United States Patent [19]

Bayliss

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[11] **3,913,666**

[45] **Oct. 21, 1975**

[54] **HEAT RESISTANT WALL CONSTRUCTION**

[76] Inventor: **Peter Bayliss,** 10 Idalia Court, San Anselmo, Calif. 94960

[22] Filed: **Mar. 20, 1972**

[21] Appl. No.: **236,274**

[52] **U.S. Cl.** **165/106;** 60/204; 60/265; 60/266; 62/467; 138/178; 161/169; 165/185; 239/265.15

[51] **Int. Cl.** **F02k 11/00**

[58] **Field of Search** 165/106; 60/265, 266, 267, 60/204; 239/265.11, 265.15; 161/69, 142, 143, 168, 169; 138/177, 178; 62/467

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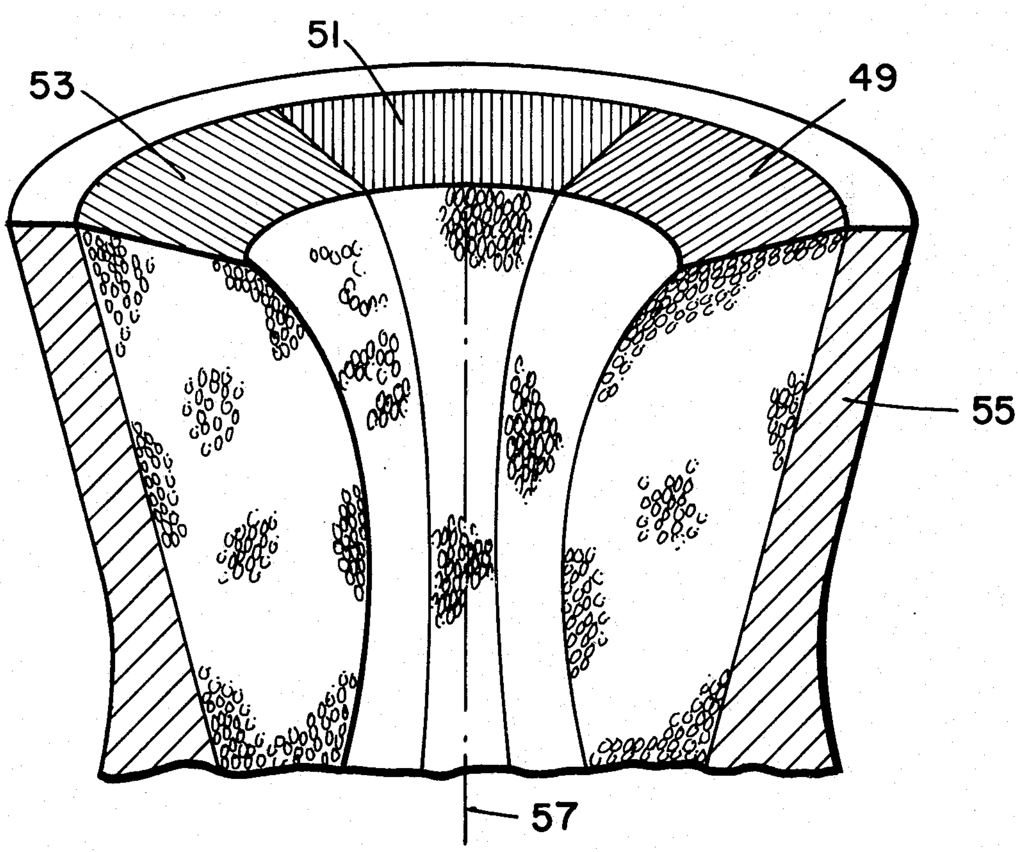
Primary Examiner—Albert W. Davis, Jr.
Assistant Examiner—S. J. Richter
Attorney, Agent, or Firm—Limbach, Limbach & Sutton

[57] **ABSTRACT**

A technique of constructing a heat resistive wall with uni-directional quills, such as fibers, wherein a heat resistant surface is formed by the ends of the quills. The structure is formed of a plurality of groups of a large number of quills each. The large number of quills of each group are held together in a parallel relationship by a matrix with substantially no cross fibers. Each group of fibers is oriented with respect to the surface so that at least one quill of each group is perpendicular to the surface in a given direction.

