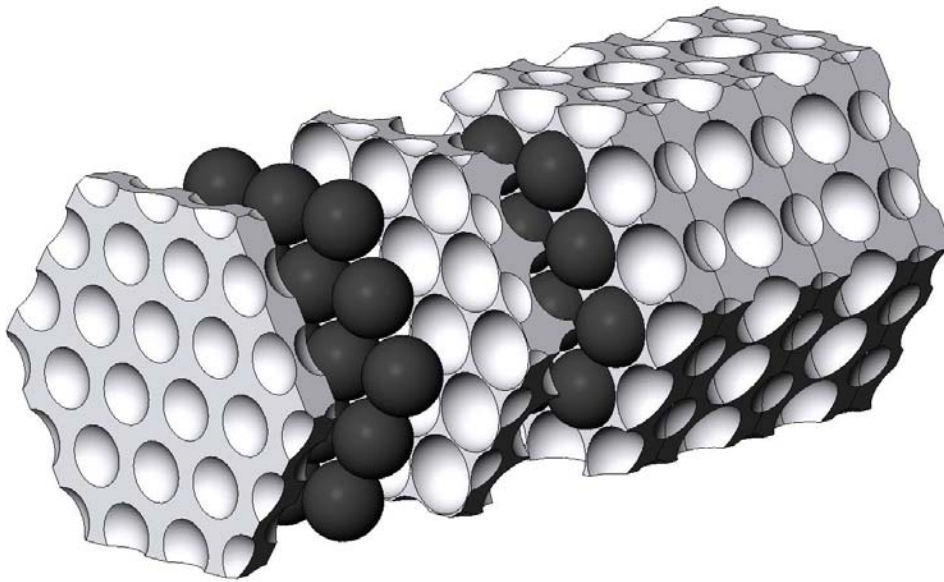


1.1.5.5 Flotation Material Comparison



Requirement to Innovate

While the glass personnel sphere may have garnered the most outward excitement, DOER research in flotation materials, particularly the manufacturability, testing and use of Alumina, Silicon Carbide (SiC) or Boron Carbide ceramic spherical shells, is also quite innovative. This work will benefit both the Deepsearch vessel as well as the Sub Sea community since nearly all subsea equipment needs at least some flotation. Deepsearch will need a substantial amount of floatation material – enough to add an estimated 4000 pounds of buoyancy. Deepsearch's driven dive profile requires a large mass of battery and motor components. A large amount of buoyancy is required to offset the propulsion mass of the vehicle and allow it to remain neutral. To add buoyancy, an incompressible, pressure tolerant material less dense than water is attached to the vehicle. The net amount of buoyancy added is the difference between the weight of water displaced and the material for a given volume. The dry or gross vehicle weight (GVW) of a submersible is always increased by adding flotation. Material with a density close to half that of water or higher can be considered inefficient flotation material and will add a significant amount of GVW to a vehicle. Typically buoyant material used in subsea craft is made from microspheres encapsulated in epoxy that is pressure cured. While the resulting product is called syntactic foam, for FOD applications, it is actually more like concrete with a density of 42 lbs/cubic foot. It comes in cubes and must be glued together and machined to shape. The material is hard on machine tools and cutters which makes the process very labor intensive and expensive. Syntactic foam is not overly efficient at .65 the density of water. To get the 4000 lbs of needed flotation with syntactic, approximately 7600 lbs of syntactic would have to be added to the craft or about 17% of the total gross vehicle weight design goal of 44,000 lbs. For these reasons DOER has engaged in significant amounts of research on new types of flotation material.

Meeting the overall design goal for GVW is important, but incorporating the flotation presents a number of other design challenges including how it will affect the balance and stability of the vehicle. Therefore, placement of the flotation material is important too. Less efficient buoyancy will consume more of the allotted design weight, but will also consume much of the enclosed volume and will consequently leave less room for other components and impact visibility from the personnel sphere. Developing efficient flotation will be a key to Deepsearch's success.

Ceramic Spheres

DOER started by researching historical use of flotation materials and picked up on a concept of using Alumina ceramic (Al_2O_3) spherical shells (referred to in this paper as spheres) in a paper by Dr. Stachiw. Stachiw had undertaken the manufacture and testing of some alumina spheres to high pressures and that data gave us a good starting point. Several issues with the use of the spheres remained. What was their service life? How could they be tested and inspected? Could there be sympathetic failures, where one failing ball would create a shock wave that would trigger the neighboring balls to also fail? What materials and method would be used to pack and hold the spheres captive on the vehicle?

