Sept. 1, 1964 A. EISENLOHR 3,147,087

CONTROLLED DENSITY HETEROGENEOUS MATERIAL AND ARTICLE

Filed Feb. 19, 1959

Fig 1

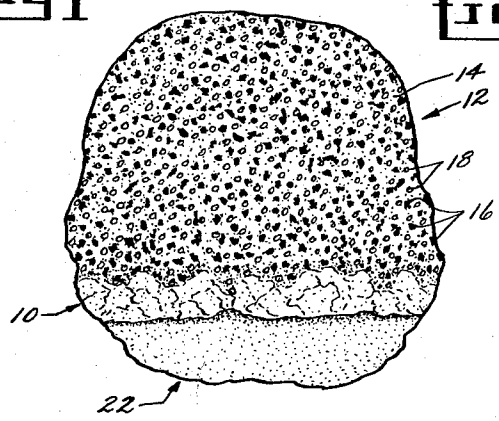


Fig 2

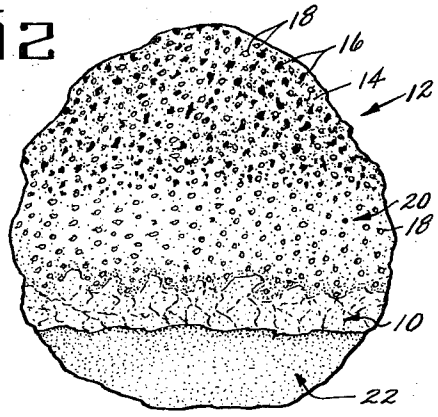


Fig 3

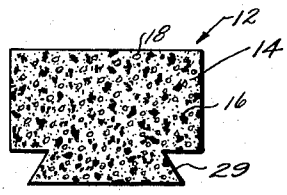


Fig 4

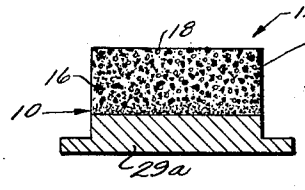


Fig 6

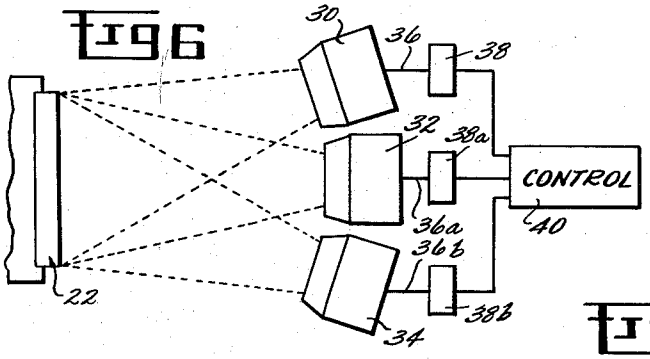
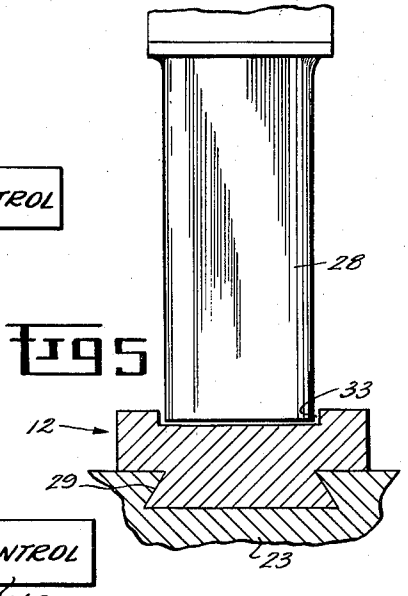


Fig 5



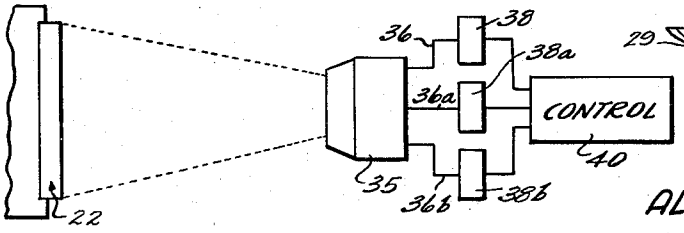


Fig 7

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CONTROLLED DENSITY HETEROGENEOUS MATERIAL AND ARTICLE

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4 Claims. (Cl. 29—191.2)

This invention relates to a heterogeneous material of controlled density and to the article produced from such material. More particularly it relates to a flame deposited material of principally a metallic nature, the density of which may be varied by varying the amount of porosity, of mechanically entrapped material through variation of the conditions of flame deposition.

