Chapter 35

Mixed Waste Plastics Derived Composites for Flood and Hurricane Protection

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Abstract

This paper investigates sustainable hybrid composites made from waste mixed plastics (wMP), waste glass fibres (wGF), and recycled carbon fibres (rCF), as viable alternatives for construction materials, including C-sections, hurricane/flood-resistant structures. Two lay-up configurations with varying rCF and wGF contents were evaluated through tensile, compressive, and flexural tests, revealing superior mechanical performance in specimens with higher rCF content. Three thermoformed hybrid C-sections containing approximately 15 vol% rCF, 10 vol% wGF, and 75 vol% wMP were manufactured and tested under axial compression, failing mainly by some delamination and crushing; their weight-specific load capacity exceeded that of comparable ultra-thin-walled steel C-sections by nearly 95%. High-velocity impact tests resisted windborne debris at velocities of 103–125 m/s, outperforming Australian and New Zealand standards and showing superior or comparable ballistic resistance to conventional plywood. These results highlight the potential of repurposed waste materials to be used as structures to benefit society and save human lives.

Keywords: *Waste mixed plastics, Waste glass fibres, Recycled carbon fibres, C-section, Hurricane-resistant panels.*

Introduction

Plastic waste is a major contributor to global landfill volumes, posing significant environmental, economic, and social challenges. Designed for single-use applications for items like food wrappers, containers, and plastic bags have short life cycles but persist in the environment for centuries. They are generally not recycled due to their low cost and low performance. Transforming such wastes or any recycled plastics into sustainable construction materials offers a promising solution, enabling landfill reduction, resource conservation, lower carbon emissions, cost-effectiveness, and the promotion of a circular economy.

By combining waste mixed plastics (wMP) from packaging with reinforcements like waste glass fibre (wGF) and recycled carbon fibre (rCF), it is possible to create durable composite materials with high

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strength-to-weight ratios and excellent corrosion resistance. These composites not only minimise batch-to-batch variability in wMP but also provide tailored performance for diverse applications. For instance, they can be formed into structural C-sections, impact-resistant transport panels, or flood barriers, enhancing both structural integrity and human safety in disaster-prone regions.

This study investigates hybrid laminates made from wMP, wGF, and rCF to address structural needs and sustainability goals. The plastic packaging film waste was first subjected to float-sink separation to segregate the wastes that were lighter than water. These low-value, lightweight mixed plastic wastes were used in their as-received form to reduce further segregation costs and environmental impact. Flat laminates with approximately 15 vol% rCF, 10 vol% wGF, and 75 vol% wMP were manufactured and then thermoformed into C-sections followed by testing under axial compression. These sections demonstrated exceptionally promising performance. Additionally, high-velocity impact testing simulating hurricane conditions revealed that these composites exceeded Australian/New Zealand standards and outperformed conventionally used plywood, highlighting their potential in critical infrastructure applications.

Results and Discussion

A: C-Section

A.1: Manufacturing flat laminates

Extensive research was carried out to characterise wMP[1], develop wMP-wGF prepregs (wMP-coated wGF nonwoven mats) (Figure **1**), and manufacture flat laminates comprising wGF plies, wGF-wMP prepreg plies, and recycled carbon fibre/maleated polypropylene (rCF-MAPP) based nonwoven mats[2]. The rCF-MAPP nonwoven mat was procured from the market[3].

Figure 1: Waste mixed plastics (wMP), waste glass nonwoven mat (wGF), and wMP-coated wGF mats.

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[1] Kit O’Rourke et al., “Diverted from Landfill: Reuse of Single-Use Plastic Packaging Waste,” *Polymers*, 14 (2022): 5485; https://doi.org/10.3390/polym14245485.

[2] Kit O'Rourke et al., “Diverted from landfill: Manufacture and characterisation of composites from waste plastic packaging and waste glass fibres,” *Sustainable Materials and Technologies*, 39 (2024): e00851, https://doi.org/10.1016/j.susmat.2024.e00851.

