PacifiCan-MMRI Accelerating Circular Economy (ACE) TechBrief Report

Project title: Replacing Legacy Materials of Aquatic Play Structures with Flexible, Durable and Low-Footprint Alternatives

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Introduction & Background:

For structural components used in leisure industries, such as those in aquaparks, high load-bearing capacity and lightweight materials are of primary interest [1]. For this purpose, rigid fibre-reinforced polymer (FRP) composites are currently used widely. However, they often result in large and stiff moulded parts, which lead to logistic challenges as well as added costs associated with transportation and handling [2]. FRP materials are also difficult to recycle, raising concerns over environmental sustainability [3]. One proposed solution is to replace such legacy materials with flexible, durable, and recyclable alternatives, offering advantages such as rollability, easier handling, and sustainability. To this end, this research investigated replacing glass fibre-reinforced polymer (GFRP) composites used in aquatic play structures with alternative polymers. The study evaluated candidate materials through mechanical testing and weathering resistance analysis, considering exposure to UV radiation, temperature variations, moisture, and chlorinated water. To address the lower strength and modulus of the flexible polymers compared to the rigid polymers, this research also investigated redesign considerations to maintain structural integrity and load-bearing capacity.

Relevance to Circular Economy:

This research represented an important step towards integrating circular economy principles into aquatic play structures. The circular model focused on replacing non-recyclable GFRP with flexible, recyclable polymers, reducing waste and improving resource efficiency. By enhancing material durability and adaptability, this research promoted longer product lifecycles and sustainable end-of-life management.

Methodology:

Three thermoplastic elastomers (TPE), including two thermoplastic polyurethanes (TPU), i.e., Texin 285A and Texin 255D, and one thermoplastic vulcanizate (TPV), i.e. Santoprene 121-67W175, were chosen as candidate materials. The physical and mechanical properties of the legacy (base) material, i.e. GRP, and candidate materials were characterized through a series of coupon-level experiments.

Density measurements were taken as the weight of the product would have important implications on logistics and transportation. Tensile tests were conducted to investigate the tensile strength and stiffness, which would be important data for structural design. Three-point bending tests were carried out to measure the flexibility of the materials, ensuring the candidate materials could be rolled or folded. Cyclic tensile tests were conducted since aquatic play structures are often subjected to cyclic loads. Hardness tests and friction tests were performed to quantify the surface hardness and frictional properties to correlate to user experience on aquatic play structures such as a water slide. Abrasion tests and puncture tests were also conducted to study the durability of the materials against abrasive actions or contact with sharp objects, which may occur during regular use or extreme events for aquatic play structures. Finally, impact tests were performed since aquatic play structures may experience impact loading from the users.

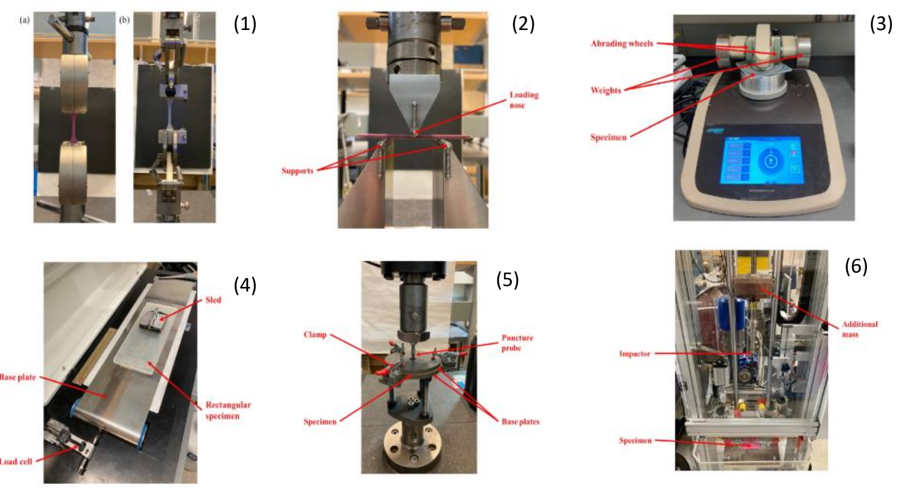

Figure 1. Mechanical test setups: (1) Wedge grips and scissor grips, (2) Three-point bending fixture, (3) Taber abrasion tester, (4) Coulomb friction, (5) Puncture fixture, (6) Instron CEAST 9340.