10 Claims, 10 Drawing Figures



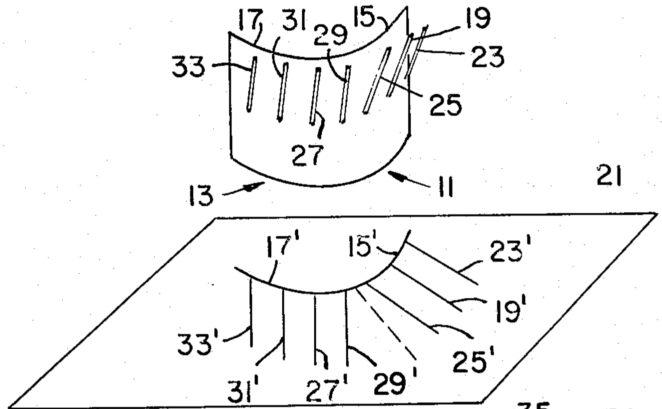


FIG_1

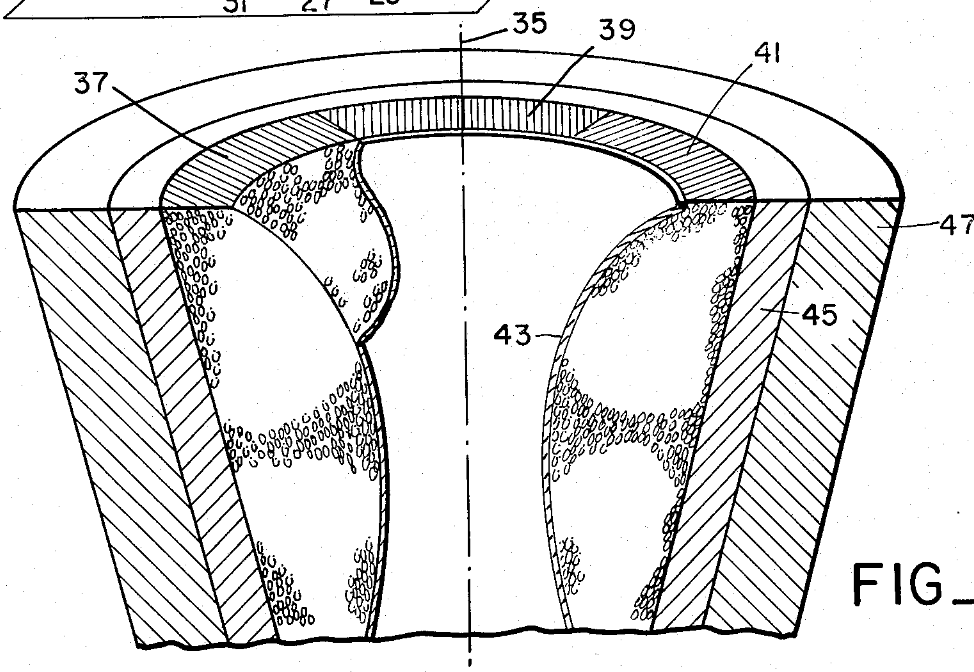


FIG_2

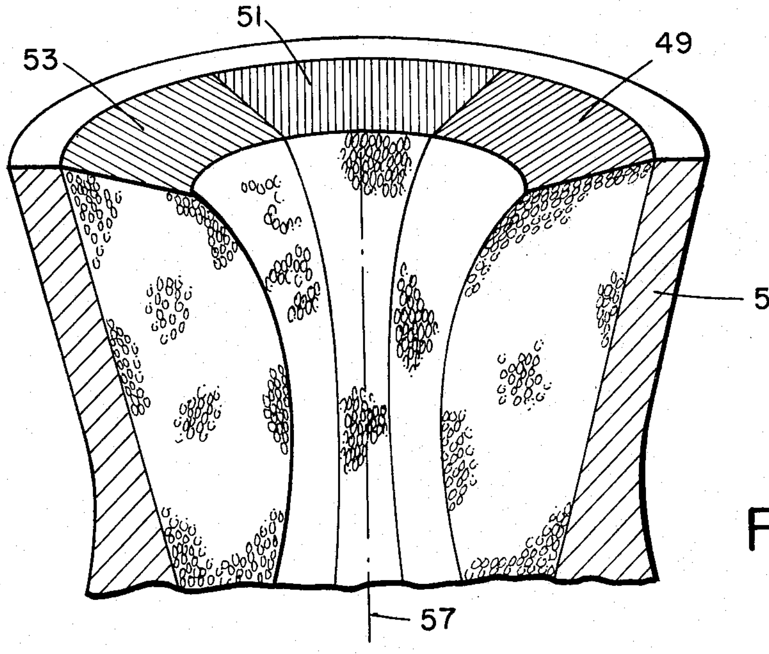


FIG_3

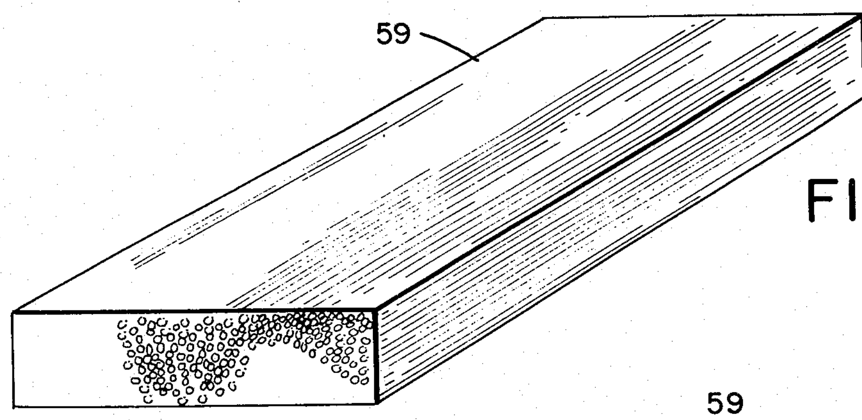


FIG_4

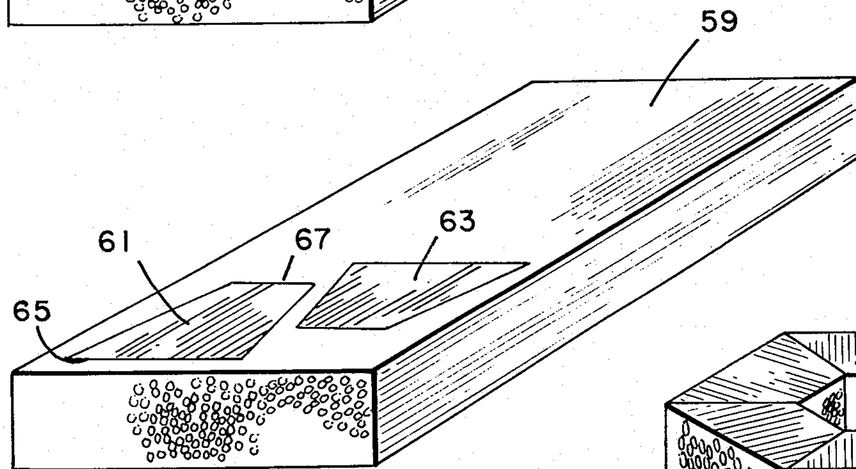


FIG_5

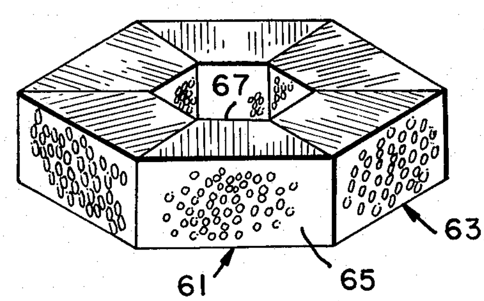


FIG_6

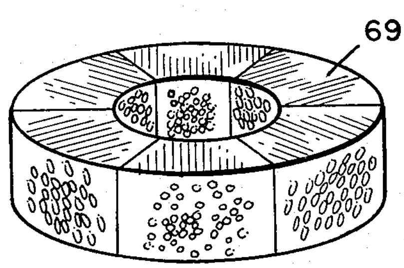


FIG_7

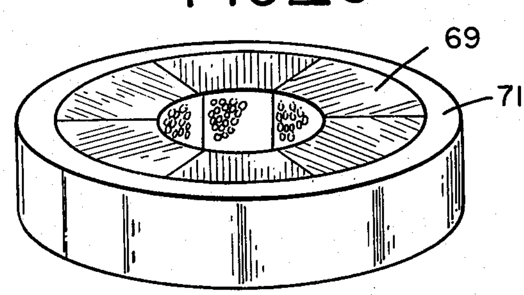


FIG_8

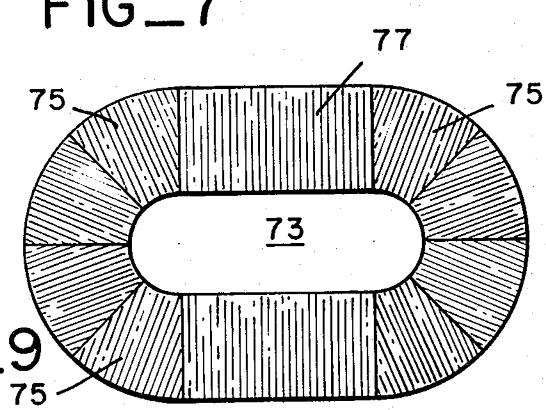


FIG_9

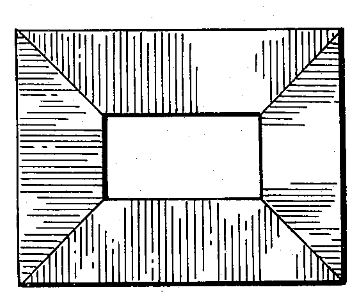


FIG_10

HEAT RESISTANT WALL CONSTRUCTION

BACKGROUND OF THE INVENTION

The present invention relates generally to structures having distinct properties in orthogonal directions, and more specifically to such structures made of uni-directional fibers, rods, tubes or tapes.

The general use of fibrous or filamentary elements to construct structures for various applications is widespread. One such application is in the forming of heat resistant structures used, for example, as rocket nozzles or as missile nose tips. Conventional techniques for nozzle contruction utilize bi-directional fabric sheets which are wrapped or otherwise formed into the desired structure. Conventional nose tips are similar except they often utilize structures woven