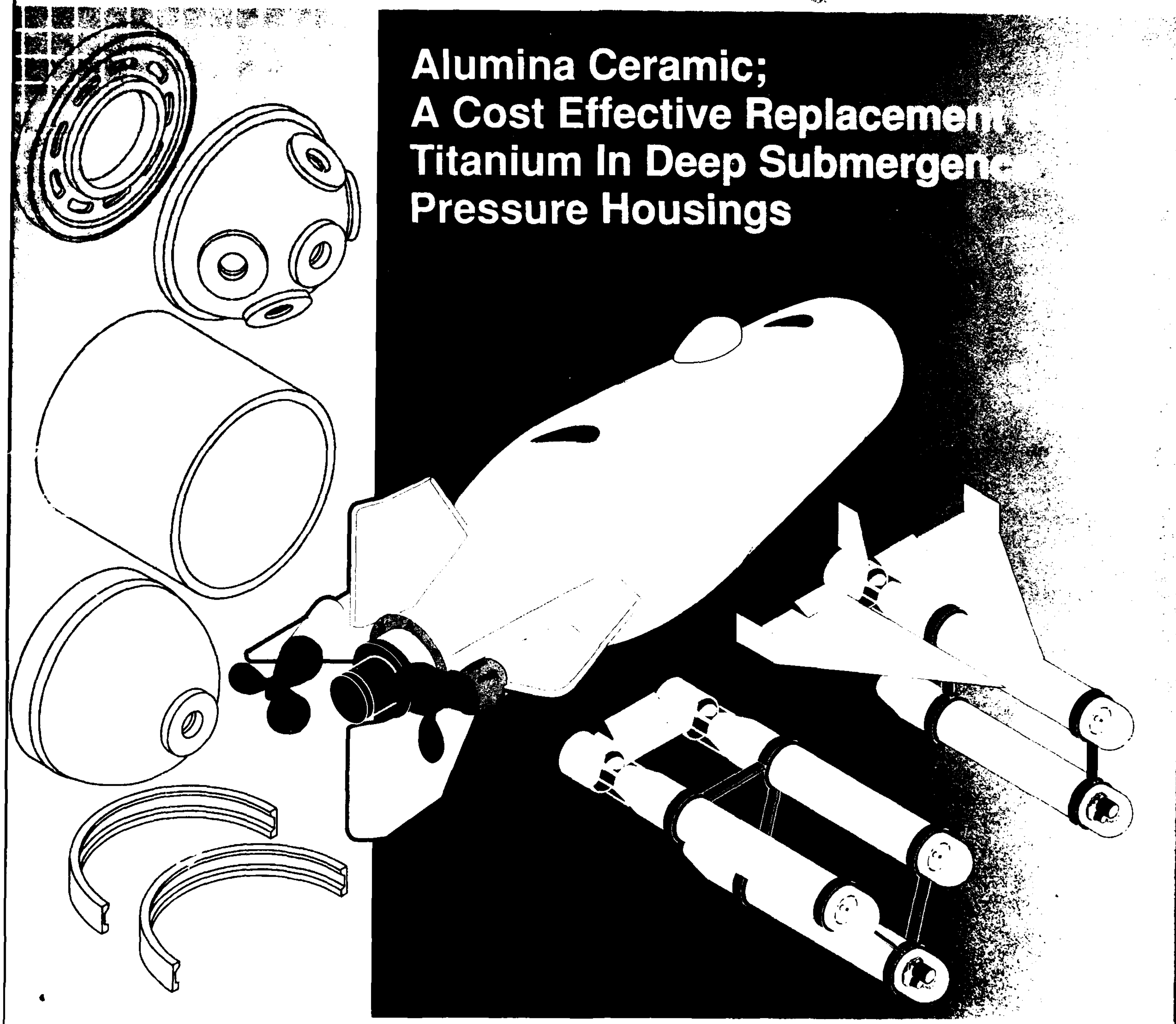
Alumina Ceramic; A Cost Effective Replacemen[t] Titanium In Deep Submergen[ce] Pressure Housings



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ALUMINA CERAMIC; A COST EFFECTIVE REPLACEMENT FOR TITANIUM IN DEEP SUBMERGENCE PRESSURE HOUSINGS

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ABSTRACT

Alumina ceramic's high compressive strength and modulus of elasticity, coupled with its low density make it feasible to routinely fabricate cylindrical pressure housings with 0.5 weight/displacement ratios for 20,000 ft (6100 m) service. This compares very favorably to optimally designed titanium cylindrical housings with 0.86 weight/displacement ratio. At these weight/displacement ratios, the payload capacity of alumina ceramic cylindrical housings is 3.5 times larger than of titanium housing of identical size with 9000 psi (62 MPa) design pressure.

To date, cylindrical housings with external diameters up to 25 in (63.5 cm) have been fabricated and successfully proof tested to 10,000 psi (69 MPa) prior to pressure cycling them to 9000 psi (62 MPa). Their cyclic fatigue life has been found to exceed 500 cycles at that pressure.

The typical alumina ceramic pressure housing for 9000 psi (62 MPa) design pressure consists of one or several monocoque ceramic cylinders with $L/D_o = 1.5$ and $t/D_o = 0.034$, supported by titanium joint stiffeners, and enclosed at the ends by ceramic hemispherical bulkheads with one, or more penetrations. The individual cylinders and hemispherical bulkheads are joined together by titanium split wedge bands clamped over titanium end caps bonded with epoxy adhesive to the edges of ceramic cylinders and hemispheres.

The fabrication process for alumina ceramic cylinders and hemispheres, consisting of isostatic pressing, followed by sintering in a furnace, does not appear to have intrinsic size limitations. Cylinders and hemispheres with 32 in (81.3 cm) diameter are being fabricated on a production basis, and cylinders with 50 in (127 cm) diameter have already been cast on an experimental basis.

INTRODUCTION

The Navy, among other organizations and institutions, is very interested in acquiring the most operationally effective and cost efficient vehicles for deep submergence operations. Three factors determine if such vehicles meet mission standards: payload, operational range, and speed. Each of these factors is a direct function of the system's buoyancy. Clearly, buoyancy is the critical issue. Optimally, buoyancy is provided by a well-designed pressure hull, and the use of premium material in the construction of the hull to obtain a pressure hull with low weight-to-displacement ratio. The reason for seeking the low weight-to-displacement ratio is to maximize payload, while minimizing hydrodynamic drag, thus, achieving optimum range and speed.

