Haydale Composite Solutions

Advanced Rotational Moulding for Ocean Renewables (ARMOR)

WES Structural Materials and Manufacturing Processes Stage 1 Public Report

Haydale Composite Solutions

This project has been supported by Wave Energy Scotland

1. Project Introduction

The Advanced Rotational Moulding for Ocean Renewables (ARMOR) project aims to reduce the capital cost of device structures by circa 45% in order to create a step change in the levelised cost of energy for wave energy converters.

Its unique selling point is that it is both technology and solution agnostic bringing the widest solution of patented rotational moulding composites (from strength enhancing carbon and graphene nano additives to unique anti-fouling composites) to the most appropriate device concepts while ensuring the solution is as broadly, commercially applicable as possible.

The project has undertaken an initial device screening exercise to identify the most appropriate concepts. This was followed up by detailed device designs and load modelling, iteratively undertaken in parallel with the material selection review. The final material selection was optimised to the final device design to maximise LCOE metrics. From this, manufacturing studies, cost modelling and risk evaluation were undertaken to ensure that the project met its target ambition.

The project brought together a strong consortium of wave energy experts (Wave Venture and the Carbon Trust) for device and LCOE modelling as well as composite material design and manufacturing experts (Crompton Moulding and Haydale Composite Solutions) for material selection and testing. This ensured that the final composite solution was both commercially applicable, ready to manufacture and fit for purpose.

Project Team

Haydale Composite Solutions (HCS) work with OEMs, fibre and resin manufacturers and end users from all industrial arenas to manufacture novel resin, composite and nanomaterial solutions for their products. Haydale have a patented technology for the plasma functionalization of graphene and other nano particulates which allows for the exfoliation of graphene nano platelets as well as effective dispersion of the nano particulates within liquids such as inks and resins. HCS have been involved in more than 20 major research and development projects (EU framework, DTI, Eureka, Innovate UK, numerous commercial programmes) resulting in a number of spin-off businesses, 3 joint ventures with major PLC companies and licensing of patented technology to 2 major organisations. HCS specialises in the commercial development of resin, adhesives and composite materials with nano-improved performance. A recent example relevant to this call is work undertaken with the Department for Transport Technology Research and Innovation Group to optimise dispersion of graphene nanoplatelets in thermoplastic polymers including the processing of nano materials within rotomoulding compounds. HCS made use of its internal capability in 3-D modelling and finite element analysis (Abaqus) and utilised its uniaxial test machine to help develop optimised materials.

Crompton Mouldings Ltd have an extensive record of developing innovative projects in response to specific customer requirements (within conventional moulding parameters) and also in developing new processes to manufacture products in unique and innovative ways. Crompton Mouldings Ltd have been part of two TSB funded projects: SHIELD utilised the patented process technique to successfully develop a panel capable of absorbing explosive blasts at close range; DURASTOR attempted to develop hydrogen storage vessel capable of withstanding high pressure hydrogen with minimal loss through permeation (this project was then extended into HOST which was completed in September 2017). Crompton Mouldings Ltd have demonstrated the ability to commission bespoke machinery to meet specific moulding requirements. In response to a project need to manufacture products beyond the current size capability of the moulding machinery, Crompton developed a unique manufacturing machine based on the rock and roll method of mould processing but with very specialised features for which Crompton are in the process of applying for a patent.

Wave Venture is a specialist wave energy consultancy and software provider. Over the past 15 years Wave Venture staff members have developed unique capabilities and understanding in wave energy technology research and development. Wave Venture comes from a base of strong engineering competence and is focused on merging engineering and economic analysis methods and on applying these to deliver wave energy technology related services with a commercial focus. Wave Venture provides advisory and analysis services to companies that are: • investing in wave energy technology • conducting research and development on wave energy conversion systems • planning deployments of wave energy farms. Wave Venture simulation software is capable of quantification of point loads (PTO/moorings/joints) as well as pressure loads on wave energy converters. These are based on a simulation which is a multi-body rigid body solver integrated with a wave-body interaction model based on a modified Cummins equation with non-linear Froude Krylov forces. This is a fast running model and is suitable for scanning multiple seastates at multiple sites to generate inputs to structural calculations. The loading information and the energy performance are calculated in the same simulation so that both are fully consistent and coupled.

The Carbon Trust have a strong history of working in the marine energy sector having programme managed circa. £50m of innovative activity to date. This has included undertaking projects such as the Marine Energy Accelerator that included Initial Device Assessments (IDAs), evaluating over a dozen early stage marine energy devices for commercial potential and technical credibility. The Carbon Trust undertook the project management within the consortium, the LCOE modelling and reviewed and supported the technical translation of Haydale and Crompton's delivery to ensure it was commercially applicable to the wave energy sector. The Carbon Trust's Marine Energy Challenge Cost of Energy Model and supporting methodology report, has been an industry standard tool for concept level costing of wave and tidal devices and we were a key partner delivering LCOE forecasts within the SI Oceans project. We hold a wealth of real-world knowledge on wave energy project costs through both previous programmes and our Technology Innovation Needs Assessments (TINAs).

