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June 28, 1966 R. B. REID 3,257,803

THERMAL BOUNDARY CONSTRUCTION

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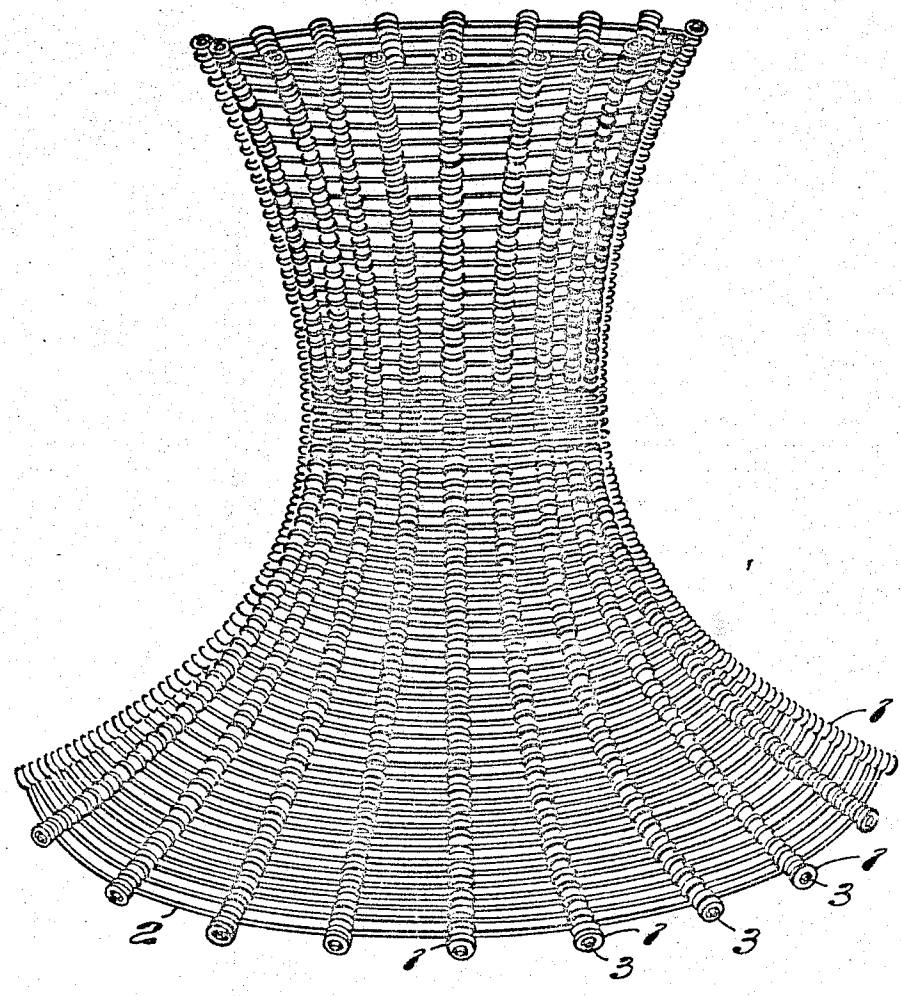


Fig. 1

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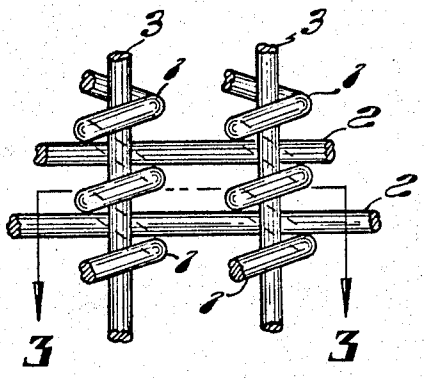


