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Madden, Jr.

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[45] **Nov. 20, 1973**

[54] **STRUCTURE INCORPORATING PRESSURIZED SPHERES**

[76] Inventor: **Baxter C. Madden, Jr.**, 680 N. Loop Dr., Camarillo, Calif. 93010

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[21] Appl. No.: **223,247**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 716,654, March 27, 1968, abandoned.

[52] **U.S. Cl.** **29/192,** 161/5, 29/420, 29/458

[51] **Int. Cl.** **B32b 33/00**

[58] **Field of Search** ..... 716/654; 29/192 R, 29/192 CP

[56] **References Cited**

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2,985,411	5/1961	Madden, Jr.	291/192 R UX
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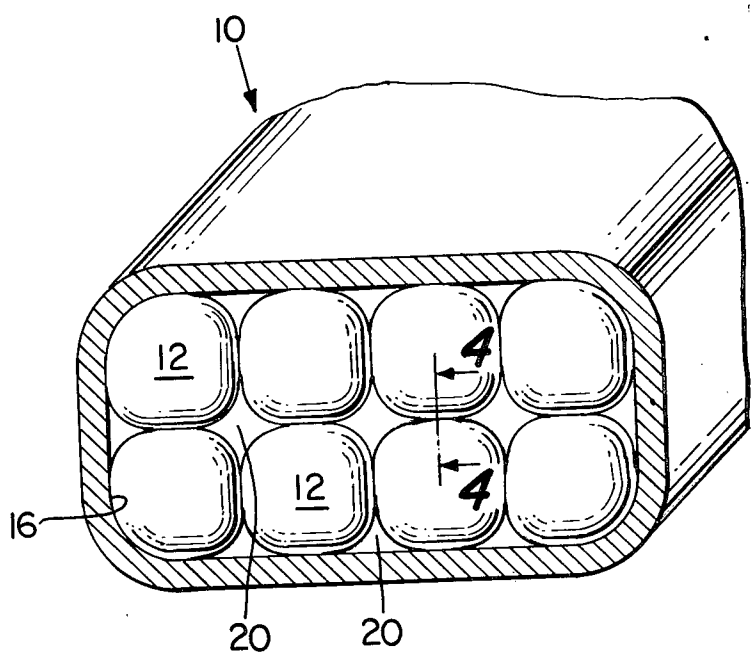
Primary Examiner—A. B. Curtis

Attorney—J. M. St. Amand and Richard S. Sciascia et al.

[57] **ABSTRACT**

A lightweight strong structure and method of making same in which a number of units such as thin walled pressurized spheres are interconnected at points of contact with each other to provide a strong and buoyant structure. In practicing the method the units are provided with a heat responsive pressure producing ingredient and are then assembled into a mass, preferably having a great number of sphere to sphere contact points. They are maintained in said relationship while being deformed as by expansion to force each unit into an increased area of contact with its neighboring unit, and the units are bonded at such areas of contact. If desired, the units may also be bonded to the inner walls of an enclosure employed to maintain the units in assembled relationship during such deformation or expansion so that the enclosure forms a part of the completed structure.