A weight-to-displacement ratio <u>less</u> then, or equal to 0.5 has been found by operational experience to be desirable for the pressure housing assembly, so it may provide the vehicle with adequate buoyancy for its propulsion, guidance, and work subsystems. Ceramics not only possess the required structural properties for construction of external pressure housing and a ≤ 0.5 weight-to-displacement ratio for service to 20,000 feet, but are also impermeable, corrosion resistant, and good conductors of heat. Their sole shortcoming is low fracture toughness and tensile strength, which, in the past, has caused some pressure housings to fail unexpectedly in service. For comparison, the weight to displacement ratios of titanium housings with the same design depth is ≥0.85 because of titanium's lower compressive strength, and higher density. Thus the ceramic housings can carry payloads that are at least three times heavier than the payloads carried by the titanium housings of the same size.

To arrive at an operationally usable external pressure housing of ceramic material, several fabrication and design problems need to be solved that have, in the past, worked against the acceptance of such housings by the ocean engineering community. These problems were economical fabrication of large ceramic cylinders, reliable mechanical joining of several ceramic cylinders into a cylindrical pressure housing of desired length, elimination of stress risers on the ceramic bearing surfaces between individual housing assembly components, secure mounting of payload components inside the ceramic housing, and protection against impact.

NCCOSC, and its predecessor the Naval Ocean Systems Center (NOSC), set out to demonstrate that the problems can be addressed and solved to a degree that will make the ceramic housings acceptable for practical applications. These solutions were instrumental in the formation of engineering opinion that the Navy should seriously consider pressure housings fabricated from 94 or 96 percent alumina ceramics for any of its future unmanned deep submergence systems.

PAST EXPERIENCES WITH GLASS AND CERAMIC PRESSURE HOUSINGS

The potential for using glass and ceramic materials for deep submergence vehicles has been discussed at technical symposia for more than 30 years. This historical overview summarizes the progress made in finding application for glass and ceramics in the deep submergence structures field, and serves as a background for the NCCOSC research program in this field.

From the very beginning, glass and ceramic housings showed variety in two ways; first, in the shape of the housing, and second, in the material chosen for the specific application. The first deep submergence use of glass and ceramics was in the construction of spherical monocoque housings for buoys. Up to the present time, deep submergence buoys have been fabricated commercially only in alumina ceramic, borosilicate glass and chemically strengthened glass, i.e. HERCUGLASS. Buoys have been fabricated from two fused, or precision mated glass hemispheres in sizes from 20 to 44 inches in diameter, and from ceramics in diameters from 4 to 16 inches. Electrical bulkhead penetrators have been incorporated successfully into some of the glass buoys that serve as oceanographic instrumentation housings.

Constructed of two hemispheres held together mechanically, by vacuum, or with the help of adhesives, deep submergence housings have served the oceanographic community well. Both types of housing have an operational depth of 20,000 feet, while their implosion depths vary from 25,000 to 40,000 feet, depending on the housing's size, type of joint, gasket material in the joint, and deviation from nominal diameter, wall thickness and sphericity.

The long established tradition of using cylindrical shapes in torpedo hulls, BPVs, AUVs, and ROVs is grounded in the well-known property of cylindrical hulls to cause less hydrodynamic drag than spherical hulls of equal displacement. In addition, the payload capacity can be varied according to payload requirements by varying the total number of cylindrical shell sections in the hull. As far as fabrication is concerned, it is technically within the present state of the fabrication art to build such cylindrical housing at an economical price.

There are, however, some problems associated with the use of cylindrical shell sections. The two major problems are the need to incorporate ring stiffeners into the cylindrical housings to make them elastically stable for abyssal depths, and the need to provide the shell sections in the hull with mechanically reliable and structurally strong metallic joints that do not introduce tensile stresses in the ceramic components under hydrostatic loading, causing them to fail prematurely.

The first approach to stiffening of cylindrical housings was to incorporate internal ring stiffeners as an integral part of the cylindrical shell sections. Pioneering work in this area was performed in 1963 by Dr. Stachiw at the Pennsylvania State University (References 1, 2). Model scale cylinders were designed and fabricated from borosilicate glass, alumina ceramic, and glass ceramic PYROCERAM. The structural performance of the integrally stiffened cylinders was acceptable, but the cost of fabrication made them too expensive, as extensive grinding was required to generate the integral ring stiffeners. A more cost effective approach had to be pursued to make cylindrical housings of ceramic, or glass for deep submergence service cost competitive with the cheaper, but 72 percent heavier rib stiffened titanium housings that must be augmented with syntactic foam for additional buoyancy.

Similarly, the first approach to joining of glass or ceramic cylinders to each other, or hemispherical bulkheads pioneered by Dr. Stachiw and others (References 3, 4) was also not successful. It relied on ceramic, or glass bearing surfaces resting directly on each other, or on metallic joint surfaces. In some cases, cork or rubber gaskets were inserted between the mating bearing surfaces to eliminate point, or line loading of ceramic or glass surfaces.

In either case, results were less than satisfactory. The brittle housings cracked and often imploded at <80 percent of material's compressive strength under a single pressurization, or at <50 percent after 10 to 20 pressurizations. Unless a more reliable way was found to join glass, or ceramic housing components to each other, or metallic bulkheads, the application of such housings to oceanographic or military diving systems would be limited indeed.

Obviously, if titanium housings were ever to be replaced by ceramic, or glass housings an innovative approach had to be found that successfully tackled all of the above problems. Such an approach was conceived in 1989 at NOSC, and subsequently fully developed at NCCOSC.

NOSC/NCCOSC CERAMIC HOUSING PROGRAM

Program Objectives

To make the glass or ceramic pressure housings cost effective for deep submergence applications, the research program had to satisfy the following criteria:

1. Select the material for construction of large pressure housings that is inexpensive, inert in seawater, possesses high specific compressive strength and modulus of elasticity, displays fair resistance to crack initiation, and is a product of a well developed fabrication technology.

2. Select the maximum design stress levels that provide an adequate safety factor for the chosen material against initiation of cracks by stress risers in the form of internal inclusions, or surface imperfections.

3. Select a housing configuration that provides maximum payload capacity at lowest manufacturing cost.

4. Develop concepts for joining of cylinders and hemispheres into housing assemblies that do not introduce additional high stresses into the nonmetallic components.

5. Develop bearing interfaces between the nonmetallic components of the housing that provide them with extensive fatigue life during repeated pressurizations of the housing.

6. Develop designs for penetrations through nonmetallic housing components.

7. Select impact protection concepts for nonmetallic components with low fracture toughness, that are inexpensive to fabricate, and that do not contribute significantly to weight of the pressure housing when submerged in water.

8. Select a concept for mounting of payload inside the housing that is inexpensive, does not introduce additional stresses in nonmetallic cylinders and/or hemispheres, and does not increase significantly the weight of the housing.

APPROACH

The approach chosen was mostly of experimental nature, as most of the variables were not well understood, and it would have required a well funded, large, and time consuming research program to discover the underlying physical principles. Since such funding was not available, the chosen modus operandi was to quickly formulate a postulate on the basis of known engineering principles, and then experimentally validate it, or disprove it with simple, inexpensive scale model test assemblies.