While Alumina ceramics is a possible solution, particularly as their manufacture is relatively inexpensive – firing is done in an open air furnace, Silicon Carbide (SiC), with its higher strength to weight ratio, shows some great advantages. This advantage will be required most in the higher safety margins needed to man rate the floatation system. SiC, however, requires firing in an inert gas environment, so a strong look was needed to weight its higher cost to its benefits.

DOER engaged Custom Tech Ceramics (CTC) to research manufacturability of different diameter spheres and at different wall thicknesses and provide us with both technical information as well as approximate costing. Working with this data we were able to compare costs and weights of different sized balls, with two different spacing amounts against the traditional syntactic foam. These costs include capital equipment improvements CTC would have to undertake for the production volumes this project requires. Other ceramics manufactures have been identified with Alumina and SiC manufacturing capabilities, but their ability to create reliable spheres is not proven, as it is in CTC's case. Pushing further into the sphere research, DOER has outlined a rigorous test program and test facility requirements to help qualify different designs in ceramics which we have slated for phase 2 of the Deepsearch project. DOER has hypothesized that designing the wall thickness of the spheres to withstand 2x F.O.D. may mitigate sympathetic failure modes. This is where SiC shows its value. Other materials, such as Boron Carbide ceramics offers advantages even over SiC. To the best of our knowledge Boron Carbide ceramics have not been formed into spheres for subsea work.

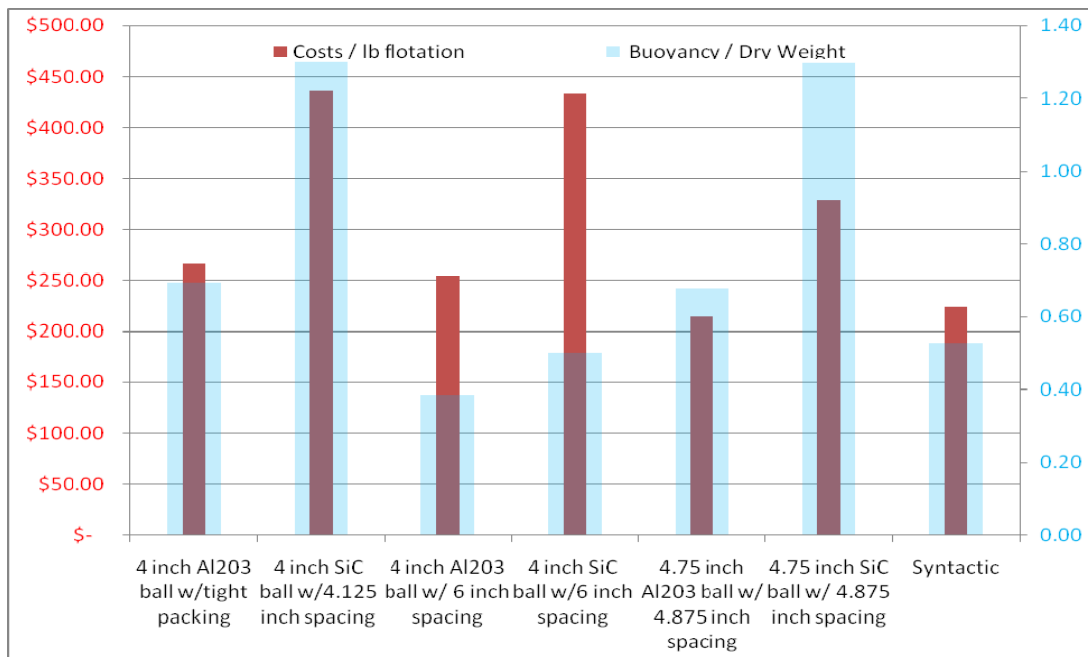
DOER has visited with the WHOI team partners (SPAWAR) that developed Al₂O₃ spheres for flotation in the HROV Nereus. They have had success in initial dives, but the vehicle has not gone to F.O.D. yet. SPAWAR has also had great success with SiC spheres, but specific information is still forthcoming. SPAWAR also serves as a positive reference for the work previously done by CTC in SiC spheres and the opposite can be said for their experience with DSPL alumina spheres.

