goldberg, & Weiss, 2005), polyethylene naphthalate (Hine, Astruc, & Ward, Hot Compaction of Polyethylene, 2004), polyamide (Hine & Ward, 2006), polymethyl methacrylate (Peers, Wright-Charlesworth, & Miskioglu, 2006), and liquid crystal polymers (Pegoretti, Zanolli, & Migliaresi, 2006).

The elementary forerunner for the generation of single polymer composites with excellent mechanical characteristics is a top-performing polymer fibre or tape. Hence, it's important to the success of such a composite that the mechanical features of the forerunner fibre be enhanced. Various reports have documented the progress of polypropylene composites (Barkoula, Alcock, Cabrera, & Peijs, 2008). Cellulosic materials have been used progressively as supplements in

thermoplastic matrix composites. Cellulosic reinforcements provide excellent mechanical properties, reduced health hazards, low density, and several well-known benefits, incorporating the availability of renewable natural resources and intensifying the biodegradability of the final materials (Raphol *et al.*, 2000). The extensive use of polymers makes it imperative to produce new materials with intensified properties while at the same time circumventing the use of chemical additives in some areas, such as medicine and the pharmaceutical industry.

In this paper, we report on the correlation of optical and mechanical properties for recycled plastic for application in wood polymer composites (WPC). This was achieved by using the injection moulding machine to make the recyclable samples.

2.0 Materials and methods

2.1 Sample preparation

Recyclable plastic waste was first sorted into different piles based on hardness and colour. The piles were then washed first with soap to remove dirt and oil. Then they were cleaned by first rinsing them in high-grade ethanol, followed by soaking in deionized water for 5 minutes. The samples were then shredded to obtain smaller particles. 10 g of each sample was transferred into a metallic melting can in an oven, and the heat was increased at an interval of 10 °C until all the plastic had completely melted. The molten plastic was transferred to a metallic plate and allowed to cool to room temperature.

Another 10 g of each sample was transferred into an injection machine and placed on an electric hot plate. This was set to rotate at 0.5 revolutions per second (0.5 HZ) for 20 minutes, ensuring even heating of the blend. The samples were then moulded into films ready for analysis of the tensile strength and elemental composition using FTIR spectroscopy.

2.2 Mechanical properties

The mechanical properties of the obtained recycled plastics were evaluated according to standard procedures. Tensile properties were determined using the SM 1002 benchtop Tensile Testing Machine (TTM) with a maximum load of 2 KN. The samples were run for each test, and all tests were performed at room temperature. The test specimen was moulded into a dumbbell shape and fitted into an adapter for TTM. The force was increased gradually until the sample fractured.

2.3 Optical property

The light absorbance of the samples was determined using a Shimadzu UV Vis-1800 spectrophotometer. This was done by placing the samples in a cuvette and setting the spectral resolution at 0.5 nm and the scanning range from 200 to 800 nm. The data was plotted using Origin Pro8 software to obtain UV-Vis spectra.

2.4 FTIR analysis

The Shimadzu FTIR spectrophotometer (FTS-8000) was used to identify the chemical bonds and functional groups present in the sample. To obtain the FTIR spectra, 2 mg of the sample and 200 mg of KBr were ground into fine particles and then fixed into the FTIR cell by skews for the determination of element content. The FTIR transmission spectra were obtained by setting the spectral resolution at 4 cm⁻¹ and the scanning range from 400 to 4000 cm⁻¹.

3.0 Results and discussion

3.1 Ultimate tensile strength and yield point

The force and the elongation of the sample were recorded at every instant until the fracture point of the sample. A graph of force against extension was obtained, as shown in Figure 1.

