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Caffrey

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[54] **COMPRESSOR BLADE**

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[52] **U.S. Cl.** **418/152,** 418/178, 418/179

[51] **Int. Cl.** **F01c 21/00**

[58] **Field of Search** 418/152, 178, 179

[56] **References Cited**

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2,905,376	9/1959	Davey	418/152
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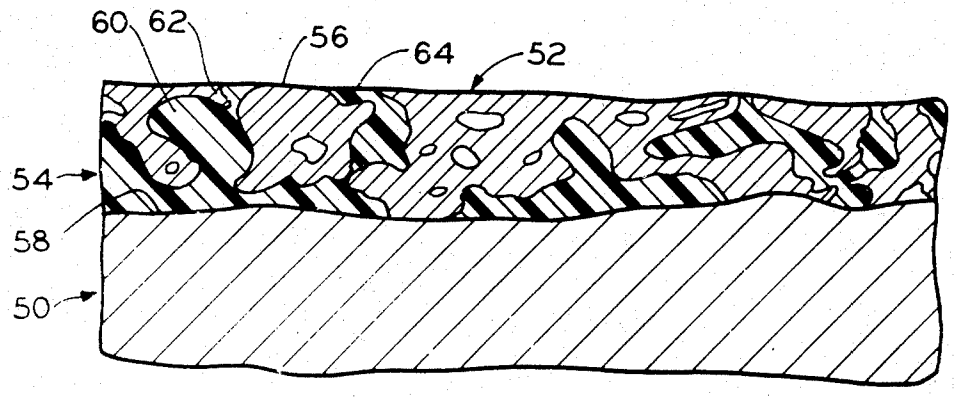
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[57] **ABSTRACT**

An improved blade or vane structure is provided for a rotary, vane-type fluid compressor. The vane has a solid body of a metal having a low density and a high heat conducting capacity. The metal body is coated with an abrasion-resisting coating which has voids therein between the outer surface of the coating and the vane body. The voids are filled with plastic material to strengthen the coating against collapse in response to forces imposed on the vane during operation of the compressor. An outer coating of self-lubricating material may be bonded to the outer surface of the abrasion-resisting coating.

6 Claims, 4 Drawing Figures



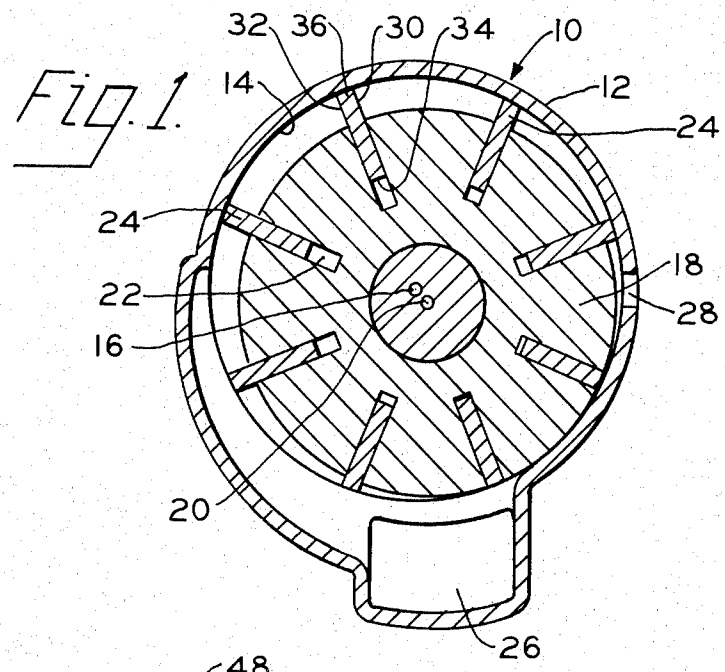


Fig. 1.

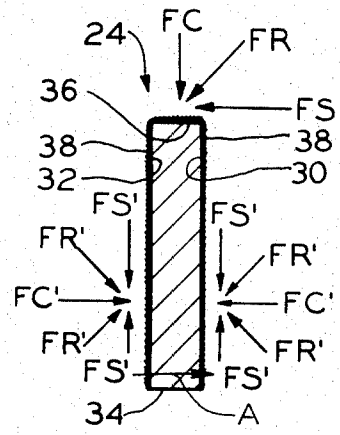


Fig. 2.

