Principal author:
François Cazenave, Monterey Bay Aquarium Research Institute

Title:
A new approach to designing, and testing a high-quality deep-sea camera dome port

Abstract:
The Monterey Bay Aquarium Research Institute (MBARI) conducts monthly video surveys of the upper 1000m of the water column in Monterey Bay using an autonomous underwater vehicle (ref. 1). A camera system was developed especially for this application, in order to obtain the highest image quality. One of the key components of this system is the camera housing's optical system, composed of a glass port and a group of three corrective lenses, based on a patented design. The glass port is exceptionally large and has the unusual shape of a partial hemisphere (outside diameter, 250mm, convex radius 162.4mm), dictated by stringent optical requirements. Unfortunately, this shape is far from ideal for resisting hydrostatic pressure and the mechanical stresses in the dome are difficult to predict. After a first iteration of the dome failed during pressure testing at 190 bar, it became obvious that a more careful design method was necessary. MBARI hired several consultants to help with this process, including a fractographer, a material scientist, a structural engineer, and a chemical strengthening expert. In this paper we describe our method to design, build and test this glass port.

A fractographer analyzed the glass fragment of the failed dome to help determine the cause of the failure. It was found that tensile stress at the base of the dome and poor edge finish were the cause.
Using finite element analysis, a new mounting system was developed. A titanium ring was bonded to the base to reduce tensile stress development.
In order to predict the strength and the reliability of the dome, the glass parameters had to be measured (they were not available in the literature). Weibull parameters, fracture toughness and slow crack growth parameters of N-BK7 and H-K9L glasses were measured using ring-on-ring and 4-point bend testing (H-K9L is manufactured in China and is marketed as an equivalent to N-BK7). It was found that H-K9L was nearly as strong as N-BK7 but was much cheaper and readily available, so it was eventually chosen for our dome.
Again, using FEA and the Ceramics Analysis and Reliability Evaluation of Structures (CARES) program, the dome reliability was predicted (for a given pressure and a given duration, the probability of failure was calculated). A proof test protocol was established.
To further improve the reliability, the glass was chemically strengthened to an optimized surface compression and case-depth. Strengthening was measured on witness specimens subjected to biaxial stresses via ring-on-ring testing. The measurements showed a large increase in strength and reliability compared to unstrengthened specimens.
Three domes were fabricated, chemically strengthened and successfully proof tested at pressures up to 345 bar. One of the domes has been in service on the AUV since 2016 and has yielded high quality images.
This paper shows that, with this systematic approach, deep-water camera domes need not be limited to the usual small diameter hemisphere; the door is open to new shapes having better optical quality with predictable reliability.

Reference 1:
Kim R. Reisenbichler, et al, "Automating MBARI's midwater time-series video surveys: the transition from ROV to AUV", in Oceans 2016 MTS/IEEE.