# Biochar filled plastics: effect of feedstock on thermal and mechanical properties

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Biochar (BC), a product of the thermochemical conversion of organic waste, has shown to have applications ranging from soil remediation to polymeric filler (Bartoli et al., 2020; Das et al., 2016). BC has become a strong candidate to maximize waste valorization and become a potential agent for a transition towards a circular economy. BC comes from a wide variety of organic matter, and differences in chemical composition, physical properties and morphology have been found (Lange et al., 2018). These properties depend on multiple production variables, including pyrolysis temperature, time at maximum temperature, feedstock, etc. (Lange et al., 2018). Antonangelo et al. (2019) detailed the effect of the feedstock source on the physicochemical properties of the resulting BC. In this paper, we explored and characterized the effects of feedstock source on the performance of different BC-filled plastics.

Two different biochars, one from anaerobically digested dairy manure (BCDM) and another from eastern white pine wood chip (BCWC) were provided by Cornell University both following the exact same production parameters. Biochar's surface area, pore size, moisture content, chemical bond, morphology, and particle size were measured to understand physical and chemical properties. These were measured with Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM) and surface area and pore size analysis. The identified differences were compared and they agree with literature (Lange et al., 2018).

These BCs derived from anaerobically digested dairy manure (DM) and eastern white pine wood chip (WC) were then used as fillers, at 10% weight loading, in three commonly used petroleum and bio-based polymeric matrices, specifically poly-caprolactone (PCL), polylactic acid (PLA), and polypropylene (PP). Samples were manufactured following a factorial design to compare the effect of the BC's feedstock in the polymeric matrix. To compare the sample properties FTIR, SEM, tensile testing (ASTM D638-V) and differential scanning calorimetry (DSC) measurements were made, with all samples tests in duplicates.

