HIGH IMPACT PROTECTIVE STRUCTURE AND METHOD
FOR MANUFACTURING SAME
Filed Oct. 21, 1966

FIG-1

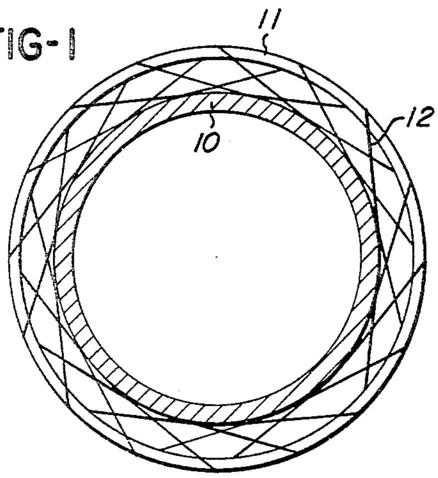


FIG-2

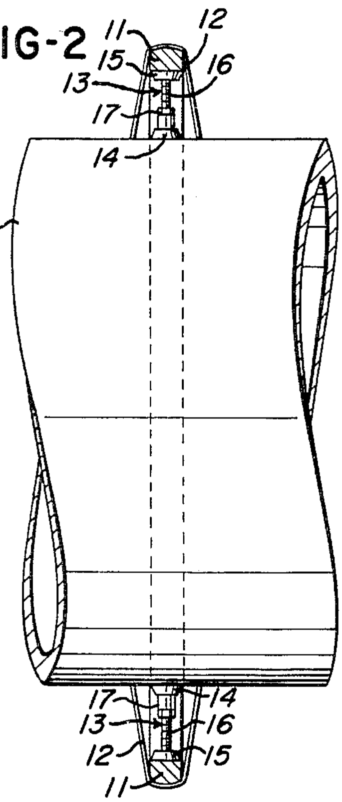


FIG-3

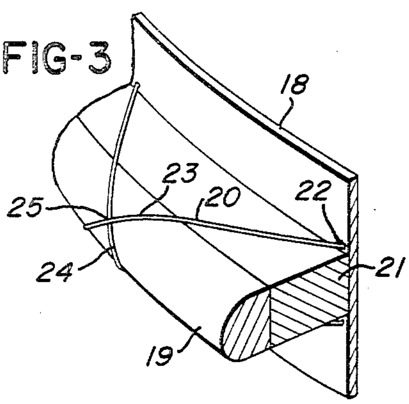


FIG-4

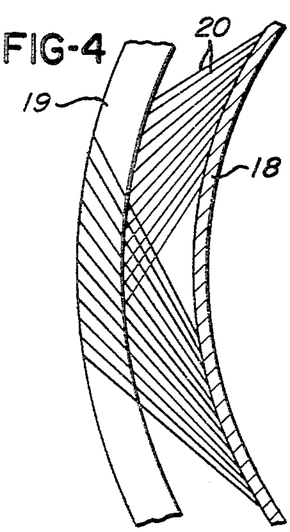
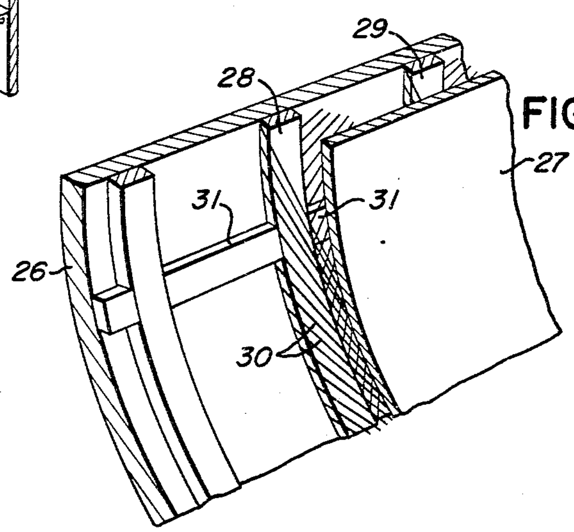


FIG-5



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HIGH IMPACT PROTECTIVE STRUCTURE AND METHOD FOR MANUFACTURING SAME

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U.S. Cl. 138—112 4 Claims

ABSTRACT OF THE DISCLOSURE

A lightweight, high impact resistant protective container assembly is disclosed. The assembly comprises an inner container, at least one annular member surrounding the container, and at least one continuous filament anchored to the container and passing outwardly therefrom and across the outwardly disposed surface of the annular member and back to and around the wall of the container. The filament is the only connecting link between the container and the annular member.