The efficiency of fluid motivating apparatus having cooperating rotating members such as in pumps, turbines and the like, depends in part on the positive movement through the apparatus from section to section of the fluid being acted upon, without intersection leakage. The prevention of such leakage is particularly important, troublesome and difficult to achieve in apparatus such as gas turbines designed to operate at high temperatures and pressures. Low temperature operating machines have included sealing materials such as rubber, plastic, cloth flock and soft, low-melting metal alloys. Such materials are not suitable for use at elevated temperatures because they will decompose or melt away.

One reported prevention of intersection leakage, or interstage leakage in the case of a turbine, involves attaching to the surface of either rotating or stationary members a uniform density, homogenous, generally friable material, such as carbon, which will withstand the intended operating temperatures. It is difficult, however, to achieve a sound bond or attachment of such a friable material to its holding member. In addition, the friable material which generally is not sufficiently ductile and has little shock resistance, must withstand both thermal and impact shocks. It must be nonabrasive to the cooperating part with which it acts as a seal.

It is an object of this invention to provide a strong, controlled density heterogeneous material suitable for use at elevated temperatures, which is easily abraded under specified condition yet nonabrasive to the materials with which it rubs.

Another object of this invention is to provide a composite, abradable material of controlled density tightly bonded to a holding member.

My controlled density, heterogeneous abradable material, in one form, comprises a porous matrix of ductile material complemented by mechanically entrapped, dispersed discrete particles which may have elevated temperature lubricity and which reduce the shear strength of the matrix material. My composite material comprises my heterogeneous abradable material joined with other portions of progressively increasing density.

According to one aspect my heterogeneous material is produced by flame depositing a ductile metal matrix while simultaneously depositing particles which are discrete from the matrix metal yet complement the matrix to produce the heterogeneous material including the particles as entrapped, dispersed bodies.

My method for producing my composite material includes first flame depositing a low porosity, metal bonding portion and then depositing my heterogeneous material as an outer portion on that bonding portion.

I intend to include in the meaning of "flame depositing" unit, equipment, apparatus, etc., all types of machines capable of receiving a solid material such as in the form of powder, rods, tubes, pellets, etc., changing at least a portion of such material from solid to molten form and then propelling that material outward from the

equipment as toward a workpiece. Examples include electric arc types, combustion types, plasma jet types, etc.

When deposited directly on a holding member such as for use as an abradable seal, my abradable heterogeneous material becomes the outer portion of my composite material or structure. Between the outer portion and the base metal or holding member, in such a case, is a relatively thin bonding portion comprising densely flame sprayed material. If desirable to build up thicker amounts of material, intermediate portions may be flame deposited between the outer and bonding portions. Generally such intermediate portions include decreasing amounts of entrapped material as they approach the bonding portion. However, the porosity of the outer and intermediate portions may be about the same because the same type of equipment and same depositing conditions may be used.

I have found that in the practice of my method, I can produce an abradable seal particularly useful in elevated temperature, elastic fluid flow apparatus to prevent interstage leakage with negligible abrasion of parts mating with and forming a cooperating part of such a seal.

The subject matter which I regard as my invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. However, my material and its method of formation together with further objects and advantages thereof, may be best understood by reference to my description taken in connection with accompanying drawing in which:

FIG. 1 is a greatly enlarged view of a partial section of my composite material in a two-portion arrangement;

FIG. 2 is a greatly enlarged view of a partial section of my material in a three-portion arrangement;

FIG. 3 is a sectional view of my heterogeneous material keyed for separate attachment to a holding member;

FIG. 4 is a sectional view of my composite material in a two-portion arrangement employing the bonding portion as a key or foot for separate attachment;

FIG. 5 is a fragmentary sectional view of a seal formed of my material positioned with a cooperating blading member;

FIGS. 6 and 7 are diagrammatic illustrations of arrangements of spray apparatus for the practice of my methods.