2. Description of Project Technology

The project establishes rotational moulding as the key process to manufacture large modular structures which can address many of the issues surrounding metallic structures within the harsh offshore environment. The rotational moulding process is a low-cost method for manufacturing large, hollow parts from thermoplastic polymer and has low capital investment, large degree of design flexibility and the ability to manufacture products using a range of different thermoplastic resins. Rotational moulding amongst other types of plastic moulding is suitable for wave energy because the moulds are unpressurised and are therefore cheaper and more suited to large shapes. In comparison, injection moulding requires pressurised moulds and the limiting size for a given investment is considerably smaller. Further, rotational moulding is well suited to forming uninterrupted watertight shapes, this property leads to one of its primary existing uses, in tank manufacture for water, bunded oil and kerosene products.

Whilst steel is a low-cost, high strength commodity material, it suffers in the offshore environment due to the effects of salt water corrosion, low levels of strain-to-failure and the combined deleterious impacts of environment, abrasion and load on its mechanical and fatigue characteristics. Whilst fatigue stress in steel can be quite high, the high modulus of elasticity leads to a fatigue strain that is very low. This phenomenon makes steel particularly unsuited to high cycle loading (especially with peaks of high strain) as is the case in wave energy. Corrosion, abrasion, geometry and loading type significantly worsens the situation for steel. Polymer and composite manufacture processes that can achieve the required size and load capacity for wave energy devices can significantly reduce the cost of manufacture, maintenance and through life costs for wave energy converter machinery thus leading to a corresponding improvement in device affordability. This can be achieved through reduced mass of the structural elements, low cost and high volume manufacturing processes, a modular transportable manufacturing process (which can be installed on quayside if necessary), better long-term fatigue and environmental performance of the thermoplastic polymers with composite structural support in comparison to steel, inherent colouration and antifouling capability and the potential for improved transportation and logistics through modular construction.

3. Scope of Work

The project had a target to achieve a credible forecasted cost reduction of the structural CAPEX by 45% (with an ambition of 50%). To achieve this, the key learning targets of this project were to:

- Clearly evaluate the potential of nano-technology and other advanced additives in rotational moulding on the survivability, affordability, availability and performance of wave energy devices.
- Clearly evaluate the potential of rotational moulding with sectional manufacture for wave energy.
- Assess several well-known wave energy concepts for suitability of application for rotationally moulded structures and make recommendations for which ones are most suited.
- Assess the overall impact on LCOE of the selected technologies to answer; does the best WEC device from polymer/composite rotational moulding construction give lower cost of energy (LCOE) than the best device with steel construction?
- Answer the question of; will the best WEC device from polymer/composite rotational moulding construction meet the WES target of a credible narrative to £150/MWh at 1GW of deployment?

Our project is wave energy converter technology agnostic while clearly focusing on the potential of polymer/composites augmented with nano-technology or other advanced additive based materials for use with a rotational moulding manufacturing process.

The eight project workstreams were:

1. Project Management
2. WEC Design Refinement
3. Detailed Concept Design
4. Quantification of Loads and Material Characteristics
5. Materials Review and Selection
6. Design Study for Manufacturing
7. Performance and Cost Modelling
8. Risk Evaluation

The methodology first undertook a preliminary investigation of a range of WEC concepts. The focus was on single hull devices, for example OWC devices, various types of bottom reacting point absorbers and internal reaction mass devices. The preliminary investigation undertook a pragmatic load analysis in static, operational and survival conditions with the aim of providing wave energy load analysis information for material experts to aid concept selection. A Backward Bent Duct Buoy (BBDB) OWC device was selected at this point.

The second stage of the project contained detailed design work, FMEA, load assessment and finite element analysis of the selected WEC concept. This allowed for design iterations to address feedback from each activity to the design. Sample materials were fabricated at a later stage in the project to undertake key tests (strength, stiffness, moisture absorption, accelerated weathering). The later work (WP6-8) packages conducted a thorough cost of energy assessment and manufacturing study to understand the practicability of scaling and undertake a risk assessment exercise to reframe the earlier findings within the broader learning targets stated above.