[3] Gen 2 Carbon, "Home," accessed July 18, 2025, https://www.gen2carbon.com/.

The lay-up configuration consisted of 16 wGF plies, 2 wMP-wGF prepreg plies, and 6 rCF-MAPP plies (Figure **2**). The laminates were produced using compression moulding at 200°C under 18 bar pressure for 20 min. This hybrid laminate is designated as wGF-wMP/rCF-MAPP.

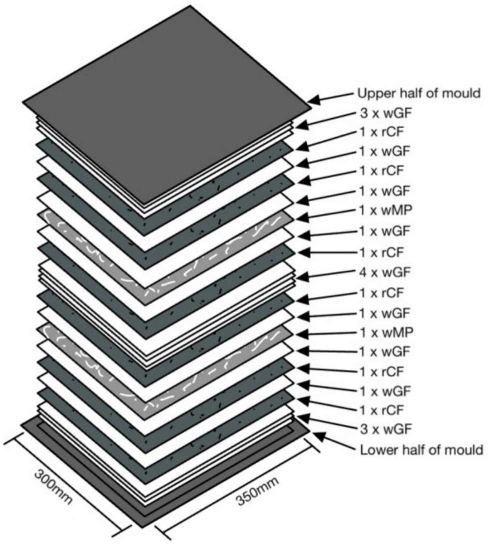

Figure 2: Exploded diagram of lay-up stacking sequence for laminate configuration.

A.2: C-Section shaping

The flat wGF-wMP/rCF-MAPP laminates (cut into 300 × 220 mm) were shaped (thermoformed) into C-sections by using a custom-made metal mould (see Figure **3**) as detailed in our published paper[4].

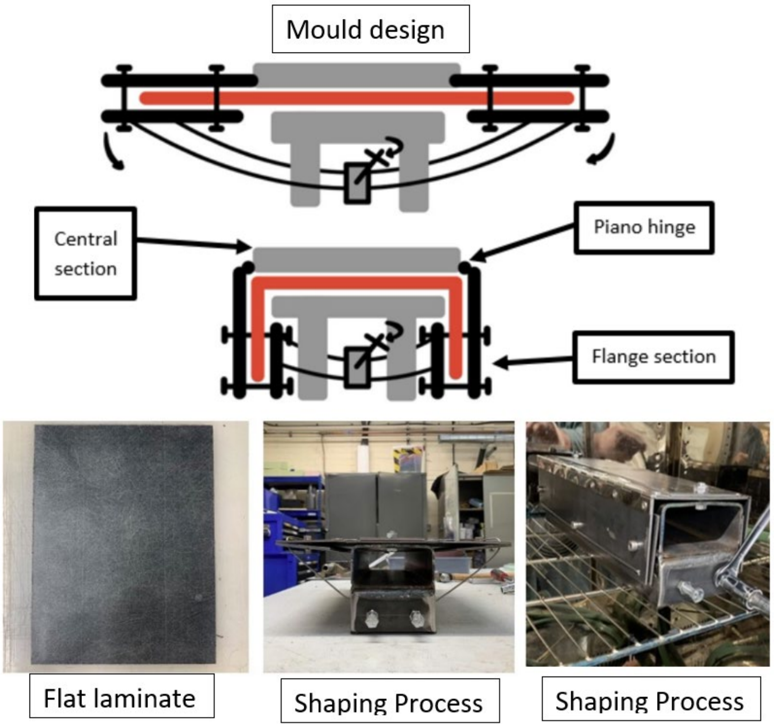

Figure 3: C-section mould: Step-by-step thermoforming of a C-section and final C-section.

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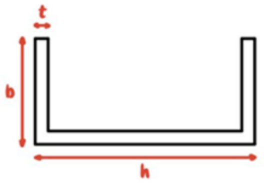
[4] Danijela Stankovic et al., Developing hybrid C-sections from waste and recycled composite materials, *Sustainable Materials and Technologies*, 41 (2024): e01102, https://doi.org/10.1016/j.susmat.2024.e01102.

