Composite End Closures for an Autonomous Underwater Vehicle

Valeria Antonelli, Maarten Labordus and Peter Nederveen

Center of Lightweight Structures TUD-TNO
Kluyverweg 1, 2629 HS Delft, The Netherlands
Corresponding Author's e-mail: V.Antonelli@lr.tudelft.nl

SUMMARY: This paper presents some of the results obtained within the framework of the EC funded MAST-III project: "Lightweight Composite Pressure Housings for Mid-Water and Benthic Applications". The primary objective of this project was to gain experience in the design and fabrication of deep-water pressure resistant, fiber reinforced plastic (FRP) structures. This was demonstrated by designing and producing the battery container made entirely of FRP. This battery container is part of an autonomous underwater vehicle with a 2000 meters operational depth capability. In an unmanned underwater vehicle, this battery pack container is the largest structure. The scope of this paper is to show the design procedures and production methods of the end closures and transition rings of the pressure vessel. Some experimental results and their verification will also be presented.

KEYWORDS: Drape, vacuum infusion, marine application, thick-walled composites

INTRODUCTION

The pressure vessel is the core of an AUV (Autonomous Underwater Vehicle), whose schematic layout is shown in Figure *10*, and is used for the containment of the battery pack, which supports the vehicle itself and the entire payload contained in it.

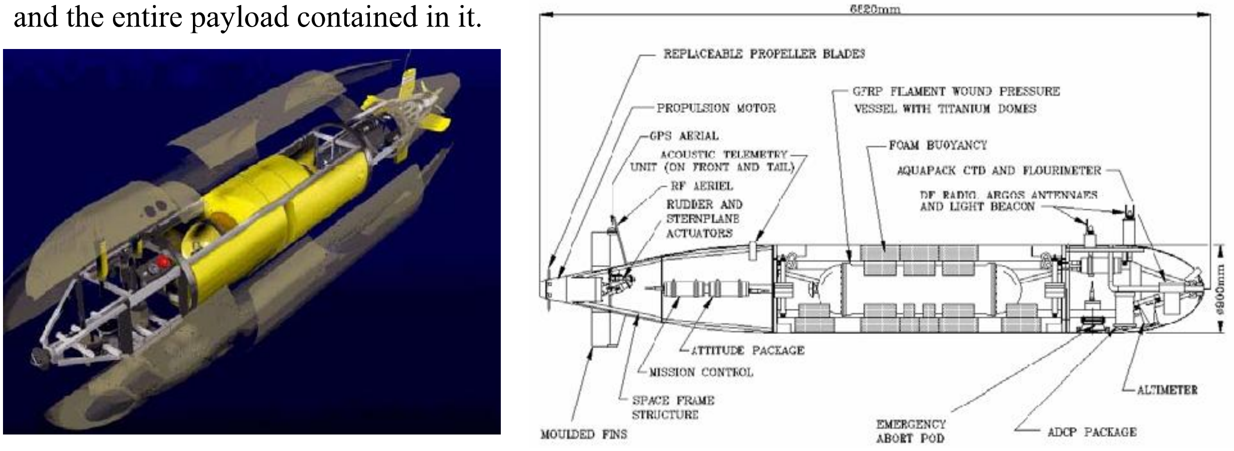

Figure 10: AUTOSUB - schematic layout.

The most important requirements that were taken into account for the design of the domes were:

- a maximum operating depth of 2000 m and ultimate design depth of 3000 m;
- an internal diameter of 450 mm;
- easiness of connection with cylinder;
- the minimisation of unusable space;
- lightness;
- producability (production technique being vacuum infusion).

DESIGN

During the preliminary design three possible shapes where evaluated: the classic hemispherical shape, a quasi-ellipsoidal which is normally used for pressure vessels subjected to internal pressure [2] and a spherical section. These three shapes where evaluated on basis of the given list of requirements with the help of the Finite Element Method and Drape, varying material (CFRP and GFRP) and thickness. The computer program Drape® [1] was used to predict the shear deformation (the so-called trellis effect) of the fabric layers during their draping onto the mold. As it was expected, the hemispherical shape is the one which needs the more material per blank, but also the one which causes the smallest locking angle. On the other hand the spherical section is the one which requires the least amount of material per blank and also the one that would be easily producible.