8 Claims, 9 Drawing Figures



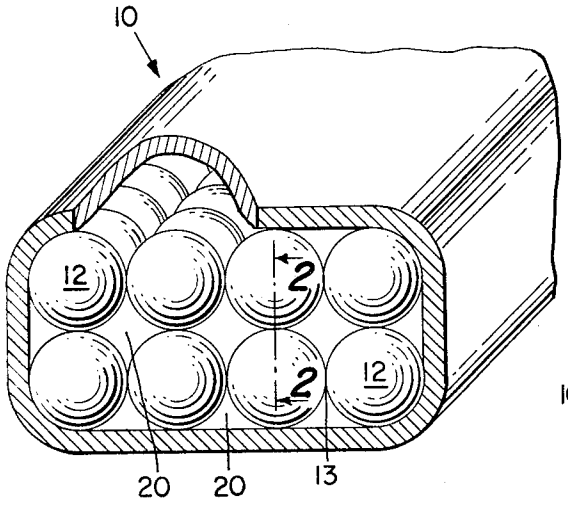


Fig. 1

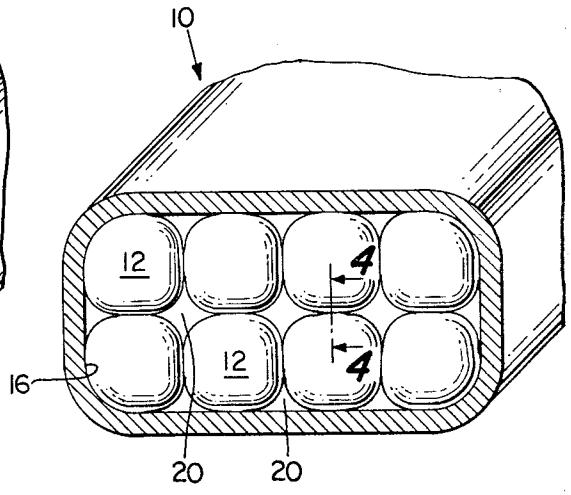


Fig. 3

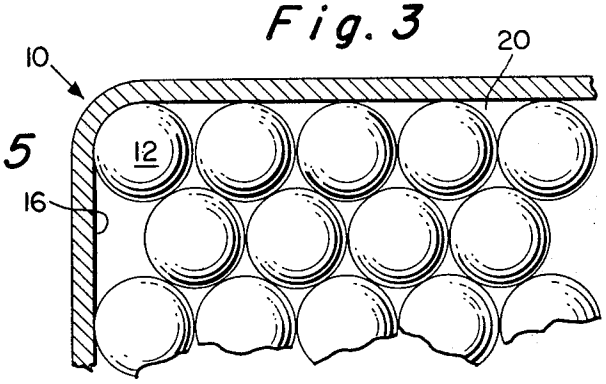


Fig. 5

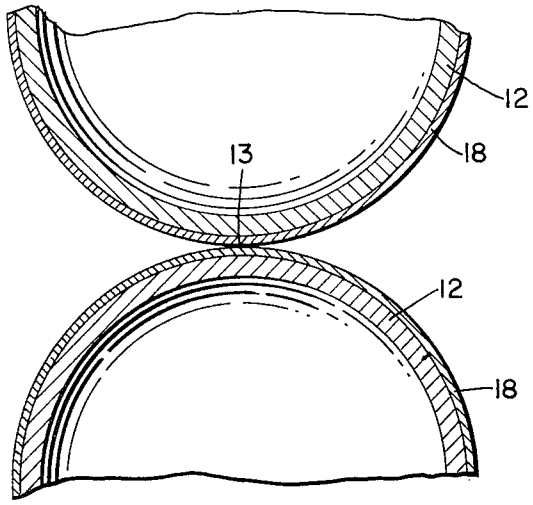


Fig. 2

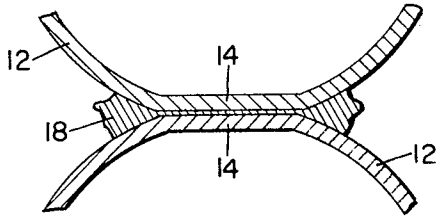


Fig. 4

INVENTOR.
BAXTER C. MADDEN JR.
BY Hayward H. Mann
O. Baxter Warner
ATTORNEYS

Fig. 6.

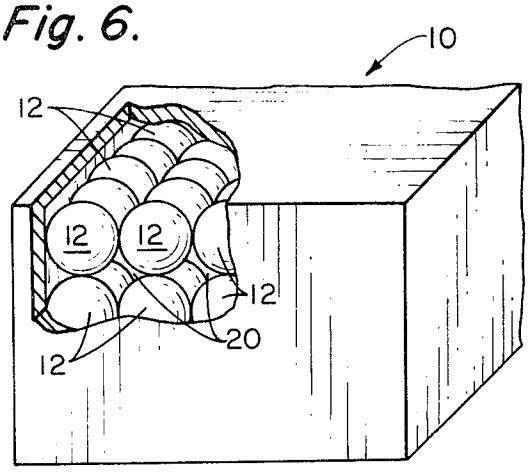


Fig. 7.