Three C-sections were produced, namely CS1, CS2, and CS3 (an extra step in the thermoforming process was used in this case only), and their dimensions are given in Table **1**. It is worth noting that CS1 is slightly shorter in length due to an accidental crush of the specimen's edge. Nevertheless, this incident did not impact the results, as discussed in the following sections.

Table 1: Dimensions and weight of the three C-sections produced.



C-section	Length, L (mm)	Flange, b (mm)	Depth, h (mm)	Thickness, t (mm)	Weight (Kg)
CS-1	189	54	116	5.0	0.20
CS-2	303	54	116	4.8	0.33
CS-3	301	53	117	4.9	0.32

A.3: Axial compression testing

For axial compression testing of C-section specimens, a DSLR Canon EOS 5D Mark IV camera was used to monitor the strain field and images were captured at intervals of 2 seconds. The centroid of the C-sections was aligned with the centre of each platen to ensure concentric axial loading, and the crosshead displacement was set to 1.3 mm/min according to ASTM D6641M-21 standard test method.

A.4: Axial compression properties of C-sections

The load versus displacement curves of CS1, CS2, and CS3 are shown in Figure **4**. Prior to failure, the C-sections displayed quite similar behaviour, characterised by nonlinear buckling. CS1 and CS2 demonstrated a drop in the load soon after the ultimate load was reached, whereas CS3 was able to retain the load after the peak load was reached.

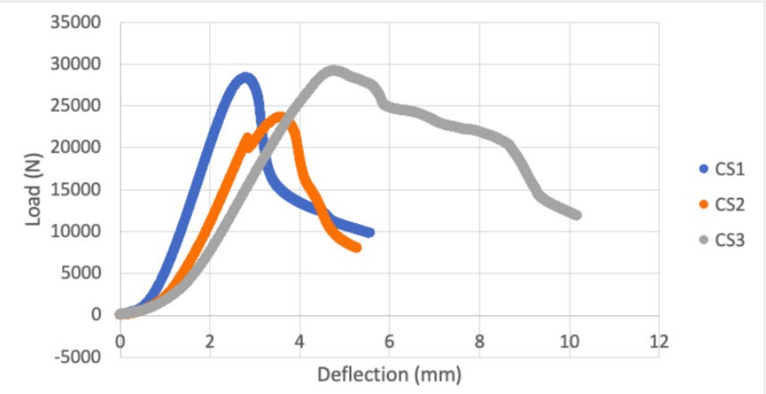


Figure 4: Load versus displacement curves of the C-section specimens (CS1/CS2/CS3).

The load retention and slightly higher peak load of CS3 (29.14 kN) compared to CS1 (28.33 kN) and CS2 (23.61 kN) may be attributed to the reduction of internal stresses induced by deformation during the thermoforming stage. This suggests that additional stages during thermoforming could enhance the load and strength capacity. These C-sections outperformed many virgin material-based C-sections as reported in our published paper.

Producing C-sections with short fibre reinforcements can be beneficial compared to unidirectional continuous fibres or tightly woven mat-reinforced composites. As short fibres exhibit greater drapeability, particularly when integrated into a ductile thermoplastic matrix, they prevent significant damage. The creep in such matrices is reduced due to the presence of the fibres.

B: Hurricane-resistant Panels

B.1: High **velocity** impact testing

High-velocity impact tests were conducted using a gas barrel gun with a pressure capacity of up to 10 bar (≈200 m/s), shown in Figure **5**[5]. Specimens were clamped between plywood frames with a central square opening (100 x 100 mm) and positioned on a height-adjustable wheeled table 2.58 m from the gun nozzle. An 8 mm, 2 gr steel ball bearing was fired at varying speeds onto the specimen surfaces (based on ASTM E1886). Impact regions followed a triangular pattern as per ASTM E1996.