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

The present invention relates to a novel high impact absorbing protective structure capable of preserving an object suspended thereby or therein against the effects of high rate impulse loadings such as might be encountered when the container structure is exposed to the concussion waves of an explosion or to an extremely high rate of acceleration or deceleration as for example upon high speed impact with another object. More particularly, the invention relates to a novel container assembly capable of protecting the contents thereof from high impulse shock loadings of the type that might be encountered upon the exposure of the container to the deposition of large amounts of mechanical, thermal or combined forms of energy. The invention also relates to a method for the manufacture of such a structure.

Man has long sought to protect himself and his property from the deleterious effects of mechanical loading. Impact loadings ranging from a relatively gentle rate of load application in the tenths or hundredths of a second to ultra-high impact rates in the millisecond or microsecond range have been particularly difficult to cope with in this regard. At the same time, man's recently acquired ability to achieve greater speeds of motion, his intensified adventures into the extreme environments of space, and his recent exposure to the highly destructive influences of modern chemical and atomic warfare have substantially increased the likelihood of damaging if not destructive encounters with such impact loadings.

Thus, while the prior art has for many years produced protective container structures, it has not addressed itself to the severe demands for such protection which exist today. Indeed, most of the related prior art devices have been concerned primarily with that degree of impact protection that is necessary to overcome the relatively nominal rigors of handling and shipment of objects via conventional means of land, water or air transportation. The prior art has therefore not been confronted with the necessity for exploiting the highest and best structural properties of even the most up-to-date materials that might be available for such protective assemblies. It follows that the variety of such prior art structures which include so-called sandwich or honeycomb constructions capable of resisting imposed relatively static loads, the use of adjacent structural members such as springs to transfer the

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load, and crushable bags capable of distributing the energy loading over a large area or combinations thereof are not adequate for meeting today's high impact loading requirements. More particularly is this true because, while the magnitude or rate of the impulse loading has steadily increased, so also has the sensitivity or destructability of many objects that are now sought to be protected. As a result, the prior art structures have failed as protective devices by fracture, tearing, buckling, crushing delamination, spalling or other mechanically induced forms of failure because of the magnitude of the total energy to which they have been exposed, of the high rate of the application of such energy and of the characteristic and isotropic or directional properties of the structural materials of which they have been composed. Moreover, many of these prior art structures have been so cumbersome and/or have involved so much mass that their use where weight is a factor, as for example in air or aerospace applications, has been completely out of the question.

It is accordingly an object of the present invention to provide an improved protective structure capable of protecting an object associated therewith against high rates of impact by mechanical, heat or other energy loadings.

Still another object of the invention is to utilize to the greatest advantage a combination of structural components to provide a container construction capable of protecting the object therein from extreme loading conditions.

Still another object of the present invention is to provide such a structure which will be extremely light in weight and can be practically and economically utilized in air or aerospace travel.

Still another object of the invention is to provide an ultra-lightweight composite construction capable of accommodating mechanically self-equiliberating, localized or unsymmetrical loads and of distributing the implied loads in a unique manner throughout the entire structure thereby eliminating localization of stress and the likelihood of localized material failures.

Yet another object of the present invention is to provide a method for the manufacture of such protective devices and constructions.

To achieve these and other objects and advantages which will appear from a reading of the within disclosure, the present invention teaches the construction of an ultra-lightweight, tension filament structure wherein the object to be protected or the container therefor is suspended within an at least partially surrounding member relative to which it is suspended by a winding or windings of one or more tensed strands or filaments passing alternately around and between the inner object and the outer member and comprising the sole interconnecting link between them. The nature of the winding of the strand or filament is such that, upon impact with the outer member, it is placed in tension; and a load applied to the outer member is uniquely transmitted via the strand in such a manner that the inner object or container is shock isolated from intense mechanical and/or thermal loading and will be thereby protected. The outstanding advantage of this type of structure is that the unusually high tensile strength of certain filamentous materials can be efficiently utilized to yield an extremely efficient, versatile and protective container for accommodating low to ultra-high rates of loading. Illustrative of the improved load-absorbing capability resulting from such a use of conventional structural materials, the tensile strength of glassy filaments such as those manufactured and sold under the proprietary designation "S-Glass" by Owens-Corning Fiberglas Corp. of Toledo, Ohio, at room temperature may range up to more than 700,000 pounds per square inch, while similar glassy compositions in bulk form have tensile strengths only on the order of about 14,000 pounds per square inch.

