Development of FDM 3D printed pressure vessels for subsea applications

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Background

Pressure vessels are containers designed to hold internal pressure or resist external pressure relative to their surroundings with examples seen in Zheng (2025). Traditionally, they are made from metals such as steel and titanium, as described by BEPeterson (2021).

Additive manufacturing is emerging in the pressure vessel field, especially in subsea applications. Formlabs (2024) highlights Stereolithography (SLA) for producing complex and cost-effective subsea robotic systems. SLA guarantees an airtight chamber but is far more complex then Fused Deposition Modeling (FDM) technology. However, there is limited research on the viability of FDM for pressure vessels. This study focuses on the possibility of using FDM 3D printed pressure vessels for subsea applications.

Methods and Materials

To properly test and evaluate the various pressure chambers, a few key pieces of equipment were necessary. The primary testing device was an air compressor connected to a modified portable paint sprayer, which acted as a subsea depth simulator. This system was used repeatedly to evaluate water ingress at varying pressures for forty-eight-hour durations. All of the test samples were printed on a Bambu Labs H2D 3D printer with specific print settings shown in Table 1.

The project was divided into two phases for simplicity. Phase one focused on preventing leaks through 3D printed solid vessels. Afterwards, phase two focused on designing or implementing a method to open and reseal the vessel while retaining the air-tight design.

Figure 1 (left): The initial design used a low-infill PLA tube with a PETG internal mounting plate. A 3 mm TPU gasket, M8 heat-set inserts, and bolts sealed the capsule, with a Schrader valve for pressurization. The vessel failed to seal, leaking faster than it could be filled, requiring a redesign.

Methods and Materials (continued)

Setting:	Value:
Nozzle Size	0.8 mm
Infill (%)	100%
Number of Walls	8
Top / Bottom Layers	10
Print Speed	250 mm/s
Layer Width	0.82 mm
Layer Height	0.25 mm
Bed Temperature	75 °C
Nozzle Temperature	270 °C
Chamber Temperature	45 °C

Table 1 (left): This table displays all the main print settings used to manufacture the testing samples after the Figure 1 test. There are numerous other print settings that were changed within the 3D slicer program, but those changes were specific to the identified 3D printer or model, so they are not included in this table.

Figure 2 (right): After determining print settings for the engineering plastics, a custom seal was developed using multi-material 3D printing. The design used fuzzy skin TPU with 45° faces and ten M3 bolts. This plan was designed to create a precise cork-style seal with fewer failure points, but proved unsuccessful.

Figure 3 (left): Identical models were created out of seven materials tested for strength, cost, and water ingress. From left to right, three of the test samples were Fiberon™ PET-GF15, PolyLite™ PLA, and Fiberon™ PA6-GF25. Materials with more composite fillers led to increased leakage.

Figure 4 (below): Three samples were 3D printed from SUNLU PLA+ 2.0 with different variations. The left sample acted as a fully sealed control without any openings, the middle sample used 5 mm O-rings (TPU or nitrile rubber), and the right sample used a pipe clamp for compression sealing. Over multiple trials no variation consistently remained sealed.

Results

All data collected was observational and influenced the next evolution of the pressure vessel design. A summary of the observational findings include: filler particles such as carbon fiber or fiber glass increase leakage via micro pores, nylon filaments become soft and degrade, filament brand and moisture content greatly impact sample quality, and *z* seams are often the failure point of a pressure vessel.

Figure 5 (right): The sample and gauge show the latest design in the development of a 3D printed pressure vessel. This model follows all the previously established conditions with the addition of two brass inserts. They allow for high tolerance and durable connections between fittings. This model was able to withstand approximately 100 PSI before leaking via the *z* seam.

Conclusion

Extensive testing demonstrated that 3D printed pressure vessels are possible, but success depends on material selection, print settings, and design. Due to the porous nature of FDM prints, achieving a consistent seal was the primary challenge. SLA prints avoid this issue, but they require greater infrastructure and technical knowledge. Testing showed that sealing improved with the addition of high tolerance components like heat set inserts or O-rings. Although FDM prints are prone to fail in high-temperature environments or with wall thicknesses under 10 mm, they may be a practical option for subsea pressure vessels when paired with traditionally manufactured components. Additionally, additively manufactured pressure vessels offer greater geometric freedom then traditional manufacturing techniques.

References

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