

1

2

3,413,136

ABRADABLE COATING

Roger C. Emanuelson, Glastonbury, and William F. Witherell, Rockville, Conn., assignors to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware
No Drawing. Filed Mar. 10, 1965, Ser. No. 438,734
5 Claims. (Cl. 117—8)

ABSTRACT OF THE DISCLOSURE

In a jet engine assembly, a method of applying an abradable sealing surface between the tips of rotating elements and the surrounding assembly, featuring the use of a bonding medium and an abradable medium, wherein the rate of application of the bonding medium is decreased while the rate of application of the abradable medium is increased so as to achieve a graded sealing surface.

This invention relates in general to the tip-sealing of rotating elements in gas turbine engines and more particularly to an improved abradable gas seal construction for such engines. It contemplates a process whereby a structurally reliable abradable coating is applied to engine stator assemblies by thermal spraying techniques.

The efficiency of a gas turbine engine is dependent to some extent upon the control of gas leakage between stages in both the compressor and turbine sections of the engine. Although the engine is typically designed and manufactured to very precise dimensional tolerances, it is necessary to provide a sufficient cold clearance between the tips of the rotating elements and the surrounding stator assembly to accommodate the differential thermal growth between the parts as the engine assumes its normal operating temperature. To this cold clearance must be added the usual manufacturing tolerances plus an additional safety factor to provide for limited engine operation at temperatures in excess of the design temperature. The requisite clearances thus provided are, however, generally not sufficiently close to permit the engine to operate at its maximum theoretical efficiency.

In an effort to remedy this condition, it has been proposed to utilize an abradable surface on the assembly surrounding the rotating elements and to permit the knife-edge of the rotor system to penetrate into the coating as a result of thermal expansion, thereby permitting the rotor to seat itself against the stator assembly with what is essentially a zero clearance. The result is considerably better sealing and consequently better efficiency than that provided by conventional air seals. A typical abradable seal construction of this type is shown in the patent to Koehring 2,930,521.

While in theory such an abradable surface may be seen to have great potential in improving engine performance, current techniques and abradable seal structures have not been entirely satisfactory in their practical application to high performance jet engines. In general, the problems that have arisen in the use of abradable coatings are attributable to the lack of structural strength in the coating itself and in its poor adherence to the metal substrate to which it is applied.

It is, therefore, an object of this invention to provide an abradable coating which is characterized by a high strength bond with the metal substrate and good structural integrity in the elevated temperature environment of a high performance jet engine. This objective is achieved by providing a coating in which the composition varies as a function of its depth.

It is a further object of this invention to provide a

procedure for effecting such a coating utilizing thermal spraying techniques.

It is a still further object to provide a technique for varying the characteristics of the coating as a function of its depth without introducing shear planes therein. This technique contemplates varying the compositions of coating powders introduced to a spray gun as the coating is effected on the metal substrate, or varying the respective spray rates of a plurality of spray guns, to form an inter-metallic at the substrate surface and an abradable composition at the outer surface of the coating, gradually phasing from one composition to another as the coating is produced.

These and other objects and advantages of the present invention will be evident or will be discussed in connection with the following description.

It is axiomatic that that the abradable surface of the coating must be selected in accordance with the anticipated environment in which it is to be run. A suitable surface material must be readily penetrated by the rotating blade with a minimum of blade wear, and yet must withstand, in jet engine applications, the erosive and corrosive effects of the hot engine gases.

Abrasion of a material by a high speed rotating knife-edge occurs either as a result of the material being pushed aside or as a result of particles being broken away. Soft materials are abraded by the first method and friable materials by the second method. It should be noted, however, that friable materials generally have reduced strength properties and are therefore not suitable for abradable coatings unless supported by a matrix of stronger materials.

The abradability of materials may be increased by decreasing the material density and increasing the porosity, although each of these factors reduces the strength of the coating and the resistance of the material to erosion. Further, the abradability may be increased by annealing. The hardness of nickel, for example, is reduced from a Vickers hardness of over 200 to less than 100 by annealing at 900° F.

As has been indicated, the abradability may be increased by introducing porosity into the coating, and this has been demonstrated to be the preferable method. The abradability index increases with the volume percent of pores, provided the pore size remains constant, but excessive porosity will reduce the mechanical and bond strengths below the desirable levels. Several methods have been utilized to introduce porosity to the material, one such method being the addition of a salt to the coating material as applied which may subsequently be leached from the formed coating. An alternate method of effecting porosity is to introduce a material into the coating as applied which may subsequently be removed by an oxidation process. A third method contemplates the addition of a constituent to the coating mixture, such as boron nitride, which will form a brittle compound at the inter-particle boundaries.

Although several methods of applying the coatings are available, the most satisfactory results have been obtained by means of thermal spraying. This process is inherently flexible since it permits the coating material to be selected and premixed in powder form before spraying, and because close control can be exercised over the spraying process. As used herein, the term "thermal spraying" will be understood to have reference to either the flame spraying or plasma spraying processes.