A second major advantage of the structure of this invention is derived from the unique manner in which an impact loading at a point on the outer member tends to compress the same whereby the impact loading is almost instantaneously distributed via the filament windings throughout the entire structure without localization, even to the extent that a part of it is absorbed by that portion of the structure which is diametrically opposite the point of impact. The likelihood of localized material failure is accordingly lessened even if the stresses should exceed the extraordinarily high strengths that the construction is capable of utilizing from conventional materials such as the glass filaments mentioned. It can be seen therefore that the unique advantages thus obtained by the practice of the within invention render it clearly distinguishable at the outset from the composite protective structures of the prior art such as honeycomb or truss core sandwich constructions, waffle type reinforcements and various reinforced skin or wall constructions such for example as involve stringers or supporting rods, whether the same be in compression or in tension and even from those involving filament windings either in the form of a continuous wall or relatively short length filament lacings.

The invention thus generally described may be more clearly understood by reference to the following detailed description of certain specific embodiments and modifications thereof in connection with which reference may be had to the appended drawings.

FIGURE 1 is a diagrammatic view in partial cross section of the major components of one form of ultra-lightweight tension filament protective structure according to the present invention.

FIGURE 2 is a diagrammatic view in partial cross section of the device shown in FIGURE 1 during an intermediate step in its manufacture.

FIGURE 3 is a fragmentary diagrammatic view of an alternative intermediate stage in the manufacture of a protective device according to the present invention.

FIGURE 4 is a fragmentary diagrammatic view of the elements of a device according to the present invention at a subsequent stage in the manufacture thereof.

FIGURE 5 is a fragmentary diagrammatic view of a modification of a device according to the present invention.

Referring now to FIGURE 1, one protective structure according to the present invention is shown to comprise the inner container **10** in the form of a closed or open ended cylindrical body within which, by conventional mounting or packing expedients, the object to be protected may be positioned and held. The inner container **10** is preferably composed of a high strength, high modulus structural material such as steel, titanium, beryllium or the like. If weight considerations are important, the container **10** may be composed of a high strength-to-density and high modulus-to-density material such as a filament-wound plastic, isotropic or composite metal. At the same time, it is to be understood that in certain instances the object to be protected may itself be of such a nature and configuration that it will be amenable to being directly supported within the protective device of the invention without the necessity for any other container. This is particularly so where the outer surface of the object is regular as in the form of a cylinder.

Spaced from and positioned about the exterior of the container **10** is the outer ring or hoop **11** which, like the container **10**, is preferably composed of high strength, high modulus aluminum, titanium or steel. Again, when weight is an important consideration, the supporting ring **11** may be composed of a uni-directional filament wound plastic composite material of the type for example having properties which include a density of 135 pounds per cubic foot, a hoop tensile strength of 280,000 pounds per square inch, an elastic modulus of 7,400,000 pounds per square inch and a horizontal shear strength of 12,700 pounds per square inch based upon a twelve end S–HTS glass roving manufactured and sold under that designation by the Owens-Corning Fiberglas Corp. of Toledo, Ohio, and a thirteen percent resin mixture prepared from 100 parts by weight of epichlorohydrin/bisphenol A type epoxy resin, twenty parts by weight of diaminodiphenyl sulfone, and 1.5 parts by weight of boron trifluoride-monoethylamine complex.