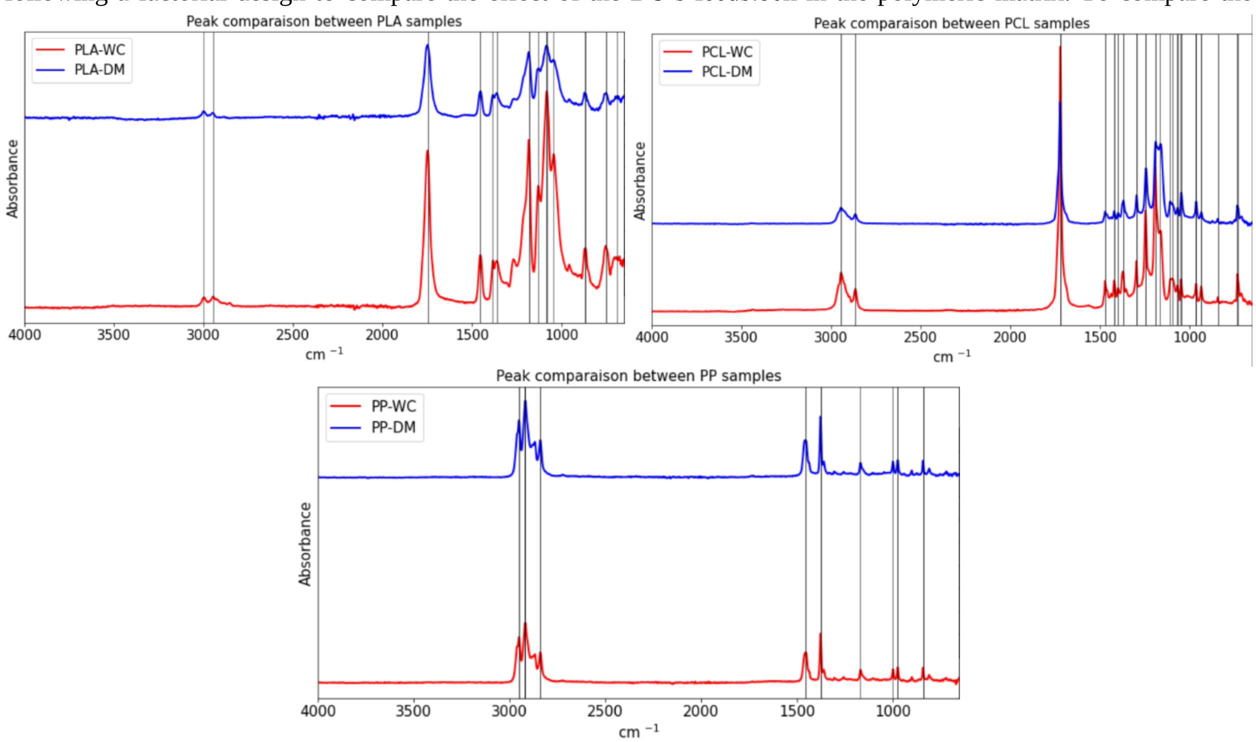


*Figure 1. FTIR spectra for (upper left) PLA, (upper right) PCL and (bottom) PP. Every vertical line shows a peak.*

Figure 1 shows the FTIR spectra of the different samples of each polymeric matrix. No differences were seen in the chemical bonds made between the different BCs and the polymer matrix.
Table 1 shows different effects on the tensile strength and strain at break for the polyesters, the PCL-DM composite outperformed the PCL-WC, but for the PLA-DM and PLA-WC blends this was reversed. Figure 2 shows no correlation between the physical properties of the biochars and this reversed effect.

| Sample | Elastic Modulus (MPa) | Tensile Strength (MPa) | Elongation at Break (%) |
|---|---|---|---|
| PCL | 126 ± 15 | 37 ± 5 | >2000 |
| PCL-DM | 166 ± 12 | 28 ± 5 ** | 1264 ± 163 * |
| PCL-WC | 170 ± 15 | 18 ± 4 ** | 371 ± 300 * |
| PLA | 952 ± 169 | 45 ± 8 | 12 ± 4 |
| PLA-DM | 1338 ± 359 ** | 27 ± 12 ** | 3 ± 1 * |
| PLA-WC | 991 ± 84 ** | 41 ± 9 ** | 6 ± 1 * |

*Table 1. Mechanical properties of the polyester-biochar samples. Statistical difference between the two BC blends was calculated for each matrix i.e., PCL-DM was compared with PCL-WC.*


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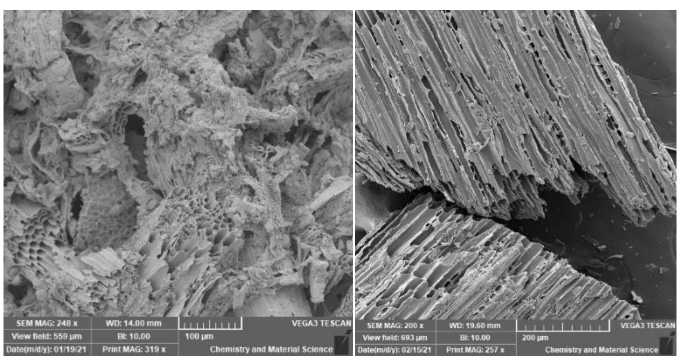
* p-value ≤ 0.01, ** p-value ≤ 0.05

A possible explanation is that the moisture content of BCDM, as low as reported in Figure 2, started a degradation (hydrolysis of the ester bonds) of the PLA, allowing the PLA-WC to show better properties. The morphologic difference between the two biochars, seen in Figure 2, would support this hypothesis. The BCWC's organization along its axis would allow a more straightforward moisture release during the high shear of the sample manufacture, as the BCDM does not show this organization, leading to a better retention of moisture and slower release. This moisture would be previously absorbed by the BC from the storage atmosphere as the Cornell process would suggest no moisture content at the end of the thermochemical conversion. In addition, thermal properties have not shown major differences and ongoing experimentation is in the process to be able to assess them.




| **Dairy Manure** | | **Wood Chip** |
|---|---|---|
| 19.3±1.7m$^2$/g | Surface Area | 47.4±3.0 m$^2$/g |
| 24.9±0.6 µm | Pore Radius | 21.3±0.4 µm |
| 6% | Moisture Content | 2.5% |

*Figure 2. (250x) SEM images of (upper left) DM and (upper right) (200x) WC biochars. (Lower table) Properties of each biochar.*

The results show that WC would be a preferable choice of BC for composite applications given its lower moisture content. In the case of PLA WC also shows an increase filler-matrix adhesion as evidenced by the increase in tensile strength. We recommended this feedstock for composite applications.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