

1

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**ABRADABLE METAL COATINGS AND  
PROCESS THEREFOR**

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This invention relates to a non-galling coating material and more specifically concerns an abradable metal coating and a process for producing same.

Designers of turbines, for example, are confronted by the formidable problem of reducing the clearance space between the turbine blade and the turbine housing. This represents a substantial physical barrier to increasing the turbine speed. If the clearance is reduced, the amount of gas that escapes, which represents available energy that has not been fully utilized, becomes less, leading to an increase in efficiency.

In view of the growing number of turbines for jet engines, the emphasis on closer tolerances is increasing. The development of new materials that can be applied as coatings to housings and that are adapted to closely conform to the path of the blade tip with a minimum of clearance will enable engineers to wring greater speeds from smaller turbines.

We have attempted to minimize the clearance between the blade and the housing of a turbine by coating the inside diameter of the housing with various coating materials of sufficient thickness to establish contact with the blade, and then allowing the blade to rotate and cut a path through the coating. Up to now, this procedure has been unsatisfactory due to galling and tearing of the coating under the forces generated by the rotating blades.

It is, therefore, an important object of the present invention to provide a novel coating material capable of being applied as a coating to a suitable base material and adapted to suitably abrade when subjected to sufficiently high forces along its surfaces.

Another object of the invention is to provide a coating that can flake off in relatively uniform particles when subjected to sufficiently high forces along its surface without galling or tearing.

Other objects, features and advantages of the present invention will be apparent from the following detailed description of a preferred embodiment thereof.

The present invention is a novel abradable metal coating that flakes off in powder form when subjected to sufficiently high forces along its surface. It not only imparts the desired abradable coating properties to a suitable base material, but possesses other beneficial properties such as oxidation resistance and suitable melting point.

The novel coating of the invention comprises a major component constituting the metal phase of the coating and consisting of one or more metals, and a minor component consisting of a high melting finely-divided powder substantially uniformly distributed in the metal phase of the major component.

The major component may be composed of one or more metals or alloys having desirable coating properties with respect to melting point, corrosion resistance, and oxidation resistance. For example, if a relatively low melting point abradable coating is desired, aluminum is preferred. For higher melting point coatings, metal such as nickel, stainless steel, Nichrome, Monel or other suitable alloys are preferred as the major component.

Among the materials that have been found to be eminently suitable as the high melting dispersed powder are boron nitride, carbon, graphite, and magnesium oxide. Preferably, the powder should be of a material which is not melted by the process used to apply the coating.

2

The ratio of metal phase content to high melting point powder content of the coating product will depend upon the desired end use of the abradable coating. A metal phase having incorporated therein between approximately 2% and 20% by weight of finely divided high melting point powder is preferred, although higher and lower amounts of powder may be employed, depending upon the particular powder and base metal. Generally, a low percentage by weight of powder is dispersed in the metal phase of a relatively soft coating material, and higher weight percent powder contents are employed in coatings of relatively harder material. For example, when a relatively soft coating material such as aluminum is used, the higher melting additive content is about 2 to 5 weight percent. On the other hand, if a coating of Nichrome is desired, the additive content may be as much as 15 to 20%.

An important feature of the invention involves the process of applying the abradable coating to the surface of a baseplate. In order to obtain good bond strength between the abradable coating and the baseplate, an undercoat of metal is first applied to the baseplate. This metal undercoat preferably comprises one or more layers, each about 0.003-0.005 inch thick. It is conveniently of the same metal as the metal phase of the final abradable coating, but it could be of any metal which is compatible with the adjacent metals in the baseplate and abradable coating. During the entire coating operation of applying both the undercoat and final abradable layer the baseplate is preferably heated to about 400-600° F. in order to obtain the most satisfactory bond strength between coating and baseplate.

The coating material can be applied by various processes employing a high temperature, high velocity means of application. Such methods are disclosed, for example, in U.S. Patents Nos. 2,714,563, 2,861,900 and 2,847,555 and U.S. applications, Serial No. 706,099, filed December 30, 1957, now abandoned, Serial No. 706,135, filed December 30, 1957, now abandoned, Serial No. 850,444, filed November 2, 1959, now U.S. Patent No. 3,016,447, and Serial No. 521,041, filed July 11, 1955, now Pat. No. 2,920,001.

The preferred process of applying the novel coating comprises feeding the metal phase material in wire or rod form into the effluent from a high temperature, high velocity burner in the manner described in copending application Serial No. 521,041. This effluent traveling at velocities greater than 2000 ft./sec. melts the wire to form finely divided molten metal particles and then rapidly impinges them on the baseplate, or part being plated, with such force that a firm bond results. The high melting point dispersed material is simultaneously introduced, preferably in powder form, into the combustion chamber of the burner, is discharged into the burner effluent and mixes with the molten metal phase particles prior to impingement on the baseplate. As an alternative, the high velocity burner effluent and molten metal particles could be directed through a gaseous suspension of high melting point powder particles prior to impingement on the baseplate. Still another method involves incorporating the powder into the metal wire prior to introduction into the coating apparatus.