In the preferred embodiment illustrated in FIGURE 1, the outer member **11** is in the form of a ring, the inside diameter of which is substantially larger than the outside diameter of the container **10** so as to provide for a spacing between the two when they are concentrically arranged. The width of such rings may vary over a wide range, but in all cases it should be adequate to accommodate the volume of continuous filament windings to connect the ring to the inner container **10** as hereinafter described. The thickness of the ring structures is adjusted according to the bending moment required of the particular section of the cylinder being considered. The outside surface of the rings **11** is preferably rounded so that the filaments ultimately to be overlaid thereon will not encounter sharp edges and be subject to breakage. Depending upon the size and shape of the object to be protected and/or of the inner container **10** therefor, a plurality of outer circumferential rings **11** may be positioned at spaced points along the axis of the container, each of which will have substantially the same relationship to the portion of the container surrounded by it as does the ring shown in FIGURE 1.

In the manufacture or assembly of the container illustrated in FIGURE 1, the ring **11** (and each of such additional rings as are positioned axially of the container) may be rigidly yet temporarily affixed to the container wall by means of spacing devices or materials such as the spacer designated generally by the number **13** to hold the container **10** and the outer rings **11** in their concentric and radially spaced relationship during the application of the filament windings **12**. A variety of such spacers are saftisfactory for thus establishing the relationship between the container **10** and the ring **11**, and they may or may not be such as can be subsequently removed after the filament winding **12** has been applied and before the structure is placed in use. One form of such a spacer which can be removed after the filament winding is completed is shown in FIGURE 2 to be in the form of a threaded jack member comprising the shoes **14** and **15**, one of which has a threaded projection **16** engaging a member **17** having a threaded opening therein and affixed to the other. The distance between the outwardly disposed surfaces of the respective shoes **14** and **15** may then be varied by turning the threaded member **16** in the threaded opening **17** so that, when the outwardly disposed surface of the shoe **14** bears against the container and the outwardly disposed surface of the shoe **15** bears against the ring, the container and the ring will be held apart by the desired distance. Other types of removable mechanical spacers may be in the form of break-out-type cardboard sandwiches, collapsible aluminum or other metal segments; and, in all cases, the width of the spacer or at least of that portion thereof contacting the container and rings should be substantially equal to but preferably nominally less than the width of the rings employed as illustrated in FIGURE 2.

Another type of spacer may be that as illustrated in FIGURE 3 wherein the wall of the container **18**, the outer ring **19** and the filament winding **20** correspond to the members designated by the numbers **10**, **11** and **12** respectively of FIGURES 1 and 2. In the embodiment of FIGURE 3 however, the spacing member **21** is shown to be in the form of a solid material; and, depending upon the characteristics of the material, it also may be designed either for removal after the filament winding is completed and before the device is put in use or to remain in place while the device is in use. Where it is desired that the solid spacer be removed prior to service, it may be composed of a material that can be leached out by water or another solvent after completion of the filament winding operation; and such materials include inorganic salts such as an alkali nitrate or an alkali nitrite eutectic mixture (such as that manufactured and sold under the proprietary designation "Paraplast 33" by the Rezolin Corporation of Santa Monica, Calif.), a sand filled water-soluble polyvinyl alcohol resin binder or a gypsum-based water-soluble plaster (such as that sold under the proprietary name of Duplitool by the Kirkhill Rubber Co. of Brea, Calif.). On the other hand, low density foams and composites or inflatable elastomeric bags, either segmented or in cylindrical shapes may be employed as solid spacers which can either be removed after the filament winding operation is completed or left in place while the device is in use with little weight penalty or interference with the inter-related movement and load distribution of the assembled components.

While the solid spacers, like the ring members **11** and **19** may be pre-formed before their association with the assembly of components, they may be formed in place by the following illustrative procedure. Referring to FIGURE 3, the container **18** is covered with a water-soluble leachable spacer material along the entire axial length of the container and in a thickness equal to the ultimately desired spacing between the container wall and the inner surface of the outer ring **19**. A continuous cylindrical shell of a material which is desired for the formation of the rings **19** is then positioned or fabricated on top of the spacer material along the entire axial length of the container. The individual rings **19** and the solid annuli **21** of the spacer material are thus formed by machining out in a direction perpendicular to the cylindrical axis of the container the unwanted material.