Results

The following set of charts presents flotation material choice data of selected candidates. Two ceramic materials, Alumina ceramic spheres (Al_2O_3) and Silicon Carbide ceramic spheres (SiC) are compared with high grade F.O.D. capable syntactic foam. DOER’s primary design candidate currently calls for 4000 pounds of added buoyancy needed to reach neutral vessel buoyancy. This 4000 pound value is assumed for all charts. The costing is based on that assumption as well as the volume discount available when buying material for two subs at once (amortized capital equipment for CTC production is included). All data for the spheres assumes they will be held captive in machined polypropylene sheets and the corresponding costs and weights are included. Syntactic foam is purchased in 1/2 cubic foot bricks and must be joined and machined, and those costs and wastages are also included in the cost data.

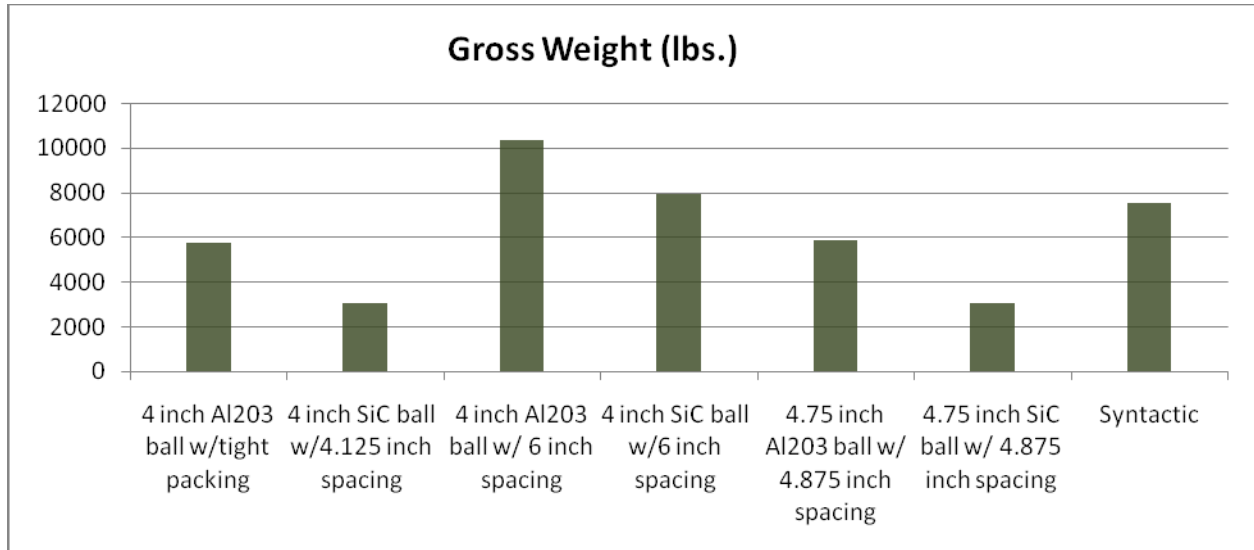
Overlay chart #1 shows both costs per pound of added flotation by material choice (in red) and the ratio of added buoyancy per unit of flotation material (in blue). Here it can be seen that the SiC spheres are efficient at adding buoyancy, particularly when used in the close spacing configuration. A surprise was that the 4.75 inch diameter Al_2O_3 spheres in a tight spacing configuration were the least expensive per pound of buoyancy added – even cheaper than traditional syntactic.

