Polyshell

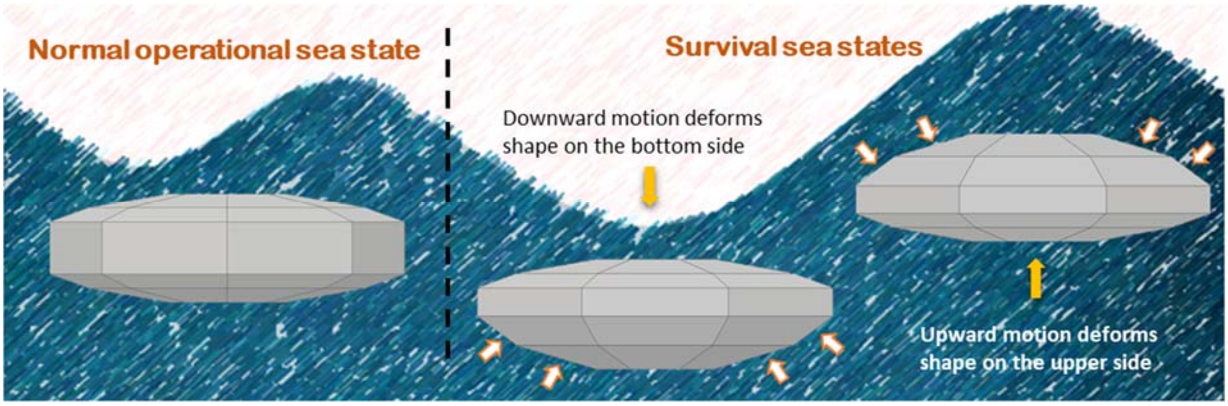
WES Structural Materials and Manufacturing Processes Stage 1 Public Report

Technology from Ideas Ltd.

This project has been supported by Wave Energy Scotland.

1. Project Introduction

Polyshell is a novel material project, where the use of novel high fatigue flexible polymers allows for the hull of a wave energy converter to change shape with changing loads. This change of shape leads to a change in drag coefficient of the shape and can have significant impact on the peak loads, the fatigue loads and the impulse loads on the hull, as well as the components attached to the hull. Ideally such changing shape does not occur in operational loads, but only in high structure load scenarios.



The material in question is Hytrel, a thermoplastic elastomer copolymer, containing two different polymers within its matrix, granting it both rubber and plastic type properties. This material has been chosen due to its superb fatigue properties, and the ability to shape the material into structural elements which behave as desired under applied loads.

The project brought together a diverse team of polymer scientists, polymer component manufacturers, simulation & modelling experts, marine renewable energy engineers, LCOE experts, and certification/standard experts, as shown in the logos of the partners cooperating in this project below.

The key questions which the project sought to answer were as follows;

- Is the polymer material suitable for the proposed use / application?
- Can we shape the material into a WEC structure to behave in the desired way?
- What are the environmental loads which a WEC manufactured from this material will experience?
- Does changing the shape of the material enhance the performance/survivability?
- How can we manufacture a WEC device using this approach?
- What would be the cost of such a flexible WEC using Hytrel?
- What would be the LCOE taking cost and performance changes into account?
- What are the certification / standards implications of the new approach?

- Is this approach of interest to WEC developers?

The project would be deemed successful if it can confirm that the approach fundamentally works and can deliver a significant enhancement to LCOE.

2. Description of Project Technology

The project technology is fundamentally the use of Hytrel material, shaped into 3D structures, which bend and flex as desired in a WEC device. The primary reason for choosing a flexible hull structure is to allow it to bend and flex in high sea states. How to use such bending capability is key to achieving a desired reduction in peak loads, reducing material costs and enhancing survivability, and also in fatigue loads, reducing wave induced cyclic loads which is the primary cause of fatigue throughout a WEC device. In the Polyshell project we aim to flex the outer edge of the hull structure whenever the loads exceed a target level, changing the fundamental shape of the device between the operational and survival sea states, and hence its behaviour. The two images below show a hull before and after such a change in shape.