Only after validation of postulates with 6 inch diameter test assemblies did the investigation proceed to larger test assemblies (Reference 5). Thus the findings made with 6 inch diameter assemblies were subsequently further confirmed, modified, or elucidated by testing of 12 and 20 inch diameter assemblies (References 6, 7, 8).

Only after all of the objectives of the program were met could some large functional pressure housings be designed and fabricated with reasonable assurance of acceptable performance.

FINDINGS

1. Alumina ceramics with 94 to 96 percent Al_2O_c content were found to be the most cost effective materials for construction of large external pressure housings. The material is inexpensive, its structural properties make it feasible for pressure housing assemblies to achieve weight to displacement ratios ≤ 0.55, and it can be reliably fashioned into cylinders and hemispheres with diameters up to 50 inches.

ALUMINA CERAMICS FOR STRUCTURAL APPLICATIONS

PROPERTIES*	UNITS	AD-94 Nom 94% Al_2O_3	AD-96 Nom 96% Al_2O_3
SPECIFIC GRAVITY		3.62	3.72
HARDNESS ROCKWELL KNOOP	R45N GPa	78 11.1	78 11.1
SURFACE FINISH AS-FIRED GROUND POLISHED	MICROMETRES (MICROINCHES)	1.6 (63) 1.3 (51) 0.3 (12)	1.6 (63) 1.3 (51) 0.3 (12)
CRYSTAL SIZE RANGE AVERAGE	MICROMETRES (MICROINCHES)	2-25 (79-985) 12 (473)	2-20 (79-788) 11 (433)
WATER ABSORP.		NONE	NONE
GAS PERM.**		NONE	NONE
COLOR		WHITE	WHITE
COMPRESSIVE STRENGTH 25°C 1000°C	MPa (kpsi)	2103 (305) 345 (50)	2068 (300) — (—)
FLEXURAL STRENGTH TYP., 25°C MIN., 25°C*** TYP., 1000°C MIN., 1000°C***	MPa (kpsi)	352 (51) 317 (46) 138 (20) 117 (17)	358 (52) 324 (47) 172 (25) 138 (20)
TENSILE STRENGTH 25°C 1000°C	MPa (kpsi)	193 (28) 103 (15)	193 (28) 96 (14)
MOD. OF ELAST. SHEAR MODULUS BULK MODULUS TRANS. SONIC VEL. POISSON'S RATIO	GPa (10^6psi) GPa (10^6psi) GPa (10^6psi) m/sec (ft/sec)	283 (41) 117 (17) 165 (24) 8.9 (29)' 10^3 0.21	303 (44) 124 (18) 172 (25) 9.1 (30)' 10^3 0.21
MAX.-USE TEMP. (No-load cond.)	°C (°F)	1700 (3100)	1700 (3100)
COEFFICIENT OF LINEAR THERMAL EXPANSION -200-25°C 25-200°C 25-500°C 25-800°C 25-1000°C 25-1200°C	10^{-6}/°C (10^{-6}/°F)	3.4 (1.9) 6.3 (3.5) 7.1 (4.0) 7.6 (4.3) 7.9 (4.4) 8.1 (4.5)	3.4 (1.9) 6.0 (3.4) 7.4 (4.1) 8.0 (4.5) 8.2 (4.6) 8.4 (4.7)
THERMAL CONDUCTIVITY 20°C 100°C 400°C 800°C	W/m-K (g-cal/(sec)(cm²)(°C/cm))	18.0 (0.043) 14.2 (0.035) 7.9 (0.017) 5.0 (0.010)	24.7 (0.059) 18.8 (0.045) 10.0 (0.024) 5.4 (0.013)
SPECIFIC HEAT 100°C	J/kg-K (cal/g/°C)	880 (0.21)	880 (0.21)

NOTE: The ceramic compositions shown above are the dea, Colorado 80401.

2. Maximum membrane design stress level of -150,000 psi in compression has been found to provide a SF (safety factor) of two for 94 or 96 percent alumina ceramic materials, even if the ceramic incorporates discrete voids with 0.15t length (where t is the thickness of the cylinder, or hemisphere). At penetrations in the hemispheres, the magnitude of local compressive stress may be safely increased to -200,000 psi without deleterious results. At the ends axial bearing stresses of -65,000 to -75,000 psi magnitude were

5. The bearing interface developed for ceramic components consists of a thin epoxy interlayer trapped between the end of the ceramic component and a circular titanium end cap with a deep annular cavity whose internal dimensions are only slightly larger than those of the ceramic shell. The axial and radial bearing support provided by the epoxy filled end cap retards spalling of the ceramic components at their ends. End caps with cavities whose depth ≥2.5 t (where t is the thickness of the ceramic shell) provide the ceramic component with a minimum fatigue life of 500 pressurizations to design depth without spalling of exterior surfaces, provided that the axial bearing stress on the ceramic surface is ≤75,000 psi.

In permanent joints where the ends of the cylinder are not inserted and bonded into end caps, but instead are inserted and bonded into annular cavities on the stiffener, the depth of these cavities must also be ≥2.5t.

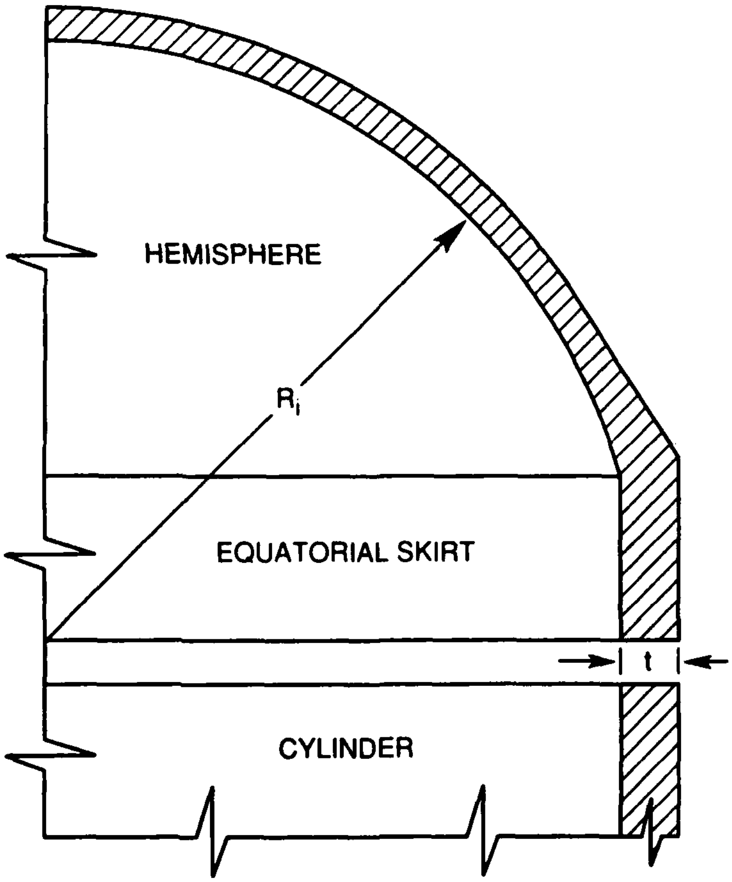


Figure 4 Arrangement for matching the bearing stress on the equatorial surface of the sphere to the bearing stress on the end of cylinders.