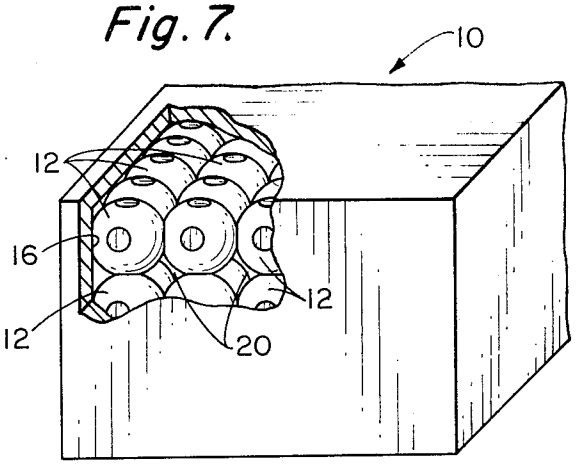


Fig. 8.

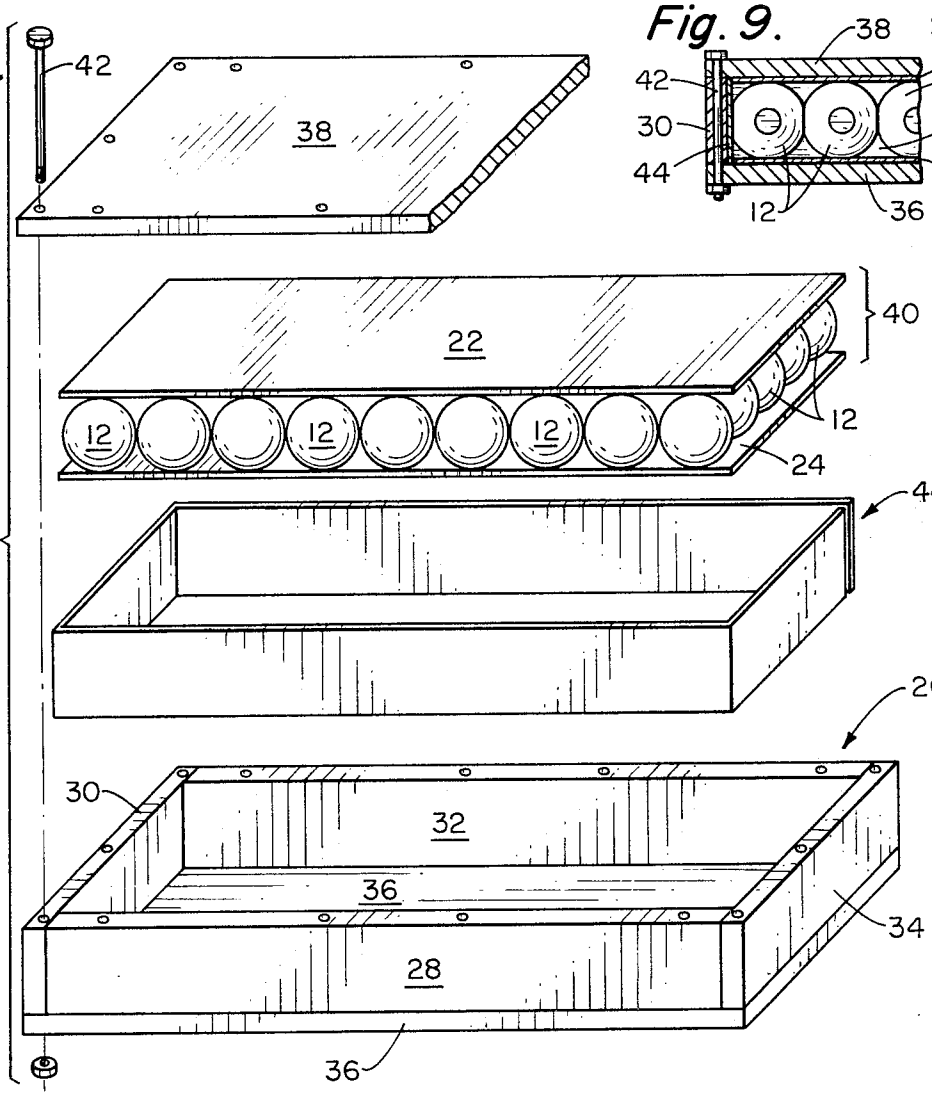


Fig. 9.