The present invention is particularly concerned with the formation of a heterogeneous abradable seal material suitable for elevated temperature operation, tightly bonded and attached to a holding member, such as a stationary band or casing, or to a rotating member, such as a blade or bucket, in elastic fluid flow apparatus. Although I prefer my flame depositing method for producing my controlled density heterogeneous material on a holding member for such uses as an abradable seal, it is understood that my material may be separately manufactured by flame deposition techniques. For example, my material may be produced in configurations best suited for mechanical attachment after manufacture to a holding or backup strip by any method of attaching rigid or semi-rigid materials to such members.

My heterogeneous abradable material **12**, FIG. 1, is shown as the outer portion of a two-portion system comprising my composite material. Such a system includes low porosity bonding portion **10** produced by flame depositing an elevated temperature resistant material such as molybdenum, chromium, nickel, columbium, tungsten, tantalum or their alloys, such as in wire, rod, tubular or powder form. Bonding portion **10** has a tightly bonded structure and a relatively rough surface which allows the subsequently applied outer portion to mechanically attach more easily to the bonding portion. It is to be noted that the flame depositing technique results in a diffused, metallurgical bond between the vari-

ous portions so that both mechanical and metallurgical bonds are achieved.

Outer portion 12 comprises a matrix 14 of a relatively ductile material capable of withstanding the operating temperatures in its intended use and an entrapped dispersed material 16 which may have elevated temperature lubricity. Examples of dispersed materials, sometimes referred to as "interrupter" or "chip-breaker" materials are graphite, mica, molybdenum disulfide, boron nitride, vermiculite asbestos and the like. Some of such materials have a layer lattice structure which gives them the property of elevated temperature lubricity thus to aid in the prevention of galling or abraded material accumulation on elements abrading such materials.

Entrapped material 16 and pores or voids 18, resulting from the conditions of flame deposition, lower the overall density of my heterogeneous outer portion material.

Another arrangement of my composite material including my heterogeneous material as an outer portion, FIG. 2, includes an intermediate portion shown generally at 20, having primarily matrix material 14 as well as pores or voids 18. A plurality of intermediate portions of a varying heterogeneous composition may be placed between bond portion 10 and outer heterogeneous portion 12 in order to achieve any desired graduation of density from a holding member such as 22 to an outer portion 12.

As will later be described in more detail in connection with FIGS. 6 and 7, flame depositing equipment may be arranged and coordinated to produce my material on a holding member starting with the bonding portion, if one is desired, and continuously varying the flame deposited material until the entire composition material is formed. It is to be noted that because of flame depositing techniques, there is no finite line representing the area between portions. Thus our flame deposition method results in a gradual change of composition and density.

My heterogeneous material, FIG. 3, or my two-portion composite material, FIG. 4, may be flame deposited in a mold or on a mandrel later to be removed for separate attachment to a holding member, for example as by a keying arrangement or foot 29 or 29*a*. In one such arrangement, FIG. 5, my heterogeneous material 12 formed as in FIGS. 3 or 4, may be attached as by foot or key 29 to a structure or holding member 23 which may be a rotating shroud or a stationary casing. Blading member 28 cooperates with my heterogeneous material 12 to form an interstage seal as by the cutting or abrading of a path or channel 33 in my material 12 during movement either of blading member 28 or of holding member 23.

According to one form of my method for depositing a relatively small amount of my controlled density, heterogeneous abradable material on a holding member, I first prefer to roughen the surface of the base or holding member such as by particle blasting employing materials such as metal or ceramic grit, sand, hard oxides, etc. However, if a relatively thick outer portion of my heterogeneous material is desirable, for example in excess of about 0.03 inch, I prefer first to produce a roughened, "captive" type of surface on the holding member such as by machining, knurling, undercutting and the like. Such a captive surface affords a foothold for a relatively thick layer of sprayed material. Thus, if stresses built up in thicker coatings exceed the bond strength achieved by flame depositing my material over a particle blasted surface, the captive type of surface will hold the material in place.

After surface preparation, and prior to or in lieu of deposition of the low porosity bonding portion according to my method, the surface may be covered with a thin portion of the same material as that of the holding member. In this way exceptionally good adherence and bonding is achieved between the base material and a subsequent portion; a more gradual transition results between the material of the holding member and that of the outer portion.