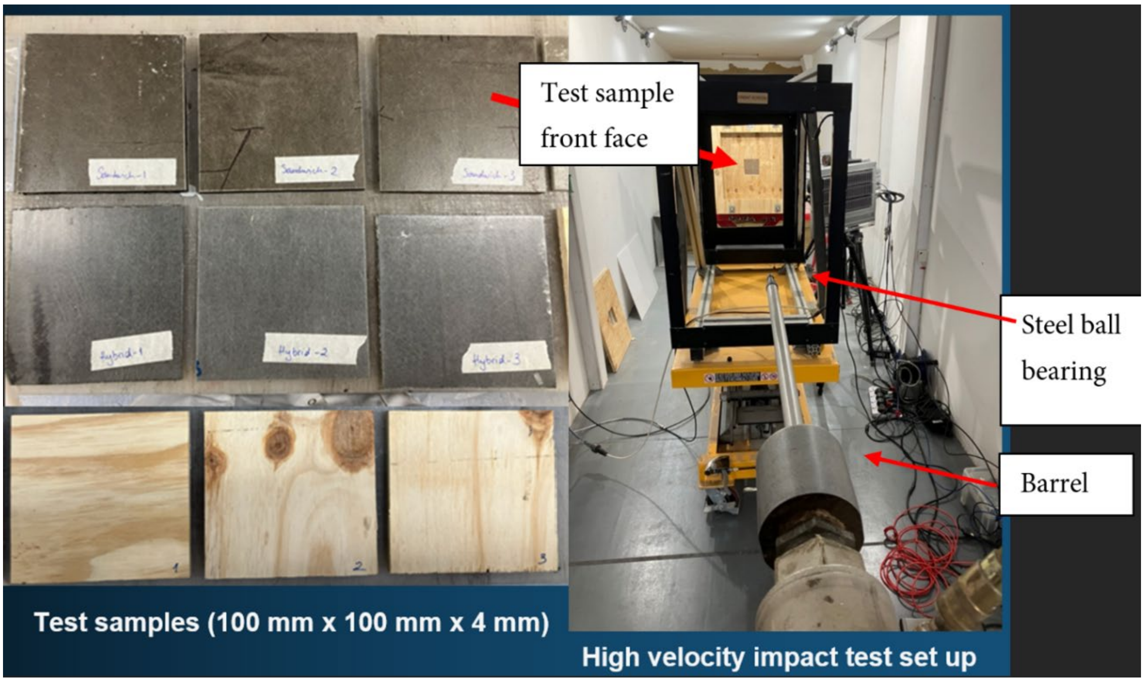


Figure 5: High velocity impact test samples and test setup.

The ballistic limit (V_{50}) and initial kinetic energy of the five different specimen types are presented in Table **2** and Figure **6**, respectively. The polycarbonate (PC) specimens experienced the highest ballistic limit despite being the thinnest specimens[6]. The results show that waste-based laminates can offer an effective solution for ballistic impacts as they can resist velocities higher than the typical design wind velocities used in the AS/NZ standards (70-80 m/s).

Table 2: High velocity impact test results for various samples.

Laminate Type		Average Thickness (mm)	Ballistic Limit V_{50} (m/s)
wGF-wMP/rCF-MAPP	Hybrid laminate (C-section made with the same laminate)	5.56	125.44
wGF-wMP laminate	Waste glass and waste mixed plastics	4.31	103.51

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[5] D.J. Goode & Associates Ltd, https://djgoode.com/.

[6] S. C. Wright et al., "Ballistic impact of polycarbonate—An experimental investigation," *International Journal of Impact Engineering*, 13 (1993): 1–20. https://doi.org/10.1016/0734-743X(93)90105-G.

Table 2: Continued.