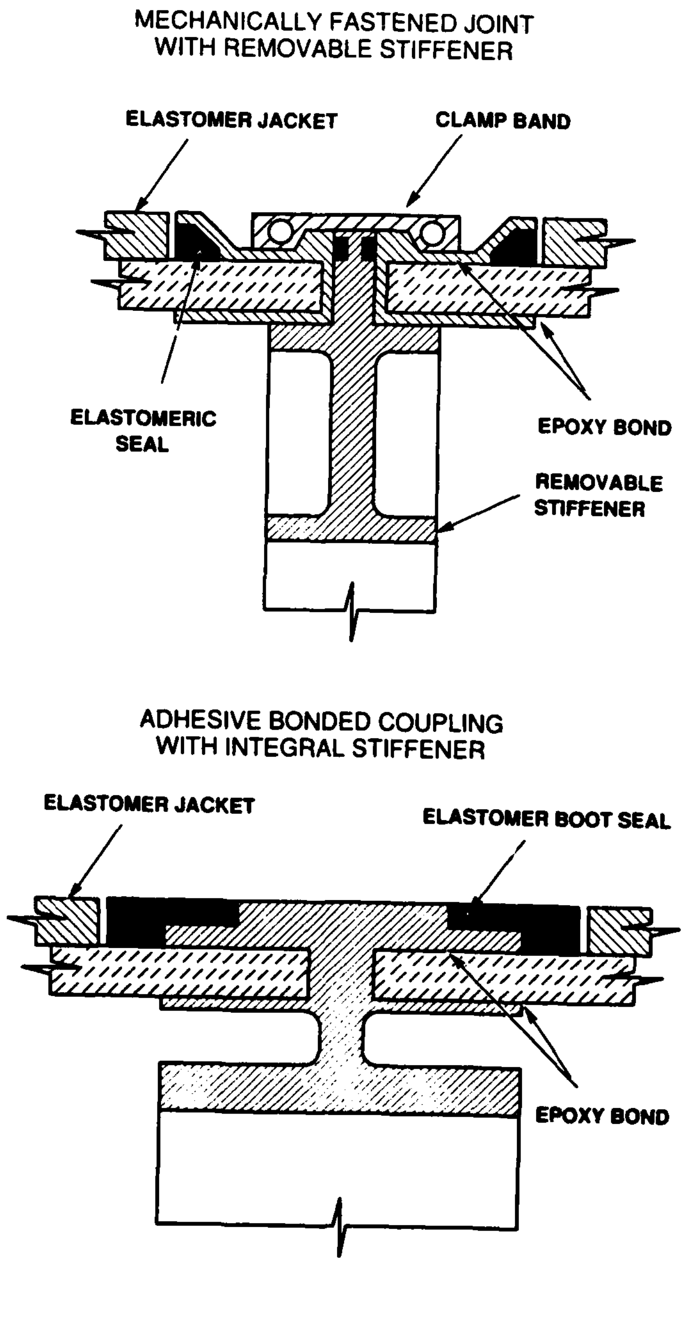


Figure 5

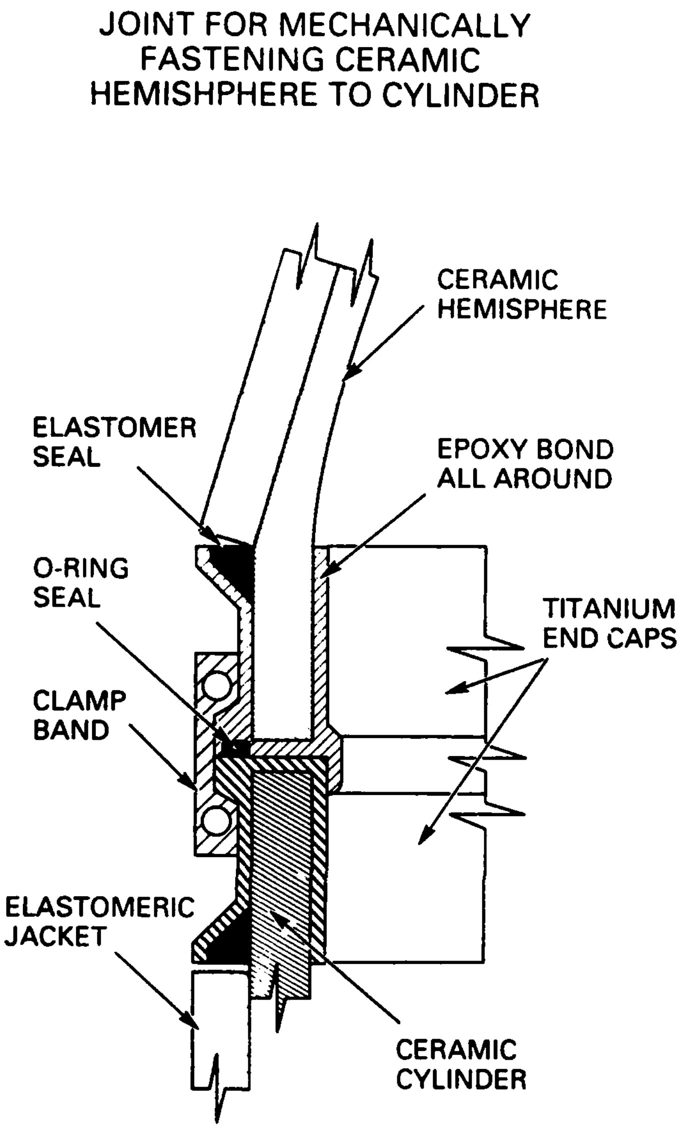


Figure 6

6. Circular penetrations with diameters $\leq 0.25\ D_o$ have been successfully incorporated into hemispherical ceramic bulkheads at locations where the nominal compressive membrane stress is $-\leq 100,000$ psi. This has been accomplished either by global, or local increase of shell thickness to $t/D_o \geq 0.023$. The number of penetrations is limited only by the minimum allowable spacing between individual penetrations. Hemispheres with five penetrations have been successfully fabricated and tested to design depth (Figure 8).

Point loading by standard steel bulkhead penetrators has been eliminated with loosely fitted titanium penetration inserts resting upon glass fiber reinforced plastic bearing pads (Figure 9).