three-dimensionally and hence the fibers are not uniformly spaced with respect to a receding section in the wall. A disadvantage of these techniques is that the uni-directional properties of the fibers are not utilized to their fullest.

Therefore, it is a primary object of the present invention to provide an arrangement of uni-directional fibers of similar elements to improve the properties of such structures.

SUMMARY OF THE INVENTION

Briefly, this and additional objects are accomplished by the techniques of the present invention wherein a structure is formed of a large number of quills extending away from a heat resistant surface in a plurality of groups (bundles) of quills, each group (bundle) having a very large number of parallel quills that are oriented with respect to the heat resisting surface so that at least one quill thereof is substantially perpendicular to the surface in at least one direction at its point of intersection therewith. The surface area contributed by the ends of each group of quills is kept small relative to the degree of curvature of the heat resistive surface formed thereby so that all of the quills of each group are generally perpendicular to the surface. Each group of quills is held closely together by an appropriate matrix, such as a thermosetting resin, a graphite or a carbon with substantially no cross fibers or quills extending in a direction perpendicular to the quills. The heat resistive surface may merely be the exposed ends of the quills of each group or these ends may form a substrate over which a layer of material having particular characteristics for a given application may be coated.

The term "quill" as used herein is meant to refer in general to any narrow, elongated element having uni-directional properties along its length. The arrangement of quills according to the techniques of the present invention makes a maximum use of these uni-directional properties, such as their thermal, mechanical and chemical properties. Examples of particular materials for the combination of quills and a surrounding matrix include graphite fibers in a graphite matrix, the fibers being either solid or hollow; carbon or quartz fibers in a phenolic matrix; pyrolytic graphite coated tungsten wire fibers in a pyrolized, graphitized or vapor deposited matrix; or pyrolytic graphite coated on carbon or graphite fibers in an ablative resin, or carbon or graphite matrix. The possibilities of materials are numerous and the techniques of the present invention are not limited to any particular composite materials.