STRUCTURE INCORPORATING PRESSURIZED SPHERES

This is a continuation-in-part of application, Ser. No. 716,654, filed March 27, 1968, now abandoned.

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to relatively strong lightweight structures and a method for making the same. More specifically, the invention relates to structural members incorporating a multiplicity of hollow elements interconnected at their points of contact and to the method of assembling such elements, and improving adherence between the contacting parts.

2. Description of the Prior Art

The problem of fabricating lightweight high strength structural members is receiving increased attention due primarily to the requirements of an expanding aircraft and missile technology. Additionally, such structural members are also finding utilization in deep sea marine activities since underwater structures require strong walls to offset the heavy hydrostatic pressures acting thereon. However, presently known structural members employed in the foregoing technologies are quite limited as to strength and in some instances are not completely reliable. Moreover, most of the prior art structures have an inherently high cost due primarily to complicated and tedious methods of manufacture.

A specific use of spherical bodies as strengthening means for structural members is disclosed in applicant's U.S. Pat. No. 2,985,411. That patent shows a structural member in which a plurality of hollow spherical bodies are rigidly connected together and to the surrounding walls of the structural member.

However, in most prior art devices difficulty is encountered in perfecting the bond between the units or elements. Such prior art bonds, or an insufficient number of bonds, result in the ultimate structural assembly being less rigid and with less strength than an assembly having a greater contact area at touching contact points between the spheres and between the spheres and the surrounding walls.

SUMMARY OF THE INVENTION

The present invention comprises an assembly of mutually bonded hollow units or spheres which may be enclosed in a non-expansible otherwise hollow structural envelope. If desired, the units and the envelope may be dimensioned for modular arrangement. The spheres may be provided with a heat responsive pressure producing filler or ingredient and may be coated with a suitable bonding agent. When heat is applied the spheres expand and increase the area of surface contact therebetween. The heat may also fuse the bonding agent which is then drawn to the points of sphere contact and binds all of the spheres and the surrounding unit walls into a rigid interstitial assembly. Thus a lightweight structural member is provided having greatly increased omnidirectional strength and very high buoyancy. This invention also contemplates the feature of pressurizing the spheres to the environmental pressure

such as the hydrostatic head at a selected underwater depth.

The method of fabricating a structure may be similar to that set forth in the applicant's patented disclosure identified above and the applicable portion of that disclosure is incorporated herein. Essentially, the method comprises filling an envelope with thin walled units having a selected internal pressure and then vibrating the envelope in any manner to cause compact rearrangement and settling of the units or spheres throughout the interior of the envelope. The spherical bodies may be provided with a pressure producing content and if desired may be coated with a suitable bonding agent. When heat is applied, internal pressure is generated which expands the units or spheres and forces them into greater contact with each other and with the structural member walls. The heat may fuse the bonding agent and bond the structural member and spherical bodies into a rigid interstitial mass.

STATEMENT OF THE OBJECTS OF THE INVENTION

One object of the invention is to provide an improved construction member for general utilization but particularly for use in aircraft, missile and marine technologies.

Another object of the present invention is to provide a strong structural member that has integrally joined spherical bodies with an increased area of contact between the spheres and the surrounding wall.

Another object of this invention is to provide a strong structural member having integrally joined spherical bodies in a modular construction adaptation with an increased area of contact between the spheres and the surrounding wall.

A further object of this invention is to provide a strong structural member in which spheres included therein are pressurized to a pressure equaling anticipated external pressures, such as the hydrostatic head at a selected underwater depth.

An additional object is to provide a simple, light and inexpensive construction member of increased omnidirectional strength.

A further object is to provide a method of manufacturing a strong lightweight structure embodying pressurized units or spheres.