7. Impact protection for ceramic housing components has been achieved, either by cladding the exterior surface of ceramic components with snugly fitted jackets of elastomeric material, or by enclosing the ceramic components with stand-off fairings laminated from Spectra cloth reinforced epoxy composite. The stand-off space between the fairing and the ceramic component is provided by integral ring stiffeners molded into the fairing skin (Figure 10).

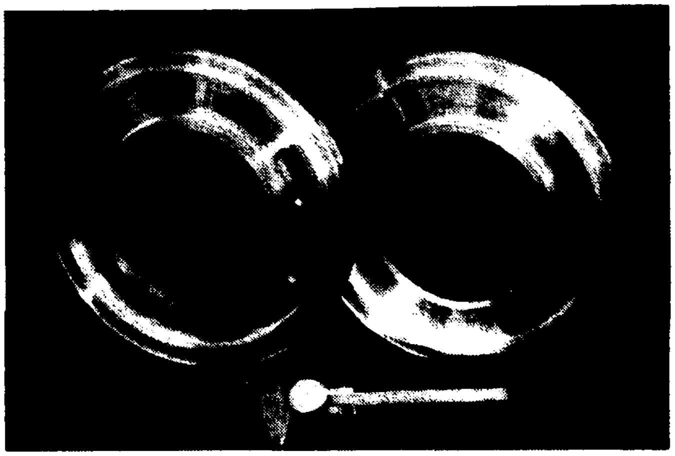


Figure 7 Typical ring stiffeners of mechanically fastened joints.

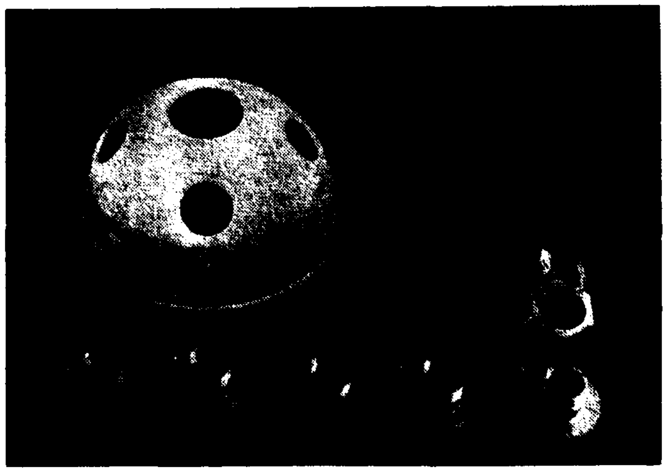
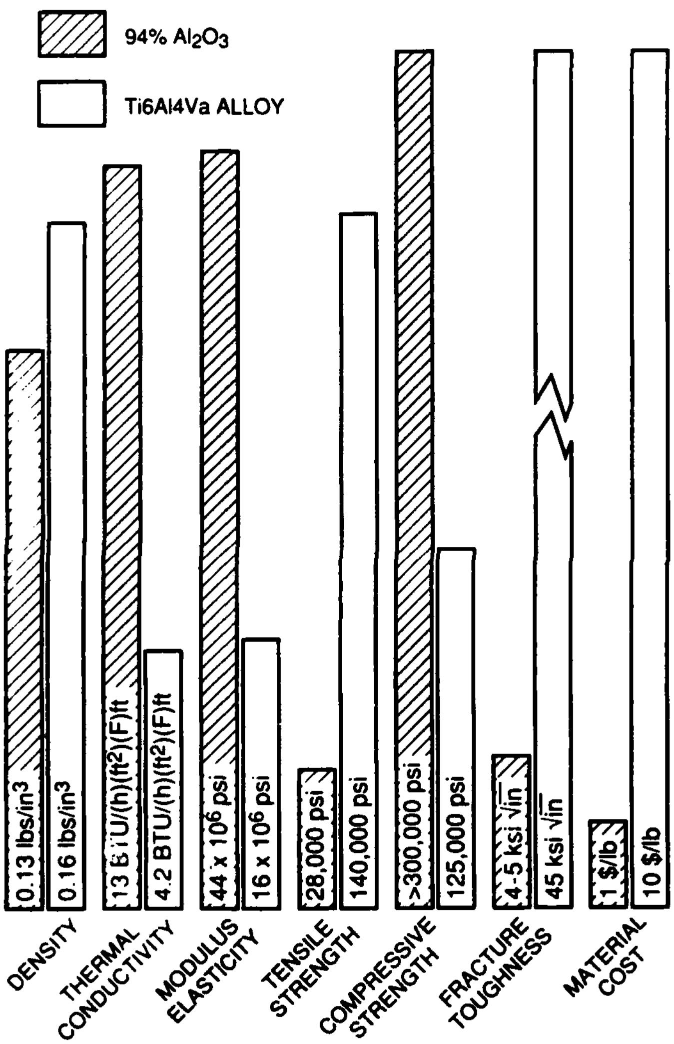


Figure 8 20 in diameter ceramic hemispherical end closure with five penetrations and the associated penetration inserts.

found to provide cyclic fatigue life in excess of 500 cycles, provided that the ends were encapsulated in NOSC type MOD I metallic end caps (Figure 1).

COMPARISON OF ALUMINA CERAMIC
TO
TITANIUM ALLOY



3. Monocoque cylinders capped with specially configured ceramic hemispheres were found to provide maximum payload capacity, at lowest manufacturing cost (Figures 2 and 3). This requires that their design be optimized for the intended design pressure. For 9000 psi design pressure, monocoque cylinders with $t/D_o = 0.034$ and $L/D = 1.5$ were found to represent an acceptable trade off between design stress, critical pressure due to buckling, cyclic fatigue life of bearing surfaces at the ends, and weight to displacement ratio.

To meet the same criteria the hemispheres had to be designed with a shell thickness of $t/D_o = 0.17$ and an equatorial cylindrical reinforcement whose thickness matches that of the cylinder (Figure 4). With this kind of configuration, not only the membrane but also the axial bearing stresses in the hemisphere would match those in the monocoque cylinder, the weight of the hemisphere would be kept to a minimum, and the end of the hemisphere

