Environmentally Intelligent Biocomposites

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Abstract
Composites made from wood residues and biomasses, together with either conventional polymers such as polypropylene (PP) and their recyclate streams or with the new emerging biopolymers such as polylactic acid (PLA), were compounded and injection moulded. Mechanical properties and biodegradation analyses were undertaken. The addition of wood flour/sander dust (SD) and wood fibres (WF), to the PP, with suitable compatibilizer, increased the flexural and tensile modulus and strength, indicating a good bond between the fibres and matrix. The tensile and flexural strengths were decreased with the addition of wood fillers, additives and biomasses to a PLA biopolymer blend. Such biomasses and additives increased the biodegradation of the PLA blend, and some control over biodegradation rates was achievable.

Introduction
Increasingly, new materials are being developed with environmentally responsible approaches. This is due to increased awareness from both consumers and governments to the problems associated with waste disposal and greenhouse gas emissions from the formation of petrochemical products. The formation of composites, which combine two or more materials, provides convenient ways to reduce the amount of petrochemical products in materials [1].

Incorporation of WF or wood fillers such as SD into polymers is now standard technology to improve the mechanical properties of the polymer, such as stiffness and strength, while reducing cost [2]. Other advantages include the use of a renewable resource and aesthetic appeal of looking like wood, which is becoming important for consumers [1]. Although the composite with conventional polymers (PP, PS, etc) is not completely sustainable, the use of plastic recyclate streams will improve sustainability. This work has shown WF and SD, when correctly compatabilized, can enhance the properties of typical plastic recyclate streams, with the use of proprietary WF technologies providing the best properties. However, completely sustainable materials can be achieved by using a bio-based polymer with a wood based filler or fibre.

Bio-based polymers, polymers which are derived from biological resources, have many attributes similar to petrochemical polymers. However, until recently, the use of bio-based polymers has been limited due to high production costs, long-term stability and limited mechanical properties of the final product [3]. The addition of fillers to bio-based polymers is widely researched and can be used to reduce the overall cost of the final product. However, such compounded or filled bio-based polymers often have reduced processability, properties and/or unknown behaviours in biodegradation evaluations.

Composites made from biomass and biopolymers have both economic and environmental benefits. The biomasses used in this work represent waste products from various commercial processes which under normal circumstances have to be disposed of (eg in landfills) causing costs for disposal as well as being an environmental burden. The selected types of biomasses are non-toxic and their use in combination with biopolymer blends lower the overall biocomposite cost, as well as reducing environmental impacts. Furthermore, we have found that unique combinations of biomasses and additives can produce an attractive balance of processability, mechanical properties and biodegradation response.

Scion has researched a wide spectrum of petrochemical to bio-based polymers, with additives ranging from wood residues to waste biomasses, incrementally changing the focus. This includes the utilisation of polymer recyclate or waste streams and wood residues, with the addition of such wood residues into bio-based or biodegradable polymers, and finally the addition of various treated food/crop/processing/agricultural and other waste biomasses.

Methods

Formulations were compounded with an OMC twin screw extruder (19 mm screws and a l/d ratio of 30:1), the extruded strand was cut into pellets for injection moulding. Vacuum dried pellets (at 60 °C for 24 hours) were injection moulded using a BOY 15 S injection moulder. The tensile test samples were injection moulded into a dog bone shape, based on ASTM D 638-95a, type 1, with dimensions of 3.2 x 165 mm. Three-point bend samples were injection moulded based on ASTM D 790, with dimensions of 12.6 x 3.2 x 125 mm.

Tensile and three-point bend testing was undertaken using an Instron 5566 testing machine, fitted with a 10 kN load cell. Tensile samples were tested with a cross head speed of 5 mm/min and a gauge length of 115 mm. Flexural samples were tested with a cross head speed of 1.3 mm/min and a gauge length of 50 mm. The tensile and flexural modulus and strength of the samples were determined.

Biodegradation was testing in accordance with ASTM D5338. Test strips of 60 x 10 mm were placed into the oxi-top soil. CO_2 measurements were recorded over 30 days.

Results

The addition of SD and WF to the PP increased the tensile and flexural modulus (Table 1). The increased stiffness also indicates a reduction in the elasticity of the material, changing the material from ductile to more brittle, which is illustrated in Figure 1.