There are several important advantages of the general structure according to the technique. of the present invention. Primarily, the quill density (number of quills per unit cross-sectional area) is uniform throughout the structure at various distances away from the heat resistive surface. Therefore, the heat conduction or ablative property of the structure can be made the same throughout the depth of the structure. At the same time, by bundling the fibers into groups having a small cross-sectional area in relationship to the contour of the heat resistive surface formed thereby provides all of the advantages of having the quills perpendicular to the surface since in fact all of the quills are generally oriented with repsect to the surface in that direction. There are substantially no cross fibers, except as may be expedient for practical handling, holding the quills together and thus the quills can be placed immediately adjacent to each other without any significant space therebetween or the quills may be spaced as desired without being restricted by cross fibers. The elimination of the necessity of cross fibers also eliminates one source of failure of present bi-directional fabric structures wherein the fibers break at their crossing points. By placing the parallel quills together without significant space therebetween, the quill concentration at the heat resistive surface is maximized, even as it erodes into the structure. By forming the quills in individual structural groups, any splitting that may occur on thermal or mechanical expansion or contraction of the structure will generally be limited to a pattern not detrimental to any of the preferred fiber properties and without the detrimental design effects of damaged, stressed or broken fibers.

The preferred technique for constructing such a structure includes first the formation of one or more blocks of parallel quills in a matrix. The block is then cut into various desired shapes to form each individual bundle (group) of quills. The bundles are then assembled together in a rigid manner and the resulting composite structure is machined in order to form the desired surface shapes. In some cases, the block need not first be formed but rather bundles of quills may be formed directly. The quills can even be pre-coated with a matrix material. If a fusible plastic is used for the matrix, the bundles of fibers may be cured after being assembled together, thereby providing a convenient means of adhering the bundles to one another. Alternatively, a secondary bonding or structural shell is used to effect the final composite structure shape. No cross fibers holding the quills together are provided except for perhaps a few to make their handling easier but not as a necessary part of the bundle structure.

Additional objects and advantages of the present invention will become apparent from the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram showing quill orientation according to the techniques of the present invention;

FIG. 2 is a cross-sectional view of one example of a structural member (solid of revolution) made according with the techniques of the present invention;

FIG. 3 is a cross-sectional view of another example of a structural element (solid of revolution) made according to the techniques of the present invention;

FIGS. 4–8 illustrate the sequential steps in the method of forming structures such as those shown in FIGS. 2 and 3;

FIG. 9 shows in plan view yet another specific example of a structure made in accordance with the techniques of the present invention; and

FIG. 10 shows in plan view still another specific example of a structure made in accordance with the techniques of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Various aspects of the present invention may be observed by reference to the simplified schematic diagram of a quill wall structure of FIG. 1. Two bundles (groups) **11** and **13** of quills held together by a matrix form sections **15** and **17**, respectively, of a curved heat resistant surface. Only these surfaces as well as a very few of the many quills of each of the bundles **11** and **13** are shown. Each of the bundles **11** and **13** are, of course, three-dimensional, solid blocks that are adhered to each other. The bundle **11** includes a quill **19** that is perpendicular to the surface **15** at its point of intersection in one direction along the surface **15.** This direction along which perpendicularity is established is parallel with an imaginary plane **21** upon which projections of the structure of the bundles **11** and **13** are shown with corresponding elements having the same reference characters but with a prime added thereto. The bundle **11** has a large number of additional quills therein, all being substantially parallel to the quill **19,** such as the quills **23** and **25** as shown. Because of the curvature of the heat resistive surface **15,** the quills **23** and **25** will not intersect the surface at a right angle but rather at some different angle depending on how far they are displaced from the quill **19.** In certain structures it is desired that all of the quills maintain a certain angle with respect to the surface **15** in a direction therealong other than the direction that is parallel to the imaginary plane **21.** This is also illustrated in the simplified diagram of FIG. **1** wherein each of the quills of the two bundles slope downwardly to the surface sections **15** and **17.**

The bundle **13** of quills similarly includes a large number of quills that are parallel to each other, at least one of which, such as the quill **27,** is perpendicular to the surface **17** in one direction thereacross parallel to the imaginary plane **21.** Other parallel quills such as quills **29, 31** and **33** of the bundle **13** will intersect the surface **17** at some angle other than a right angle in a direction parallel to the plane **21.** A construction utilizing a number of bundles of fibers has the advantage that the cross-sectional area of the bundle which is to become the heat resistive surface **17,** for instance, may be limited in size in a dimension parallel to the plane **21** so that none of the quills in that direction intersect the surface **17** with an angle that is very far removed from a right angle. The adjacent bundles **11** and **13** are joined together so that their respective parallel fibers form an acute angle with each other.