NOSC TYPE MOD 1
END CAP

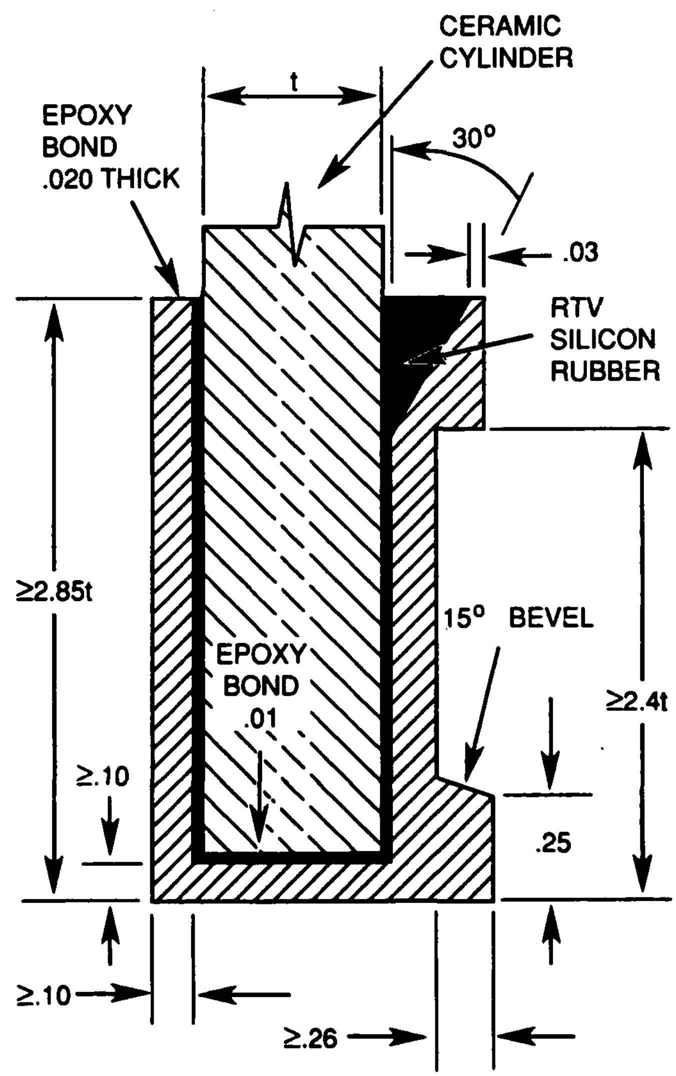


Figure 1

Figure 2 Monocoque 20 in ID X 30 in L X 0.685 in thick alumina cylinder for deep submergence housing.

could be fitted into the same type of end cap as the monocoque cylinder.

If the length of the cylindrical housing has to exceed $L/D_o = 1.5$ in order to provide larger payload capacity, ring stiffeners must be provided at $L/D_o \leq 1.5$ intervals that compensate for the reduced resistance to buckling associated with longer monocoque cylinders. These ring stiffeners, fabricated from titanium, are designed to form an integral part of the joint between individual cylindrical shell sections (Figure 5). These joints may rely on adhesive bonding to form a permanent joint, or they may utilize clamp bonds to form mechanical joints that are assembled or disassembled at will for placement of payload.

4. Mechanical joints have been developed for secure fastening of ceramic cylindrical sections to each other, and to ceramic hemispheres. All the components of the joint are of titanium, eliminating any point loads to the ceramic components being joined.

The joint design between a cylinder and a hemisphere, proven on many ceramic housings, consists of only three parts: two end caps bonded to adjacent ceramic components, and a split wedge band pulling the end caps together (Figure 6). The joint between cylindrical sections incorporates one more part; a removable metallic ring stiffener (Figure 7).

Figure 3 Alumina hemisphere serving as end closure for 20 in OD ceramic cylinders.

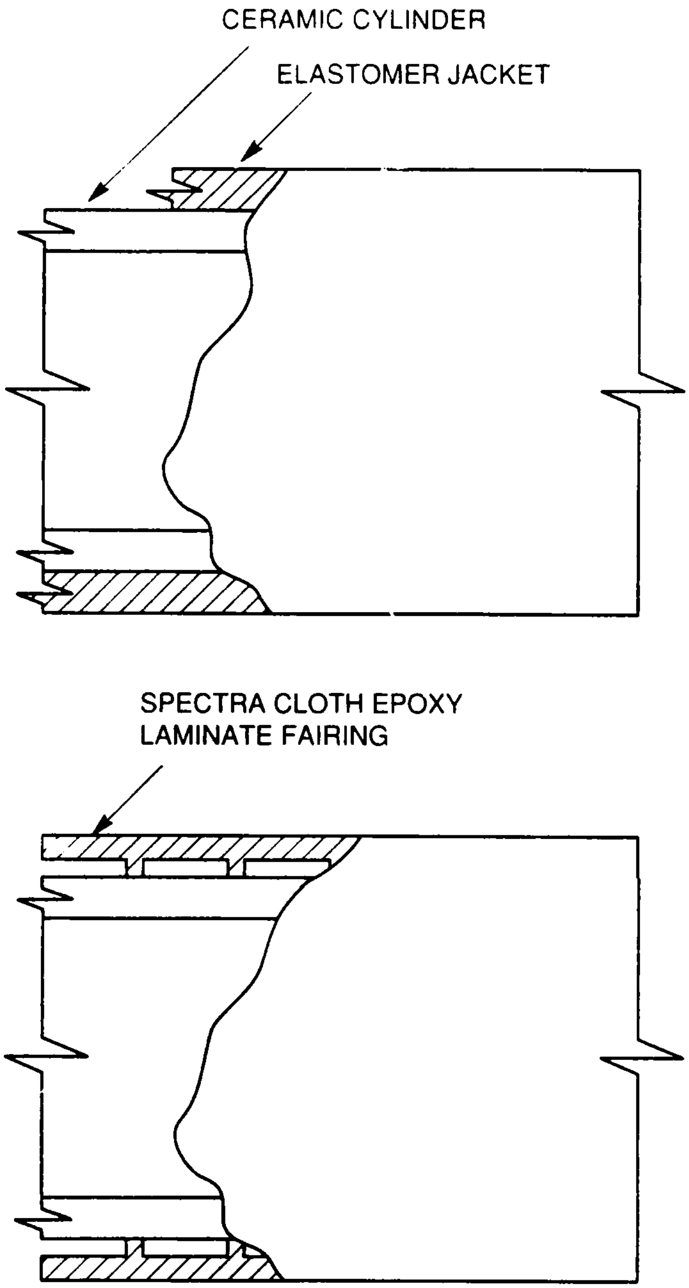


Figure 10 Approaches to mitigation of point impact shock loading.

Future

The successful fabrication of cylindrical alumina ceramic pressure housings with diameters up to 32 inches does not represent by any means the largest housings that can be fabricated from alumina ceramic. Attempts to fabricate on an exploratory basis cylinders with 50 in diameter from 94 percent alumina composition by COORS Ceramics were successful, and there is no doubt that even larger

Figure 11 25 in OD X 64.8 in L X 0.9 in thick ceramic cylindrical housing assembly joined together by an adhesive bonded coupling with an integral ring stiffener.

