Engineering Notes

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Sympathetic Collapse in Water of Glass Spheres with Filler Material

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THE proposed use of thin-walled glass spheres as buoyancy material in deep submergence vehicles has stimulated new interest in studies of the flowfield in the vicinity of a collapsing sphere. The transient pressure field created by the collapse of a glass sphere often is followed by the sympathetic or induced collapse of nearby spheres, a phenomenon made predictable by the theoretical work of Hickling and Plesset[1] and Lilliston,[2] and verified by the experimental work of Freed.[3]

When a sphere collapses, there is first an inward movement of the liquid accompanied by an outward traveling expansion wave, and then a rebound which generates a compressive wave that travels outward from the center of collapse. Theoretical studies[1,2] have shown that the ratio of maximum overpressure to ambient liquid pressure at the time of collapse, P_{max}/P_c, can be reduced by increasing values of initial gas pressure within the sphere, p_0, and the gas index γ. But it is doubtful that this will effectively prevent sympathetic collapse. Alternatively, it may be possible to reduce the magnitude of the transient pressure field by filling the glass spheres with a crushable substance to control the collapse rate.

The present experiment was conducted to investigate the effects of such filler materials on the pressure field. In single-sphere tests, test spheres of soda-lime glass were prepared from Christmas-tree ornaments with outside diameters of 1.75 ± 0.02 in. and wall thicknesses of 0.010 ± 0.003 in. Polyurethane foam of various densities, made by the CPR Division of the Upjohn Company, was used as filler material. Both test sphere and pressure transducers were mounted on a test assembly 16 in. high, attached to the receiver cap of a high-pressure tank. This tank had a diameter of 7.50 in. and was 20 in. deep; it was rated up to 5000 psi. The signal output of the pressure transducers yielded scope traces of pressure history, recorded on Polaroid film. Detailed description of the experimental apparatus and test procedure is given in Ref. 4.

The results show that, at collapsing pressures of 600 to 900 psig (1400–2100 ft underwater), the use of CPR 334-6 foam (nominal density, 6 lb/ft^3) can eliminate overpressure completely and reduce the intensity of the unloading wave to a certain extent. But the results also indicate that the range of collapsing pressures was not noticeably affected by the filler material. Hence, it would be difficult to interpret the results if two spheres 1.75 in. in diameter were used in two-sphere tests, since the second one to collapse would already have been near the fracture point.

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In two-sphere tests, the second sphere was prepared the same way as the first (from the "grape mold" of lead glass), with an outside diameter of 1.00 ± 0.06 in. and a wall thickness of 0.010 ± 0.003 in. Such a sphere has higher thickness-to-radius ratio and does not collapse, except in a range of pressure much higher than that in which the 1.75-in. sphere of the single-sphere test collapses.

The results of the two-sphere tests show that none of the five hollow 1-in. spheres survived when the hollow 1.75-in. spheres collapsed at surface-to-surface distances up to 6.125 in. On the other hand, the hollow 1-in. spheres survived in 10 out of 13 collapses of 1.75-in. spheres filled with CPR 334-6 foam. This was true even when the 1-in. spheres were placed only 0.5 in. from the collapsing 1.75-in. sphere. The total density of a filled 1.75-in. sphere was about 14.2 ± 0.4 lb/ft^3.

The 1-in. spheres failed in the two-sphere tests at surface-to-surface distances of 2.625, 2.75, and 0.5 in. In the first two cases, the 1-in. spheres failed in spite of the absence of any overpressures, although examination of the oscilloscope traces did reveal that unloading waves had higher intensities. In early tests with two 1.75-in. spheres filled with CPR 334-6 foam, the second sphere failed after the first had collapsed, but it retained its shape with only crack lines on its glass surface, in contrast to the result with the hollow 1.75-in. spheres, where high pressure caused the collapse of the spheres. Taken with the evidence of Ref. 4, this suggests that, in the present cases, sympathetic collapse was due entirely to the unloading wave rather than to maximum overpressure.

The mechanism that caused the phenomena observed in the underwater collapse of a glass sphere filled with foam is not yet completely understood. For a given hollow sphere, the pressure of the expansion wave on a given point outside the sphere is a function of the gas index γ, inside gas pressure p_0, and ambient liquid pressure p_c. The range of the collapsing pressure (p_c) was not changed significantly in the presence of foam. However, the foam inside the sphere may have a higher p_0 and behave differently in the compression process than does a perfect gas with a gas index γ. This behavior may yield expansion waves with intensities so low that nearby spheres do not fail in tension.

Although additional experimental work and theoretical evaluation of unloading-wave and shock-wave attenuation by the crushable substance in an underwater glass sphere are needed, present test results indicate that such filled spheres are promising candidates as low-density buoyancy material for deep submergence vehicles.

References

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