Chart #1



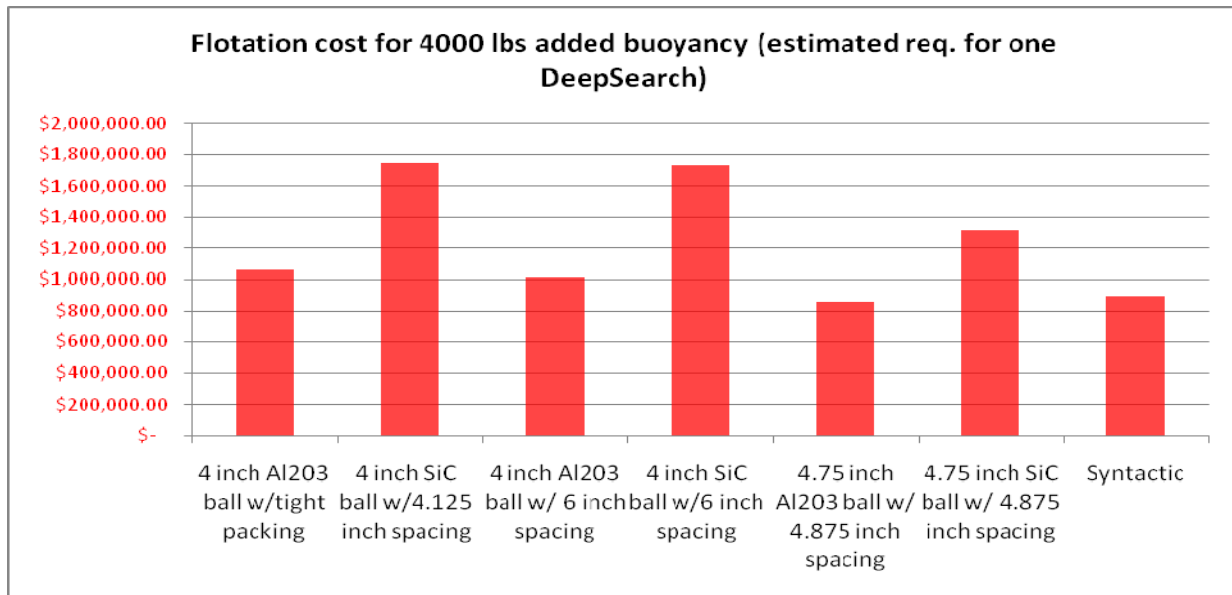
Estimated dry weight for each of the flotation configurations being considered are shown in Chart #2. Here one significant advantage of SiC spheres is visible. The use of SiC spheres with tight packing will save thousands of pounds in GVW and perhaps allow DOER engineers to include other equipment, and better tune the balance of the craft. Boron Carbide ceramic spheres could shave even more weight off but were not evaluated in time for this report.

Chart #2: Weight of flotation by material and packing configuration



The following chart presents estimated costs for each type of flotation being considered. The data includes machining costs, and packing material costs where applicable. Again the surprise is that the larger Alumina spheres in tight spacing could be cheaper than the traditional syntactic foam!

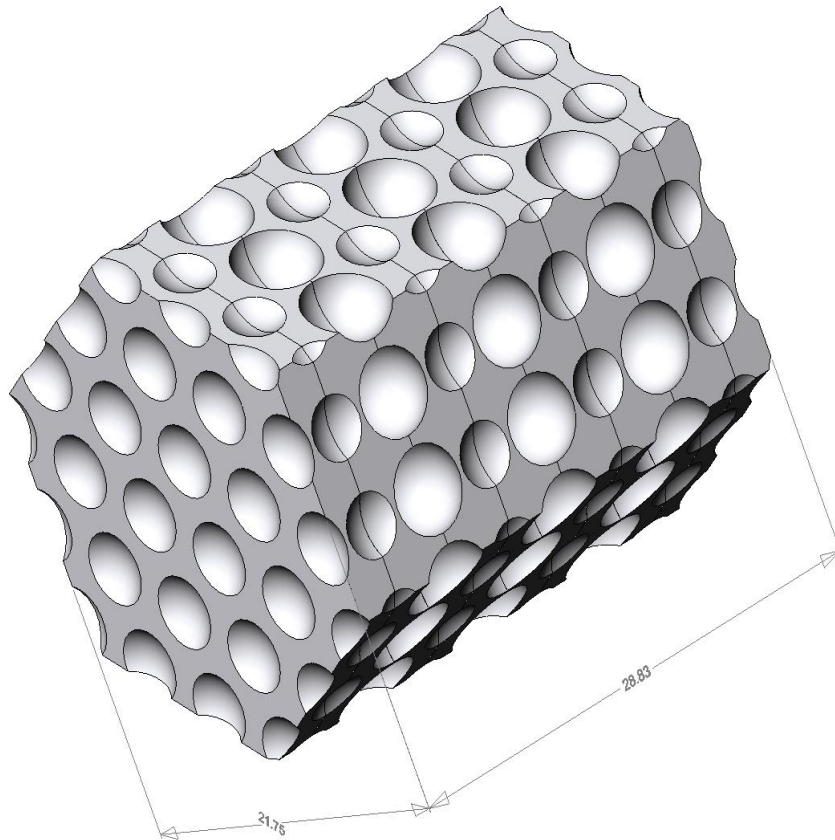
Chart #3: Estimated costs for flotation by material and packing format