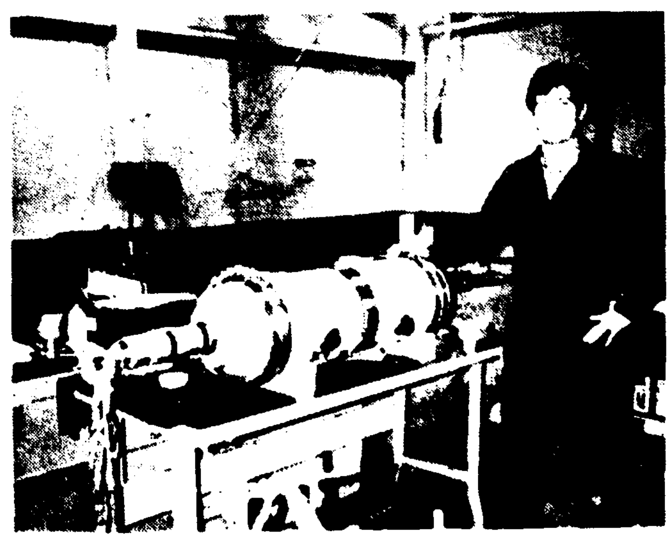


Figure 12 12 in OD model scale ceramic pressure housing with 66 lb payload rating for 9000 psi design pressure.

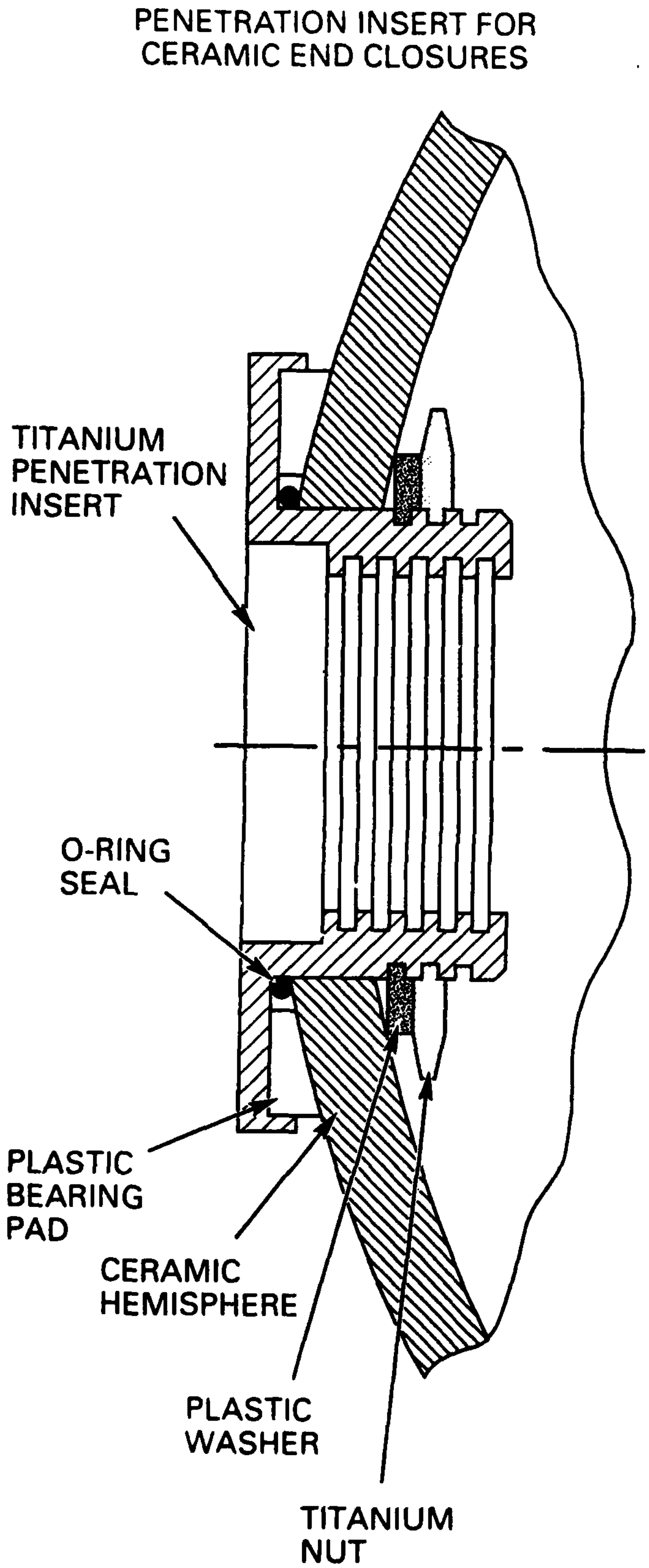


Figure 9

8. Payload was securely mounted on metallic guide rails fastened with bolts to metallic end caps and/or stiffeners. In this arrangement there is no physical contact between the payload and the interior surface of monocoque cylinders, as there is a small stand-off between the backside of the rails and the ceramic surface (Figure 11).

To facilitate the insertion and removal of payload from the interior of the housings, the components of the payload, are as a rule, permanently mounted to a cage, or framework, which in turn can slide in, or out on the rails.

APPLICATIONS

Past

Alumina ceramic housings, incorporating the previously discussed design approaches, have been fabricated from 94 percent alumina composition by COORS Ceramics in sizes from 6 to 20 inches in diameter and 9 to 82 inches in length (Figure 12, 13). These housings have demonstrated 0.5 to 0.6 weight to displacement ratios for 20,000 ft design depth with a proven fatigue life in excess of 400 dives to design depth. Their payloads range from about 10 to 800 lbs when assembled from three cylindrical sections capped with ceramic hemispheres.

Present

Encouraged by the successful structural performance of alumina ceramic pressure housings with diameter in the 6 to 20 in range, the Marine Materials Office of the NCCOSC RDT&E Division decided to expand the scope of the Ceramic Housing Program to include ceramic housings with diameters in to 25 in to 32 in range (References 9-12). These housings are being fabricated by WESGO Inc. from 96, instead of 94 percent alumina ceramic, as this ceramic composition provides higher modulus of elasticity, tensile strength, fracture toughness and Weibull Modulus, without any increase in fabrication costs. The end result is longer cyclic fatigue life for the housings.

ones can be successfully made utilizing existing fabrication processes.

EPILOGUE

Ceramics with 94 to 96 percent aluminum have successfully met the challenge of providing economical external pressure housings with 0.5 to 0.6 weight to displacement ratios for 20,000 ft design depth.

To provide cylindrical pressure housings with <0.5 weight to displacement ratios, and/or cyclic fatigue life in excess of 500 dives to 20,000 feet will require ceramic compositions that, albeit more expensive, possess higher specific strength and/or higher fracture toughness. Some of the ceramic compositions being evaluated for fabrication of pressure housings because of their superior fracture toughness are zirconia toughened alumina, silicon nitride, and $SiC/Al_2O_3/Al$ ceramic composite produced by the DIMOX process (Reference 13).

Other materials, for example, B_4C/Aluminum composite, beryllia, and SiC are being evaluated for their high specific compressive strength and modulus of elasticity.