In another set of experiments, material samples were also subjected to weathering exposures, including water and chlorinated water immersion, hygrothermal aging, and accelerated weathering in a Xenon lamp chamber.

Finally, unaged and aged (from xenon lamp chamber weathering) specimens of GFRP, Santoprene, and Texin 285A were imaged using a confocal laser scanning microscope (CLSM) and a scanning electron microscope (SEM). The images were used to investigate the surface quality, roughness, tensile fracture, and effects of weathering.

Results & Discussion

Results indicated that GFRP exhibited superior tensile strength and modulus, while the TPE candidates showed higher flexibility and strain at break. TPU showed better abrasion and puncture resistance than the TPV candidate, but higher water absorption. Yellowing could be observed for TPU after weathering in the xenon lamp chamber. No statistically significant changes in the tensile properties could be concluded for all materials upon weathering.

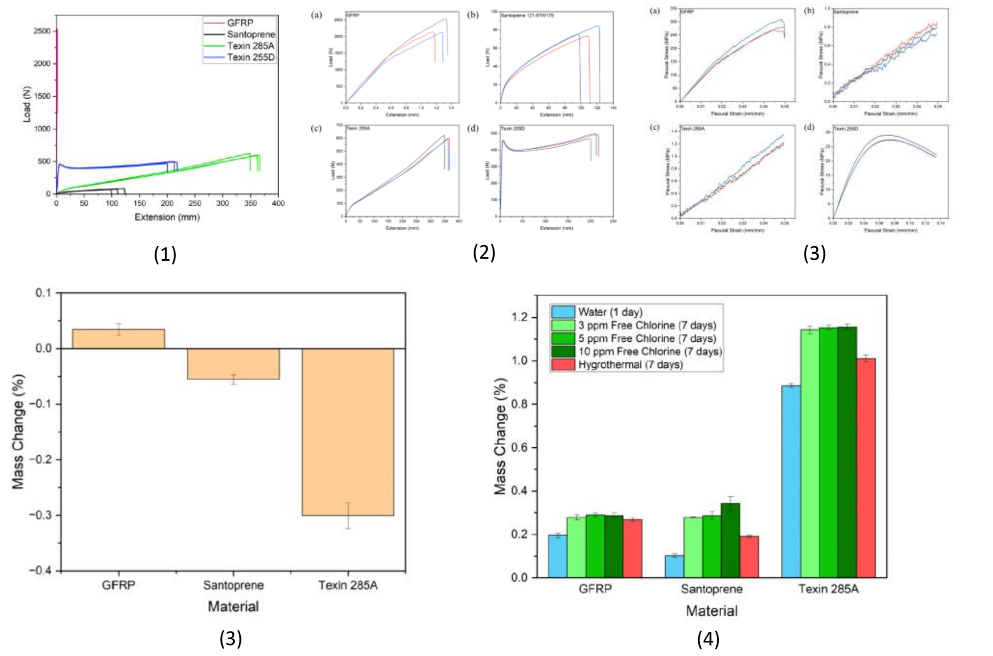

Figure 2. A summary of mechanical test results and weathering performances of GFRP, Santoprene, and Texin: (1) and (2) Load-extension curves, (3) Flexural stress-strain curves, (3) Mass change of specimens after aging in xenon lamp weathering chamber, (4) Mass change of specimens after weathering conditioning exposures.

Building on the characterization test data, a multicriteria decision-making method, namely PROMETHEE II, was implemented to evaluate and rank the legacy and candidate materials based on typical design criteria including cost, mechanical properties, weathering performance, and recyclability. According to the results, Texin 285A was ranked as the top alternative, followed by Santoprene and GFRP.

Design ideas to incorporate the flexible material into water slide flumes, including a honeycomb sandwich structure design and a diaphragm design, were also proposed.

Conclusion & Next Steps

In this research, mechanical, weathering, and microscopy characterization methods were applied to compare the performance of legacy material and candidate material for use in aquatic play structures. Specifically, the mechanical tests included density, tensile, hardness, abrasion, flexure, cyclic tensile, puncture, friction, and impact. The weathering exposure conditions included water immersion, chlorinated water immersion, hygrothermal, and xenon lamp chamber. The microscopy characterization methods included CLSM and SEM. In future research, LAC and LCCA can be used to quantify environmental impact in terms of resources used and emissions, as well as the costs of ownership.

References:

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Further reading: Liu, Haoyang. "Towards redesigning legacy GFRP-constructed aquatic structures with flexible, durable, and recyclable alternative materials: a multicriteria approach." PhD diss., University of British Columbia, 2023.

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