The heat resistive surfaces **15** and **17** of the quill bundles **11** and **13,** respectively, may merely be formed from the cross-sectional areas of the various quills and matrix material that terminate along the surfaces. Alternatively, for some applications, the exposed quill ends may serve as a substrate for a coating of an appropriate material. In this latter case, the structure is "heat resistive" in that it provides a means of supporting and maintaining a heat resistive coating in a manner not otherwise convenient. In either case, the quill density in the sense of spacing per unit area is the same at a distance behind the surfaces **15** and **17** as it is right on the surface because of the parallel relationship of the quills. This would not be the case if each of the quills were made to be perpendicular to the surfaces **15** and **17** in at least one direction since their spacing would then become a function of the distance from the surfaces **15** and **17.** The structure illustrated herein as part of the present invention still has the advantage of perpendicular quills, however, by making the bundles of quills individually small enough so that none of the quills deviates very far from a right angle intersection with the heat resistive surface to be established, at least in one direction such as that parallel with the imaginary plane **21.**

A particular application of the general aspects of the technique described with respect to FIG. **1** is shown in FIG. **2.** The structure of FIG. **2** shows a cross-section of a portion of a rocket nozzle including the throat choke and adjacent regions such as a throat inlet and an expansion cone zone. The same construction could also be used for entrance caps, throat approaches, nose pieces, inlets, etc. For the half of the rocket nozzle shown in FIG. **2,** three bundles **37, 39** and **41** of quills are provided immediately adjacent one another. Each of these bundles contains a large number of quills that are parallel to each other while remaining at an acute angle with the quills of the other bundles. At any plane perpendicular to a throat center line **35** and at any position therealong, there is at least one quill in each of the bundles **37, 39** and **41,** which is in a radial direction while the others parallel thereto in the respective bundles are non-radial by a slight amount. A radial quill is, of course, perpendicular to the interior throat surface while the non-radial quills are not perpendicular to the surface when projected onto a plane perpendicular to the center line **35.**

A surface formed by the ends of the quills within the center of the rocket nozzle of FIG. **2** is coated with an erosion resistant layer **43** of material. A preferred material for this coating is pyrolytic graphite. The quills within the bundles **37, 39** and **41** are preferably pyrolytic graphite coated fibers held together in a fully graphitized matrix. The primary function of the quill structure of FIG. **2** is to carry heat away from the erosion resistant coating **43** to keep it below that temperature above which it rapidly sublimes or ablates. For instance, the gases passed through the interior throat opening may be in the vicinity of 6,000° F. or more while the coating **43** must be kept at something in the order of 5,400° F. or less in order to prevent its rapid destruction by sublimation or ablation. The high density of quills that is possible with the techniques of the present invention, wherein their unilateral heat conduction properties are maximized, makes such operation possible. Surrounding the quill bundles **37, 39** and **41** is a shell **45** for conducting heat axially away from the outer ends of the quills within the bundles **37, 39** and **41.** Surrounding the shell **45** is yet another shell **47** which may serve as an external heat sink or an insulating shell and which may be a rigid structural element or a non-structural element, depending on the particular application.

In the embodiment of FIG. **2** wherein the heat conduction properties along the length of the quills is the most important, hollow fibers filled with a liquid, a liquefying solid, a subliming solid, or a gasifying liquid may be used in place of some or all of the solid quills described above with respect to FIG. **2.** The fluid moves between the ends of the hollow quill and thus aids in transferring heat from its high temperature end to its low temperature outer end.

Another advantage of the structure of FIG. **2** is in its axial properties (in a direction along the center line **35**). For instance, the uni-directional quill structure accommodates axial stresses better than a fabric or other bi-directional structure where low tensile or compressive modulus is required, such as in the substrates for pyrolytic graphite or refractory metal, oxide or carbide coatings.

In a rocket throat embodiment illustrated in FIG. **3,** bundles of quills **49, 51** and **53** are joined together within a solid supporting shell **55** to form a circular opening having a center extending along an axis **57.** In this embodiment, there is no coating along the inside circular opening but rather the ends of the quills themselves with their matrix are used to form the heat resistive surface. It is the resistance to ablation and/or irregular erosion of the quills or matrix that becomes the most important property in the structure of FIG. **3.** As the exposed quill ends and matrix erode away, the same quill to matrix area density is maintained along the heat resistive surface because of the parallel orientation of the quills within each of the bundles. The quills in the embodiment of FIG. **3** are preferably quartz, glass, silica, carbon or graphite fibers bound together in an appropriate resin such as an organic matrix.