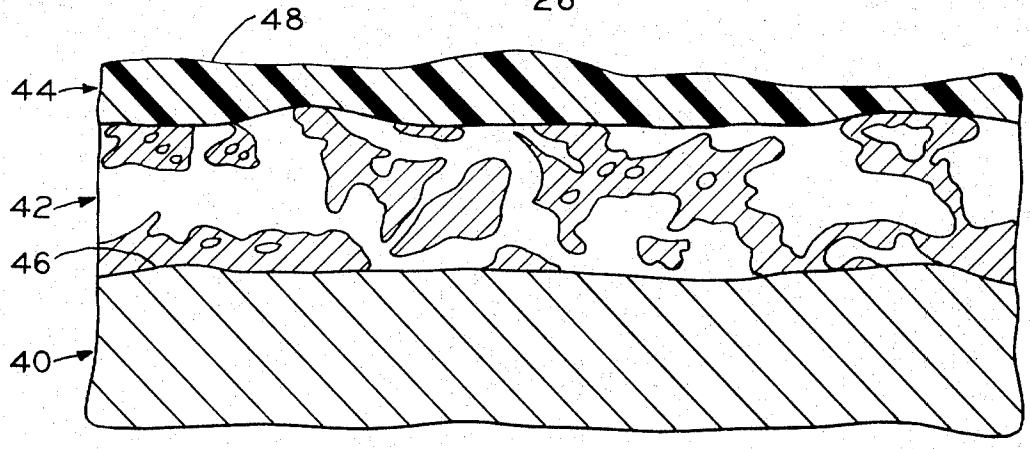


Fig. 3.

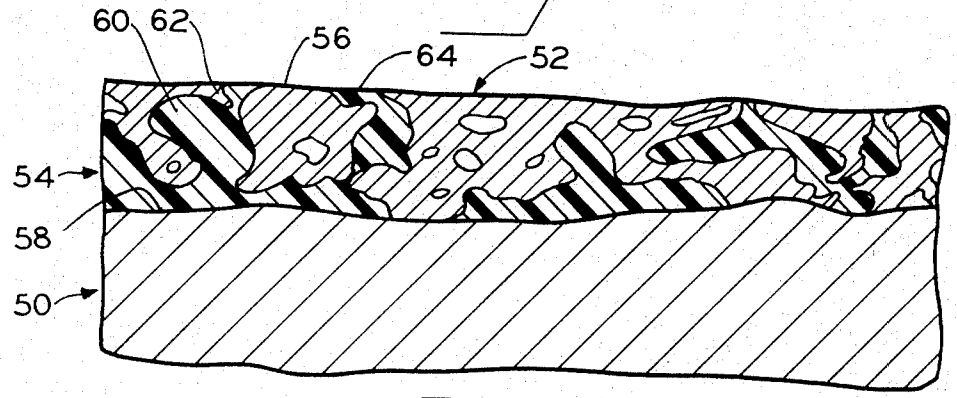


Fig. 4.

COMPRESSOR BLADE

The invention relates to the art of rotary compressors and, more particularly, to an improved vane structure for a vane-type rotary compressor.

As is well known, vane-type rotary compressors include a cylindrical stator and a rotor which is supported within the stator for rotation about an axis eccentric to the axis of the stator. The rotor is provided with a plurality of radially extending slots, and radially reciprocable blades or vanes are disposed in the slots for sliding engagement with the inner surface of the stator in response to rotation of the rotor. The rotor, stator and blades cooperate to define variable volume compression cells which receive fluids to be compressed, such as air, from an inlet opening in the stator and compress and transfer the fluid to an outlet opening provided in the stator at a location circumferentially spaced from the inlet in the direction of rotation of the rotor.