Flame spraying is a coating process in which powdered material is injected into a flame, melted, and subsequently carried in the molten state and deposited on a substrate by a gas jet. The flame is produced by the combustion of hydrogen or acetylene with oxygen or air. The carrier gas is usually air or one of the inert gases. The efficiency

and quality of the coating processes depends on the flame temperature and heat production rate, the gas flow rates, the powder feed rate, and the distance between the substrate and the spray gun. Adjustment of the gas flow rates changes the combustion rate and the time that the powder particles remain in the combustion zone. Changing the substrate-to-gun distance changes the particle cooling time before impact and is probably the most important spraying parameter.

Plasma spraying is similar to flame spraying except that the heat is derived from an electrical arc and no combustion products are produced. Considerably more energy is generated during plasma spraying than during flame spraying, however, and the temperature produced is 40,000° whereas the maximum temperature produced by flame spraying is about 3600° F. As a result, the coatings produced by the two processes have somewhat different properties. For example, salt added to metallic powders to produce porosity is vaporized during plasma spraying and consequently its usefulness as a porosity developer is lost.

Flame spraying has been demonstrated to be somewhat more suitable than plasma spraying in the application of abrasible coatings since less energy is added during the process, and the resulting coating is softer and less dense. Although the flame spraying process has been shown to be the most suitable method of applying abrasible coatings, it has nevertheless been necessary to develop special spraying techniques and coating compositions before truly suitable coatings are obtained. Early experiments revealed that an adequate bond could not be formed between the abrasible coating, for example, porous nickel, and the metal substrate. Mechanical methods, such as knurling the substrate, have been attempted but were found to be impractical. In flame spraying the bond strength is weakened by thermal stresses which develop at the coating-substrate interface and, although the coefficients of thermal expansion may be similar, the stresses are developed during the formation of the bond while the coating material and the substrate are at different temperatures. Consequently, it was found necessary to interpose between the substrate and the abrasible material an intermediate medium to improve the bonding to the substrate. It was further found necessary to effect a gradual phasing of one component into the other as a function of the coating thickness in order to eliminate shear planes therein which lead to laminar separation in the coating.

For turbine applications, nickel and chromium were selected as the most suitable abrasible materials since they were known to have melting points in excess of 2000° F., and were further known to be compatible with the corrosive engine gases. Ceramics were not seriously considered since they are inherently brittle and not easily bonded to the non-rotating engine parts. Alloys are generally unsuitable because of their tendency to form low melting point eutectics or hard metallurgical phases which reduces the abrasibility. Mixtures of nickel and silver, however, have been determined to be suitable candidate materials since no alloy or solid solution is formed therebetween. The metals palladium, platinum, and rhodium are known to possess the requisite temperature and corrosion resistance characteristics but are not suitable for engine applications because of their cost.

The intermediate medium selected to form the bridge between substrate and the abrasible surface is nickel aluminide which will bond metallurgically to the substrate if properly applied. The nickel aluminide phase of the coating is formed on the substrate by means of a plasma spray utilizing nickel-coated aluminum powders, known commercially as METCO 404, as the feed material, the powder analyzing at approximately 80% nickel and 20% aluminum. Since the nickel and aluminum mixture in this form is both exothermic and synergistic, it will form a strong metallurgical bond with the metal substrate when applied from a plasma gun.

While the deposited nickel aluminide forms an excellent base for a subsequent topcoat, it was found that laminar separation could occur at the nickel aluminide-porous nickel interface during engine operation. Consequently a technique was developed whereby the coating was graded gradually from pure nickel aluminide at the substrate surface to pure nickel at the outer surface of the coating. This technique involves spraying each constituent separately, the nickel coated aluminum powder from a plasma gun and the nickel from a flame gun, but sequentially to produce the desired material gradient in the coating. Attempts to apply a graded coating with a single gun by changing the characteristics of the powders in the charge was unsatisfactory because the constituents required different spraying parameters. With different materials, however, particularly those having similar characteristics, there is no reason why a single gun could not be used for this purpose.

This process is suitable for effecting a coating on a variety of metal substrates, the only requirement being the establishment of a metallurgical bond between the substrate and the intermediate medium. For example, the nickel coated aluminum powders applied by plasma spray techniques are known to bond to nickel base alloys, steels, aluminum, titanium, tantalum and columbium.

A porous nickel abrasible surface has been applied to engine parts utilizing the above-mentioned technique by gradually phasing the coating from nickel aluminide to a nickel salt mixture and subsequently leaching out the salt after formation of the coating.

The highest abrasibility was exhibited in tests on a coating with a porous surface containing 33% nickel but the excessive porosity resulted in a significant reduction in structural integrity. The optimum nickel concentration in the abrasible surface has been established at between 50 and 75 volume percent nickel.

Example

Nickel salt mixture:

Nickel powder ----- 90% by weight (68.6% by volume).

Salt (sodium chloride) -- 10% by weight (31.4% by volume).

Aluminum phosphate --- 1 cc. per 8 grams salt.

The powders fed to the flame spraying apparatus were prepared in the indicated proportions and were thoroughly blended.