Fig. 2

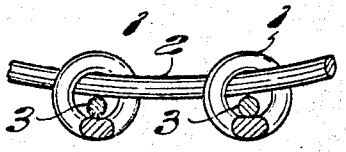


Fig. 3

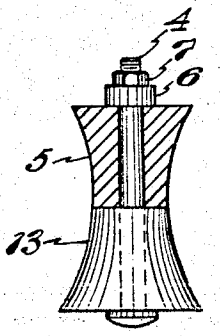


Fig. 4

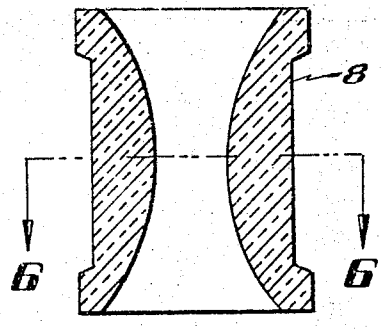


Fig. 5

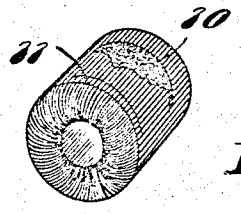


Fig. 8

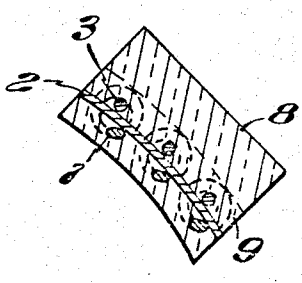


Fig. 7

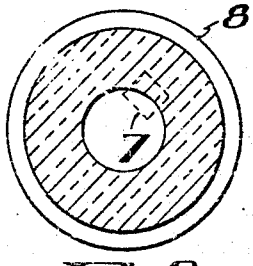


Fig. 6

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United States Patent Office 3,257,803 Patented June 28, 1966

3,257,803

THERMAL BOUNDARY CONSTRUCTION

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3 Claims. (Cl. 60—35.6)

My invention relates to thermal boundary constructions, and particularly to a novel plexus and an improved wall structure made therefrom for sustaining a high thermal gradient between a region of high temperature and a region of low temperature. While various applications are detailed below, and still others will be suggested by my description, my invention is most immediately applicable to the construction of rocket nozzles, in which an incandescent and corrosive gas, at temperatures currently in the order of 7000° F., must be accurately bounded and thermally shielded from the body of the rocket, missile or other vehicle propelled by the rocket.

The requirements for a successful rocket nozzle are readily stated; it must be physically strong, resistant to thermal shock, and have an aerodynamically smooth, dimensionally stable contour which is not eroded by the flaming gases which pass through it. They are not so easily met. So far as I am aware, prior to my invention, the attempts to meet these requirements have been directed at a compromise favoring some of the requirements at the expense of others. On the one hand, there have been developed ceramic and refractory materials of extremely high melting point and low heat transfer coefficient, which can be formed into efficient aerodynamic surfaces and are little affected by combustion products at flame temperatures. As is well known, such materials are physically weak, and are readily fragmented by thermal shock. On the other hand, high melting-point metals such as tungsten have been machined into nozzles which are smooth, strong, and resistant to thermal shock. Such nozzles, however, are somewhat erodible in a flame, have a high heat transfer coefficient, and are more or less susceptible to thermal warping and metallurgical changes at the high temperatures encountered in a rocket nozzle. Moreover, as the art is well aware, tungsten nozzles are undesirably heavy and exhorbitantly expensive, as well as being so difficult to machine that, assuming that a small model of a desired configuration has been built and tested, it cannot be scaled up to production size without a major engineering effort. Thus, the prior attempts to solve the problem of rocket design have not been entirely successful, and a solution which would avoid the difficulties previously encountered would be of substantial benefit to the art. My invention is primarly directed to the attainment of such a solution.

My invention is based on the discovery that a thermal boundary meeting all of the above requirements can be constructed by embedding connected filaments of thermally conductive, physically strong material in a refractory insulating material which has an inert, aerodynamically smooth surface and which is sufficiently massive to make the net heat transfer coefficient low. I have found that the dimensional stability of such a structure is much greater than has previously been obtained with a conductive material, while the susceptibility to thermal shock will be far less than that encountered with a non-conductive material. This structure can be manufactured by conventional techniques, and can be scaled to various sizes without significant tooling changes. Moreover, the construction of my invention is light in weight, compared with solid metal structures, and physically small, compared to ceramic structures of similar strength.

Briefly described, in accordance with a preferred embodiment thereof, a three-part thermal boundary in accordance with my invention comprises first a superstructure, consisting of a relatively massive member of relatively high heat capacity and relatively low thermal conductivity, such as graphite or the like, secondly a plexus comprising filaments of relatively strong, thermally conductive material such as tungsten or the like overlying the massive member on at least the side toward the thermal boundary, and thirdly a refractory material, which may be the same or a different material than the massive member, permeating the interstices between the plexus and the massive member and covering the plexus to form a gas-contacting surface. In accordance with a preferred embodiment of my invention, the plexus is formed from tungsten wire, by disposing a plurality of elongated helical coils of wire on a mandrel having a shape complementary to the shape of the gas contacting surface to be formed, and winding wire over the mandrel transversely of the elongated coils to form a flexible filamentary network. The completed plexus is placed on a form of graphite or the like, which conforms to the shape of the desired surface. A refractory material is then coated over the plexus, covering it and filling the interstices between the wires and the form, as by spraying the coating material in a plasma flame. If desired, fusing treatment can be applied to the refractory coating so formed to increase its density and surface smoothness, and improve the bond to the form.