The addition of SD and WF to PP also increased the tensile and flexural strength. The increase in strength suggests a bond between the PP matrix and fibre. This was supported by SEM images (Figure 2) where holes could be seen, indicating that the SD was ripped out of the matrix instead of breaking. Failure occurred at the interface between the matrix and WF.

Table 1 Mechanical Properties of Composites

	Tensile Modulus (GPa)	95% CI	**Tensile Strength (MPa)**	95% CI	**Flexural Modulus (GPa)**	95% CI	**Flexural Strength (MPa)**	95% CI

PP	1.39	0.05	25.16	0.11	1.05	0.03	33.81	0.68
PP + WF (compatibilized)	4.43	0.58	29.56	0.55	3.06	0.06	53.55	0.84
PP + SD (compatibilized)	4.05	0.85	45.84	0.85	3.70	0.27	76.93	2.86
PLA Blend	3.10	0.01	54.52	1.10	3.10	0.25	86.05	1.90
PLA Blend + WF	2.47	0.30	44.75	2.29	4.70	0.08	70.67	2.39
PLA Blend + SD	4.90	0.40	33.96	1.47	4.20	0.30	56.28	4.30
PLA Blend + Biomass Formulation 1	3.20	0.39	12.56	3.31	3.30	0.39	12.56	3.31
PLA Blend + Biomass Formulation 2	1.90	0.21	27.57	2.19	3.46	0.15	51.37	5.32
PLA Blend + Biomass Formulation 3	4.94	0.59	36.56	5.89	3.35	0.22	54.50	1.46
PLA Blend + Biomass Formulation 4	4.43	0.37	37.54	1.26	4.22	0.70	66.09	1.73

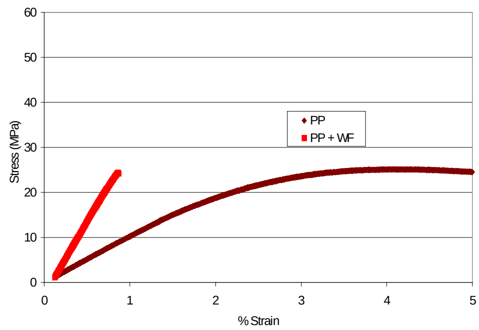


Figure 1 Stress-Strain Curve of PP and PP with WF

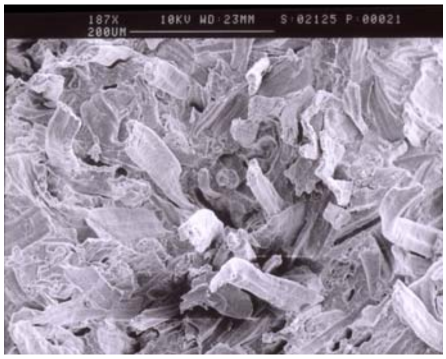
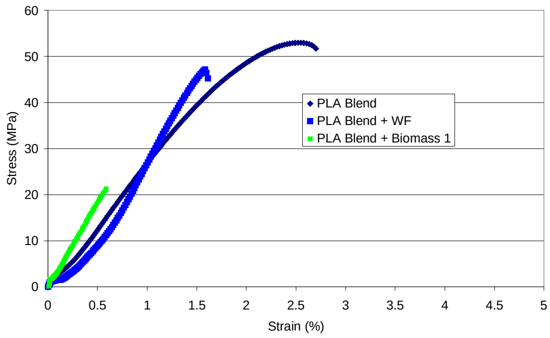


Figure 2 SEM of PP with WF Fracture Surface

The PLA blend is a relatively brittle matrix, as shown in Figure 3. The addition of WF to the PLA blend decreased the tensile modulus but increased the flexural modulus. The addition of SD to the PLA blend increased both the tensile and flexural modulus, producing a stiffer material.

Both the tensile and flexural strength were deceased with the addition of WF and SD. This indicates that the bond between the PLA blend matrix and the WF and SD was weak, in fact weaker than the bond between the polymer chains. Other work in Scion has led to improvements in these properties, including toughness and/or fibre-matrix bonding.