During the operation of a compressor of the foregoing character, the blades reciprocate inwardly and outwardly of the slots and the radially outward edges thereof are maintained in contact with the inner surface of the stator by centrifugal force. One complete reversal of movement by a blade or vane relative to its slot occurs each time the rotor makes one revolution relative to the stator. It will be appreciated, therefore, that if the compressor is operated, for example, at a speed of 3,500 rpm, each blade undergoes a similar number of reciprocating movements. It will be further appreciated that the high speed at which such compressors are capable of operating cause forces of extremely high magnitude to be imposed against the radially outward edge of the blade and the sides of the blade engaging the rotor slot. The forces imposed on the blades and the heat generated during compressor operation are of course detrimental to blade life and, accordingly, considerable effort has been made heretofore to provide vanes which have sufficient strength, resistance to heat and wear, and suitable sealing contact with the inner surface of the stator to prevent leakage of fluid being compressed from one compression cell to a trailing compression cell. Such leakage, of course, reduces the efficiency of the compressor operation. The problems of fluid leakage and heating have been diminished by introducing a fog of coil into the compressor to lubricate and seal the areas between the outer vane edge and stator and between the sides of the vane and its slot. The oil is removed from the compressed air leaving the compressor and is returned to the compressor, through cooling means if necessary. Therefore, the oil operates to dissipate a portion of the heat generated during compressor operation.

Previous attempts to provide blades or vanes having sufficient strength, resistance to heat and wear and good sealing contact properties have included the production of blades from light-weight low-density materials such as aluminum and magnesium, and alloys thereof, and which have at least the slot engaging faces and radially outward edge thereof treated to provide an abrasion-resisting coating thereon. Such abrasion-resisting coating may be provided on blades of this character in the manner set forth in U.S. Pat. No. 2,905,376 to Davey. It is disclosed in the Davey patent that such coatings have an outer surface which is substantially uniformly covered with minute irregularities, and that an outer smooth coating of a self-lubricating material is bonded to the abrasion-resisting coating to

enhance the lubricating and sealing engagement characteristics between the blade, stator and rotor slots, and to reduce stator and rotor slot wear resulting from direct contact of the abrasion-resisting coating therewith.

Blades of the foregoing character provide a considerable improvement over the blade structures which were in use prior thereto. Davey's contribution to the art was a compressor blade which, compared to previous blade structures, had a longer life due to the abrasion-resisting coating and at the same time provided for longer rotor and stator life as a result of the outer self-lubricating coating which reduced stator and rotor slot wear to a minimum.

While the Davey blades enjoy extremely good life characteristics, applicant advantageously provides an improvement in the blade structure which further increases blade life. In this respect, the abrasion-resisting coating provided on these blades has voids between the outer surface thereof and the underlying metal blade body in addition to the surface irregularities referred to in the Davey patent. Such voids are microscopic, and are of non-uniform size, shape and distribution in the coating. The wall area between adjacent voids or between the voids and the outer surface of the coating are in some cases quite thin, and it has been determined by applicant that after extended periods of blade use, at least some of these voids collapse as a result of the forces imposed on the coating during compressor operation. Such collapse of the voids results in deterioration of the coating. Moreover, the collapse of such voids expose extremely sharp edges adjacent the outer surface of the coating which, following wear-away of the self-lubricating coating, abrasively engage the stator surface and rotor slots causing wear thereof. Such a breakdown or deterioration of the abrasion-resisting coating accordingly results in a much more pronounced wearing of the rotor slots and stator surface than is experienced during the long period of blade life prior to such breakdown.

Applicant discovered that the foregoing disadvantages can be avoided and that blade, stator and rotor life can be further increased by preventing void collapsing. In accordance with the present invention, the voids in the abrasion-resisting coating are strengthened against collapsing by filling the voids with a suitable filler material or impregnant after the abrasion-resisting coating has been applied to the blade surfaces. Thus, all of the advantages of the latter coating are retained and the stability of the coating is advantageously enhanced. Various impregnants can be employed to fill the voids, and various methods can be employed to introduce the impregnants into the voids. It will be appreciated that certain of the voids are open to the outer surface of the coating through openings which may be minute in size in comparison to the voids. Further, it will be appreciated that certain of the voids between the outer surface of the coating and the metal of the blade body may not be open to the outer surface of the coating. Some of these voids, however, will be in communication with adjacent void areas through narrow void passageways therebetween. It would be extremely difficult if not impossible to determine whether each and every fillable void is completely filled with material and, of course, there will be some voids completely closed to communication with adjacent voids or the outer surface of the coating whereby these voids will

not be filled at all. Microscopic examination of the cross-section of a blade produced in accordance with the present invention is indicative of the fact that all of the fillable voids are at least substantially filled to capacity with filler material.