4. Project Achievements

We focused on reduction of the forecasted LCOE metric, structuring our analysis on the WES approach of impact upon Affordability, Survivability, Availability and Performance. Past experience has shown that proxy measures such as kWh/m3 or kWh/kg are not reliable indicators of WEC quality or potential, neither is analysis of CAPEX or OPEX alone a reliable measure. We therefore addressed the impact of materials choice on productivity, CAPEX, OPEX and decommissioning costs so that high fidelity LCOE estimates were possible.

This project found a structure cost reduction of over 50% compared to steel, corresponding to a total LCOE reduction of 30% in a 1GW deployment scenario. A manufacturability review and other analyses established the viability of manufacturing a horizontal oscillating water column device with rotational moulding and composite manufacturing technologies. Engineering modelling combined with material testing was used to demonstrate successfully that the ARMOR materials can accommodate the required load requirements for deployment in Orkney South. A number of areas for substantial improvements in subsequent phases have been identified, including strengthening and stiffening structural elements as well as different composite solutions.

Manufacturability was found to be a key benefit to the ARMOR device. The interchangeable parts do not require a specific expensive metal press and therefore the manufacturing facility can be located at portside. This reduces transportation costs, and this facility can also act as a maintenance centre to reduce the cost and duration of deployment and maintenance.

These findings represent success against the project's objective of demonstrating the beneficial impact of advanced rotational moulding techniques on the LCOE of a wave device. The potential improvement in LCOE resulting from rotational moulding techniques is clear, providing sufficient justification for further development of this concept for wave energy applications. The overall LCOE, for now, remains relatively high, but this is to be expected at an early stage of development. The next steps identified for subsequent phases, combined with continued optimisation through activities such as scale model testing, are likely to demonstrate further benefits of the ARMOR approach. We believe there is significant potential for reaching the WES target of 150 £/MWh for a 1GW deployment scenario.

5. Applicability to WEC Device Types

We believe there is a high level of suitability for the application of rotational moulding as either full or part structural replacement for a wave device concept due to its inherent suitability for high-volume/low-cost manufacturing, low marine degradation profile and high level of survivability (due to the natural buoyancy of the material). A range of WEC types were reviewed for material suitability and the most promising concept was investigated in more detail.

Our project focused on the deployment of a Backward Bent Duct Buoy Device. This device is a floating oscillating water column formed from a tube with a right angle bend so that a vertical part of the tube breaks the water surface and a horizontal part of the tube has a mouth that is open to the water and pointing in the direction of wave propagation (away from incoming waves). The B2DB was selected in an earlier deliverable due to the suitability for construction from rotational moulding and the large volume of structural material required in the construction of the B2DB compared to other wave energy devices. A manufacturability review and other analyses established the viability of manufacturing a horizontal oscillating water column device with rotational moulding. Engineering modelling combined with material testing was used to demonstrate successfully that the ARMOR materials can accommodate the required load requirements for deployment in Orkney South.

Two other device-types that were identified as potentially suitable for rotational moulding, though less so than for floating OWC devices, are bottom reacting point absorbers and pitching CAMs. These and other device considerations are given in our Device Screening Report.

6. Communications and Publicity Activity

At this stage, the project's primary public activity has been within the Wave Energy Scotland programme where the consortium have attended two of the WES workshops to showcase the project and look for suitable implementation project partners for Stage 2 and beyond.

7. Recommendations for Further Work

The data generated in this project establishes a platform to further develop during stage 2. The initial stage materials testing in this project has shown the strengths and weaknesses of rotationally moulded materials selected for a wave energy device. Extended accelerated ageing, material testing and small-scale prototypes will complement load evaluations based on dynamic pressure load in this project. Structural design, material development and load evaluations should be carried out to further determine material capability, device performance and realise cost savings. Extended seawater survivability testing is needed alongside a biofouling test regime to establish material viability.

Key properties essential in delivering a device capable of surviving in an energetic marine environment are high elastic modulus, tensile and flexural strength and strain properties. Impact resistance and low moisture absorption are also important to ensure the device will survive for long periods submerged in the ocean. Whilst compared to a traditional steel device, the polymer properties are lower, they can be enhanced with fillers and structural reinforcement profiles, e.g. composite pultrusions or stiffening sections. The inherent corrosion resistance, increased service life, reduction in maintenance and affordability are significant benefits of the novel design proposed. These benefits should be experimentally verified.

There are a number of other potential applications for rotational-moulded polymers for wave energy devices that should be explored in subsequent projects, including rotational-moulded floats for other WEC types. The benefit is that many WEC types, that are less suited to being fully rotational-moulded, still utilise floats. These floats are ideal for rotational-moulding, and this possibility will be proposed for exploration in subsequent development phases. There is further scope to utilise rotational moulded polymers in other marine applications outside of wave energy: examples include tidal energy; navigation buoys; and floating wind turbines.

8. Useful References and Additional Data

None.