In the embodiment of FIG. **3,** it will be noted that the quills form an acute angle with the axis **57** rather than being orthogonal therewith as in the embodiment of FIG. **2.** The quills may be oriented in a range from 5° angle with respect to the axis **57** to a 90° angle therewith. A projection of the quills on some plane that is perpendicular with the axis **57** will show one or more quills in each of the bundles **49, 51** and **53** to be along a radial line passing through the center axis **57** while the other quills of each bundle are parallel thereto are along a non-radial line.

Referring to FIGS. **4–8,** a preferred method of forming a structure, such as that of the specific examples of FIGS. **2** and **3,** is illustrated. In the first step, a block **59** is constructed by grouping a large number of quills closely together in a parallel relationship with each other. A matrix or binder is now or has already been applied which may be in a liquid or a solid form. The matrix of binder may be cured in the forming of the block **59** or curing may be postponed until a later step. Alternatively, a vapor deposited matrix may be infiltrated to effect the structure. The primary purpose of this step is to establish the quill spacing as desired in the final structure.

Referring to FIG. **5,** the next step is to cut from the block **59** a plurality of quill bundles, such as bundles **61** and **63,** each of which, in the very specific example being described, has a shape on two sides of a regular trapezoid. The bundle **61,** for instance, includes parallel end surfaces **65** and **67** that are each substantially perpendicular to the quills within the block **59.** The number of trapezoidal shaped bundles of quills that must be cut from the block **59** depends upon the shape of the trapezoid and specifically upon the angles that the sides joining the parallel sides **65** and **67** make therewith.

Referring to FIG. **6,** it can be seen that enough quill bundles are required to form a closed circle when several bundles are joined together at their angled sides. The specific angles of the angled sides with respect to the parallel sides such as **65** and **67** depend upon the number of such bundles that are desired to be used. The larger the number of bundles, the less deviation will exist of any quill from a radial line of the structure.

From FIG. **6,** it will be observed that the plurality of trapezoidal shaped bundles are fitted together and their angled sides are joined one to the other. This joining may be done by an adhesive if the matrix has already been cured or, alternatively, the bundles with an uncured matrix may be assembled and then the entire assembly cured by application of heat.

After the assembly indicated in FIG. **6** is complete, the inside surface (the shorter of the two parallel trapezoidal sides) and the outer surface (the longer of the two parallel trapezoidal sides) of each trapezoidal section are machined to form a circular shape as shown in FIG. **7.** The structure of FIG. **7** is then mated with an auxiliary structural or thermal effect sleeve **71,** to complete the structure as shown in FIG. **8.**

It should be noted that the thickness of the trapezoidal shaped quill bundles may be made equal to the total thickness of the desired structure, such as the entire thickness from top to bottom of the quill bundles **37,** 39 and **41** of FIG. **2.** Alternatively, the thickness of the trapezoidal shaped bundles may be made less than the desired total resultant thickness and then a plurality of bundles stacked together with seams therebetrween alternated one layer from another. In order to obtain the structure of FIG. **3** wherein the quills are oriented at some angle other than 90° with respect to the center line **57,** the trapezoidal sections, such as the section **61** of FIG. **5,** is cut with its parallel sides **65** and **67** tilted to form that same finite angle with respect to the quills in a vertical direction through the block **59.** Even then, of course, the quills of the block **59** remain perpendicular to the sides **65** and **67** of the trapezoidal bundle **61** in a direction along the width of the block **59.**

This technique of construction has the additional advantage that small holes may be easily provided through the material from its interior hot gas containing aperture to the outside of the quill structure. One way of providing such holes is to include a few stiff wires among the quills when the block **59** of FIG. **4** is first assembled. Sometime prior to final machining one surface of the assembled block into the form shown in FIG. **7,** these stiff wires may be pulled from the structure, thus leaving holes therethrough. Holes so formed may be used to inject or infuse fluid from the outside into the hot gas stream within the circular aperture or may be utilized for heat transfer by radiation through the hole. of such a porous structure or for controlled fluid flow through the walls.

