THE UNIVERSITY of EDINBURGH

Rotohybrid

WES Structural Materials and Manufacturing Processes Stage 1 Public Report

The University of Edinburgh

This project has been supported by Wave Energy Scotland.

1. Project Introduction

Materials and processing technology has been developed to enable a novel, hybrid, polymer and composites manufacturing process to be employed in the design of wave energy converters. The overall long-term aim is to offer a step change in LCOE through significant CAPEX reductions, with further OPEX reductions due to lower maintenance requirements and improved corrosion resistance in the ocean. The Stage 1 project concentrated on an engineering design study to demonstrate the feasibility of constructing a full-scale WEC using rotationally-moulded polymer buoyant tanks, reinforced with glass fibre (GRP) composites.

The project team involved two Universities, a leading wave energy device OEM, a supplier of engineering design services, a plastics rotational moulding company and a composite materials structures manufacturer.

The project included four major activities: 1) materials testing and development 2) manufacturing studies of materials and production of a scaled demonstrator structure, 3) engineering design of the WEC based on hybrid technologies, and 4) techno-economic analysis leading to LCOE predictions.

The project's success is dependent on the following key measures: 1) Identification and development of promising polymer and composite material combinations and designs for replacement of metallic structures; 2) measurement of critical material properties such as static modulus and strength, fatigue resistance, water absorption; bolt pull-through strength, creep loading of bolts, and the effect of water immersion on these properties; 3) detailed engineering design, including finite element analysis, of the WEC using hybrid material construction methods; and 4) development of an LCOE model to assess the technology and provide a business case and commercialisation strategy for the proposed technology.

2. Description of Project Technology

The goal of the Rotohybrid project is to replace large sections of a welded steel WEC with a modular construction method, where fibre-reinforced rotationally-moulded polymer sections can be brought together and assembled close to the deployment site of the intended wave farm. Reductions in CAPEX, compared to the baseline steel design are predicted. Rotational moulding of large hollow polymer structures is a very cost-effective method of producing buoyant structures, however, the mechanical properties of polyethylenes are not sufficient to resist the external hydrostatic forces usually encountered in these devices. The project developed innovative technology for the localised reinforcement of rotationally-moulded polymer structures, which would enable them to perform structurally while being manufactured at competitive costs. This modular construction will enable large WEC devices to be transported internationally and assembled at a lower cost, or alternatively manufactured near to site. Further cost savings can be expected in Operation and Maintenance, due to the excellent long-term performance of the materials in seawater. The type of WEC hybrid construction developed has the potential to offer lower cost designs for future devices.

3. Scope of Work

Rotational moulding is a very applicable and cost-effective method for the manufacture of very large, stress-free, (i.e., lack of manufacturing residual stress) hollow structures made from polymeric materials, most typically polyethylene, which are tough (i.e., absorb high levels of energy prior to fracture) and do not rust. The rotational moulding of High Density Polyethylene (HDPE) products is widely used for marine products, such as buoyancy modules, clamps, saddles, centralisers and spacers for oil and gas risers, buoys and modular buoys, drill riser buoyancy, riser towers and floats. Rotational moulding of HDPE is also widely used for aquaculture structures such as fish farm tanks, pontoons, containers, crates, pallets and insulated fish and cooler boxes. These structures can be large and quite complex in shape and have demonstrated a 20-year lifetime in marine environments.

Rotational moulding generally facilitates the fabrication of multi-layer structures, e.g., the use of a skin/foam or skin/foam/skin (sandwich) construction to avail of the greater moment of inertia and stiffness that these structures can provide. In this project, however, the benefits offered by increased moment of inertia were not sufficient to overcome the intrinsically low material modulus of either the MDPE or HDPE polymers used.

To overcome this, a structure incorporating polyethylene and fibre-reinforced composites can be manufactured to give an acceptable degree of rigidity. Manufacturing trials were carried out on a scaled prototype tank (diameter 265 mm, length 480mm) in order to demonstrate the Rotohybrid concept. The manufacturing trials indicate that a rotationally moulded liner can be successfully reinforced to produce a sufficiently stiff structure for the WEC applications envisaged.

Fusion-welding of PE materials was a second manufacturing process investigated, in order to assess the possibility of manufacturing large buoyant actuators in sections, in order to introduce internal stiffening elements. The process investigated is the Powercore© electrical resistance welding process.

Conceptual, front-end and detailed design of a novel WEC structure based on the Carnegie Wave Energy CETO-6 device was carried out in the project. This involved detailed design and finite element analysis of various loading scenarios including external pressurisation, creep loading and application of an overturning moment.

A significant effort was also expended on materials and process investigation of rotationally moulded polymers that would be suitable for the Rotohybrid WECs, including static, fatigue and creep loading of both dry and seawater-conditioned materials and the testing of bolt pull-through specimens. Polyethylene materials in general exhibited low mechanical properties, such as modulus, tensile strength, bolt pull-through forces, creep and fatigue loadings, which necessitated the use of fibre composites for reinforcement of the polymers.