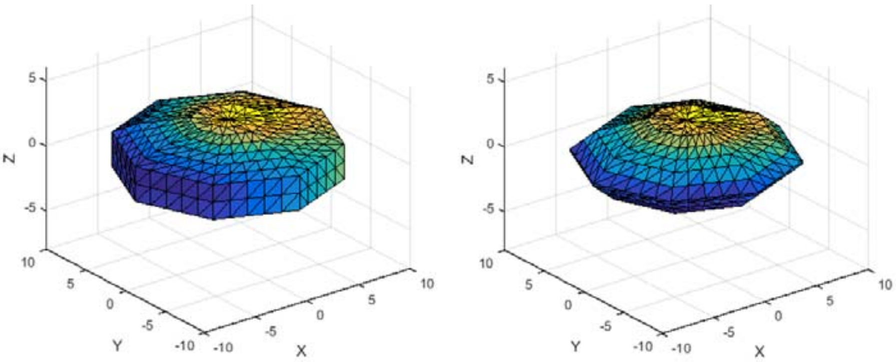


*Figure **Error! No text of specified style in document.**-1: Example of flexing hull structure between operational (left) and survival (right) sea states*

The deforming hull will round the sharper edges, reducing the drag coefficient leading to a noticeable reduction in the drag. The drag coefficient of an object is not constant but instead varies as a function of flow speed, flow direction, object position, object size, fluid density, and fluid viscosity. Speed, kinematic viscosity, and characteristic length scale of the object are incorporated into the Reynolds number, so the drag coefficient is a function of Reynolds number. Larger velocities, larger objects and lower viscosities all contribute to larger Reynolds numbers which contribute to larger drag coefficients.

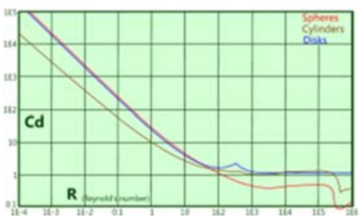


*Figure **Error! No text of specified style in document.**-2: Drag Coefficient dependence on Reynolds Number (ref: CalQlata)*

The drag coefficient in turn impacts on the loads experienced by the structure from the water flowing around it. Calculating the drag coefficient of a changing WEC structure over time is a numerically intensive task and may be better achieved through physical testing of WEC shapes. Initial estimates can be made however based on the shape of the structure and the ratio of its various widths, radii and lengths.

As a basic assumption, we can treat the WEC device as a series of curved or flat panels, facing different directions. The shape of these panels will play an important role in the drag coefficient in that direction. The drag coefficient of a cylindrical shape is affected by the length to diameter ratio, as well as the leading edge and trailing edge geometries. Numbers that have derived from experimental testing show a disk having a drag coefficient of 1.15, while a long cylinder (L>2D) has a much lower drag coefficient of ~0.8, which by rounding its edges becomes 0.2 (Figure **Error! No text of specified style in document.**-3). Having a flexible structure which changes the shape from a cylinder to a rounder cylinder in high sea states could therefore quarter the drag coefficient and shed three quarters of the original applied load.

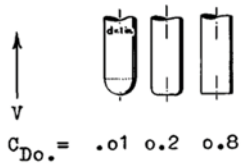


*Figure **Error! No text of specified style in document.**-3: Forebody drag coefficients for cylinders with rounded edges (ref: Hoerner, Fluid Dynamic Drag)*

Figure **Error! No text of specified style in document.**-4 shows the effect that rounding corners has on the drag coefficient of different shaped sections. There is sudden change in the drag coefficient as the corners are rounded. As an approximation, the drag coefficient halves from sharp corners to fully rounded corners.