Laminate Type		Average Thickness (mm)	Ballistic Limit V_{50} (m/s)
wGF-wMP skins, crosslinked polyethylene foam core	Sandwich	8.94	78.33
Plywood	From market	9.43	96.58
Polycarbonate	From market	2.97	>130

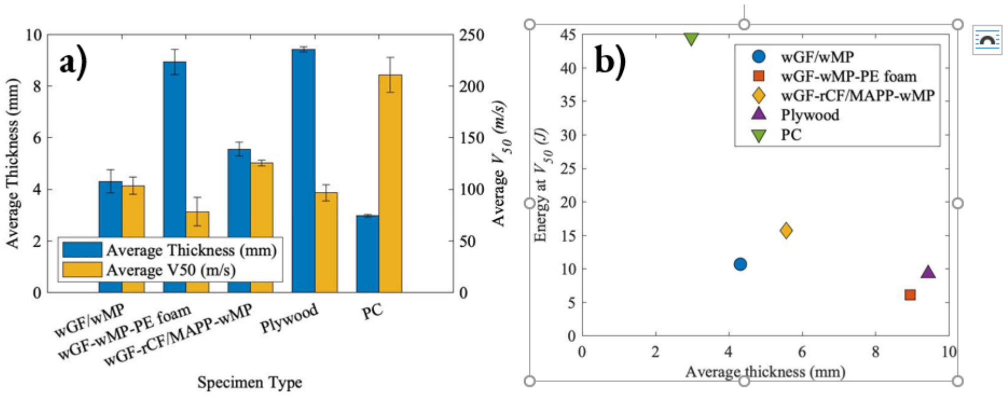

Figure 6: (a) Average thickness and ballistic limit (V50) for each specimen type along with standard deviation values; (b) Initial energy versus average thickness of each specimen type.

Figure 7 shows that all specimens were perforated except the wGF-wMP/rCF-MAPP hybrid one (V_{50}=125 m/s). For the plywood specimens, perforation occurred at an impact velocity of 119 m/s. Both the front and rear faces showed a clear hole, and as the ball bearing exited, plywood pieces were ejected from the rear face (Figure 7).

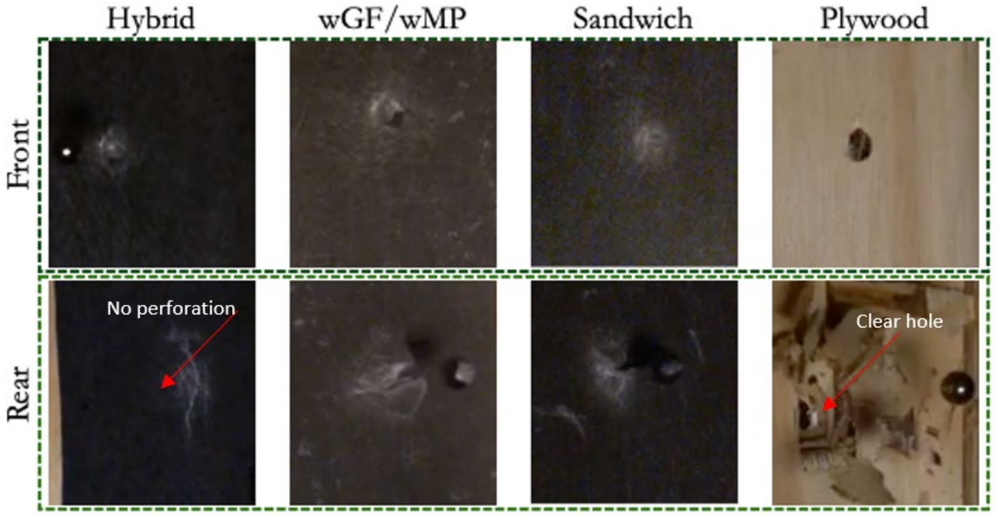

Figure 7: Surfaces of the front and rear faces of the tested specimens following impact.

Prototypes Planned:

Once funding is available, these laminates would be made into the following prototypes:

1) Single slot-in flood barrier panels of approximate size (0.9m wide x 0.3m high x suitable thickness) in collaboration with Flood Control International, UK[7].
2) Hurricane-resistant panels (approximate size 1m x 1m x thickness to decide) will be produced, and a tornado test will be carried out at an external institute in Italy[8].

Conclusion

This technology will serve a dual purpose:

1) Divert low-value plastic waste and glass fibre waste from landfill into useful product forms and lock them for a long period of time.
2) Save human lives in disaster-prone areas at a low cost/easy availability. These can be locally made using local plastic waste.

Acknowledgements

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