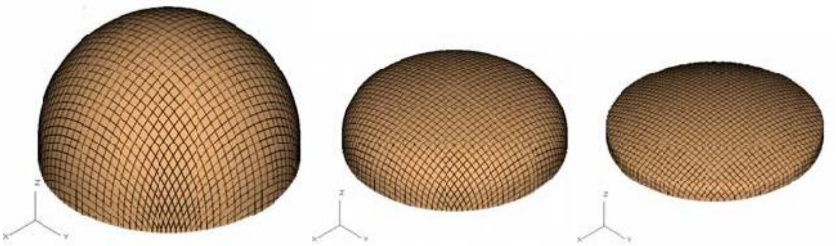

Figure 2: Results of fiber shearing in the three different shapes obtained by DRAPE.

Through the Finite Element Analysis, buckling behavior and strength of the three shapes were analysed. Since the buckling behavior of the end closures is depending on the behavior of the cylinder to which they are connected, also half of the filament wound cylinder was included in the model. Both linearised eigenvalue analysis and linear static analysis have been carried out. The design load consisted of a uniform external pressure of 30.0 MPa on the entire structure. The design load included a safety factor of 1.5 as prescribed by the requirements. The results for the different designs, obtained by the FE-Analysis and the DRAPE analysis were evaluated for producability, material cost and weight. The ellipsoidal shape was finally chosen, being the one that performed better in terms of production and weight. This design was further developed in order to make a product which could be extractable from the two molds. Figure 3 gives the basic dimensions of the dome. In figure 4, shows the transition rings to connect the domes to the filament wound cylinder.

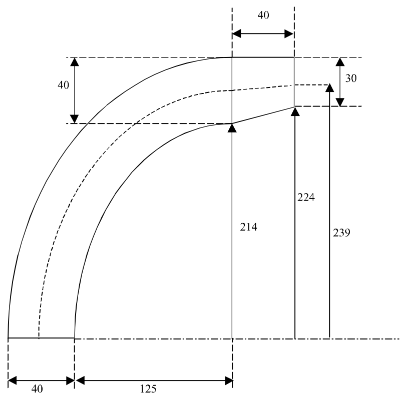

Figure 3: Dimension of the dome

This configuration, quite unusual and requiring a certain degree of precision during machining, was chosen for two main reasons: the V-seal configuration in fact provides protection of the sealing surfaces on the cylinder transition ring by recessing them into a V-section groove and facilitates the fitting of the transition rings because of the V-shape. The presence two O-rings, one per ring surface, allows a good sealing protection.