The impregnant employed must, of course, be in a liquid state to achieve impregnation. Further, the material must be capable of being transformed after impregnation to a solid state. Another requirement of the impregnant is that it must be stable at the maximum operating temperature of a given compressor, which temperature generally will not exceed about 250° F. Many impregnants for porous metal products are available which have the above characteristics. Among these are thermosetting synthetic polyester resins, epoxy resins, phenolic resins, anaerobic materials and water glass materials. The selection of the impregnant will depend on several factors including cost, ability to satisfactorily penetrate the porous material and the time and complicity of curing or setting. Preferably, the impregnant employed in producing a compressor-blade in accordance with the present invention is a thermosetting polyester resin since these resins cure under heat to a rigid plastic having good strength and heat resistance properties.

In accordance with another aspect of the present invention, the self-lubricating coating bonded to the outer surface of the abrasion-resistant coating to enhance lubricating and sealing characteristics of the blade can be selectively employed after the voids in the abrasion-resisting coating are impregnated with filler material. In this respect, it has been determined that the high degree of abrasion of the stator and rotor slots experienced heretofore in the use of blades having an abrasion-resisting coating without the self-lubricating coating thereon resulted in part from the fact that the voids in the abrasion-resisting coating would break or collapse during sliding engagement of the blade with the stator and rotor slot surfaces as opposed to being uniformly worn or eroded as a result of the frictional sliding contact with the surfaces. Such breakage of the voids produces sharp edges which cut into the surfaces against which they are forced and along which they are moving during compressor operation. With blades made in accordance with the present invention, however, collapse or breaking of the voids is substantially eliminated because of the support provided within the voids by the filler material. Thus, the exposed surface of the abrasion-resisting coating is slowly and uniformly worn or eroded by engagement thereof with the stator and rotor slot surfaces so that the sharp edges heretofore created are not formed, whereby abrasive wear of the surfaces is considerably reduced. If the lubricating characteristics provided by the outer self-lubricating coating are desired, then the latter coating can be employed for this purpose.

It is an outstanding object of the present invention to provide an improved abrasion-resisting coated compressor vane having a longer use life than similarly coated vanes heretofore known.

Another object of the present invention is to provide an improved compressor vane of the above character in which the abrasion-resisting coating is internally supported against deterioration resulting from the collapse of voids therein.

Still another object of the present invention is the provision of a compressor vane of the above character wherein the abrasion-resisting coating has improved strength and wear characteristics.

Still a further object of the present invention is the provision of a compressor vane of the foregoing character wherein the abrasion-resisting coating has voids therein which are at least substantially filled with a non-metallic, solid impregnant to strengthen the voids against collapsing or otherwise breaking whereby the strength and wear characteristics of the coating and thus the life of the vane are advantageously increased.

The foregoing advantages and objects of the present invention will in part be obvious and in part more fully pointed out hereinafter in conjunction with the description of the drawing in which:

FIG. 1 is an end view, in section, of the rotor and stator portions of a fluid compressor;

FIG. 2 is an end view, in section, of a compressor vane;

FIG. 3 is an illustration of a microscopic section of a coated compressor vane made in accordance with the prior art; and

FIG. 4 is an illustration of a microscopic cross-section of one embodiment of a compressor vane made in accordance with the present invention.

Referring now in greater detail to the drawings wherein the showings are for the purpose of illustrating a preferred embodiment of the present invention and not for limiting the same, a rotary vane-type compressor **10** is illustrated in FIG. **1.** As is well known, such a compressor includes a cylindrical stator **12** defining a stator chamber having an inner surface **14** and a longitudinal axis **16.** A cylindrical rotor **18** is supported within the stator chamber for rotation about an axis **20** which is eccentric with respect to stator axis **16.** Rotor **18** is provided about its periphery with a plurality of radially extending slots **22** each of which receives and supports a compressor blade or vane **25** for reciprocating movement radially inwardly and outwardly of the slot. The stator is provided with an inlet **26** for fluid to be compressed and an outlet **28** for compressed fluid. The space between circumferentially adjacent blades **24,** inner surface **14** of the stator chamber and the outer surface of the rotor between adjacent blades defines a variable volume compression cell adapted to receive fluid to be compressed from inlet **26** and to compress and deliver the fluid to outlet **28.** In the embodiment illustrated, rotor **18** is driven clockwise, whereby the cell movement during compression and delivery of compressed fluid is clockwise.

