

CERAMIC FACED OUTER AIR SEAL FOR GAS TURBINE ENGINES

This invention relates to outer air seals of gas turbine engines, and particularly to seals coated with abradable ceramic materials.

5 ~~The concepts were developed in the gas turbine engine industry for use in the turbine sections of gas turbine engines, but have wider applicability within that industry and others as well.~~

10 In modern gas turbine engines, working medium gases having temperatures in excess of 1093°C are expanded across rows of turbine blading for extraction of power from the flowing medium. A shroud, termed an outer air seal, circumscribes each row of turbine blading to inhibit the leakage of working medium gases over the blade tips.

15 Outer air seals of some engines are formed of a metallic substrate to which a thermal barrier coating is applied for protection of the seal from the high temperature, working medium gases. Ceramic materials are generally known to be effective thermal insulators and are in wide use in such seal applications. As long as the ceramic coating remains intact, the ceramic prevents unacceptable deterioration of the metallic form to which it is adhered.

20 Durable structures capable of long term, reliable service in the hostile turbine environment are sought. Specific needs are high temperature capability, and good resistance to thermal shock. Additionally, for turbine seal applications the structure must have adequate surface abradability to prevent destructive interference upon the occurrence of rubbing contact of the seal by circumscribed rotor blades and good erosion resistance, particularly at the leading edge of the seal to prevent excessive wear at the incidence of particles entrained in the working medium upon the seal. In some engines the hot working medium gases alone may be erosive.

35 U.S. Patents Nos. 3 091 548 to Dillon entitled "High Temperature Coatings"; 3 817 719 to Schilke et al entitled "High Temperature Abradable Material

and Method of Preparing Same"; 3 879 831 to Rigney et al
entitled "Nickel Base High Temperature Abradable Material";
3 911 891 to Dowell entitled "Coating for Metal Surfaces
5 and Method for Application"; 3 918 925 to McComas
entitled "Abradable Seal"; 3 975 165 to Elbert et al
entitled "Graded Metal-to-Ceramic Structure for High
Temperature Abradable Seal Applications and a Method
of Producing Said "; 4 109 031 to Marscher entitled
10 "Stress Relief of Metal-Ceramic-Gas Turbine Seals";
4 163 071 to Weatherly et al entitled "Method for Forming
Hard Wear-Resistant Coatings"; and 4 289 446 to Wallace
entitled "Ceramic Faced Outer Air Seal for Gas Turbine
Engines " are representative of the known concepts appli-
15 cable to ceramic faced seals.

Although many of the materials and methods
described in the above patents are known to be highly
desirable, the structures resulting therefrom have yet to
achieve full potential in hostile environment applications.
20 Of particular remaining concern in outer air seal appli-
cations is the balance needed for good abrasability in
response to blade rubbing contact and good erosion
resistance to the effects of particles entrained in the
working medium stream.

25 According to the present invention ceramic
facing material of a turbine outer air seal is formed to
first surface density at the leading edge of seal and to
a lesser surface density downstream thereof such that the
area of the first density is more resistant to wear by
30 foreign particle erosion and the area of lesser
density is more easily abraded by passing rotor blades
in the installed environment.

According to one detailed embodiment of the
invention the ceramic facing material is formed of two
35 or more layers of decreasing density with the top, and
least dense, layer having a glazed surface at the leading
edge region thereof.

A primary feature of the present invention is

the high surface density of the ceramic at the leading edge region of the outer air seal. In at least one embodiment high surface density is achieved by glazing an otherwise
5 porous ceramic. Other features of specific embodiments are the porous ceramic in the midregion of the seal and the dense ceramic layer between the porous ceramic and any metallic materials.

A principal advantage of the present invention
10 is reduced susceptibility of the seal to erosion at the leading edge. Particles entrapped in the working medium stream are deflectable from the glazed surface at the leading edge region without serious erosion. Notwithstanding, good
15 abrability over the rotor blade tips is maintained by leaving surface porosity in that region unaffected.

The foregoing and other features and advantages of the present invention will become more apparent from the following description and the accompanying drawing.

Fig. 1 is a simplified side elevation view of a
20 gas turbine engine with a portion of the turbine casing broken away to reveal the relationship of the outer air seal to the turbine blades;

Fig. 2 is a partial perspective view of the
25 outer air seal of Fig. 1 illustrating the area of high surface density at the leading edge region of the seal;

Fig. 3 is a partial perspective view of the
outer air seal of Fig. 1 illustrating areas of high surface density at both the leading and trailing edge regions of the seal;

30 Fig. 4 is one alternate embodiment of the Fig. 2 structure;

Fig. 5 is one alternate embodiment of the Fig. 3 structure; and

Fig. 6 is a photomicrograph of a ceramic coat-
35 ing which has been surface densified to a depth of approximately 0.127 mm.

The invention is described with respect to a

preferred turbine outer air seal embodiment for a gas turbine engine. Such an engine is illustrated in Fig. 1.

The engine principally is formed of a compression section 10, a combustion section 12, and a turbine section 14. A rotor assembly 16 extends axially through the engine. Rotor blades, such as the single blade 18 illustrated are arranged in rows and extend outwardly on the rotor assembly across a flowpath 20 for working medium gases. Each rotor blade has a tip 22.