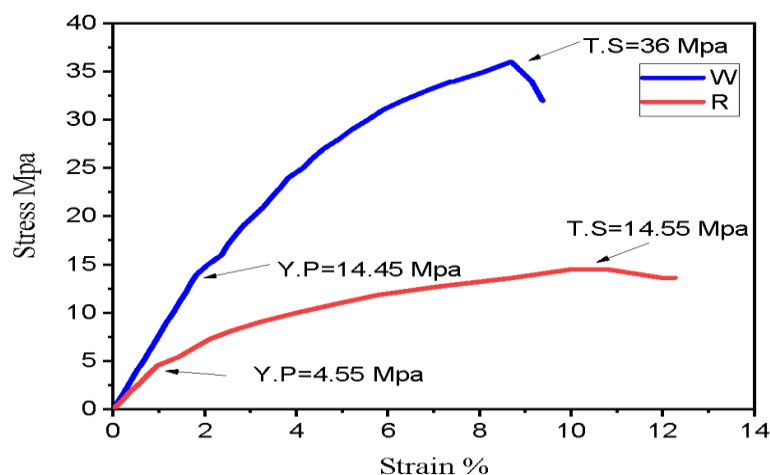


Figure 1: Stress against Strain for recycled plastics

From the graph, at lower strain values, the materials have lower stress values. Both stress and strain increase, though not uniformly. White cups (W) had a yield point of 14.55 MPa and an ultimate strength of 36 MPa. Basin tubs (R) had a yield point of 4.55 MPa and an ultimate strength of 14.45 MPa. This shows that sample W had a higher value for the yield point and ultimate tensile strength as compared to sample R. This is attributed to the fact that the intermolecular forces in sample W were higher than those in sample R. Thus, sample R attained a plastic deformation at a lower stress than sample W, implying that it is a weaker material. Initially, the samples exhibit visco-elastic behaviour, meaning that the recycled plastics recoil instantly due to the elastic portion. Later, with increased stress, they undergo a permanent deformation. After retrieving the stress, the spring recoils elastically, but it is controlled by a dashpot as in the Zener model (Rajabi & Hosseini, 2017).

3.2 band gap energy of the recycled PP samples

The UV-Vis transmittance spectra for the samples were obtained from a UV-Vis spectrophotometer (UV-1800). From the UV-Vis transmittance spectra in figure 2, there is a relatively higher transmittance in the UV region and a low transmittance in the visible region for both sample W and sample R.

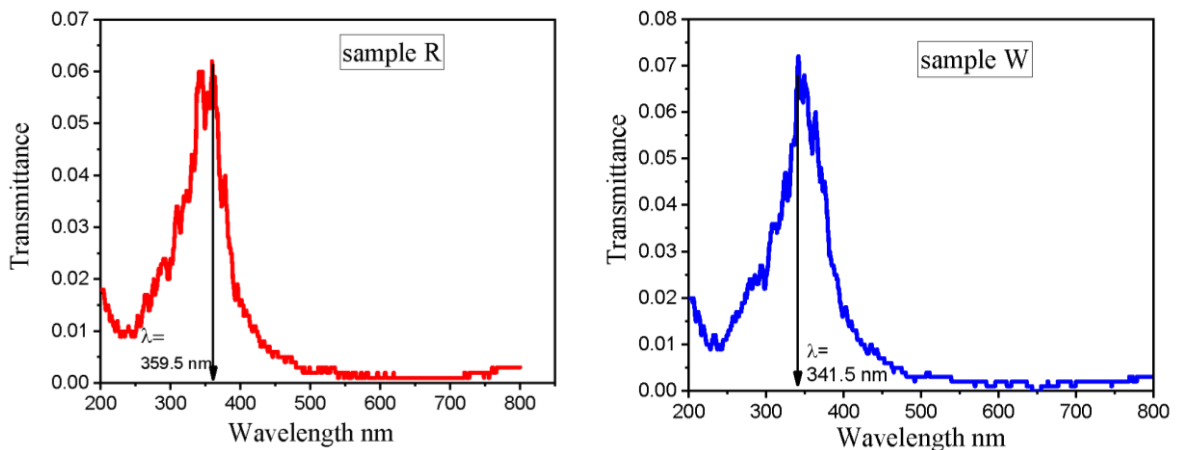


Figure 2: UV-Vis transmission spectra for the recycled plastics

Sample R had a lower peak transmittance obtained at a relatively higher wavelength of 359.5 nm, as compared to sample W, which was higher at a wavelength of 341.5 nm. The UV-Vis transmittance spectra were analysed to obtain the absorbance coefficient and energy band gap using Tauc’s model. Tauc’s plot was obtained using equation 1, where the α value represents the amount of incident photon intensity that is absorbed per unit thickness by the sample. It is related to absorbance A as in equation 2, when $n = \frac{1}{2}$ for direct allowed transition (Choudhary, 2022).

$$\alpha hv = k(hv - E_g)^n \tag{1}$$

$$\alpha = 2.303 \frac{A}{t} \tag{2}$$

The band gap was determined by extrapolating the linear part of the graph, as shown in figure 3.