The bonding portion, when applied directly to the surface of a holding member, should be relatively thin so that it can expand and contract with that material. It need be just thick enough to cover the holding member with a relatively rough, tightly adherent material. When the bonding portion is thin, the differences in coefficients of expansion between the material of the holding member and that of the bonding portion is eliminated as a factor affecting adherence. I have found a bonding portion of about 0.002–0.004 inch in thickness to be satisfactory for such an application.

After flame depositing my bonding portion, I then flame deposit the outer portion 12, FIG. 1, directly to the rough surface of the bonding portion without additional surface preparation. The matrix material 14 may be flame deposited simultaneously with the deposition of particles or dispersed material 16 which complement the matrix material in producing outer portion 12. The outer portion including entrapped, dispersed material 16 may be deposited from various combinations of matrix and dispersed materials such as powder mixtures, coated or filled tubes, coated rods, coated or filled hollow spheres, coated particles, various strand constructions of wires, tubes, rods, etc. However, I prefer to flame deposit my outer portion material from a powder mixture prepared by intimately blending or mixing ductile matrix powder with powdered material to be dispersed and entrapped.

The matrix material of the outer portion may be any ductile material which can be flame deposited to entrap the dispersed material. As will be described later in connection with specific examples, I have found aluminum to be unusually useful as a matrix material for applications up to about 900–1000° F., and graphite or mica as the dispersed, entrapped material. Tests have shown that boron nitride and molybdenum disulfide can be used as the entrapped material. However, the current cost of boron nitride limits its present practical application and the formation of the fairly abrasive molybdenum trioxide from molybdenum disulfide makes that compound less attractive than graphite or mica.

Although a relatively large quantity of graphite was blended with the powdered aluminum in some of our tests, it is believed that an entrapment of more than about 8 percent by weight graphite is not practical to produce a suitably bonded material. I have found that about 2.5–5.5 percent by weight entrapped material produces a well bonded abradable structure. I conducted a series of tests varying the ratio of graphite to aluminum from 12:1 to 1:4 to determine the optimum range. I found that no more than about 8–10 percent by weight of entrapped material can be effectively dispersed through the matrix without causing the matrix material to become excessively friable.

Example 1

In order to produce a composite abradable seal tightly bonded to the inside surface of an annular shroud member, I first grit blasted that inside surface with clean, angular, No. 25 mesh steel grit using air filtered to remove oil, dirt, etc. I then flame sprayed onto that surface a 0.003–0.004 inch thick bonding portion from wire material having the nominal composition in percent by weight of about 60 nickel, 24 iron and 16 chromium. I used an oxyacetylene flame spraying gun held at a distance of about five inches from the workpiece. Gas pressures in pounds per square inch were about 35 for oxygen, about 15 for acetylene and about 60 for air. Only one pass was required to deposit a dense adherent layer.

Over the bonding portion, and without additional surface preparation, I flame sprayed my heterogeneous material as an outer portion from a powder principally about 325 mesh size including about 2 parts of powdered alumi-

num and 1 part of powdered graphite. The aluminum powder employed in that aluminum-graphite mixture was a minimum of 98.6 percent aluminum, free from oil, grease, dust, moisture and other foreign substances. About 90 percent of the aluminum was smaller than 200 mesh size and about 10 percent was smaller than 325 mesh size. About 90 percent of the graphite powder used was smaller than 325 mesh size, the remainder being smaller than 200 mesh size.

The two parts of aluminum powder and one part graphite powder first were intimately blended and then were flame deposited from a standard commercially available powder-type flame spraying gun held about 8 inches from the workpiece. The portion was deposited to a thickness of about 0.15 inch at the rate of about 0.002–0.003 inch per pass. The powder flame spraying gun included an oxyacetylene torch with air for cooling and for propelling the molten material. The gas pressures of this example in pounds per square inches were acetylene 8, oxygen 26 and air 45, with the flow of air used as propellant being at the rate of about 57–58 cubic feet per hour.

I noted that in spraying this material, the temperature of the member in the area as it was coated was raised to about 350–400° F. Therefore, heat was applied to the member to maintain the portions of the member not being sprayed approximately within that temperature range. The member was rotated at a rate of about 6 revolutions per minute, the gun being in a stationary position.