While we do not wish to be limited by the following theory, it is believed that the abradable characteristics of our novel coating are caused by the dispersed material preventing the formation of a solid, dense, strongly cohesive metal phase. For this reason, it is desired that the dispersed material not be molten during formation of the coating. Otherwise, a fused or inter-metallic bond between the metal phase and the dispersed material could be strengthened and form a coating which would gall or tear instead of uniformly flaking. Under our preferred

3

coating conditions, some of the high melting point material applied to the coating area may not be deposited since it may not be molten.

A spot test used to determine degree of abrasability is to take a blunt tool and scratch the surface of the coating. Powdery material consisting of small flakes will be removed from an abrasable coating while the surface of a non-abrasable coating will simply be scratched with no metal removal or will gall and tear.

In order to indicate still more fully the nature of the present invention, the following examples of typical procedures are set forth, it being understood that these examples are presented as illustrative only and that they are not intended to limit the scope of the invention.

#### EXAMPLE I

##### *Aluminum-Boron Nitride Abradable Coating*

The plating apparatus comprised a throat combustion burner having an unstricted combustion chamber  $\frac{1}{4}$ -in. I.D. and 4-in. long. Acetylene at 160 c.f.h. and oxygen at 230 c.f.h. were fed to the burner, combusted and discharged as a high temperature effluent having velocity greater than 2000 ft./sec. Aluminum wire having  $\frac{1}{16}$ -in. dia. was fed at 13.5 grams/min. into the effluent from the burner where it melted and formed finely-divided metal particles which were in turn impinged on a baseplate. This baseplate consisted of a steel ring 4-in. dia. and  $\frac{5}{8}$ -in. wide which was heated to 400–600° F. This coating operation was continued until a layer of aluminum 0.003–0.005 in. thick was deposited on the inner surface of the ring. The aluminum wire feed was then continued and finely-divided boron nitride powder at 2 grams/min. was introduced by means of a 40 c.f.h. nitrogen carrier gas stream into the combustion burner throat. The resulting mixture of aluminum and boron nitride particles were then impinged on the aluminum undercoat to form a coating about 0.080 in. thick. This outer coating was analyzed to contain 97 weight percent aluminum. The coated ring was mounted in a lathe and rotated at 800 r.p.m. while a blunt-edged tool was forced onto the coated surface. The coating abraded satisfactorily and formed small particles which readily flaked off. A similar coating was successfully applied to the compressor housing of a jet engine.

If the boron nitride flow is reduced to less than 1.0 gram/min. while maintaining the other coating conditions constant, the resulting coating loses its abrasability. If the boron nitride flow is increased above 4.0 grams/min., the resulting coating is too weak and unreliable.

#### EXAMPLE II

##### *Aluminum-Graphite Abradable Coating*

The same apparatus and burner operating conditions were used as described in Example I. An undercoat of aluminum 0.003–0.005 in. thick was applied to a heated baseplate. The abrasable coating was applied using feed rates of 13.5 grams/min. for the  $\frac{1}{16}$  in. diameter aluminum wire and 17 grams/min. for graphite powder. The resulting 0.070-in. thick coating was easily abraded.

The above described aluminum-boron nitride and aluminum-graphite coatings are satisfactory for use at relatively low temperatures.

The following examples describe formation of abrasable coatings which retain their useful properties at temperatures as high as 1400° F. These coatings find utility in the turbine sections of commercial jet engines which operate at higher temperatures than the compressor section.

#### EXAMPLE III

##### *Nickel-Chromium-Boron Nitride Abradable Coating*

The same apparatus and burner operating conditions were used as described in Example I. An undercoat of nickel 0.003–0.005 in. thick was applied to the heated

4

baseplate followed by a second coat of Nichrome V (80% Ni–20% Cr) of same thickness. The final abrasable coating was applied using feed rates of 25 grams/min. for the 0.063-in. dia. Nichrome V wire and 6.0 grams/min. for the boron nitride powder. The resulting 0.060-in. thick coating had desirable abrasable characteristics up to about 1400° F.

#### EXAMPLE IV

##### *Nickel-Chromium-Graphite Abradable Coating*

The same apparatus and burner operating conditions were used as described in Example I. An undercoat of nickel 0.003–0.005 in. thick was applied to a heated baseplate. The abrasable coating was applied using feed rates of 25 grams/min. for the 0.063-in. dia. Nichrome V wire and 14.0 grams/min. for the graphite powder. The resulting 0.050-in. thick coating was easily abraded.

#### EXAMPLE V

##### *Nickel-Chromium-Magnesium Oxide Abradable Coating*

The same apparatus and burner operating conditions were used as described in Example I. An undercoat of nickel 0.003–0.005-in. thick was applied to a heated baseplate followed by the abrasable coating. Feed rates of 25 grams/min. for the .063-in. dia. Nichrome V wire and 10.0 grams/min. for the magnesium oxide powder were employed. The resulting .030-in. thick coating had desirable abrasable characteristics.

