Feasibility Study Final Report

Please submit this report to alex.hammond@nottingham.ac.uk

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Feasibility Study (FS) Title: Manufacturing Value-Added Composites for the Construction Sector Using Mixed Waste Plastics and Waste Glass Fibres
PI name: Dr Dipa Roy
Research staff/students (*include names and % of time*): Dr Danijela Stankovic Davidson (100%, 4.5 months)
Partners (include support from Industry): Johns Manville, Paltech, Capvond.
Start date: November 2021
End date: April 2022

Executive Summary

Packaging plastic wastes are mostly polyethylene (PE)-based and PE is not commonly used as a matrix in composites due to its lower mechanical properties. PE combined with reinforcement fibres, however, can produce useful composites with an optimum combination of toughness and stiffness. Here the opportunity lies in combining soft packaging waste plastics with waste reinforcement fibres. This was the main objective of this project to develop suitable technology that can combine waste mixed plastics (wMP) with waste glass fibres (wGF) to produce value-added composite products for the construction sector. Such technologies can divert huge volumes of low value wastes (that are not currently recycled) from landfill to a circular economy.
Thermoplastic composites were manufactured with wMP/wGF; the tensile, compressive and flexure properties were investigated for the wMP/wGF specimens. Cee-section members were produced as demonstrator components with wGF/wMP (and wGF/wMP/waste carbon fibre hybrid) composites and their axial compressive performance was assessed. The project fits well with the Hub objectives, as recycling and reusing waste materials are the prime focus in this project.
The preliminary results of this project have shown promising properties and two construction companies (end users) are interested in the work. A follow-on project (EPSRC Impact Acceleration Account-Commercialisation Project), which is a continuation of this project, has been funded and has commenced on October 1st 2022. There is a discussion ongoing for a patent application which will be decided in next 2-3 months. The Cee-sections produced have shown very encouraging results and there is a possibility that will be taken forward in a separate industry funded project (discussion ongoing, no decision yet). An Outline Proposal (stage 1) has been submitted in the EPSRC Call and decision is awaited.

Background

The main objectives of this project were:

- To identify a suitable technique that can produce thermoplastic prepreg material combining waste glass fibres (wGF) with mixed waste plastics (mWP) originating from flexible low value plastics packaging wastes.
- To manufacture wGF/wMP laminates and investigate tensile, flexure and compressive properties to assess their suitability for semi-structural applications (in consultation with industrial partners).
- To manufacture and test a demonstrator Cee-section member made of wGF/wMP (or their hybrid) for their compressive loading performance. .

Being a waste product, wGF/mWP composites provide a solution to reuse waste. Thus, re-using the wGF/wMP composites hybridised with rCF for Cee-section members that can be used in the construction industry provides a sustainable solution for waste treatment. In addition, other industrial applications include handrails, non-load bearing wall frames, or other semi-load bearing structures.

Results/Deliverables/Outcomes

The most challenging part in this project was the prepreg fabrication using wMP/wGF. Significant manufacturing challenges were encountered at the start of the project to produce wMP/wGF prepregs and the first trial was unsuccessful. Finally prepregs could be produced successfully, but at the very end of the project.

Work carried out before prepreg could be produced: Although prepreg could not be produced at the start of the project, but work was continued to manufacture wMP/wGF composites in lab scale. The manufacturing was not optimised at that point. The fibre content was only ~16 vol% and void content was high (approx. 15%). The mWP primarily consists of different grades of LDPEs. The mechanical properties of wMP/wGF composites (FVF ~16 vol%) were evaluated in comparison to virgin LDPE/wGF composites (FVF ~15 vol%). The properties are presented below in Figure 1.

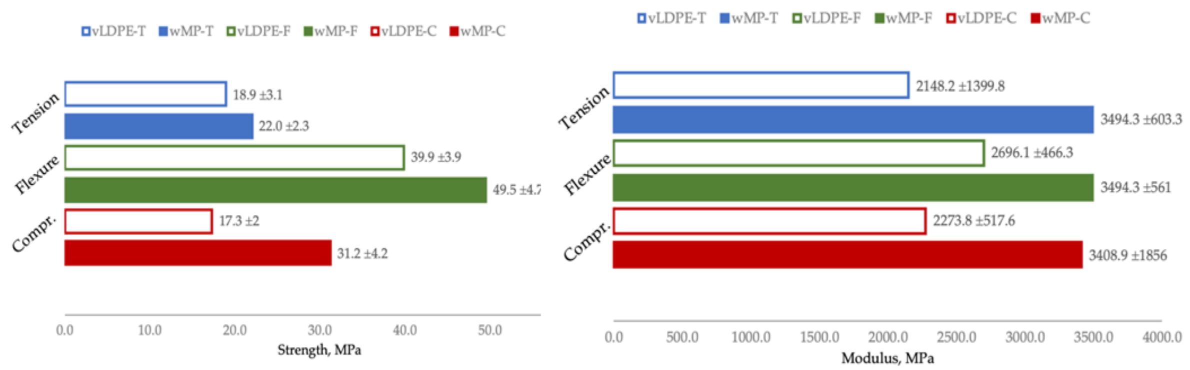

Figure 1: Tensile, flexural and compression strength (MPa) of wMP/wGF composites and virgin LDPE/wGF composites.