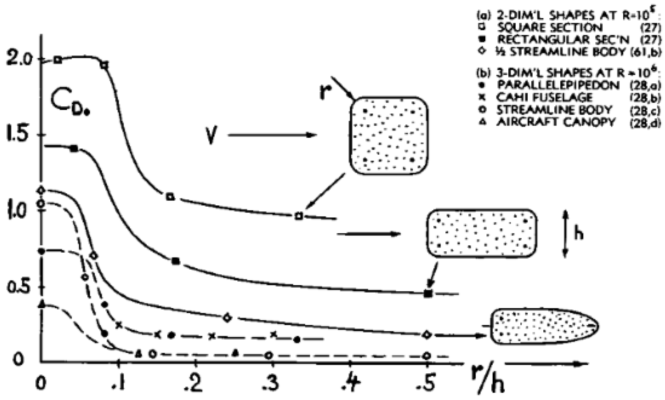


*Figure **Error! No text of specified style in document.**-4: Influence of rounding radius on the drag coefficient of blunt bodies (ref: Hoerner, Fluid Dynamic Drag)*

The effect reduces as the corners are rounded towards a half sphere. The higher the drag the greater the motion capture by the device and the greater the energy captured. Common WECs typically try to balance between good capture but reasonable load shedding in higher sea states and may be approximated by the cylinder with slightly rounded corners.

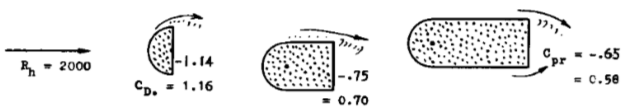


Figure 53. Drag and rear-side pressure of bluff sections (41,g) tested at b = 30 h, between end plates.

*Figure **Error! No text of specified style in document.**-5: The effect of trailing edge on the drag coefficient of an object (ref: Hoerner, Fluid Dynamic Drag)*

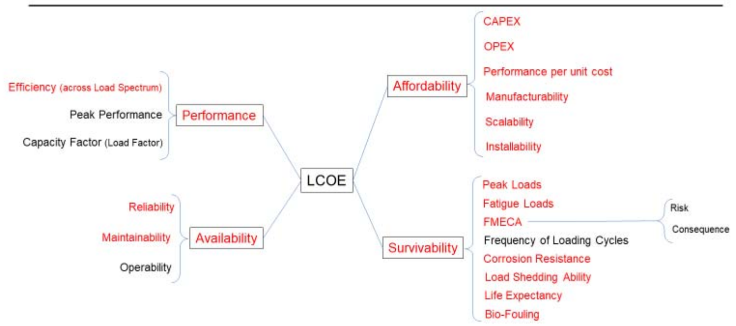
The trailing edge also has a major effect on the drag of an object. Figure **Error! No text of specified style in document.**-5 shows the drag coefficient halves as the trailing edge of the body is lengthened. The length of the body has an effect on the flow remaining attached to the body. If the flow remains attached, the turbulent effects and drag coefficient are kept low.

It is important to the behaviour of the device to tailor the flexibility behaviour so that the reduction in drag coefficient only occurs in those sea states where survivability is key. Reducing the drag coefficient in operational sea states would result in reduced energy capture.

It is also important to note that changing the shape impacts on more than just the drag, with buoyancy and moments of inertia also changing, and these impacts will also play an important role in the behaviour of the device.

The LCOE metric produced by Wave Energy Scotland was used as the basis for identifying the metrics that are significantly impacted by use of the Polyshell solution.

Metrics potentially impacted by results



The primary metrics expected to be impacted using our material are coloured in red in the image above. The Polyshell concept is expected to impact on most of the metrics used to calculate the LCOE, with a net positive impact.

The key expected advantages of this material / approach are;

- Passive survivability built into WEC structures (reduction in peak loads)
- Reduction in wave induced fatigue on WEC structure and ALL internal components
- Polymer outer hulls with corrosion and impact damage resistance
- Reduction in LCOE

3. *Scope of Work*

The following tables contain the outcomes expected from the Stage 1 project, according to the original WES guidance documents, along with a description of the work undertaken to deliver these outcomes.