Biodegradation is measured in mmols of evolved CO_2. The CO_2 of the PLA blend was 0.50%, which increased to ~2.00% with the addition of additives (Figure 4). Figure 5 shows the test strips of PLA with additives after 28 days, the test strips are still intact, but have turned white. This is the first step in the degradation of PLA. The additives absorb water, which may lead to an increase the degradation rate of the PLA blend.



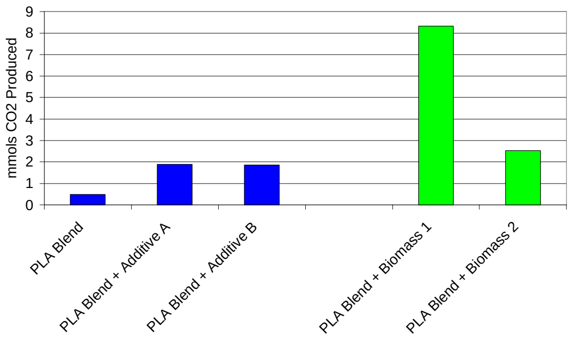


Figure 3 Stress-Strain Curve of PLA Blend and PLA Blend with WF

Figure 4 Total mmols CO_2 Produced Over 28 Days For Composites

The addition of Biomass 1 to the PLA blend did not significantly change the tensile and flexural modulus. From Figure 3 it can be seen that the PLA blend with Biomass 1 required very little strain to cause failure, indicating that the composite was very brittle. The addition of Biomass 2 to the PLA blend decreased the tensile modulus but increased the flexural modulus. The addition of both Biomass 3 and 4 to the PLA blend increased both the tensile and flexural modulus.

The tensile and flexural strengths of the PLA blend decreased with the addition of all biomasses. The PLA blend with Biomass 2 had greater flexural and tensile strength, when compared to Biomass 1, similar to the PP with WF composite.

The biodegradation of the PLA blend increased significantly with the addition of Biomass 1 (Figure 6). The test strips turned white and broke down into fragments (Figure 7). The increased biodegradation could be due to many factors, including displacement of polymer by biomass and because the biomass degrades first leaving many holes in the polymer matrix. The polymer matrix then degrades faster as it has more surface area for degradation to occur. Further studies are ongoing.

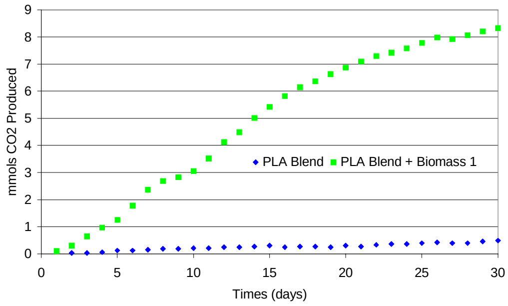


Figure 5 Strips of PLA blend + Additive After 28 Days

Figure 6 Biodegradation of PLA Blend and PLA Blend + Biomass 1

Scion has developed a database of formulations of various biomass derived additives and mixtures of additives. These can be used to tailor degradation profiles along with processability and mechanical integrity. Commercial applications are being developed (Figure 8).

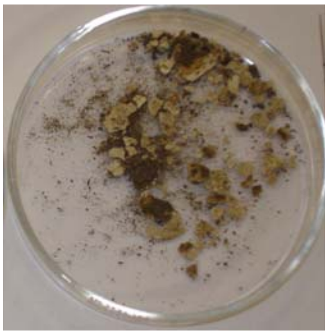


Figure 7 Strips of PLA + Biomass 1 After 28 Days

Figure 8 Biodegradable Pots, an Example of Commercial Applications

Conclusions

- The addition of WF/SD to the PP increased the tensile and flexural modulus and strength indicating bonding between the fibre and matrix. This approach has been applied to improve the mechanical properties of the polymer recyclate streams.
- The addition of WF and SD to a PLA blend decreased the tensile and flexural strength.
- The addition of various waste biomasses and additives to PLA and other blends decreased the tensile and flexural strength but by various approaches the mechanical properties can be optimised or tailored to the end application needs.
- Biomass and additive mixtures can significantly increase the biodegradation of PLA blends and programmable degradation profiles can be developed for end applications.
- Knowledge of compatibilities and synergies in biomass addition has been joined and now applied to commercial product developments using, in some cases waste streams as the sources of functional additives.

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