A second set of wMP/wGF composites were fabricated taking learning from the first set. The tensile modulus (~500 MPa) and tensile strength (~9 MPa) of unreinforced wMP were increased to ~5.5GPa and ~30 MPa with 23 vol% of wGF content (Figure 2a). The void content was still ~12 vol% and the manufacturing was not fully optimised. If the wGF content can be raised further (target 40-45 vol%) and the composite manufacturing is optimised, the tensile properties can be increased further. The predicted tensile modulus as a function of GF vol% is shown in Figure 2b (using Halpin Tsai eqn.). The interfacial bonding between the wMP and wGF is very promising, as shown in Figure 2c.

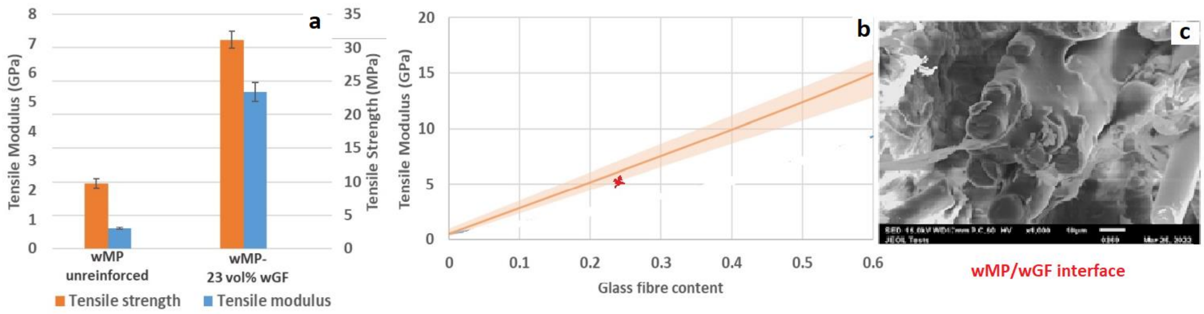

Figure 2: (a) Tensile properties of wMP/wGF composites and unreinforced wMP b) Predicted tensile modulus of wMP/wGF composites (red dot indicates experimental value with 23 vol% wGF) c) wMP/wGF interface.

Feasibility Study Final Report

Demonstrator component: Cee sections as load carrying members were manufactured. Three 175mm web width and 55mm flange width Cee sections (shown as 175*55PFC in table 1) were fabricated and tested under concentric axial compression (Figure 3). Due to manufacturing error, one of the specimens resulted in 25mm flange width instead of expected 75mm (this specimen is shown as 175*25PFC in Table 1). In addition, one 175*55PFC hybrid specimen was fabricated from mWP reinforced with wGF and recycled carbon fibre (rCF). Once fabricated, specimens were tested under concentric axial compression (Figure 3). The hybrid one performed extremely well and opened up new opportunities of hybridisation. The results of the tested fibre reinforced waste plastic Cee-sections are given in Table 1. Results from HFT Cee sections and a similar steel Cee section are also given in Table 1 for comparison.

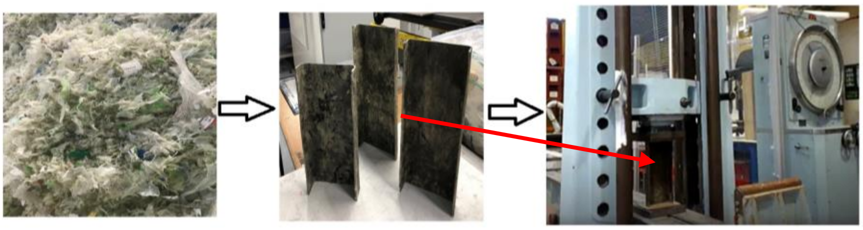

Figure 3: wMP/wGF converted into Cee-sections.