Table – Scope of Work

Design	Work Undertaken
a) Detailed design of the WEC structures constructed from the selected project material	FEA analysis was used to model different design approaches, apply the environmental loads, determine how the shapes would change, and refine design parameters to achieve the desired response.

b) A thorough understanding of the properties of the material through analytical, numerical and/or practical means, and a demonstration of its application to withstand full-scale WEC loading conditions	Material data was reviewed to ensure compatibility of such data with existing and likely future standards. Some material testing was undertaken to refine the FEA models, before they were used to model material and design behaviour under full-scale WEC loading.
c) A comprehensive assessment of the limitations and opportunities introduced by the alternative material on device parameters (size, weight, buoyancy etc.)	Technical analysis was undertaken on the final proposed polymer structure design and compared against a base case steel structure to determine physical property changes. Engineering analysis was then undertaken to determine opportunities and limitations.
d) An understanding of how failure of other system elements could jeopardise structural survivability, and proposals for how this risk can be mitigated.	Engineering analysis was undertaken based on proposed designs to identify changes in potential risks (compared to a steel structure) from failure of other system elements. These changes and associated risks were then evaluated.

Loads	**Work Undertaken**
a) A thorough understanding of the non-linear loading environment to which the primary structure will be exposed.	A generic WEC structure was chosen and modelling across a range of sea states as per DNVGL standards to determine environmental loads
b) Detailed assessment of the impact of expected mechanical loads and force regimes on the material under assessment, including the ability to withstand mooring forces, hydrostatic forces, slam loading and the ability of the material to provide a load path through the structure	FEA analysis looked at a range of fixed and transient loads (as identified from the environmental modelling) on different shaped polymer components, as well as load pathways through the structure.
c) At initial concept engineering level, a structural design that is likely to be adequate to survive the extreme design wave conditions, and which minimises significant over-design routinely necessitated by the magnitude of the extreme loads relative to normal operating loads.	Design, engineering and manufacturability work, has developed an initial concept engineering level design, meeting the project requirements.

Performance	**Work Undertaken**
a) An assessment of the theoretical and practical limitations of the performance LCOE of the material, along with the likely performance capabilities of WEC concepts constructed from the proposed material.	Simulation has analysed the performance of flexed hull shapes. Detailed LCOE analysis has examined the impact of a flexing hull, and its cost, on the overall LCOE. Sensitivity analysis has also been undertaken.

a) Detailed assessment of the impact of material usage on the WES metrics (section 6), with particular attention given to Affordability and Survivability, and the subsequent impact on Availability and Performance	Assessment of the WES Metrics has been undertaken, supported by simulation, material analysis, concept design, and engineering activities.
b) Initial concept engineering level cost estimates for main structural elements (best estimate and uncertainty ranges) and cost/benefit analysis to estimate the potential impact that the material(s) or manufacturing process in the assessment could have on the LCOE	The feedback from the manufacturability assessment and the engineering design work was integrated with the LCOE analysis work, and changes were made to design, and manufacture based on the LCOE analysis.
c) Confidence, as part of a collective narrative involving reliability, performance, survivability and cost, that the material is likely to be able to facilitate longer term LCOE targets.	The feedback from material, design, performance, manufacture and engineering analysis were brought together to inform the LCOE modelling.

Risks	**Work Undertaken**
a) Through initial engineering studies, a well-defined technical/engineering risk register for material use on the reference structures, identifying positive features (opportunities) and difficulties/challenges to be overcome prior to technology adoption, together with recommendations for targeted component testing in a representative environment during Stage 2.	Engineering studies along with an FMECA analysis were undertaken and form the basis for the risk register. This was reviewed during the project with activity to refine, mitigate and address risks. The risk register was reviewed at the end of the Stage to identify activities required for Stage 2 risk reduction.
b) An appreciation of the technical and engineering challenges for interfacing with the wider system elements	Engineering and manufacturability work looked at the challenges in interfacing the polymer components with the wider system elements.

Manufacturing	**Work Undertaken**
a) Analysis of the methodology and costs for material manufacturability, quantifying how the proposed solution can take advantage of production methods, machinery and mass production facilities currently available, thereby avoiding the need for designing a bespoke methodology and process for a particular WEC.	Detailed manufacturability studies have been undertaken to determine how to fabricate the proposed structures, considering existing manufacturing processes and investment costs.
b) A high-level review into maintainability of the primary structure using the proposed material.	The material partners and marine engineers undertook a review into the maintainability of the material in the proposed design on a WEC structure

Testing	Work Undertaken
a) Further work recommendations, and development of a test plan for representative environmental testing during Stage 2	Recommendations for testing in Stage 2 were made as part of the final deliverables of the project, based on the risk register.