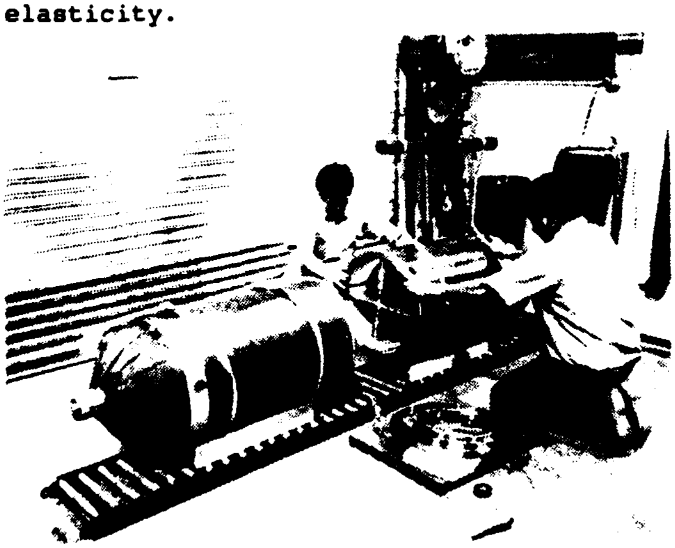
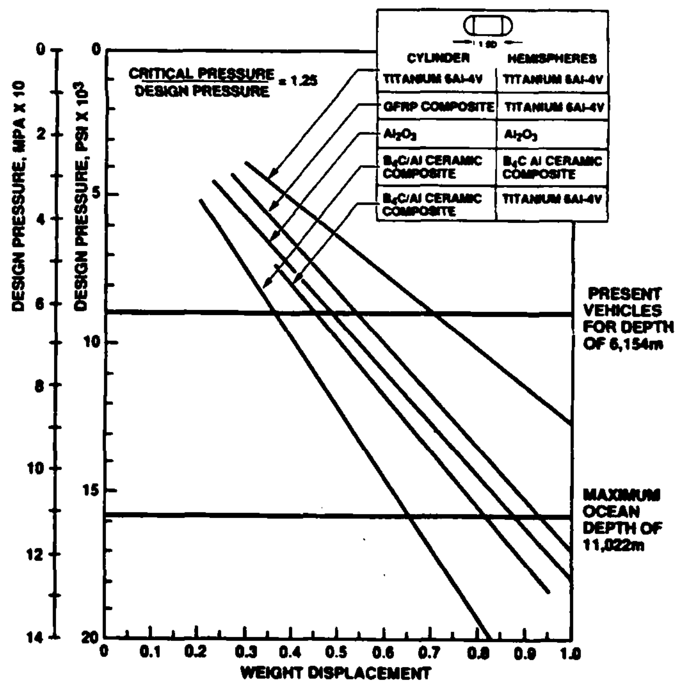


Figure 13 20 in OD ceramic pressure housing with 370 lb payload rating under assembly from two cylinder sections, removable titanium stiffener and two ceramic hemispheres with penetrations.

The material which, to date, has resulted in the lowest weight to displacement ratios for cylindrical housings is boron carbide/aluminum ceramic composite. Model scale 6 in OD X 9 in L X o.2 in thick cylinders with 0.36 weight to displacement ratios have already been fabricated from this ceramic composite by DOW CHEMICAL Inc. When tested hydrostatically with hemispherical bulkheads, they failed at 15,600 psi, demonstrating a safety factor ≥1.5 for 20,000 ft design depth (Reference 14).

Someday full size, light weight housings of such material may become reality provided that the development of the fabrication process initiated by the NCCOSC ceramic program is supported by the future potential users of such housings to its successful conclusion.

HOUSING ASSEMBLIES FOR DEEP SUBMERGENCE SERVICE



	Compressive Strength	Modulus of Elasticity	Density
B_4C/Al Ceramic Composite	400 Kpsi	45,000 Kpsi	0.09 lbs/in^3
Graphite Fiber Reinforced Plastic Composite	82 Kpsi	16,000 Kpsi	0.057 lbs/in^3
Titanium 6Al-4Va Alloy	120 Kpsi	16,500 Kpsi	0.160 lbs/in^3
Al_2O_3 Ceramic	300 Kpsi	44,000 Kpsi	0.13 lbs/in^3

If ever autonomous underwater vehicles are built to challenge the 35,800 feet (10,912 meters) depth record established by TRIESTE I in 1960 they will in all probability be equipped with pressure hulls of boron carbide/aluminum ceramic composite as at that depth their weight to displacement ratio is still an operationally acceptable 0.65.

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13. ABSTRACT *(Maximum 200 words)*

Alumina ceramic's high compressive strength and modulus of elasticity, coupled with its low density make it feasible to rountinely fabricate cylindrical pressure housings with 0.5 weight/displacement ratios for 20,000 ft (6100 m) service. This compares favorably to optimally designed titanium cylindrical housings with 0.86 weight/displacement ratio.

This presentation, by J.D. Stachiw, describes past experiences with glass and ceramic pressure housings and presents NCCOSC ceramic housing program objectives, approach, findings, and applications

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BIOGRAPHICAL INFORMATION

Dr. Jerry Stachiw is Staff Scientist for Marine Materials in the Ocean Engineering Division of the Engineering Department. He received his undergraduate engineering degree from Oklahoma State University in 1955 and graduate degree from Pennsylvania State University in 1961.

Since that time he has devoted his efforts at various U.S. Navy Laboratories to the solution of challenges posed by exploration, exploitation, and surveillance of hydrospace. The primary focus of his work has been the design and fabrication of pressure resistant structural components of diving systems for the whole range of ocean depths.

Because of his numerous achievements in the field of ocean engineering, he is considered to be the leading expert in the structural application of plastics and brittle materials to external pressure housings.

Dr. Stachiw is the author of over 100 technical reports, articles, and papers on design and fabrication of pressure resistant viewports of acrylic plastic, glass, germanium, and zinc sulphide, as well as pressure housings made of wood, concrete, glass, acrylic plastic, and ceramics. His book on "Acrylic Plastic Viewports" is the standard reference on that subject.

For the contributions to the Navy's ocean engineering programs, the Navy honored him with the Military Oceanographer Award and the Naval Ocean Systems Center with the Lauritsen Bennett Award. The American Society of Mechanical Engineers recognized his contributions to the engineering profession by election to the grade of LifeFellow, as well as the presentation of Centennial Medal, Dedicated Service Award, and Pressure Technology Codes Outstanding Performance Certificate.

Dr. Stachiw is past-chairman of ASME Ocean Engineering Division and ASME Committee on Safety Standards for Pressure Vessels for Human Occupancy. He is a member of the Marine Technology Society, New York Academy of Science, Sigma Xi, and Phi Kappa Phi Honorary Society.