Table 1:

Table Comparison of current study results with existing test results

Section	Materials	Source	Ultimate load, kN	Weight specific load capacity, kN/(kg/m)
175*55PFC	wGF/wP		5.5	5.6
175*55PFC	wGF/wP		7.1	8.4
175*25PFC	wGF/wP		4.7	5.6
175*55PFC	wGF/rCF/wP		14.1	15.1
130*40PFC	GFRP-Timber	[4]	14.7	25.7
C15012	steel	[4]	48.5	20.8
83*34PFC	GFRP-timber	[5]	13.0	26.7
108*54PFC	GFRP-timber	[5]	17.7	22.0
238*79PFC	GFRP-timber	[5]	27.1	19.1
150*75PFC	GFRP-timber	[3]	16.5	16.3
150*75PFC	NFRP-timber	[3]	23.4	14.7
150*75PFC	NMFRP-timber	[3]	24.5	14.3

GFRP glass fibre reinforced polymer
NFRP biotex flax fibre reinforced polymer
NMFRP hemp fibre reinforced polymer
wGF-waste GF,
wP-waste plastics and
wGF/rCF/wP is a hybrid Cee section.

Prepregs Produced: A discussion is ongoing for a patent application. No details are mentioned here on prepreg or composite manufacturing. The composites manufactured from prepregs are shown in Figure 3. The mechanical characterisations, void content and fibre volume fraction analysis will take place in the IAA project.

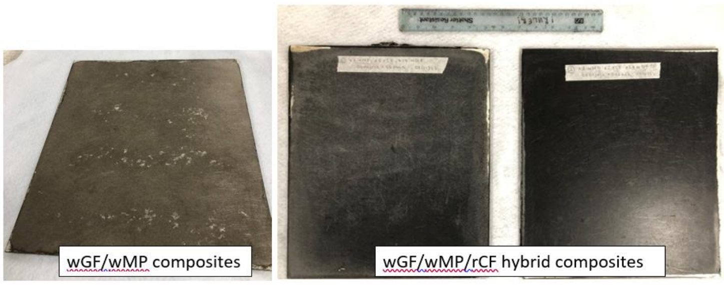

Figure 4: Composites manufactured with waste materials.

Future Direction/Impact

- An EPSRC Impact Acceleration Award project (~£76,840) has been funded to continue this work and the project has started on 1st October 2022. Capvond is industrial partner in this commercialisation project. The prepreg produced in the Feasibility study project is being used in the IAA project as the starting material.
- The work in the IAA project is being carried out in consultation with Capvond keeping in mind the possibility of translating these composites into real products.
- A discussion is ongoing between University of Edinburgh, our industrial collaborators Johns Manville and Paltech for a possible patent application.
- We are also in discussion with BMI group regarding the possibilities of applying such composites in their product line. They are coming to meet us on 13.02.2023.

Feasibility Study Final Report

- An outline proposal has been submitted to EPSRC Call and we are awaiting the decision.
- A discussion is ongoing with an industry to take forward the Cee-section work.
  There is a strong potential of real societal impact as industrial partners are involved and highly interested in the work.

Synergy with other Hub projects: *No such synergy known.*
Please complete the table below:

		Target / project	Actual achievements
	Project duration (yrs)	0.5	
	Project Value (80% FEC)	£ 50,000	
Project Metrics	**PhD students**	0	0
	PDRAs (FTE per year)	1	100% for 4.5 M
	Person years	0.5	
	Project based partners	1	3
	Institutional support	£ -	One PhD student contributed significantly (PDRA time was only 4.5 months). Technician contribution was there to prepare the Cee-section mould.
	Industry support (Letters of Support)	£ 12,500	£38,800
	Additional leveraged grant income	£ 125,000	£76,840* -
	Additional industry leveraged income	£ 60,000	Technical meetings with BMI group (their time contribution for this project)
	Journal publications	0.5	Not yet **
	Conference papers	1	Not yet **
	Patent applications	0	Discussion ongoing
	New collaborative research activity	0	Submitted proposal EPSRC Call (Stage 1)

* £ 76,840.00 (£48,040 IAA funding + £28,800 Industry in-kind contribution) **As discussion ongoing for a patent application, journal paper or conference papers are not yet published.

Feasibility Study Final Report

References:

- Min et al, Experimental study on the behaviour of hybrid fibre reinforced polymer–timber thin-walled Cee section columns, Thin-Walled Structures, Volume 163, June 2021, 107723.
- Thesis, Li Min, Behaviour of Hybrid FRP-Timber Thin-walled Cee section Columns: an Experimental and Numerical Investigation, A thesis submitted for the degree of Doctor of Philosophy at The University of Queensland in 2020, School of Civil Engineering.
- https://www.sciencedirect.com/science/article/abs/pii/S0950061814010861