As best seen in FIG. **2,** each blade **24** is defined by generally parallel opposed sides or faces **30** and **32,** a longitudinally extending inner edge **34** and a longitudinally extending outer edge **36.** During compressor operation, a given blade **24** reciprocates outwardly and inwardly of its slot **22** and between its outermost and innermost positions relative to the slot one time for each revolution of the rotor. The blades are forced radially outwardly of the slots by centrifugal force in response to rotation of the rotor and are moved inwardly of the slots as a result of the engagement of outer edges **36** thereof with inner surface **14** of the stator chamber. Blades **24** preferably are produced from a solid, low-density metal having a high heat conducting capacity such as, for example, aluminum, magnesium, and alloys of aluminum and/or magnesium. Such a material has low wear characteristics and accordingly, is provided with a coating of an abrasion-resisting material **38**

which may, for example, be a coating provided in the manner set forth in U.S. Pat. No. 2,905,376 to Davey. From the standpoint of economy in time, coating **38** is provided on blade surfaces **30, 32, 34** and **36** and on the end faces of the blade, not designated numerically, but it is only necessary that the coating be applied on surfaces **30, 32** and **36** since these are the surfaces which are most subject to wear by frictional engagement with the rotor slot surfaces and stator surfaces during compressor operation. A coating of a self-lubricating material, not illustrated, may be provided over coating **38** as is disclosed in the Davey patent. In accordance with the present invention, however, such additional coating is not necessary.

During compressor operation, presuming blades **24** to be rotating clockwise as indicated by arrow A in FIG. **2,** coating **38** on blade edge **36** is subjected to a compressional force FC as a result of the centrifugal force by which the blade is moved radially outwardly of its slot. Further, coating **38** on blade edge **36** is subjected to a shearing force FS as a result of the sliding engagement between the blade edge and stator chamber surface **14.** Forces FC and FS, of course, product a resultant force FR against the coating on blade edge **36.** Further, reciprocating movement of a blade **24** inwardly and outwardly of its slot imposes shearing forces FS′ on the coating **38** on blade surfaces **30** and **32** and which shearing forces are in alternately opposite directions. Moreover, during reciprocating movement of the blade, different portions of the opposite sides thereof will be pressed against the corresponding face of the blade slot whereby compressional forces FC′ are imposed on coating **38.** Thus, during reciprocating movement of the blade in opposite directions relative to its slot, resultant forces FR′ are imposed on coating **38** on the opposed faces of the blade. The magnitude of the forces imposed on the coating will, of course, depend in part on the speed at which the compressor is operating, but in any event it will be appreciated that the forces are imposed on the blade continuously during operation of the compressor and accordingly over a considerable period of time during the life of the blade.

In FIG. 3 of the drawing, there is illustrated a cross-section of a portion of a blade of the character disclosed in the aforementioned Davey patent. FIG. **3** is a representation of a structure depicted in a micro-photograph of the cross-section of a blade and in which the dimensions of the cross-section are magnified 500 times. In this figure, area **40** of the cross-section is the metal of the blade body, area **42** is the abrasion-resisting coating applied to the blade body, and area **44** is the coating of self-lubricating material bonded to the outer surface of coating **42.** More particularly, the blade from which the cross-section of FIG. **3** was taken corresponds to the blade described in example **1** of the Davey patent, and reference is made to this example in the latter patent for the details relating to the blade structure and coating materials.