My invention will best be understood by reference to the accompanying drawings, and the following detailed description, of various embodiments thereof.

In the drawings,

FIGURE 1 is a perspective sketch of a hyperboloidal plexus in accordance with a first embodiment of my invention;

FIGURE 2 is a fragmentary and enlarged detail view of a portion of the plexus of FIG. 1;

FIGURE 3 is a plan view, partly in cross section, taken along lines III—III in FIG. 2;

FIGURE 4 is an elevational view, partly in cross section, of a mandrel used in making the plexus of FIG. 1;

FIGURE 5 is a cross-sectional elevation of a toroidal form adapted to be combined with the plexus of FIG. 1 to form a rocket nozzle;

FIGURE 6 is a cross-sectional plan view taken along lines VI—VI of FIG. 6;

FIGURE 7 is an enlarged view of a portion of FIG. 6 in the area indicated by the dotted line VII, showing details of the wall structure of a completed rocket nozzle in accordance with my invention; and

FIGURE 8 is a perspective sketch of a partially completed rocket nozzle in accordance with a second embodiment of my invention.

Referring now to FIGURE 1, a preferred form of the novel plexus of my invention comprises a series of elongated coils 1 of a strong, conductive, high-melting material, which may, for example, be tungsten wire, and preferably a cleaned and annealed grade of tungsten wire such as NS55, as made by Sylvania Electric Products, Inc. The diameter of the wire should be relatively small compared to the size of the plexus. Such wire may be wound on standard tungsten wire coiling machines, to form resilient elongated coils of suitable shape for use as ribs in the plexus.

As shown, for the hyperboloidal plexus illustrated, the coils 1 are arrayed to form ribs along the hyperbolic contours of the plexus, and are secured together by a transverse strand, here shown as a single strand 2 wound about the coils and secured to the coils at the intersections by locking wires 3, to be described. For simplicity of illustration, the details of the means for interconnecting the coils 1 and strand 2 have not been shown in FIG. 1, but will be made clear below by reference to FIG. 2.

In practice, the plexus is formed by placing the coils 1 on a mandrel, such as that shown in FIG. 4. This mandrel may comprise a lower form 13 having an upstanding stud 4 which passes through a corresponding aperture in an upper form 5, shown in cross section. The upper and lower forms may be secured together by a washer 6 fastened by a nut 7 threaded on stud 4. The coils may be temporarily secured to the form by taping, tying, or other suitable means, and the transverse strand 2 is then wound over the form. Strand 2 may be secured at the ends by a turn around one of the coils, or by a weld or other suitable means. It could be similarly secured at each intersection with a coil, but a simpler means resulting in a more flexible plexus is shown in FIGURES 2 and 3. As there shown, each intersectoin between coils 1 and transverse strand 2 is secured by a strand 3 of wire passed down the center of the coils and overlying the transverse strand 2. In many instances, it may not be necessary to extend locking strands 3 the full length of the coils 1; it may be sufficient to lock the network only at the upper and lower ends.

When the plexus is completed, the mandrel may be removed by removing nut 7 and washer 6, and then separating upper form 5 from lower form 3.

The completed plexus is next placed on a form consisting of a relatively massive member of refractory material that will serve as an insulator in the finished rocket nozzle. A typical form is shown at 8 in FIGURES 5 and 6. This form may be made of any suitable material, such as boron nitride, pyrolytic graphite, silicon carbide, thorium oxide, or the like. As shown, it will typically have a throat portion smaller than the entrance and exit portions, and in some instances the diameter of the throat portion may be sufficiently close to the diameter of the entrance and exit portions that the plexus, which is quite flexible, may be distorted enough to slip it into place without permanent deformation or damage. If not, the member 8 may be divided into sections and later secured by fusion, or by an external band or the like, or the plexus may be made in two portions, which can be joined together, after placing on the form, by a few turns of wire.