Mounting and Other Considerations

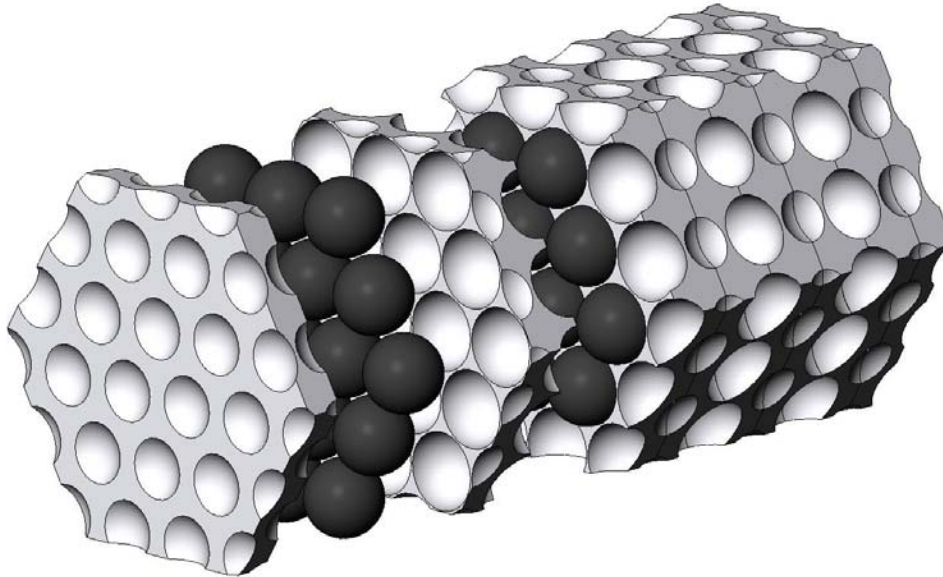
The prior analysis is based on a mostly ideal packaging. In reality, considerations have to be made for mounting and packaging. In the case of ceramic spheres, protection from handling damage is required for man rating. A system will most likely be developed at a unit level that allows for testing, rating, serializing, and shipping that prevents handling in the field of individual balls. A dropped ball can sustain catastrophic damage without any visual indicators. It is envisioned that such a system would consist of units capable of a specific buoyancy that have a more mounting friendly shape (versus truly space efficient polyhedron). Below is shown a hexagonal prism form factor:

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This unit would consist of 112 4.75" ceramic balls nested in polypropylene blocks. In this case, FoS 2x SiC balls. Net buoyancy would be 170 lbs for a unit weight of 202lbs. This brings down the buoyancy to weight ratio to .84 from an ideal of 1.30 but still performs better than conventional syntactic at .53. Further, these simple shapes can be encased in additional polypropylene envelopes to further mitigate failure shock waves if required.

Below is an exploded view of the sphere packaging.



Increasing volumetric efficiency by Apollonian packaging (nesting of smaller balls in voids) quickly creates difficulties in ball handling and placement. No single split planes will exist. Point contact between balls is highly undesirable as these points create wear and stress points that ceramics are very sensitive to and will lead to failures. DOER and CTC investigated a two size nesting arrangement. This created a 5% increase in buoyancy efficiency but no good mount arrangement was found.

Casting of balls in a syntactic matrix has been shown to be failure prone (SPAWAR) due to non-uniform stress reaching each ball wall and initiating premature buckling failures.

One major detractor from conventional syntactic not mentioned previously is water absorption. Up to 10% absorption (or loss of buoyancy) can be expected over time from conventional syntactic. As can be imagined, loss of buoyancy at depth in a submersible system is best described as unacceptable. As a result, an additional overhead of material must be carried or and the capability to trim against this loss must also exist. In comparison, ceramic spheres do not absorb any water. In fact, their stiffness (lack of volumetric compression) results in a gain in buoyancy at extreme depths due to the increased salinity of deep water. The polypropylene absorbs minimal water (0.010% at saturation). In the above example, this would equate to much less than 1/10 of a pound of water.

Conclusions

The only next step required for use of ceramic spheres for manned submersibles to full ocean depth, or other benthic depths, is testing and qualification – preferably under a classification agency. With the material capabilities of ceramic, the time has come. The technology, manufacturing, need, cost point, and quality are all favorable and only in need of a use.