While the appearance of the metal blade body prior to the applications of the coatings thereto and the appearance of the coated blade appear to the naked eye to be quite smooth, it will be seen from the magnified cross-section that the outer surface **46** of the blade body and the outer surface **48** of the self-lubricating coating are continuous and of irregular contour, and that the outer surface of abrasion-resisting coating **42** is not only of irregular contour, but is interrupted by openings leading to and in part defining voids in the coating between the outer surface thereof and the outer surface of the blade body. These voids are depictd by unshaded areas in FIG. **3,** and the solid portions of the material of the abrasion-resisting coating are depicted by the shaded areas. While the voids appear to be both numerous and large, it will be appreciated that the actual thickness of coating **42** is approximately 0.001 inch whereby, without magnification, the voids would be most difficult if not impossible to see with the naked eye. It is to be further noted that the self-lubricating coating **44** is bonded to the outer surface of the abrasion-resisting coating but fails to enter the void openings in the outer surface.

A blade of the structure depicted in FIG. **3** can be employed for a considerable period of time with very little wear resulting to the blade, the rotor slots or the stator surface. While it was believed heretofore that the self-lubricating coating and abrasion-resisting coating would wear uniformly and smoothly once enough of the self-lubricating coating was worn away to expose portions of the outer surface of the abrasion-resisting coating, whereby earlier abrasion problems encountered with blades having only the abrasion-resisting coating thereon would be avoided, such smooth and uniform wear did not occur in practice. Thus, when the self-lubricating coating wore away to the extent that portions of the outer surface of the abrasion-resisting coating were exposed, abrasive damage was experienced with regard to the blade slots and stator surface and a loss of sealing properties was experienced between the outer blade edge and stator chamber surface. It was discovered that the voids in the abrasion-resisting coating collapse after long periods of use during which the aforementioned forces are imposed on the coating. Further, it was discovered that this breakdown in the coating causes sharp edges of the coating material to be exposed upon wearing away of the self-lubricating coating and such sharp edges, of course, abrasively engage the rotor slots and stator surface.

In accordance with the present invention, the good blade life achieved with a blade of the foregoing character is further increased and, moreover, a blade is provided which advantageously has uniform wearing and sealing characteristics without having to employ the self-lubricating coating to the abrasion-resisting coating. In this respect, the abrasion-resisting coating is strengthened against collapse of the voids therein by filling the voids with an impregnant or supporting filler material to the outer surface of the abrasion-resisting coating. The outer blade surface defined by the outer surfaces of the abrasion-resisting coating and the material filling the voids thereof uniformly wears away during blade use to provide a smooth surface for engagement with the faces of the rotor slots and inner surface of the stator chamber.

A blade having the desired structural characteristics in accordance with the present invention is illustrated in FIG. **4,** which figure like FIG. **3,** is an illustration of an actual micro-photograph of a blade section in which the dimensions of the section are magnified 500 times. In FIG. **4,** portion **50** is the metal body of the blade, portion **52** is the abrasion-resisting coating and portion **54** is the impregnant filling the voides between the outer surface **56** of coating **42** and outer surface **58** of blade body **50.** In the specific blade illustrated, blade body **50** and abrasion-resisting coating **52** are of the

character described in example 1 of the aforementioned Davey patent. Further, coating 52 is approximately 0.001 inch thick. While there will be some voids in coating 52 which will not be open to the outer surface 56 thereof or to an adjacent void, it will be appreciated that a substantial amount of the total void area will be impregnated with material 54 through entrances thereinto from outer surface 56 or through passageways between the voids. The voids in coating 52 are, therefore, strengthened substantially against collapse in response to the aforementioned forces imposed thereon during use of the blade. It will be further appreciated that this support prevents breakage of portions of the coating 52 which might otherwise occur if the coating were unsupported and which would tend to expose sharp edges of the coating material 52 for engagement with the rotor slots and stator surface. In this respect, for example, if void 60 in the blade illustrated in FIG. 4 was not filled with material 54, the forces imposed on coating 52 would tend to cause the thin wall portion 62 of the coating to collapse inwardly toward blade body 50 to produce a sharp edge at this location on outer surface 56. Material 54 advantageously resists such collapse. A further advantage derived by filling the voids of coating 52 is that the voids are strengthened against collapsing so that the outer surface of the blade, as defined by outer surface portions 56 of coating 52 and outer surface portions 64 of plastic material 54, will wear smoothly and uniformly during blade use so that the abrasive action heretofore experienced with the abrasion-resisting coating alone is not encountered. Thus, by filling the voids with suitable filler material, the provision of a self-lubricating coating such as coating 44 provided on the blade illustrated in FIG. 3 is no longer essential to achieve the desired sealing and wear characteristics for the blade. Accordingly, a step in the production of the blade can be eliminated as well as the cost of the material of the self-lubricating coating all of which lends to economical production of the blade.