Other objects, advantages, and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a transverse sectional view through an elongate channel like structural member embodying unexpanded units or spheres shown in a modular structural arrangement.

FIG. 2 is a greatly enlarged detail view taken along line 2—2 of FIG. 1 showing the contact points of a pair of unexpanded spheres each having a bond coating thereon.

FIG. 3 is a transverse sectional view similar to FIG. 1 but with the spheres in expanded condition showing the greatly increased contact area therebetween and between the spheres and with their enclosing structural member and depicting the intercommunicating voids between spheres.

FIG. 4 is a greatly enlarged detail view taken along line 4—4 of FIG. 3 and showing the greatly increased contact area between two expanded spheres.

FIG. 5 is a view similar to FIG. 1 but showing a different arrangement of adjacent spheres.

FIG. 6 is a partially cut away view of a sphere confining enclosure showing how spheres located therein may be restrained from displacement in any direction.

FIG. 7 is a view similar to FIG. 6 but with the spheres in expanded condition showing the greatly increased area of contact therebetween, and between the spheres and the interior walls of the non-expansible enclosure.

FIG. 8 is an exploded view of one embodiment of apparatus for assembling a reticulated core of spherical elements.

FIG. 9 is a cross-sectional view of a small portion of the embodiment shown in FIG. 8 but with the exploded parts shown in assembled form.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings in detail, and particularly to FIGS. 1 and 3 there is shown generally a hollow structural envelope member **10** which provides a confining enclosure for a number of hollow units or spherical bodies **12** shown in modular arrangement. It will be noted that the spheres **12** may contact each other at points **13**, shown in enlarged detail in FIG. **2**, and also may contact the inner wall **16** of the envelope member **10**. If bonded at such contact points, a reinforced structural member would be formed.

The spheres **12** and the structural member **10** may be cooled or heated by a heat transfer medium circulated through the labyrinth of interconnected voids or passageways formed by the interstitial spaces **20** between expanded spheres **12**, as shown in FIG, **3**, for example. Moreover, the contained sealed spheres create a buoyant structural member capable of floating in water should this ever become necessary, as for example, in airframes, missiles and waterborne structures.

It is pointed out that underwater structural units may be made from an assembly of spheres bonded together in the manner shown in FIG. **4** in which the spherical bodies **12** are pressurized, ideally to a pressure substantially equivalent to that of the hydrostatic head at the intended operating depth. Thus, the spheres **12** may be provided with any appropriate internal pressure for use at any suitable depth.

In carrying out the method of this invention, an elongate hollow structural member **10** may be supported on a stand with an open portion thereof positioned upright to receive a supply of pressurized spherical bodies **12** therein from a supply chute. The spherical bodies fall to the bottom of the structural member **10** and gradually build up, all of which is shown in applicant's patent disclosed above.

The structural member **10** may be vibrated in any conventional manner, such as by an offset eccentric drive arrangement to achieve uniform distribution of the spherical bodies **12** throughout the member such as shown in FIGS. **1, 3** and **6.**

It will be observed that the spheres need not necessarily be critically dimensioned and that they will arrange and accommodate themselves to the space available.

The filled non-expansible structural member **10** is then placed in a controlled atmosphere furnace heated to about 1850°F which causes the pressurized spherical bodies **12** to expand into greater area of contact with each other as shown in FIG. **3** and in detail in FIG. **4.** The increased contact between spheres is indicated at **14** and between spheres and the surrounding walls of the enclosure is indicated at **16** shown in FIG. **7.** Such expansion deforms the spheres at the points of contact and forms flattened faces at such points. The heating step also melts any bonding substance **18** initially coated on the spheres **12** during the manufacture thereof which substance bonds them together as shown in FIG. **4.** When desired, it also bonds the adjacent spheres to the wall **16** to form a rigid and strong interstitial mass. FIGS. **6** and **7** show plainly how a non-expansible structure may be provided to surround and enclose the spherical mass on all sides. Since the spheres **12** are not ruptured during expansion, the resulting structural member is buoyant and will deter sinking, even if accidentally distorted or damaged. If a projectile passes through the structure, only those spheres actually punctured would contribute to the loss of buoyancy; the other spheres would still contribute to buoyancy.