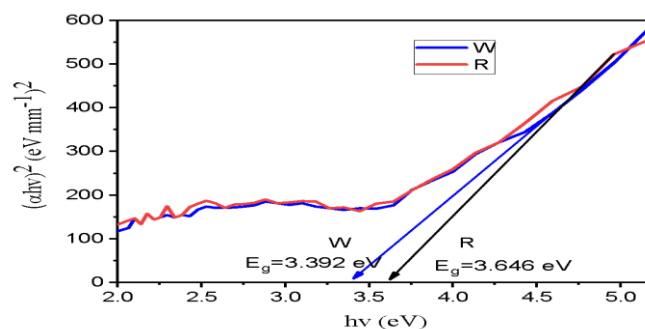


Figure 3: Tauc's plot for recycled plastics

Sample R was noted to have a higher E_g of 3.646 eV than sample W of 3.392 eV, indicating a widened forbidden gap. This is consistent with other reports that the individual photon of light was not sufficient to make the valence electron of an atom transition to a higher electric energy level (Madan & Monika, 2018).

3.3 Elemental distribution for recycled polypropylene

The FTIR data was plotted using Origin Pro8 software to obtain UV-Vis spectra and is displayed in Figure 4. For the white cups (sample W), the absorption peaks are noted to occur at: 1) the O-H

stretch corresponding to the hydroxyl group due to moisture at 3379 cm^{-1} ; 2) C-H stretch at 2932 cm^{-1} . 3) C=C Bend at 1589 cm^{-1} ; 4) $-\text{CH}_3$ Asymmetrical stretch at 1396 cm^{-1} ; 5) $-\text{CH}_3$ Asymmetrical stretch at 1342 cm^{-1} ; 6) C-H wagging at 1111 cm^{-1} ; 7) Overlapping of rock vibration at 702 cm^{-1} (Veerasingam *et al.*, 2021).

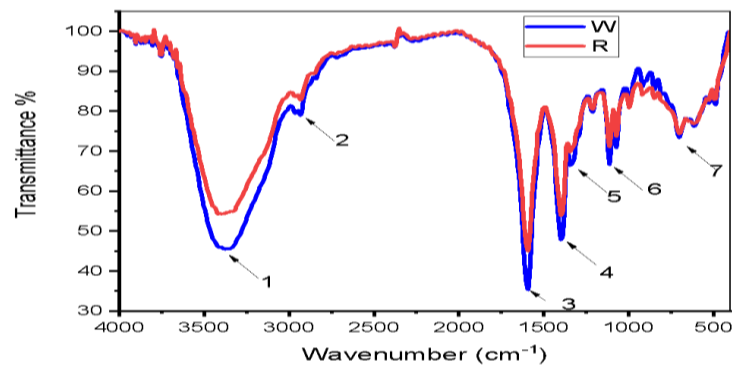


Figure 4: Elemental distribution for recycled polypropylene

For sample R, the absorption peaks were: 1) O-H stretch corresponding to the hydroxyl group due to moisture at 3417 cm^{-1} , 2) C-H stretch at 2932 cm^{-1} , 3) C=C bend at 1589 cm^{-1} , 4) $-\text{CH}_3$ asymmetrical stretch at 1396 cm^{-1} , 5) $-\text{CH}_3$ asymmetrical stretch at 1342 cm^{-1} , 6) C-H wagging at 1111 cm^{-1} , 7) overlapping of rock vibration at 702 cm^{-1} . W has a higher peak intensity as compared to sample R. Peak intensity is related to the functional group associated with the molecular bond. The results of the sample were qualitative and confirmed that the vibration was similar to PP spectra (Dutta, 2017). This shows that these recycled plastics have different intensities as per the pile, with the intensity of the peaks of sample R being weaker than those of sample W. This is consistent with the fact that sample W had higher mechanical properties as compared to sample R. Thus, sample W can be used in the manufacturing of composite panels of higher tensile modulus as compared to composite panels manufactured using sample R.

4.0 Conclusion

Results for tensile stress for white cups (sample W) were found to be higher than that of basin tubs (sample R), which is much lower than the theoretical value for polymer (12–45 MPa) and for PP (31–45 MPa). The band gap energies for sample W were found to be 3.392 eV, while those for sample R were 3.646 eV, which was higher than the theoretical value of pure PP at 3.28 eV. This is attributed to the fact that some household plastics are made using additives from pure. The FTIR spectra indicated that the recycled plastic sample had different intensities as per the pile, with the intensity of the peaks of sample R being weaker than those of sample W, consistent with mechanical properties. These results show household plastics can be recycled for use as polymer composites for manufacturing panels with high tensile strength.

5.0 Acknowledgements

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None

5.2 Conflict of interest

Authors have declared that no competing interests exist.

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