Regardless of the manner in which they are thus temporarily or permanently held relative to the container or the object to be protected by the structure, the individual rings are thereupon permanently though not rigidly affixed to the inner container or the object by means of a continuous element in the form of a strand, one or more filaments, a roving, yarn or wire. High strength and high elastic modulus filaments in continuous form which have been found particularly satisfactory for such use include those having an oxide composition such as "S-Glass" manufactured and sold under that proprietary name by the Owens-Corning Fiberglas Corp. of Toledo, Ohio, a metallic composition such as "Chromel R" manufactured and sold under that name by Hoskins Manufacturing Co. of Detroit, Mich., 304-stainless steel of the type manufactured and sold by the American Steel Wire Division of the United States Steel Corporation of Pittsburgh, Pa., or beryllium or a ceramic-metal composition such as boron overcoated on a tungsten wire substrate such as is available from the United Aircraft Corporation of East Hartford, Conn. As indicated, the continuous strands may be in the form of a single or a group of filaments, a twisted yarn of multiple filaments or fibers or a yarn composed of filaments and/or fibers of different compositions and materials, all of which are referred to as continuous filamentous materials.

The filament winding may be accomplished by mounting the assembly of the container, rings and spacers such as shown in FIGURES 2 and 3 upon a supporting and winding arm which can be successively rotated through 360 degrees and moved back and forth axially of the arm. As best shown in FIGURE 3, the strand **20** of the filamentous material is anchored at its end **22** to a point on the outside of the cylindrical wall of the container **18** by conventional mechanical or adhesive means such as glue. The filamentous strand is then positioned generally perpendicular to the axis of the container **18** and the arm upon which the container is mounted is rotated so that the container itself rotates. After about a three-quarters turn of the rotating arm, the incoming filamentous material, which is disposed in a generally perpendicular relationship to the cylinder axis, is moved laterally across the width of the ring as shown at **23**, for example, either by a slight axial movement of the arm or by movement of the filament feeding apparatus as a result of which the filament will cross diagonally about the outer surface of the ring **19** as at **23** and down along the opposite side thereof. The arm is then rotated through one or more turns to wind the strand circumferentially about the container wall one or more times to deposit a layer of the filament thereon. Thereafter, the filament may again be crossed diagonally over the width of the ring, as for example by a reverse axial movement of the arm, so that it will again pass diagonally across the outer surface of the ring **19** as at **24** thereby intersecting the first diagonal traverse of the filament **23** and forming a general *x*-pattern with the filamentous material touching only at the mid-point **25** of the cross-over. This process may then be repeated with each succeeding filament or bundle being deposited in closely spaced or contiguous succession circumferentially of the container and ring as shown in FIGURE 4. After the desired amount of the filamentous material has been thus applied, the end of the continuous filament may be affixed to the container wall in the same manner as its other end was so affixed at the commencement of the winding operation. Where desired and where the spacer material is of such a nature, the spacers may then be removed from their interposition between the container and the ring; and these components will thereupon be held in their desired relative positions solely by and under the influence of the continuous filament windings.

In lieu of thus mounting and rotating the container, it will be understood that conventional filament winding equipment and processes may be used to associate the continuous filament with the components either manually or by the use of filament feeding creels placed in motion about the container and ring. To assure proper and positive maintenance of the relationship between the filaments and the container and ring components, it is preferred that the filament be maintained under tension while it is being so wound.

In a preferred modification of the invention, organic resins or adhesives are applied to the filamentous material, either throughout or at various pre-determined portions along its length, to prevent or minimize slippage thereof along or around the container and ring components and to provide points of attachment for the filamentous material betwen the rings and container wall at those points where it comes in contact with them. Either liquid resins or so-called "B-Staged" resin-impregnated filamentous material may be used, with the deposition of the resin upon the filament being accomplished by standard filament treating processes such as are involved in the preparation of rovings. In one specific example of such a modification, the filamentous material is manufactured and sold under the proprietary designation "Poly-Preg EF–787/S–994" by U.S. Polymeric Chemicals, Inc. of Santa Ana, Calif., which is an S–994 glass filament coated with an epoxy resin. This material has sufficient tack to remain in place during the winding operation after which it can be hardened to a rigid material by the application of heat in accordance with the manufacturer's recommendations to ring-stiffen the container wall. As an alternative to the use of the B-Staged resin-impregnated filaments, a liquid resin or liquid adhesive filament winding process may be employed. According to established practices, the filaments are first immersed in a liquid bath of the resin or adhesive and are then laid down on the container and ring in the manner above described. Such a resin bath may be composed of 100 parts by weight of epichlorohydrin bisphenol A epoxy (such as that sold under the proprietary designation Epon 828, by the Shell Chemical Company of Union, N.J.), 50 parts by weight of an aromatic amine curing agent (such as Epon Curing Agent RTH sold under that designation by the Shell Chemical Company) and five parts by weight of an accelerator (such as Epon Accelerator RTA sold by the Shell Chemical Company). Where the resin is to be applied only at pre-determined portions of the length of the continuous filament such as only at those portions which are ultimately to be in contact with the ring or container walls of the assembly, the deposition of the liquid resin upon the filament may be accomplished by the intermittent contact between the filament and an applicator such as a brush or roller.

In many instances, depending of course upon the environmental factors expected to be encountered, it is preferred that the protective assembly according to the present invention shall also comprise an external shell **26** of an appropriate structural material. As shown in FIGURE 5, such a shell may be associated with the container **27**, the laterally spaced rings **28** and **29**, and the filament windings **30** by affixation to the outer surface of the rings **28** and **29** at the points where they and such other similar rings as may be employed contact the shell. The type and thickness of the material of the structural shell should be such that the externally applied load it is expected to receive will be transmitted into the filament supported unit. Isotropic metals such as aluminum, steel, titanium and others are satisfactory shell materials for applications involving very high bending moments. As a further modification of the invention, where a plurality of axially or laterally spaced ring elements such as **28** and **29** are employed, the same may be joined and held in their axially spaced position by rigid stringers **31** extending longitudinally of the assembly between and affixed to the successive ring members to minimize their axial movement during loading and to resist bending and buckling forces. In such a case, the protective shell **26** may be of a relatively thin walled construction with attendant gains in weight reduction.

In certain other applications it may be desirable to provide extra thermal protection to the exterior structural wall to safeguard it and the contents of the container against intensive convective, radiative or combined forms of heating. In such a case, the outer shell **26** may be composed of or coated with a variety of ablative plastics and composites, particularly those of fiber reinforced charring resins such as a phenol formaldehyde or an epoxy novolac matric reinforced with bi-directional or three-dimensional woven fabric or fibrous constructions composed of filaments, yarns, or fibers of such materials as carbon, graphite, quartz, silica, glass, asbestos or the like. Where intense optically radiative heating is to be encountered, opaque fillers such as graphite or carbon powder may be dispersed in the resin matrix to prevent the transfer of radiant energy into the sacrificial ablative plastic material. In lieu of forming the structural shell of such ablative materials or of bonding or otherwise applying a coating thereof to a metallic shell as a substrate, the material may be wrapped about the shell in successive layers of the resin coated or resin-impregnated fabric. In certain applications, it may be desired to employ a thin elastomeric adhesive or layer between the external heat shield and the underlying structural shell.

As a demonstration of the outstanding advantages obtainable by the use of tension filament structures according to the present invention, a number of embodiments thereof have been subjected to mechanical shocking and high rate loading conditions; and in all cases the mechanically sensitive articles contained within the inner container have survived intact even though the external members experienced irreversible structural damage.

While the within invention has been described in detail in connection with certain specific examples and embodiments thereof, it is to be understood that the foregoing particularization has been for the purpose of illustration only and does not limit the scope of the invention.

We claim:

1. An ultra-lightweight high impact resistant protective container assembly comprising an inner cylindrical-walled container, at least one annular member surrounding and spaced from said container and at least one continuous filament winding anchored at one of its ends to a point on the wall of said container passing outwardly therefrom and across the outwardly disposed surface of said annular member and back to and around the wall of said container to which it is anchored at its other end, said filament winding comprising the sole connecting link between the said container and said annular member.

2. A container assembly according to claim **1** wherein said container also comprises an outer shell overlying and affixed to the outer surface of said annular member.

3. A container assembly according to claim **1** comprising a plurality of laterally spaced annular members about said container, at least some of which are held in their spaced position relative to each other by rigid stringer members extending between them and affixed thereto.

4. A container assembly according to claim **3** comprising a relatively thin-walled outer shell overlying and affixed to the outer surfaces of said annular members.

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