Resulting from this deposition was a composite abradable seal material in excess of about 0.15 inch thick and having a density of about 0.07 pound per cubic inch. The entrapped graphite was analyzed to be about 4.5 percent by weight of the total outer heterogeneous portion.

Although in this example we maintained the member being sprayed at a temperature of about 350–400° F., satisfactory abradable materials can be deposited with the member at temperatures ranging from room temperature up to about 800° F.

Example 2

Employing the same equipment and conditions as described in Example 1, a composite abradable seal material was produced by first flame depositing a bonding coat of essentially molybdenum and then depositing on the molybdenum a porous aluminum portion using aluminum in powder form as material being sprayed. Over the porous aluminum intermediate portion I then deposited my aluminum-graphite heterogeneous outer portion employing a blended powder mixture of about 3 parts aluminum to 1 part graphite to produce a matrix having about 1.3 percent by weight graphite.

Example 3

I repeated Example 1 except that powdered alkali aluminum silicate in the form of mica was substituted for the graphite powder to obtain essentially the same results.

In the above examples the various amounts of dispersed materials were entrapped using the conditions as described, nevertheless the configuration of the member, the amount of overspray, the type of gun used, etc. will produce variation in the amount of entrapped material. The actual ratios of material to be entrapped to that of the matrix can be determined by experiment on a member.

Although I have described my method as one for the deposition of a series of portions using a single flame spraying gun, arrangement such as are shown in FIGS. 6 and 7 may be used to produce my composite abradable material continuously from the bond portion to the outer portion.

In the arrangement of FIG. 6, the dispersed material is deposited on a workpiece **22** such as a holding member, mold, mandrel etc., from a flame depositing unit **30**, the matrix material from a second flame depositing unit **32** and the bonding portion material from a third such unit **34**. The various materials may be fed as through or along paths **36**, **36***a* and **36***b* to such flame depositing units in the form of a powder, wire, rod, tubing, etc. by any suitable commercially available feed mechanism **38**, **38***a* and **38***b* (not shown in detail). The rate of feed is controlled and scheduled by a control **40** by such control means as cams, timing switches, electronic devices or other commercially available adjustable timed switching devices. Thus control **40** may adjust the feed to any of the units in order to develop on holding member or workpiece **31** a continuously deposited, controlled accumulation or deposit of material of any desired composition and density.

As was mentioned before, flame deposition not only results in good mechanical bonding due to the surface roughness created but also achieves sufficient metallurgical bonding so that the material is welded together without any heat treatment.

In another arrangement, FIG. 7, material to be deposited is sprayed from a single unit **35** which in turn is fed by paths **36**, **36***a* and **36***b* from feed mechanisms **38**, **38***a* and **38***b* which may carry respectively the dispersed material, the matrix material and the bonding material. Control **40** schedules and coordinates the flow of material through the feed mechanisms.

Although I have described the various forms of my material in connection with specific examples, it will be obvious to those skilled in the art the modifications and variations of which my invention is capable.

What I claim is:

1. A heterogeneous, abradable material consisting essentially of about 2.5–10 weight percent of dispersed, discrete, entrapped particles of a material selected from the group consisting of graphite and mica as a minor, discontinuous phase; with the balance of the abradable material being a porous mechanically bonded matrix of aluminum.

2. A heterogeneous, abradable material consisting essentially of about 2.5–10 weight percent of dispersed, discrete, entrapped particles of graphite as a minor, discontinuous phase; with the balance of the abradable material being a porous mechanically bonded matrix of aluminum.

3. A seal member including an outer heterogeneous abradable portion consisting essentially of about 2.5–10 weight percent of dispersed, discrete, entrapped particles of a material selected from the group consisting of graphite and mica as a minor, discontinuous phase; with the balance of the outer abradable portion being a porous mechanically bonded matrix of aluminum.

4. A seal member including an outer heterogeneous, abradable portion consisting essentially of about 2.5–10 weight percent of dispersed, discrete, entrapped particles of graphite as a minor, discontinuous phase; with the balance of the outer abradable portion being a porous mechanically bonded matrix of aluminum.

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