The ability of a rotational moulding process to manufacture the large parts required by the tank design in the Rotohybrid project is clearly evident. For example, a Chinese company (Wenling Rising Sun Rotational Moulding Technology Co.) has made the world's largest rotational moulding machine for a customer in Canada. The gigantic machine (measuring 6.5 meters in diameter, 27 meters in length, 17 meters in width, and 8 meters in height) travelled across the globe and now is used to rotomould storage products.

4. Project Achievements

The project demonstrated that large, heavily loaded structures can be constructed from polyethylene materials. A range of techniques were investigated to provide sufficient strength and rigidity to the inherently flexible material, including the use of skin-foam and skin-foam-skin sections, kiss-off construction[1], and single and double curvature geometries. However, even employing the best of these techniques, at the scale of the CETO-6 device, very large HDPE wall thicknesses are required to meet the loading requirements, and a purely polymer design was deemed to be unlikely to offer a commercial advantage.

[1] The 'kiss-off' moulding process increases stiffness of a section by creating an array of points where the opposing walls of the moulded part are joined together. Typically this is achieved by the addition of truncated conical inserts on one wall of the mould tool that leave a gap of less than twice the wall thickness to the opposite side of the mould. This gap fills with polymer during the moulding process, creating the 'kiss-off' point.

The designs were found to be dominated by material modulus rather than strength. Fibre-reinforced polymers have vastly superior stiffness (e.g > 40 GPa for GRP versus < 1 GPa for HDPE) and can be cost effective when applied using a rapid layup technique such as filament winding. In this project, it was found that a technically sound, and lower cost solution could be produced by reinforcing a relatively thin HDPE liner with filament wound GRP. The feasibility of this approach was demonstrated through the production of a scaled prototype component.

The predicted savings in CAPEX over the baseline steel construction was, however, seen not to be significant in terms of LCOE for the device studied. These predictions are specific to the size, geometry and loading of the CETO-6 BA, and are not intended to be taken as general LCOE predictions for the Rotohybrid concept. There is however, a significant performance opportunity for the modular Rotohybrid approach that is not reflected in this analysis. WEC performance increases with diameter and as all steel designs continue to increase in size (towards say 30m diameter) they may become impracticable. A modular Rotohybrid design could enable a very large WEC with higher power capture and a lower LCOE.

In a commercial context, O&M costs may also be more significant than the initial capital expenditure on the BA structure. This is an area of weakness for the baseline design, which may be susceptible to fatigue, corrosion and bio-fouling. The Rotohybrid design has better characteristics in these areas and could therefore offer a lower LCOE.

5. Applicability to WEC Device Types

The manufacturing processes investigated in the Rotohybrid project are applicable to any structure that can be composed of convex shaped elements. This could be a complete WEC structure, such as the modular array of buoyant tanks proposed for a large point absorber. Smaller devices may use a single component as the point absorber buoy, or as a node in a 'net type' system.

Alternatively, the techniques could be applied to any WEC type that requires elements of flotation or buoyancy / ballast modules. Examples might include pontoons on an attenuator raft or ballast tanks on a submergible system. In this latter example, the elimination of steel from the interior of ballast tanks is a notable advantage of the technology.

6. Communications and Publicity Activity

- Wave Energy Scotland Annual Conference, Edinburgh, 28th November 2017: Elevator Pitches. "Rotohybrid Project" Presentation by Prof. Conchúr Ó Brádaigh.
- EWTEC 2017 – 12th European Wave and Tidal Energy Conference, Cork, Ireland, August 2017. Elevator Pitches at Wave Energy Scotland Workshop. "Rotohybrid Project" Presentation by Donald Naylor.
- Wave Energy Scotland Materials and Structures Workshop, Glasgow, 11th April 2018. Presentation: "Rotohybrid Project" by Prof. Conchúr Ó Brádaigh.
- We are investigating a possible patent application and are planning posters/academic papers once the patent application has been examined.

7. Recommendations for Further Work

The Rotohybrid design concept needs to be further developed and de-risked by carrying out design, manufacture and testing activities at larger dimensions. This could include:

1. Demonstration of the feasibility of the concept by design and construction of a 1:2 scale component. The chosen scale may need to be altered to meet project budgets and available manufacturing and test facilities. The skin thickness should be scaled to give similar deflection: diameter ratios as the full scale component and the following features should also be included:
    - Similar geometry to the intended WEC device tanks
    - May also include non-axisymmetric sections.

The component(s) manufactured by this process may then be used in further tests described below:

1. External hydrostatic pressure test and buckling resistance.
2. Design, manufacture, strength and fatigue testing of critical design details such as the attachment to steel structures.

Design and analysis work should continue to mitigate the risks and to take advantage of the opportunities presented by the Rotohybrid concept. The following activities are anticipated:

1. Detailed design and analysis of the scaled component.
2. Energy capture performance of the Rotohybrid design should be confirmed using non-linear hydrodynamic analysis. A minimum of two iterations of analysis and design should be considered in order to adapt the design to equal or exceed that of the baseline design.

A study could be conducted into the wider application of the Rotohybrid technique to other types of wave energy converter, demonstrating the flexibility of the manufacturing technique and its generic applicability

8. Useful References and Additional Data

http://www.plasticsnews.com/article/20150909/NEWS/150909932/rotomolding-a-very-big-future