Overall	Work Undertaken
a) Confirmation that the material can make a significant impact in the sector	An initial 'voice of the customer' survey was undertaken, to determine initial interest as well as perceived risks and barriers.

4. Project Achievements

The key project achievements were;

- Validation that the Hytrel material is suitable and required data is available
- Design of a 3D structure that bends as required under the expected environmental loads, with suitable load pathways.
- Confirmation from numerical modelling that a flexed structure experiences lower loads (e.g. 30%)
- Identification of a suitable manufacturing method, along with costs, using existing equipment and facilities
- Validation that the LCOE is substantially lower with such a structure
- Evaluation of the engineering challenges and issues with using the material and approach in a WEC structure
- FMECA analysis of the material and approach with an evaluation of the risks.
- Confirmation of interest in the solution from WEC developers

Lessons learnt in the project;

- Modelling of performance and behaviour in simpler scenarios (i.e. 100 seconds of monochromatic waves as opposed to multiple 3 hour long full design load case sea states) during the fundamental design stages would have allowed much faster iterations and more options to be considered.

5. Applicability to WEC Device Types

The material / design concept is applicable to any marine structure, whether a WEC, platform, or vessel which could benefit from changing its shape based on applied loads. The specific way in which an individual device may change shape and the impact of those shape changes on behaviour is a decision for individual WEC developers. based on their design needs.

The project has shown that different types of loads (e.g. peak tension loads on lines and shock loads within the structure) can be managed and reduced through the technology. Potential partners are those who would like to change the behaviour of their device between the operational and extreme sea states, in order to shed load and increase survivability. This could be any device type and could involve changing overall shape or just the shape in one direction/dimension. The key requirement is that the shape change has to be directly linked to applied load or pressure on the surface of the WEC device which is to bend. The way that bends versus applied load can then be controlled.

6. Communications and Publicity Activity

There was a high level of innovation during the project with many of the innovations under review for patent protection. Because of this, the exact design approach used to deliver the shape change, the manufacturing approach, and the performance versus change information is currently kept confidential. This has limited ability to publicise details from the project, but the team have taken the opportunity wherever available to inform WEC developers of the project and its purpose.

Information about the project was publicised at two WES events during 2017, with brief presentations and through a poster. Private conversations have been had with a wide range of developers.

Once patents are filed, scientific papers will be prepared for submission to leading Wave Energy conferences.

7. Recommendations for Further Work

During Stage 1 a detailed risks register was developed and identified several areas where additional work is required to de-risk the technology.

A Stage 2 plan has been prepared focussed on the following risk reducing activities;

- Drag Coefficient Measurements: The simulation to date has used drag coefficient values from literature. More accurate measured values are needed for a range of standard WEC shapes. These need to measure drag in each direction (ideally in 6 DOF). This data can then be used to refine simulation models.
- Change shape evaluation: In Stage 1 the simulations were restricted to fixed shapes to allow for a wide range of options to be explored. In Stage 2 we will upgrade the simulations to focus on changing shapes based on applied loads.
- Localised shape change evaluation: As well as changing overall shape we also need to upgrade the model to allow for localised changes in shape. This needs to be matched to the fabrication and design, linking simulation behaviour to actual load transfer pathways within the design.
- Performance validation: Some experimental work is desirable to validate performance seen in simulations with real tank test data at a small scale. This would ideally be done in a flume tank.
- Manufacture risk reduction: Focussed manufacturing experiments need to be conducted to de-risk these processes, using existing large moulds to investigate process control, and using existing welding equipment to explore welding of dissimilar materials.
- Optimised shape changing response: Based on the simulation and testing, and working with one or more WEC developers, a Polyshell solution should be designed and refined for testing on a developer’s actual device shape, rather than a generic design.

8. Useful References and Additional Data

None