Although abrasibility testing of coating indicated that large grain sizes produced the more abrasible coatings, the finer powders were shown to be more suitable for spraying. It is also advisable to abrade particles from a coating which are fine enough not to damage downstream engine parts. Accordingly, the powders utilized were in the range of 200-250 mesh.

The nickel powder was previously reduced in a hydrogen-rich atmosphere to control the oxygen content since powders with an oxygen content of 3 percent or more do not spray effectively.

Aluminum phosphate was added to the mixture to bind the salt crystals to the metallic powder. Without the binder, the salt separates from the metallic powder in the vibrating hoppers used in conjunction with the spraying equipment.

Nickel aluminide powder:

METCO 404

Spray equipment:

Giannini Plasma Spray Gun SG-1—

Current -----amperes-- 550

Arc gas flow (argon) -----c.f.h.-- 55

Powder gas (argon) -----c.f.h.-- 27

Colmonoy Spray Gun—

Oxygen -----c.f.h.-- 27

Hydrogen -----c.f.h.-- 58

Power gas (nitrogen) -----c.f.h.-- 45

Coating process

After degreasing, Inconel engine parts to be coated were grit blasted to roughen the surface. Silicon carbide #24 grit was used for this purpose. The surface to be coated was rotated at approximately 47 inches per minute at a distance of approximately four inches from the plasma gun and preheated to 200° F. using the plasma torch with the powder feed turned off. The nickel aluminide was applied to the rotating part to a thickness of .003-.005 inch and, while the plasma gun application of nickel aluminide was continued, the nickel-salt mixture was simultaneously phased in as a separate stream from the flame gun, the nickel aluminide feed rate being gradually decreased while the nickel-salt feed rate was increased. The transition from nickel aluminide to nickel-salt was effected within .015-.020 inch of the Inconel substrate. The nickel-salt application was then continued until the desired abrasible surface thickness was attained. Although this is a function of the design requirements, the abrasible surface was generally .025 inch thick after machining.

The salt inclusions in the coating were then leached out with agitated water at 180° F. For engine applications it is essential that all of the exposed salt is removed from the finished coating since residual chlorine catalyzes a sulfidation reaction to which high temperature, high nickel content aircraft alloys are particularly vulnerable. For this reason, the salt removal is preferably undertaken before any machining of the coating has been performed since metal flow during machining tends to entrap salt particles.

After the salt has been removed, any necessary machining was performed followed by annealing at 1300° F. to eliminate the surface work hardening produced in the machining operation.

Over 150 engine parts were coated with abrasible materials and tested in experimental engines. An abrasible porous nickel coating of 30 volume percent porosity bonded with nickel aluminide by the foregoing method was tested in the turbine section of an experimental engine and demonstrated a capability of over 200 hours of engine service. Analysis indicates that an improvement in turbine efficiency of at least 1½ percent is realized.

While a preferred process and abrasible seal composition has been described, the present invention in its broader aspects is not limited thereto but departures may be made from such details within the scope of the accompanying claims.

We claim:

1. The method of producing an abrasible coating on a jet engine assembly comprising the steps of: plasma spraying the surface of the assembly with a nickel-coated aluminum powder to form an intermetallic with the base metal of the assembly,

after the intermetallic has been formed and while continuing the plasma spray, initiating flame spraying of the surface with a nickel-salt mixture, gradually decreasing the plasma spray rate while increasing the flame spray rate until the plasma spray is phased out, whereby a graded coating is effected, and

leaching the salt from the applied coating to form a porous nickel surface.

2. The method of claim 1 wherein:

the plasma sprayed coating is applied to a thickness of .003-.005 inch before flame spraying is initiated, and the transition from full plasma spray to full flame spray is effected within .015-.025 inch of the surface of the assembly.

3. The method of claim 2 wherein:

the nickel-salt mixture consists of essentially 50-70 volume percent nickel and 25-50 volume percent salt.

4. The method of claim 3 wherein:

the salt is sodium chloride.

5. A method of producing an abrasible coating on an engine component comprising the steps of:

thermally spraying the surface of the component with an exothermically-reacting powder to form an intermetallic with the component substrate metal,

after the intermetallic has been formed and while continuing spraying of the exothermically-reacting powder, initiating flame spraying of the component surface with a nickel-salt mixture,

gradually decreasing the rate of deposition of the exothermically-reacting powder while increasing the rate of deposition of the nickel-salt mixture until the powder is phased out, whereby a graded coating is effected, and

removing the salt from the applied coating to form a porous nickel surface.

References Cited

UNITED STATES PATENTS

2,233,304	2/1941	Bleakley	117-105.5
2,930,521	5/1960	Koehring	230-133
3,010,480	11/1961	Ragsdale	117-71
3,020,182	2/1962	Daniels	117-105 X
3,084,064	4/1963	Cowden et al.	117-71
3,091,548	5/1963	Dillon	117-71
3,138,857	6/1964	Kuchek	29-423
3,246,114	4/1966	Matvay	117-105.1 X
3,254,970	6/1966	Dittrich et al.	29-183.5

ALFRED L. LEAVITT, *Primary Examiner*.

A. G. GOLIAN, *Assistant Examiner*.