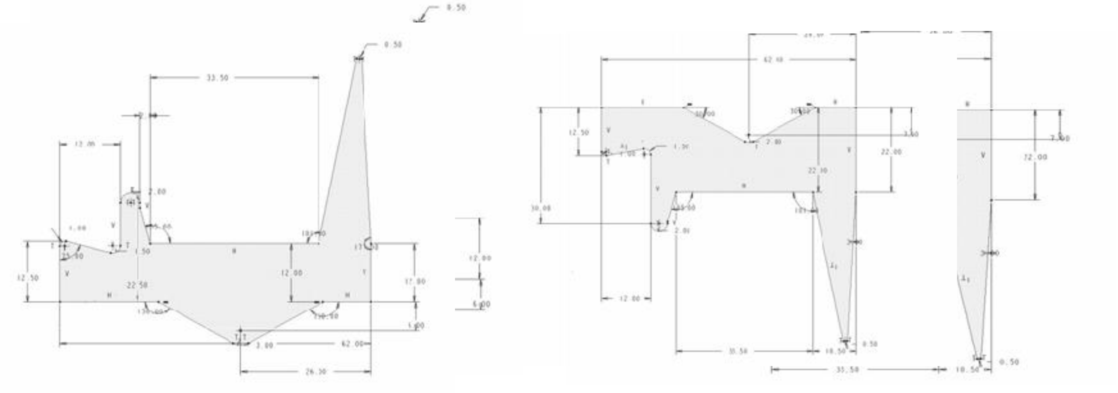

Figure 4: Titanium transition rings

PRODUCTION OF THE DOMES

Carbon domes will be produced with a vacuum infusion process. To ensure a good geometry definition, two stiff molds are used. However, only vacuum is used to force the resin into the mold. This makes the process more critical for leakages, but simplifies the mold-construction. Double O-rings are used for sealing of the mold. Carbon Injectex fabric is used, since this material has a high permeability and allows for a fast impregnation of the reinforcement. The material is also very drapeable to allow for preforming without wrinkles.

Figure5. The two mold halves

Size and shape of the blanks has been determined with the program DRAPE [3]. DRAPE is also used to calculate the thickness increase due to shearing. With this information, it can be determined which layers have to be cut to a smaller diameter to achieve the correct product thickness.

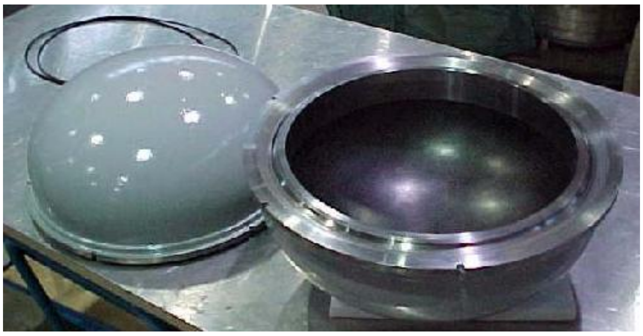

Figure 6: Finished product

When all the layers are placed in the mold, the mold is closed, sealed and the resin inlet and outlet hoses are applied.

The Epikote 860 epoxy resin system requires infusion at 60°C; therefore the complete mold system is heated. The resin components are also heated to infusion temperature and mixed. After mixing, the resin is degassed at a pressure level below infusion pressure. This is done to avoid outgassing of dissolved components in the resin during the infusion. The degassing method used is described in more detail in reference 4. When the mold is completely filled, the resin inlet is kept open to allow continuous resin feeding to compensate resin shrinkage. The prescribed cure cycle is started. After curing, the parts can be removed from the mold. Then the transition rings are bonded onto the domes and a protective coating is applied. The finished domes are shown in figure 6.

TESTING

Six domes were manufactured and they where all tested. Two sets were tested back-to back without a central cylinder. The first set was tested in a long-term test, deployed at 2000 meters depth, to verify its long-term behavior. The second set was destructively tested to verify the predicted strength. Prior to the test, a scan of the structure was made to verify the quality of the product. Strain gauges where placed in the domes to verify the strength of the material both inside and outside the structure, in order to be able to capture also eventual bending. The test was carried out at IFREMER, in the 1000 bar ACB tank. The domes showed a perfectly linear behavior up to failure, which happened at an external pressure of 542 bar. The theoretical results showed good accordance with the tests. The last test was the full-scale test of the demonstrator. In this test the domes were positioned at the ends of a carbon fiber cylinder produced by filament winding. Also in this second test both domes and cylinder where fully instrumented to verify the strength at failure and the buckling pressure of the cylinder. Failure occurred in this case at 398 bar, due to buckling of the cylinder. The domes remained intact up to failure of the cylinder. The numerical predictions were also in good accordance with the test results, demonstrating the possibility of designing thick walled composite structures by means of finite element analysis.

CONCLUSIONS

The present paper has shown feasibility of carbon fiber reinforced epoxy domes for deep-water application. The major difficulty was the ability to design a product which was not only fulfilling the structural requirement, but that could also be manufactured with the vacuum infusion technique.

ACKNOWLEDGEMENT

Financial support of this research was obtained by the EC within the framework of EU Contract No. MAS3–CT97–0091. The authors would like to thank all other partners of the projects, QinetiQ (formerly Defense Evaluation Research) (UK), Constructions Industrielles de la Mediterranee (CNIM, F), Southampton Oceanography Center (UK), Marinetech South Ltd. (UK) and National Technical University of Athens (GR).

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