#### EXAMPLE VI

##### *Nickel-Copper-Iron-Graphite Abradable Coating*

The same apparatus and burner operating conditions were used as described in Example I. An undercoat of nickel 0.003–0.005 in. thick was first applied to a heated baseplate. The abrasable coating was applied using feed rates of 27 grams/min. for the .063-in. dia. Monel metal (60% nickel–33% copper–6.5% iron) wire and 8.0 grams/min. for the graphite powder. This .030-in. thick final coating was easily abraded.

#### EXAMPLE VII

##### *Nickel-Chromium-Aluminum-Graphite Coating*

The same apparatus and burner operating conditions were used as described in Example I. An undercoat of nickel 0.003–0.005 in. thick was first applied to a heated baseplate. The final coating was applied using feed rates of 25 grams/min. for the .063-in. dia. metal alloy wire containing 96 weight percent of a nickel-chromium alloy (80% Ni–20% Cr) and 4 weight percent aluminum and 15.0 grams/min. for the graphite powder. The resulting 0.015-in. thick coating was easily abraded.

#### EXAMPLE VIII

##### *Iron-Chromium-Nickel-Graphite Abradable Coating*

The same apparatus and burner operating conditions were used as described in Example I. An undercoat of nickel 0.003–0.005 in. thick was first applied to a heated baseplate. The final coating was applied using feed rates of 24 grams/min. of .063-in. dia. Type 302 Stainless Steel (iron-carbon alloy containing 17–19% Cr and 8.10% Ni) wire and 12 gram/min. graphite powder. The resulting 0.020-in. thick coating was easily abraded.

#### EXAMPLE IX

##### *Nickel-Carbon Abradable Coating*

The same apparatus and burner operating conditions were used as described in Example I. An undercoat of nickel 0.003–0.005-in. thick was first applied to a heated baseplate. An abrasable coating was then applied to the undercoat by feeding 0.063-in. dia. nickel wire at 17 grams/min. into the high velocity burner effluent and passing the molten metal particles through a gaseous sus-

5

pension of carbon particles prior to impinging on the baseplate.

It will be understood that modifications and variations may be effected without departing from the spirit and scope of the invention.

What is claimed is:

1. An article comprising a structure having thereon a coating which produces a powder-like scraping when scratched with sufficient force along its surface consisting essentially of metallically bonded metal particles defining a fused metal phase having substantially uniformly incorporated therein in a non-fused relationship, particles of a high melting powder in minor amounts between 2 and 20% by weight, there being lesser amounts of high melting powder in said metal phase when said metal phase consists of relatively low melting metal than when said metal phase consists of relatively high melting metal.

2. An article comprising a structure having thereon a coating according to claim 1, said metal phase consisting of aluminum and said high melting point powder consisting of boron nitride.

3. An article comprising a structure having thereon a coating according to claim 1, said metal phase consisting of aluminum and said high melting point powder consisting of graphite.

4. An article comprising a structure having thereon a coating according to claim 1, said metal phase consisting of an alloy of nickel and chromium and said high melting point powder consisting of boron nitride.

5. An article comprising a structure having thereon a coating according to claim 1, said metal phase consisting of an alloy of nickel and chromium and said high melting point powder consisting of graphite.

6. An article comprising a structure having thereon a coating according to claim 1, said metal phase consisting of an alloy of iron, chromium and nickel and said high melting point powder consisting of graphite.

7. An article comprising a structure having thereon a coating according to claim 1, said metal phase consisting of an alloy of nickel, copper and iron and said high melting point powder consisting of graphite.

8. An article comprising a structure having thereon a coating according to claim 1, said metal phase consisting of an alloy of nickel, chromium and aluminum and said high melting point powder consisting of graphite.

9. An article comprising a structure having thereon a coating according to claim 1, said metal phase consisting of nickel and said high melting point powder consisting of graphite.

6

10. An article comprising a structure having thereon a coating according to claim 1, said metal phase consisting of an alloy of nickel and chromium and said high melting point powder consisting of magnesium oxide.

11. A coated body comprising a base member and a metallic coating having good antigalling properties, bonded thereto, said coating consisting of a fused metal phase consisting of interbonded particles of a fused metal having incorporated therein dispersed non-fused refractory particles in quantities of from 2 to 20% by weight, said coating being abradable upon the application of a firm force across the surface thereof.

12. A method of producing an abradable metal coating on a base material comprising applying to said base material an undercoating of a metal bondably compatible with the coating desired, impinging a high velocity high temperature stream of molten metal phase coating material against said undercoating to form a firm bond therewith, and simultaneously introducing about 2 to 20% by weight of a high melting point powder into said stream of metal phase coating material prior to impingement on the undercoat.

13. A method of producing an abradable metal coating on a base material comprising: forming a high velocity stream consisting of molten particles of a metal to be deposited, impinging said stream against the surface of the base material to be coated, forming a second high velocity stream consisting of molten particles of said metal and unmelted particles of a high melting point powder, impinging said stream at high velocity against the base material to fuse the molten metal particles into a metallically bonded mass having interspersed there-through in an amount between 2 and 20 percent by weight and in non-fused relationship, said particles of high melting point powder, and maintaining said base material and coating at a temperature between 400° F. and 600° F. during said coating method.

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