Referring to FIG. **9,** a cross-sectional view of a different shaped quill structure is indicated where the hot gas containing aperture in the middle is not circular but rather is in the form of a slot **73.** The wall structure surrounding the slot **73** is made from the quill structure in the manner described hereinabove with separate bundles of quills, such as the bundle **75** in a wedge-like shape and the rectangular shaped bundle **77.** The bundles 75 and 77 are typical of those which are rigidly joined together to form the wall structure of FIG. 9. In each bundle, the quills remain parallel to each other and at least some of the quills are oriented perpendicular to a heat resistive surface which forms the aperture 73, at least in the plane of the drawing of FIG. 9.

FIG. 10 is like FIG. 9 except the aperture is rectangular rather than having curved sides.

The various aspects of the techniques of the present invention have been described with respect to specific embodiments thereof, but it will be understood that the invention is entitled to protection within the full scope of the appended claims.

I claim:

1. A wall structure forming a heat resistive surface, comprising a plurality of bundles of quills, each quill being characterized by uni-directional properties along its length, each of said plurality of bundles including a large number of straight quills immersed in a matrix material to form a three-dimensional solid structure with said quills parallel to each other in a plane cutting across more than one bundle, said bundles being attached to one another with an acute angle in said plane between their respective parallel quills to form said wall and said heat resistive surface, wherein said bundles are oriented with respect to said heat resistive surface wth at least one quill of each bundle being perpendicular thereto in said plane, whereby the quill density and resulting heat conductive and ablative properties remain uniform at various distances away from the heat resistive surface.

2. A wall structure according to claim **1** wherein the quills of each bundle are held together by said matrix with substantially no cross fibers or filaments holding the quills together.

3. A wall structure according to claim **1** wherein at least some of the quills of each bundle are hollow fibers, whereby material may be placed therein that has a different composition than said fibers for heat transfer along the length of said fibers.

4. A wall structure according to claim **1** which additionally includes a coating attached to the ends of said quills along said heat resistant surface.

5. A heat resistant wall structure forming an aperture of substantially a circular cross-section, comprising a plurality of bundles of quills joined together along substantially an extension of a radial line of said aperture, each quill being characterized by uni-directional properties along its length, each of said bundles including a large number of straight quills immersed in a matrix material which hold said quills parallel to each other in two orthogonal planes and oriented with respect to the circular aperture a defined plane passing through said aperture substanitally perpendicular to an axis, whereby the quill density and resulting heat conductive and ablative properties remain uniform at various distances away from the heat resistive surface.

6. A wall structure according to claim **5** wherein the quills of each bundle are held together by said matrix with substantially no cross fibers of filaments holding the quills together.

7. A wall structure according to claim **5** wherein at least some of the quills of each bundle are hollow fibers, whereby material may be placed therein that has a different composition that said fibers for heat transfer along the length of said quills.

8. A wall structure according to claim **5** which additionally includes a coating attached to ends of said quills along the wall of said aperture.

9. A wall structure forming an aperture with a heat resistive internal surface, said wall structure comprising a plurality of bundles of fibers, each of said bundles including a large number of straight fibers immersed in a matrix material which holds the fibers parallel to each other in two orthogonal planes said bundles being oriented with respect to said aperture so that at least one fiber within each bundle is substantially perpendicular to said heat resistive surface in a projection on a given plane cutting across said aperture and more than one bundle from each of the plurality of bundles, said fibers characterized by significantly differing thermal or mechanical properties in directions along their lengths and across their widths, whereby the fiber density and resulting heat conductive and ablative properties remain uniform at various distances away from the heat resistive surface and whereby the thermal and mechanical properties may be maximized for the specific materials employed.

10. The wall structure according to claim **9**, wherein the fibers of each bundle are held together by said matrix with substantially no cross members holding the fibers together.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,913,666

DATED : October 21, 1975

INVENTOR(S) : Peter Bayliss

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 5, Column 8, Line 6: the following sentence has been omitted after the word "aperture"

--so that at least one quill generally in the center of each bundle lies along an extension of a radial line of said aperture when projected onto a projection on--

Claim 15, Column 8, Line 33: the following sentence has been omitted after the word "bundle"

--,said bundles being attached to one another with an acute angle between their fibers in said given plane, said surface being formed at one end of at least a plurality of fibers--

Signed and Sealed this

Sixth Day of July 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks