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Applicant: **BRUNSWICK CORPORATION**
One Brunswick Plaza
Skokie Illinois 60077(US)

84

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Inventor: **Beaton, Michael Steve**
2726 Palm Terrace, DeLand
Florida 32720(US)

74

Representative: **Spencer, Graham Easdale et al**
A.A. Thornton & CO Northumberland House
303-306, High Holborn
London WC1V 7LE(GB)

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Seamless oriented metal fiber structure.

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A tube-like, abradable seal, exhibiting superior abradability and gas flow blockage, is produced by laying metal fibers into an open-ended annular die such that the fibers are oriented substantially perpendicular to the longitudinal axis of the tubular die. The fibers are thereafter compressed within the die and sintered to achieve a strong abradable seal.

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SEAMLESS ORIENTED METAL FIBER STRUCTURE

Background of the Invention

1. Field of the Invention

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This invention relates to metal fiber structures and more particularly to molded metal fiber structures.

2. Description of the Prior Art

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Abradable seals made from metal fibers have been used to seal various areas in rotary compressors and in turbine engines and their compressor sections, including the space between the turbine blade tips and the engine housing and the space between the turbine shaft and the turbine vanes.

15 These seals must provide sufficient abrasability, gas flow blockage and erosion resistance. Increasing density enhances erosion resistance and gas flow blockage, but it adversely affects abrasability.

The prior art seals are fabricated by working with a flat brittle porous sheet of sintered metal fibers. The sheet is cut to size and a reinforcing backing is welded to it or it is brazed into a ring. An undesirable "butt joint" results in the ring seal due to the welding or brazing operations. In these prior art seals there is a random orientation of the fibers in the porous sheet which cannot be changed once the sheet is formed.
20 Also, the density throughout the sheet and hence throughout the resulting seals is substantially uniform.

Summary of the Invention

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According to the present invention the fibers are charged directly into a pre-shaped mold of a desired configuration. The fibers are then compressed and heat treated while still in the mold.

The compression of the fibers in the mold also produces a gradation in the density along the direction of compression. The density is greatest near the compressing member. Increased density portion of the seal is desirable for providing more effective fluid blockage while decreased density is desirable for areas in
30 which enhanced abrasability is desired without compromising gas flow blockage. By combining a plurality of green unsintered compressed elements at different points in the mold, desired density areas different from other areas may be produced.

The fiber metal structures produced according to the present invention have no seams, require no brazing of sheet ends, and are easier to make than prior art structures.

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The ability to heat treat the seals or other fiber metal structures while they are still in a mold eliminates many handling steps and also permits the use of weights on the mold to control density and to prevent expansion during heating operations.

The prior art seals, since they are manufactured in sheet form, are characterized by two "strength directions": (i) the tensile strength measured in any direction within and parallel to the plane of the sheet;
40 and (ii) the tensile strength perpendicular to the plane of the sheet.

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The seals of the present invention are manufactured in annular configuration rather than in sheet form. The resultant tube-like seals may have any particular annular configuration including but not limited to a hollow cylinder, a hollow conic section, or a toroidal section. These seals can be characterized by three "strength directions"; radial, axial, and circumferential. Thus, one of the great advantages of this invention is the ability to preselect the tensile strength in the axial, circumferential, and radial directions and make them
different or the same, as desired.

Description of the Drawings

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FIG. 1 is a perspective view of a compression fixture according to the present invention.

FIG. 2 is a schematic depiction of a fiber metal seal made with the fixture of FIG. 1.

FIG. 3 is a schematic depiction in cross-section of a compression fixture according to the present invention with the compression ring inserted in the fixture for making a seal such as shown in FIG. 2.

FIG. 4 is a photomicrograph at 100 X magnification of a cross-section of a conventional seal.

FIG. 5 is a photomicrograph at 100 X magnification of a cross-section of a seal according to the present invention.

FIG. 6 is a photomicrograph at 100 X magnification of a cross-section of a seal according to the present invention, the section taken through the part of the seal which in manufacture was near the compression ring.

FIG. 7 is a photomicrograph at 100 X magnification of the middle of the seal of FIG. 6.

FIGS. 8, 9 and 10 depict solids of revolution according to the present invention.

10 Description of Preferred Embodiments

As shown in FIG. 1 one embodiment of a compression fixture 10 according to the present invention has the baseplate 12, the inner cylinder 14, the outer cylinder 16, and the compression ring 18. All of these parts are precisely sized so that the compressing ring 18 will fit into the cavity 17 between the two cylinders 14, 16 which are secured to the baseplate 12. FIG. 3 shows the portion that is cut out of the outer cylinder 16 to accommodate a solid backing ring 22 to which the seal to be produced can be attached or bonded during processing.

Metal fibers 21 are introduced into the cavity 17 between the cylinders 14 and 16. The compression ring 18 is then pressed down on the fibers 21 forcing them further into the cavity 17 and into the area encircled by the ring 22. A fiber mass or seal of a desired density can be produced by introducing a known weight of fiber into the cavity 17, measuring its height, calculating the height of the mass at the desired density, and compressing the mass to that height.

The metal fibers 21 used for the embodiment shown in FIGS. 1, 2, and 3 are of random irregular geometry with a relatively high aspect ratio of about 75 ("aspect ratio" means ratio of fiber length to fiber diameter). The normal bulk density of a mass of such fibers is about 10% (or a porosity of 90%), which is too low for the gas flow blockage and erosion resistance required of an abradable seal. By densifying the mass or body of fibers in a compression fixture such as fixture 10, the required density results. "Density" is expressed here in percentage and means the ratio of material in a given volume compared to 100% solid material in the same volume.

In order to maximize gas flow blockage the fibers 21 are compressed in the direction of the gas flow to be encountered by the seal. The seal 20, in FIG. 2, has had its fibers in the mass densified by a compression ring moving in the same direction as the indicated gas flow direction. The random irregular fibers used to form the seal 20 tend to accumulate in a random spatial orientation in planes parallel to the plane of deposition.

The axial compression according to the present invention causes the fibers to be re-oriented toward planes perpendicular to the direction of compression. This re-orientation, although difficult to quantify, is readily apparent upon a visual examination of a compressed product and is shown clearly in the photomicrograph of FIG. 5. A section cut from a prior art seal ring is depicted in the photomicrograph shown in FIG. 4 wherein the backing metal portion of the ring is shown on the left-hand side of FIG. 4 in the vertical direction and the airflow through the seal ring is depicted by the arrow on the right-hand side indicating that the airflow through the seal is also in the vertical direction. As can be seen, the fibers are generally randomly oriented with more of the fibers in the vertical direction which was the direction of formation of the prior art sheet prior to forming the seal ring. A section cut from one of the embodiments of this invention is depicted in the photomicrograph of FIG. 5 wherein the backing ring is shown in a vertical position on the left-hand side of the figure and the airflow is depicted by the arrow on the right-hand side of the figure. The fibers in this embodiment are generally oriented perpendicular to the backing ring and thus perpendicular to the airflow. The fibers were compressed perpendicular to the base as well as perpendicular to the airflow direction as shown in FIG. 5. In other words, the compression is parallel to the airflow and perpendicular to the backing ring, thus providing flow impedance to the airflow through the seal and thereby making the turbine more efficient.

The orientation of the fibers results in enhanced abrasability as compared to conventional seals. Abradability can be evaluated by simulating the conditions under which rotating parts "rub" into the abradable seal. An explanation of how such tests are conducted is given in Proceedings of the ASME, International Gas Turbine Conference, 1984, Paper No. 84-GT-67. Table I lists rub test results for one "conventional" fiber metal seal and two "invention" fiber metal seals.

TABLE I
KNIFE EDGE RUB TEST RESULTS

5	<u>SEAL TYPE</u>	<u>DENSITY, %</u>	<u>UNIT RUB ENERGY¹</u> k ft.lb./cu.in.	<u>WEAR²</u> RATIO
	Conventional	18.2	196.6	+ 0.046
10	Invention	17.8	5.6	0
	Invention	22.8	126.2	- 0.008

15 ¹Unit Rub Energy = energy absorbed from rotor system to
create the rub groove

²Knife Edge Height Change/Rub Depth - units are in./in.

20 It is seen that at comparable densities, the "invention" seal rubbed with only about 3% (5.6/196.6) of the unit rub energy of the conventional seal. At a density of 22.8%, the rub energy of the "invention" seal is still well below that of the conventional seal. Equally important, the wear ratios of the "invention" seals are less than that of the "conventional" seamed seal.

25 Fibers can be introduced into the cavity 17 in a variety of ways including hand sifting, hand sifting through a hand-held sieve, and hand sifting through a hand-held sieve held over a funnel which is inserted into the cavity.

30 Surprisingly, axial compression of the fiber mass in the cavity 17 has produced a remarkable density gradient effect in the final product which is not present in prior art structures made from slurry-produced sheets of fiber metal. The density of the compressed fiber mass is greatest near the area which is contacted by the compression ring (the "top"). The density of the mid-portions is less than that of the top portion and the density of the portions which were located near the base plate (the "bottom") is greater than the density of the mid-portions yet slightly less than the top portions' densities.

35 The density gradient effect can be modified by varying compression parameters and modes of fiber introduction into the cavity. A variety of techniques can be used to deposit fibers into the fixture cavity. For example all of the fibers can be introduced into the cavity prior to any compression or portions of the total fiber mass can be introduced and compressed in separate steps to form a structure with varying or alternating density portions.

40 The photomicrographs of FIGS. 6 and 7 illustrate visually the density gradient across a seal made with a fixture such as that of FIG. 1. FIGS. 6 and 7 show portions of a molded seamless seal according to the present invention. The densities of the two portions vary. Relative quantification of the densities was achieved by using the reciprocal of the exposure time for each photomicrograph with illumination held constant to establish a relative areal concentration of fibers in each portion of the seal. The cross-sectional portion of the embodiment depicted in FIGS. 6 and 7 is arranged in such a manner that the microstructure shown in FIG. 6 has an airflow in the vertical direction through the material and the direction of the compression of the fibers was also in the vertical direction. It can be seen in the photograph that the preferred orientation of the fibers is in a horizontal arrangement perpendicular to both the airflow and the direction of compression. The midsection or middle zone of the seal material represented by the photomicrograph of FIG. 7 shows the fibers having less density than the fibers in FIG. 6 while the airflow and direction of compression are the same as shown in FIG. 6. It is also obvious from the photograph that besides the density being less than is shown in FIG. 6 the fibers are more in a random array than the more horizontally oriented fibers in FIG. 6.

50 The combination of a fiber-charged fixture with a compressing load such as is shown in FIG.3 can be introduced into a heat treatment unit, e.g., a sintering furnace. The load on the fiber mass restricts expansion during heating assuring that the resultant structure will have the desired dimensions and eliminating the need for time-consuming sizing and trimming. This method also obviates the need for multiple heat treatment steps because the fibers are joined together by sintering in a mass of the size and shape of the final product, and the mass is joined to its backing ring by brazing simultaneously or in the same operation; thus requiring only one heat-treat operation. Also the hot deformation step required to permit work with low ductility materials such as materials containing nickel aluminides is no longer

necessary with the present invention. Furthermore, intimate contact in the fiber mass in the fixture cavity is achieved before sintering making it possible to more closely meet prescribed size tolerances. Finally, products made according to the present invention have no seam. Prior art products with seam are undesirable because such seams present a path for low gas flow resistance.

5 The effectiveness of a gas seal is, of course, related to its ability to resist the flow of gas internally. The greater its gas flow resistance, the more gas is forced to impinge upon the working surfaces of the blades to produce useful work, and therefore the greater the engine efficiency. "Conventional" seamed seals and "invention" seamless seals were evaluated at nominal 21% densities at a flow velocity of 430 ft./hr. From pressure drop measurements and the airflow settings, an Air Permeability Coefficient ("APC") can be
10 calculated. The test results are reported in Table II.

TABLE II
AIRFLOW MEASUREMENT THROUGH FIBER METAL SEALS

<u>SEAL TYPE</u>	<u>DENSITY, %</u>	<u>ΔP SEAL in. H₂O</u>	<u>AIR² PERMEABILITY COEFFICIENT</u>
Conventional (a)	20.8	20.7	4796.7
Conventional (b)	20.8	26.1 ¹	3804.3
Invention	20.9	42.8	2319.9

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¹Butt Joint treated with rubber cement to eliminate flow through joint.

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²Units are: cfh/ft²/in. H₂O/1/16 in.

The "conventional" seamed seals were tested (a) as fabricated and (b) treated with cement to prevent flow of air through the joint. It is seen that at gas flows of 430 ft./hr., the amount of air flowing through a given frontal area of seal material for a given pressure drop and thickness, was less than 50% of the
35 "conventional" seal and only about 61% of the APC for the conventional seamed seal in which the seam had been treated with cement to block flow through it.

A porous metal fiber structure exhibits an anisotropic character for gas permeability. Permeability parallel to the felting plane ("felting plane" is the plane of the porous membrane on which the sheet of fibers is deposited) of conventionally produced fiber metal structures can be up to twice as great as
40 permeability perpendicular to this plane. The methods of and means of the present invention effectively invert this relationship because the felting plane of a product produced according to the present invention is perpendicular to the direction of the fluid that will flow through the structure. The fiber orientation pattern of structures and seals according to this invention enhances abrasability, reduces axial fluid leakage through the seal, increases erosion resistance and improved strength in the radial direction.

45 The porous metal fiber body described herein has a structure made up of the plurality of discrete metal fibers, each of these metal fibers having a generally uniform diameter or cross section along the length of the fiber with the fibers having a minimum diameter of about 3 microns and up to a maximum diameter of about 145 microns. The maximum fiber diameter in any one body is no more than about four times the minimum fiber diameter of a fiber found in the same body. Included within the scope of this invention is the
50 requirement that the fibers within a body have a minimum length of at least about 30 microns and a maximum length no more than about 7,620 microns and the individual fibers have a length to diameter ratio ranging from at least about 10 to 1, to no more than about 180 to 1. The adjacent fibers within the body that are touching exhibit interfiber diffusion bonding such that a meniscus between the touching adjacent fibers is formed and that the total fiber bonding produces a lattice network of autogenously bonding or diffusion
55 bonded fibers, one to the other. It has been found that the maximum density of this fiber network is no more than about 70% and no less than about 12%. The fiber network can have a greater density such that the maximum density of the network is no more than about 50% greater than the minimum density of the network and that the difference between the minimum and maximum densities should be at least about

25%. It has been found that within the fiber network the highest density range has a tensile strength profile such that the lowest tensile strength, by direction, ranges from about 50 to 65% of the maximum tensile strength and that the intermediate tensile strength ranges from about 65 to 85% of the maximum tensile strength. Further, it has been found that the portion of the lowest density area of the network has a three dimensional tensile strength profile such that all three directions have approximately equal tensile strengths.

Although the description above has been directed to a tube-like object in the form of a right circular cylinder, it should be evident that the instant invention is not limited thereto. For example, tube-like objects, such as shown in FIGS. 8-10, can readily be produced, having the controlled fiber orientation of this invention.

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Claims

1. A process for making a tube-like abrasable metal fiber seal exhibiting superior abrasability and gas flow blockage, comprising:

15 felting discrete metal fibers into a tube-like recess in a fixture, the felting done in planes perpendicular to the longitudinal axis of the recess, the fixture having only one open end with the recess formed of that open end, said fibers having a diameter of 3 to 145 microns, a length of 30 to 7,620 microns, and a length to diameter range of 10 to 180,

20 compressing the fibers in the recess by applying pressure in a direction coincident with the recess's longitudinal axis to compress the fibers into a lattice network having a density 12 to 70%, heating the fibers to produce interdiffusion bonding between a majority of adjacent fibers.

2. The process of Claim 1, in which said tube-like recess is in the form of a right circular cylinder.

3. The process of Claim 2, in which a predetermined height of the outer circumferential surface of said recess is fitted with tubular backing ring, such that said backing ring may bond to the metal fiber seal during the heating of the fibers.

4. A tube-like, metal fiber abrasable seal exhibiting superior abrasability and gas flow blockage, characterized by said fibers being oriented substantially perpendicular to the longitudinal axis of the seal, said seal having been produced by the process of Claim 1.

5. The seal of Claim 4, produced by the process of Claim 2.

6. The seal of Claim 5, produced by the process of Claim 3.

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Neu eingereicht / Newly filed
Nouvellement déposé

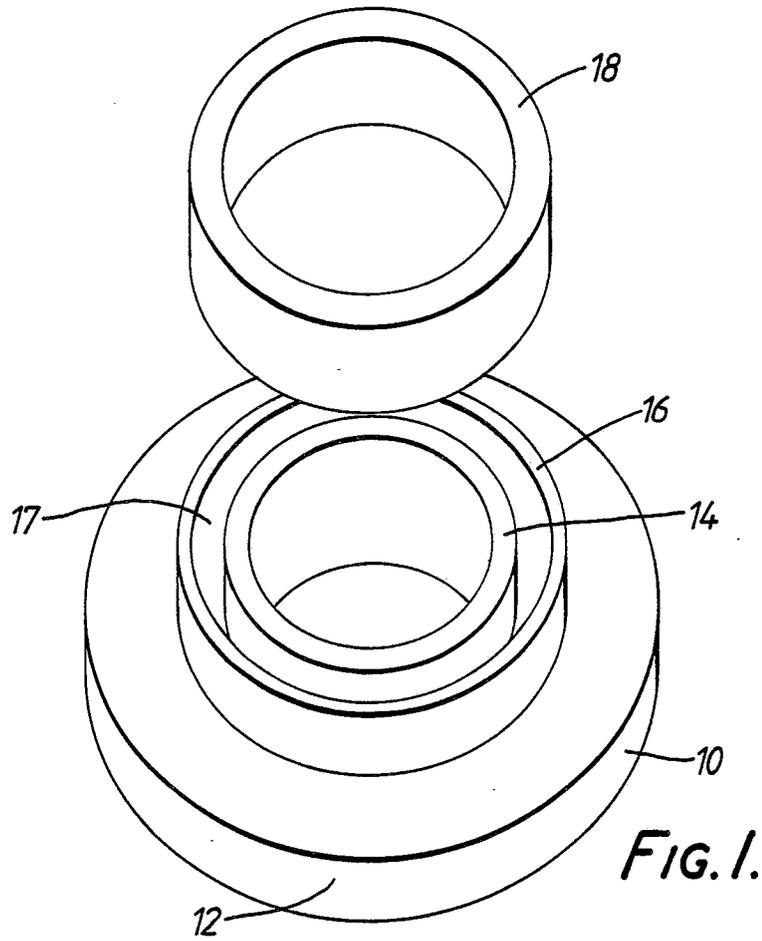
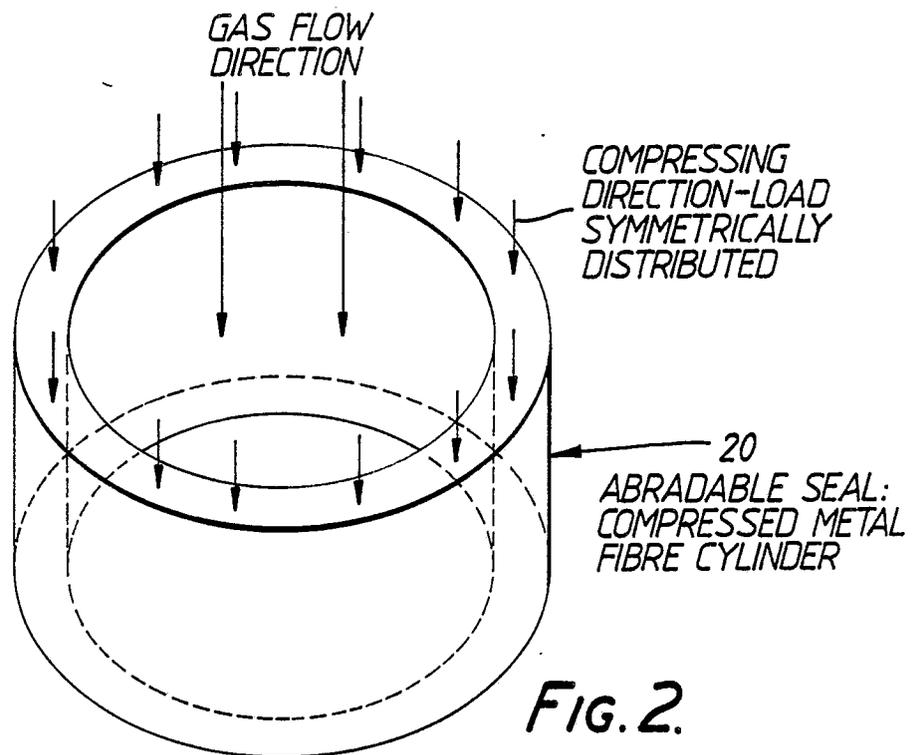


FIG. 1.



Neu eingereicht / Newly filed
Nouvellement déposé

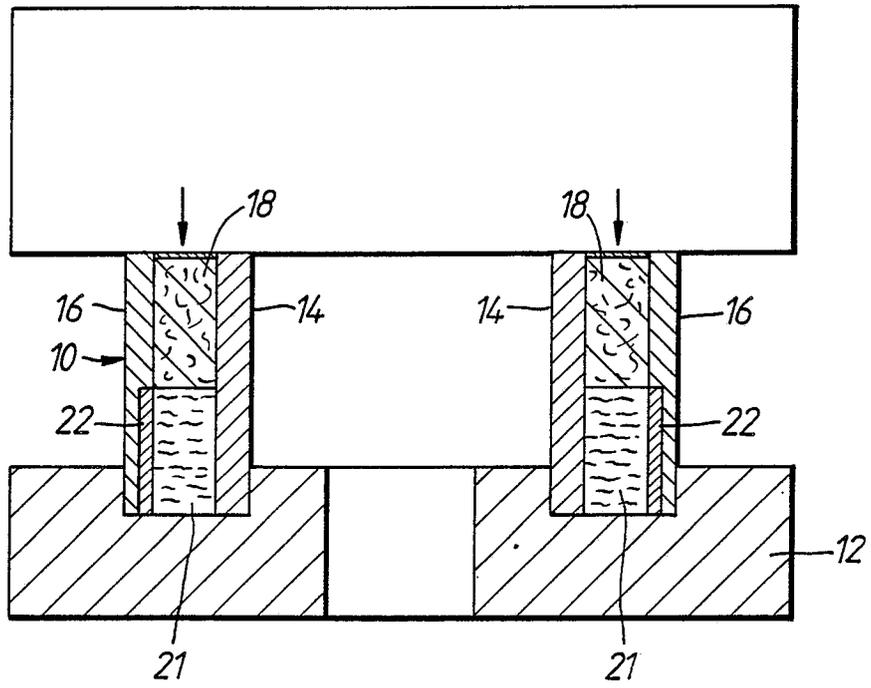


FIG. 3.

Neu eingereicht / Newly filed
Nouvellement déposé



FIG. 4.

HA: CROSS SECTION OF CONVENTIONAL FM 515B SEAL.
BACKING RING IS SHOWN FOR ORIENTATION REFERENCE.

100X

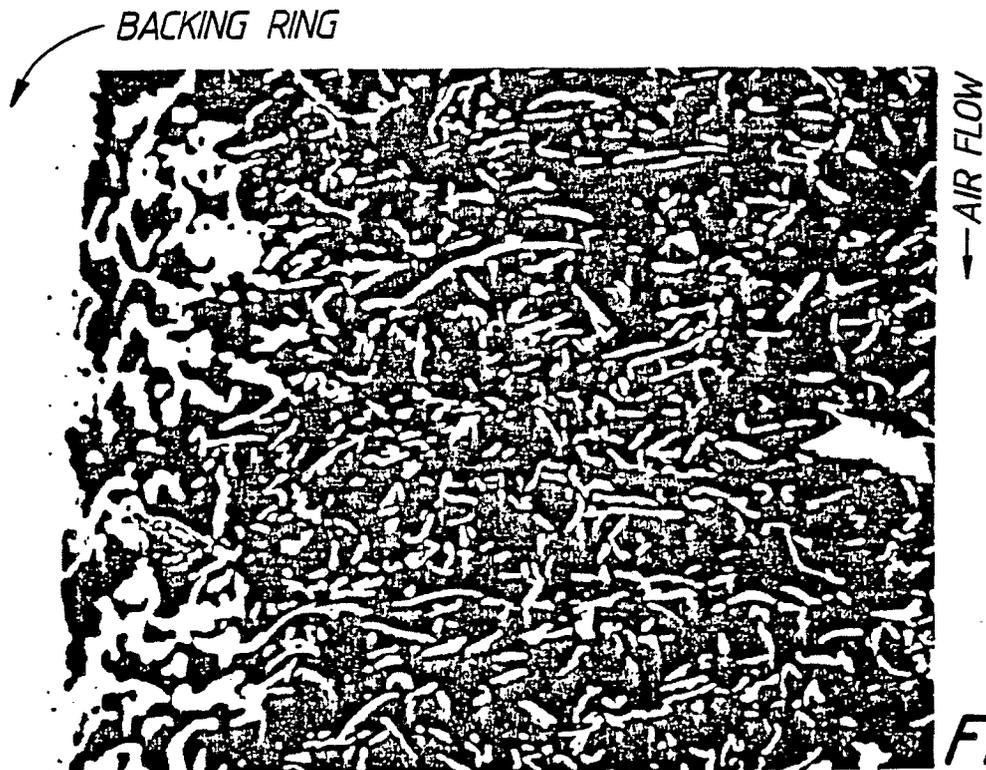


FIG. 5.

HB: CROSS SECTION OF GRADED DENSITY MOLDED
SEAMLESS SEAL ANALOG OF FM 515B. BACKING RING IS
SHOWN FOR ORIENTATION REFERENCE.

100X

Neu eingereicht / Newly filed
Nouvellement déposé

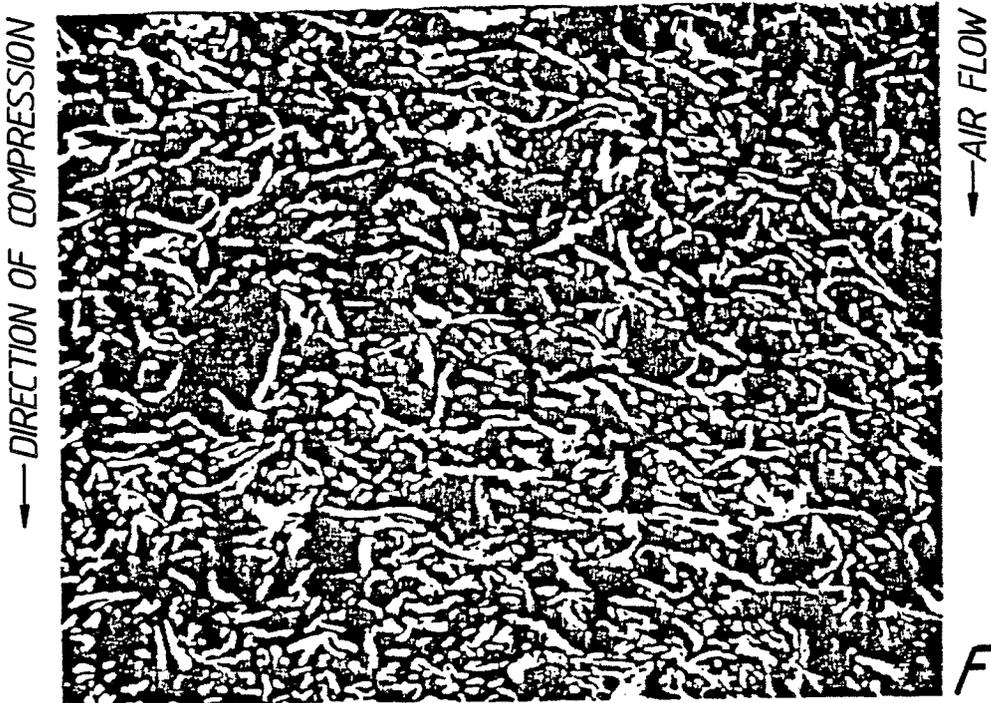


FIG. 6.

IB: MICROSTRUCTURE OF "TOP" ZONE OF SEAL, NEAREST THE PRESSING RING. RELATIVELY MORE HORIZONTAL FIBRE ORIENTATION 100X

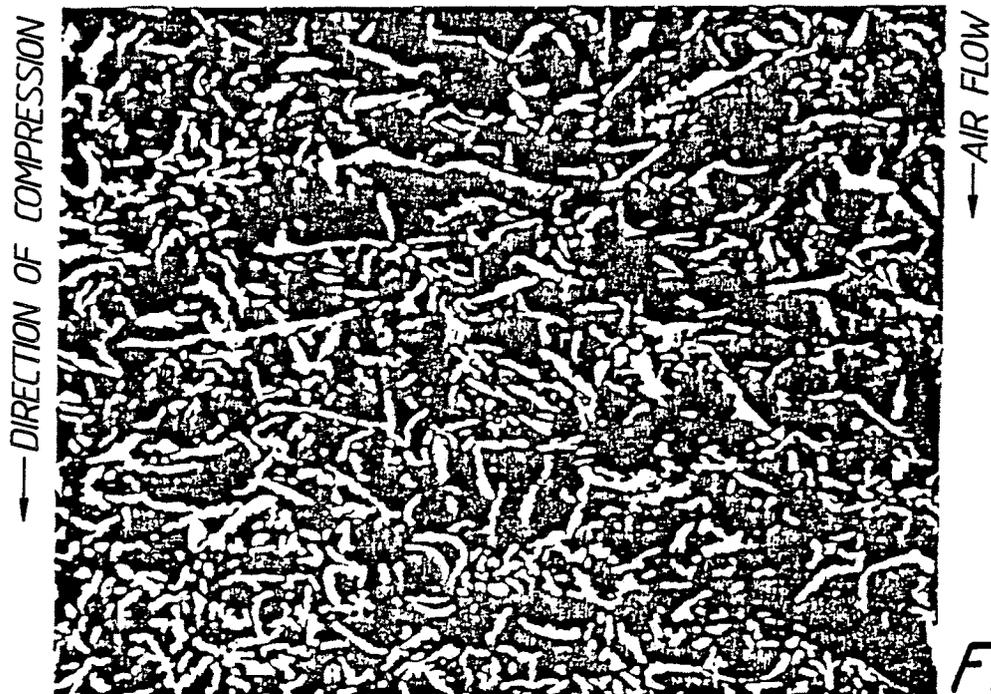


FIG. 7.

IC: MICROSTRUCTURE OF MIDDLE ZONE OF SEAL RELATIVELY RANDOM ORIENTATION OF FIBRES 100X



Neu eingereicht / Newly filed
Nouvellement déposé



FIG. 8.

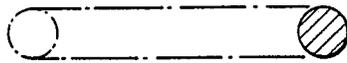


FIG. 9.

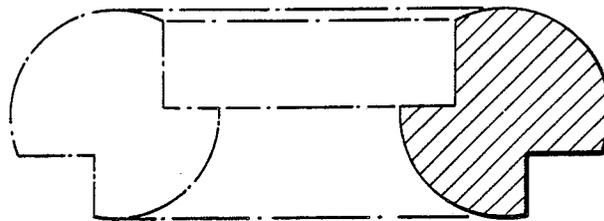


FIG. 10.



DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	GB-A- 464 727 (HEVALOID AG) * Page 3, lines 81-97 *		B 22 F 3/00 F 01 D 11/08
A	US-A-3 127 668 (W.C. TROY) * Claim 3; column 6, lines 10-22 *		
A	US-A-3 759 708 (B.J. SUNDBERG et al.) * Column 19, line 64 - column 20, line 11 *		
A	US-A-3 519 282 (D.R. DAVIS) * Column 3, lines 19-45 *		
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			B 22 F F 01 D C 22 C
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
THE HAGUE		12-02-1987	SCHRUERS H. J.
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone		T : theory or principle underlying the invention	
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