Many materials are suitable for filling the voids of the abrasion-resisting coating and the choice of the materials will depend in part on the cost thereof, the ability to fill the voids therewith, and characteristics of the filler material under the conditions of operation which will be imposed thereon. Among the materials which are adapted to be employed are polyester resins, phenolic resins, epoxies, anaerobic materials and waterglass materials and from these materials, thermosetting polyester resins, are preferred.

Impregnation of the voids with filler material can be achieved in any desired way and, preferably, the voids are vacuum-filled. While pressure filling can be employed it will be appreciated that a certain amount of air is likely to be trapped in some of the voids to prevent complete filling thereof and, therefore, vacuum-filling is preferred. In the vacuum-filling process, a blade provided with an abrasion-resisting coating is disposed in a vacuum chamber in which a vacuum is drawn to remove air from the voids in the blade coating. The filling material at this time is in a liquid form and the coated blade may, for example, be dipped into a bath of the material which then impregnates and fills the voids by capillary action. Thereafter, the filling material is solidified and the outer surface of the coated blade is suitable cleaned to remove excess filling material therefrom. Alternatively, the blade can be first dipped in the bath of filler material and the vacuum then drawn to achieve impregnation.

In the embodiment described above, the blade illustrated in FIG. 4 is filled with a thermosetting synthetic polyester resin of low viscosity and low solvent content. One such resin is available from Impco, Inc., of Providence, Rhode Island, under their customer designation, RC-2. The latter is a thermosetting synthetic polyester resin of low viscosity designed specifically for impregnation of porous castings and which converts with heat to a hard resilient plastic. This resin exhibits resistance to thermal shock and has a temperature resistance range of from −65° F to 350° F. A low-viscosity resin enhances penetration of the material into the voids and accordingly assures a more complete filling thereof. The thermosetting resin is cured following the vacuum-filling operation and forms a hard resilient plastic filling. If desired, the outer surface of the coated and impregnated blade can be polished such as by a silicon carbide wheel to refine the outer surface.

It has been found with regard to the blade of the preferred embodiment that the abrasion-resisting coating is approximately ten times more resistant to a crushing force imposed thereon than is a blade wherein the voids of the abrasion-resisting coating are unfilled and the latter coating is coated with self-lubricating material.

While considerable emphasis has been placed herein on the fact that the abrasion-resisting coating is of the character described in the patent to Davey, it will be appreciated that the present invention is applicable to the strengthening of any protective coating which may be applied to a compressor blade and which is of a porous nature. Further, it will be appreciated that the present invention is applicable to a compressor blade having a body of any low-density high-thermal conductivity metal which is protectively coated to enhance the abrasion-resistant characteristics thereof.

As many possible embodiments of the present invention may be made and as many possible changes may be made in the embodiment herein disclosed, it is to be distinctly understood that the foregoing descriptive matter is to be interpreted merely as illustrative of the present invention and not as a limitation.

Having thus described my invention, I claim:

1. In combination, a rotary compressor having a cylindrical stator and a rotor supported therein for rotation about an axis eccentric to the stator axis, said rotor having radially extending slots therein, radially reciprocable vanes in said slots for engaging the inner surface of said stator in response to rotation of said rotor, each of said vanes comprising a body of metal having a low density and a high heat conducting capacity, an abrasion-resisting coating on said body and having voids therein between the outer surface thereof and said body, said coating being subject to collapse by forces imposed thereon during compressor operation, and a non-metallic impregnant filling substantially all of said voids to restrain collapse of the material of said coating.

2. The combination according to claim 1, and a coating of self-lubricating material bonded to said abrasion-resisting coating.

3. The combination according to claim 1, wherein said impregnant is a thermosetting plastic resin.

4. The combination according to claim 3, wherein said thermosetting resin is a polyester resin.

5. The combination according to claim 7, wherein said metal body is essentially magnesium.

6. The combination according to claim 7, and a coating approximately 0.0002 inch to 0.0001 inch thick of a self-lubricating material bonded to said abrasion-resisting coating.

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