After the plexus has been placed on the form 8, it is coated with a refractory material, which is preferably the same material as the form 8, but which may be of another material. Various materials suitable for the purpose are hafnium carbide, titanium boride, tantalum carbide, boron nitride, titanium carbide, and solid solutions of hafnium and tantalum carbide, in powdered form. Since these refractory materials are among the highest melting-point substances known, they are most conveniently applied by spraying the powder in a plasma flame; that is, a high intensity discharge in an ionized gas. Apparatus for plasma flame spraying is known in the art, and is commercially available. Thus, since the spraying apparatus itself does not form a part of my invention, it will not be described in detail.

Other methods of applying the refractory coating to the plexus can also be employed, if desired, without departing from the scope of my invention. For example, a paste may be formed from the refractory powder and water or another suitable dispersant, and this paste may be molded into place on the plexus and then baked to remove the dispersant and finally fused to form a continuous refractory matrix.

It is not necessary, in the practice of my invention, to apply the refractory coating to the pluxus while in place on the refractory form. Thus, if desired, the coating could be molded or flame-sprayed on the plexus, and later secured to the refractory form, without departing from the scope of my invention in its broader aspects. If the coating is molded on, the desired surface finish can be formed during molding. If flame spraying is employed, an additional surface forming step, such as grinding, lapping or machining may be desirable, depending on the closeness of spacing of the wires and the desired surface

finish. To eliminate grinding or machining, it is possible to plasma spray the high melting materials onto a highly polished or machine cut brass mandrel. The tungsten superstructure may now be wound over the layer of sprayed material and the process repeated to obtain as many layers and combinations as is desired. The brass mandrel may then be chemically dissolved leaving a highly polished interior.

In operation, the particular embodiment of my invention just described has a number of important advantages. The coil form of the ribs of the plexus gives depth to the plexus without adding appreciably to its weight or rigidity and in fact makes the plexus more flexible. Flexibility of the plexus is important, since a flexible plexus will not impart any stresses due to thermal distortion. The depth of the plexus makes for a uniform distribution of heat throughout the hottest portion of the wall, and prevents large thermal gradients, which might cause fragmentation of the refractory, from existing in the outer layer. Any tendency toward the propagation of thermally induced cracks in the refractory is resisted by the high tensile strength of the filaments of metal in the plexus. At the same time, the refractory wall surface presents a smooth, unreactive surface of low thermal conductivity to the corrosive gas stream, and the massive form of refractory material backing up the plexus makes is possible to sustain an extremely high thermal gradient between the gas stream and the surrounding structure of the rocket and the missile which carries it.

Many of the advantages of my invention can be obtained by a simpler construction, of the type illustrated in FIG. 8. As there schematically shown, an interconnected filamentary substrate of tungsten wires 10 can be laid over a refractory form 11, which may correspond in shape and construction to form 8 in FIG. 5, by simply winding a strand of wire over the form with a conventional torodial coil winding machine. While, for the sake of simplicity, only a few turns of the strand 10 have been shown, in practice enough turns would be used to form a toroidal coil of two or more layers over the form. The coil would then be coated with refractory material in the same manner as described above for the first embodiment.

While I have described my invention as particularly applicable to rocket nozzles and the like, it will be apparent to those skilled in the art that the invention can be applied to any wall structure which is required to support a high thermal gradient and that it is particularly applicable in any structure required to separate an incandescent corrosive gas from a region which must be maintained at a low temperature. For example, it will be apparent that my invention has application to the construction of outer walls for reentrant missiles, nose cones and the like, and to the construction of crucibles and other containers for molten, high melting point materials.

After reading my description, it will be apparent to those skilled in the art that many changes and variations from the detailed embodiments shown are possible without departing from the scope of my invention.

Having thus described my invention, what I claim is:

1. A rocket nozzle, comprising an annular form of pyrolytic graphite, a plexus of tungsten filaments within said annular form, and a coating of tantalum carbide embedding said filaments and bonded to said form.

2. A heat and corrosion resistant wall, comprising, in combination, a metal plexus embedded in a refractory material, said plexus comprising a plurality of elongated helical coils of wire in a non-intersecting array defining a surface, transverse strands of wire intersecting said coils, and locking strands of wire disposed within said coils, and overlying said transverse strands to secure them to the coils.

3. A self-supporting wire plexus comprising a series of ribs of elongated helical coils of refractory wire held together along the approximate surface of a concave surface of revolution by wires wound transversely around the

coils on the same approximate surface of revolution and in which the transversely wound wires are held to the coils by wires passing through the center of the coils and overlying said transversely wound wires.

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