There are various bonding means which may be utilized in this invention and no specific preference is indicated. The type and thickness of the spheres as well as the intended use are all considered in determining any bonding material used. For example, a coating suitably deposited, as by electrodeposition, may be used on the spheres which coating melts and performs a bonding function when heated and allowed to cool. Other commonly used bonding agents may include adhesives having a resinous or rubber base.

Instead of bonding the units or spheres to the interior wall of a structural envelope or enclosure there may be instances where it is desired to prevent bonding to such interior wall at all or at certain points. To accomplish this the interior wall, or portions thereof, may be lined or coated with a substance to which bonding will not occur. When the reticulated core of spheres is then withdrawn from the enclosure the bonded together spheres provide a structure formed of a number of expanded units with increased areas at the points of contact and flattened faces at those points of contact which have no exterior covering. Such construction is particularly useful where maximum lightness and buoyancy with strength are desired.

Of course, the shape of the ultimate reticulated core is determined by the overall shape of the enclosure. This may be straight or curved, large or small, and the enclosure may be either bonded to the ultimate core or bonding of the enclosure to the core of spheres may be prevented and the core used alone.

The individual units or spheres **12** may be manufactured in any suitable manner. One method is to blow hot metal bubbles which are allowed to descend in a shot tower. Or they may be constructed of two hemispheres, preferably of PH15-7Mo stainless steel, which are welded or otherwise integrally fused together to form a single sphere.

The pressurizing substance in the unit or sphere may be a gas, or a liquid, or may be a solid material which will transform into a vapor or gas upon the application of heat or after the passage of time, with a corresponding increase in pressure within the unit This pressurizing material may be inserted within the sphere either during or after the fabrication thereof. For example,

during the fusing of two separate hemispheres a solid or liquid pressurizing substance may be placed in one or both hemispheres prior to being actually sealed or, after fabrication of the sphere, a hole may be drilled and the proper amount of solid or liquid pressurizing material placed therein, after which the hole is plugged or sealed. A pressurizing gas may be inserted in the sphere by making a hole therein and then maintaining a controlled pressure of substantially **60** p.s.i. on the outside of the sphere as the gas is being inserted. The pressure is maintained as the sphere hole is plugged. Specifically, the fabricated unit or sphere **12** may be placed in a suitable jig and a hole drilled therein. A pressurizing gas is admitted to the interior of the sphere **10** and a plug is then firmly secured in place as by welding over the drilled hole.

As a further example, in the shot tower method of sphere fabrication described above the tower interior may be pressurized during the manufacturing process so that the resultant units or spheres, when formed, are already internally pressurized to a prescribed degree.

In some instances, the sphere **10** may be resealed by inserting a tapered pin into the hole.

For a given material, the following variables are interrelated:

d_1 — initial diameter of sphere
d_2 — final diameter of sphere after expansion without restraint
t — wall thickness of sphere
p_1 — initial gas pressure trapped in sphere
T — temperature to which spheres are heated for purpose of expansion and bonding together

It was determined that the conditions leading to a 10 percent increase in diameter without restraint provided ample flattened surfaces for strong joints between spheres when they were restrained by a non-expansible enclosure. In the following calculations the small effect of the flattened areas on the volume of the sphere is neglected.

Thus, in a panel having the following values:

$d_1 = 1$ inch
$d_2 = 1.1$ inch
$t = 0.008$ inch
$p_1 = 60$ p.s.i.g.
$T = 1850°F$

The maximum pressure (p_2) existing in the sphere at temperature (t) is derived from the gas laws whereby PV/I = constant,

$$\text{or } P_2 = P_1\ T_2/T_1\ V_1/V_2 \qquad (1)$$

$$\therefore p_2 \approx (60 + 15)\ 1850 + 460/70 + 460\ (1/1.1)^3$$

$$\approx 245 \text{ p.s.i.a. or } 230 \text{ p.s.i.g.}$$

An approximation of the stress (S) causing expansion of the sphere is the force developed on a disc of diameter d_2 divided by the annular cross-sectional area of the wall of the sphere at diameter d_2.

Therefore $S \approx p_2\ \pi\ d^2_2/4 \div \pi\ d_2 t$

$$\text{or } S \approx p_2\ d_2/4t \qquad (2)$$

For the case at hand,

$$S = 230 \times 1.1/4 \times 0.008 = 8000 \text{ p.s.i.}$$

This would be the approximate yield strength at 1850°F of the material used for the sphere.

If bonding were to be accomplished at a different temperature, the initial pressure (p_1) should be adjusted accordingly.

In considering the use of spheres other than 1-inch diameter, it is of interest to note that the ratio of diameter to wall thickness is an important criterion. Assuming fixed values of p_1, T and the ratio d_1/d_2, equation (2) may be rewritten

$$S = 230 \times 1.1 d_1/4 = 64\ d_1/t \qquad (3)$$

It is evident that the ratio of initial diameter to wall thickness should be constant for a given yield strength and value of T. Thus, for the above stated constraints, a 2-inch diameter sphere should have a wall thickness of 0.016-inch; or a ½-inch diameter sphere should have a wall thickness of 0.004-inch.

Consider a 1-inch diameter sphere of 0.008-inch wall thickness, but made of material with a yield strength of 1000 p.s.i. at 1850°F. From equation (2)

$$p_2 = 4ts/d_2 = 4 \times 0.008 \times 1000/1.1 = 29 \text{ p.s.i.g.}$$

With a typical value for p_2/p_1 of 4,

$$p_1 \approx 7.0 \text{ p.s.i.g.}$$

Thus, an initial pressure as low as 7.0 p.s.i.g. may be used.

Consider a 10-inch diameter sphere with a wall thickness of 0.10-inch made of a material having a yield strength of 8000 p.s.i. at 1850°F. From equation (2),

$$p_2 = 4ts/d_2 = 4 \times 0.10 \times 8000/11 = 2900 \text{ p.s.i.g.}$$

Again, with a typical value for p_2/p_1 of 4,

$$p_1 \approx 700 \text{ p.s.i.g.}$$

In this case an initial pressure as high as 700 p.s.i.g. is required.

In the preparation of a specific panel **40** of expanded sphere sandwich construction, the following materials and processes were used. Note FIGS. **8** and **9.**

Flanged hemispheres were formed from 0.010-inch thick PH15-Mo heat treatable stainless steel. The wall thickness of a hemisphere after forming was approximately 0.008-inch. One pair at a time were welded together in a specially designed chamber, pressurized to 60 p.s.i.g. with argon, by rotating the abutting flanges past a tungsten electrode. Current of the order of 6.0 amperes caused the flanges to melt and form a weld between the hemispheres thus producing an hermetically sealed 1-inch diameter hollow sphere **12** containing argon at a pressure of 60 p.s.i.g.

Each sphere **12** was stress relieved by holding at a temperature of 375°F for one hour. This was followed by the electrodeposition sequentially of nickel, copper and silver over the surface of each sphere. The total thickness of deposited metal was approximately 0.002-inch with the ratio of silver to copper being approximately 10 to 1 by weight. A second stress relief treatment of 375°F for one hour followed.

The portion of the enclosure to which it was desired to bond the expanded spheres (the facings **22** and **24**) had an electrodeposit identical to that described for the

spheres **12**. No stress relief treatment was used inasmuch as no weld was present.

Any portion of the enclosure to which a bond was not desired was masked with 0.001-inch thick stainless steel on which an oxide coating was previously formed by exposure in a furnace for 15 minutes at 1950°F.

A non-expansible enclosure **26** having ½-inch thick steel plates **28, 30, 32, 34, 36** and **38** was secured in place by bolts **42** and accompanying nuts so as to surround the assembled panel **40** and surrounding oxidized steel band **44** on all six sides. The enclosure containing the panel **40** was placed in a stainless steel chamber through which argon circulated at a rate of 5 cubic feet per hour. The chamber was placed in a furnace and brought to a temperature of 1850°F, held at 1850°F for 10 minutes, and then air cooled to room temperature. During this portion of the heat treating, the spheres expanded and flattened at each point of contact with another sphere or a facing. Also occurring was the melting of the electrodeposited silver. The electrodeposited copper diffused into the silver resulting in a silver-copper alloy brazed joint at each contact of the flattened portions of each sphere.

The assembled panel was then placed in a mixture of acetone and solid carbon dioxide at a temperature of approximately minus 110°F for 16 hours followed by aging for one hour at 1025°F in the chamber mentioned above through which argon flowed at 5 cubic feet per hour. The chamber was then cooled in air and the assembled panel was removed. The sub-zero temperature and aging treatments completed the heat treatment of the PH15-7Mo steel material which at this point had a tensile strength in excess of 200,000 p.s.i.

It is apparent that as a result of this invention a structural member is provided which is lightweight, of high omnidirectional strength and of low cost. It provides buoyancy in water and has great utilization in submerged structures. The rigid interstitial arrangement allows free circulation or storage of fluids in the interstices between spheres if desired. It will also be apparent that the units or spheres need not be perfect in dimension but for the purpose of illustrating this invention hollow bodies of substantially spherical shape have been illustrated.

In order to render a structure formed of these spheres fire retardant or fire suppressant they may be filled with a suitable foaming fire repelling or extinguishing material or with a gas which will not support combustion such as CO_2 or nitrogen, or the like.

A distinct advantage of a structure formed with non-intercommunicating spheres of this character is the fact that upon damage, as by penetration or puncture by a bullet or a piece of shrapnel, there is minimal loss of structural integrity and buoyancy and minimal damage to adjacent units or spheres. This is particularly significant when the structure is employed in applications wherein a puncture might otherwise cause complete failure of a unit.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A strong lightweight internally reinforced structural member having greatly increased omnidirectional strength and high buoyancy comprising:

a. an enclosure forming the outer periphery of said structural member;

b. said enclosure completely surrounding and enclosing a plurality of intercooperating discrete components located therein, said discrete components and enclosure being assembled together in bonded relationship;

c. said discrete components comprising a plurality of internally pressurized spheroidal units; said spheroidal units containing pressurized gas;

d. said internally pressurized spheroidal units each being composed of a thin wall, high tensile strength material and being hermetically sealed for maintaining the internal pressure of each pressurized unit at greater than a selected environmental pressure of an atmosphere having greater density than that normally existing about the earth's surface to neutralize the effect of such external environmental pressure thereon and increase the overall structural strength of each unit;

e. each internally pressurized spheroidal units being arranged in adjoining relationship and bonded together along close contacting surfaces;

f. the thin wall of each said internally pressurized spheroidal unit being flattened along said contacting surfaces;

g. said spheroidal units adjacent said enclosure forming the outer periphery of the structural member having at least one flattened surface bonded to said enclosure;

h. said bonded internally pressurized spheroidal units and enclosure forming a rigid interstitial assembly having a labyrinth of interconnected passageways therein formed by interstitial spaces between said spheroidal units.

2. The structural member of claim **1** wherein the gas contained by said units is a fire suppressant.

3. The internally reinforced structural member as defined in claim **1** wherein:

the spheroidal units are coated with bonding material.

4. The internally reinforced structural member as defined in claim **1** wherein:

the thin wall of said spheroidal units are formed from approximately 0.010 inch thick material.

5. The internally reinforced structural member as defined in claim **1** wherein:

the thin wall material of each spheroidal unit is metal, and said pressurized spheroidal units are uniformly arranged and mutually bonded and fused together at said flattened areas of contact.

6. The internally reinforced structural member as defined in claim **1** wherein:

the thin wall material of each spheroidal unit is stainless steel.

7. The internally reinforced structural member as defined in claim **1** wherein:

the enclosure surrounding and enclosing said units is substantially non-expansible.

8. A structural member as in claim **1** wherein said spheroidal units are internally pressurized to a pressure at least equal to a selected external environmental pressure of a hydrostatic head at a selected underwater depth to neutralize the effect of such external pressure thereon.

* * * * *