A stator assembly 24 having a case 26 houses the rotor assembly 16. An outer air seal 28 circumscribes the tips 22 of the rotor blades. Each outer air seal is conventionally formed of a plurality of arcuate segments, disposed in end to end relationship about the interior of the engine.

A portion of an outer air seal segment 30 fabricated in accordance with the concepts of the present invention is illustrated in Fig. 2. Working medium gases of the engine flowpath 20 traverse the seal from the upstream end or leading edge 32 to the downstream end or trailing edge 34. For identification purposes the surface of the seal is divided into a leading edge region 36, a midregion 38, and a trailing edge region 40. The midregion essentially comprises that portion of the seal surface which is brushed by the passing rotor blade. The leading edge region is forward of that portion and the trailing edge region is rearward of that portion.

In the illustrated construction each outer air seal segment 30 is formed about a metal substrate 42. Multiple layers of graded metal/ceramic material are adhered to the substrate to produce a ceramic faced seal. As illustrated the multiple layers include a bond coat 44 of nickel-chrome-aluminum alloy, two interlayers 46 of mixed zirconium oxide (ZrO_2) and cobalt-chromium-aluminum-yttrium (CoCrAlY) alloy, a dense all ceramic layer 48 of zirconium oxide (ZrO_2) and a porous all ceramic layer 50 of zirconium

oxide (ZrO_2). The layer materials and application techniques are more fully discussed in U.S. patent application Serial No. (EH-7599) which is of common assignee herewith.

5 The purpose of the ceramic layers in an outer air seal structure is twofold: to provide a thermal barrier, shielding the substrate from the hot working medium gases of the turbine to which the substrate would be otherwise exposed, and to provide an abradable seal accommodating
10 thermal excursions of the circumscribed rotor blades without destructive interference. Desired material characteristics include good abradability when struck by passing rotor blades and good resistance to erosion. The two characteristics are not always consistent in identically formulated
15 compositions. Achieving both characteristics in the same structure is the object of the present invention. Working medium gases of the engine flowpath may contain particles of dirt or other foreign matter and, by the time the medium gases reach the turbine area, may also contain carbon
20 particles from the engine combustor. Such particles as strike the surface of the outer air seal are likely to erode material therefrom, particularly if the material is porous and of moderate or low strength. In some engines the hot gases in and of themselves may be erosive.

25 It is, therefore, that seals of the present invention are fabricated to include an area 52 of high surface density ceramic in the leading edge region 36 relative to the surface density of the ceramic in the mid-region 38 over the rotor blades. Resistance to erosion
30 is improved without destroying desired abradability over the blade tips.

 In the form illustrated by Fig. 2 the area of high surface density is produced by directed energy techniques with localized heating for example by plasma torch or
35 laser. Ceramic at the surface is melted by the directed energy and when cooled forms to a very dense condition and glazed appearance. Particles and gases striking the

glazed area deflect from the surface with little erosion.

The preferred depth of the glazing or high density material is on the order of 0.127 - 0.254 mm into the ceramic with especially dense structure at the surface. Greater or lesser depths may be acceptable but the depth must first be sufficient to provide erosion resistance over sufficient part life and second not be so great as to be thermally incompatible with the porous substrate to which it is adhered. Thermal incompatibility is likely to cause lateral cracking at the interface between the glazing and the substrate and resultant spalling of the glazed material. When held to depths within the preferred range a desired vertical crack network in the substrate will likely penetrate the glazed surface and spalling will be avoided. In some embodiments it may also be desirable to similarly produce an area 54 of dense or glazed ceramic at the trailing edge region 40 as shown in Fig. 3.

The advantages of the present invention may be collaterally achieved in other forms such as the structure illustrated by Fig. 4. Dense ceramic, such as comprises the first ceramic layer 48, is deposited in the leading edge region 36. Porous ceramic in the layer 50 remains over the blade tips. Dense ceramic may also be deposited at the trailing edge region as shown in Fig. 5.

Acceptable densification of zirconium oxide (ZrO_2) ceramic has been achieved by plasma gun melting utilizing the METCO 7mb gun with type GE nozzle under conditions shown in the following table:

30 Gun

Distance to Workpiece	31.75 mm
Current	680 amperes
Potential	75 volts

Arc Gas

35 Primary - Gas	Nitrogen
- Pressure	0.344MPa
- Flow Rate	2265.36 dm ³ /hour
Secondary - Gas	Hydrogen

-Pressure 0.344MPa
-Flow Rate 1415.85 dm³/hour

Heat Traverse

5 Speed 18.3 m/min.
Number of Passes 1
Increment between Passes 3.17 mm

Substrate Preheat

Temperature - start Room temp.
10 Temperature - finish Room temp.
Cooling None

The photomicrograph of Fig. 6 shows the depth of penetration achieved. Densification effects are greatest to a depth of 0.025 mm with penetration to a depth of approximately 0.127 mm.
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Although the invention has been shown and described with respect to detailed embodiments thereof, it should be understood by those skilled in the art that various changes in form and detail thereof may be made without departing from the scope of the claimed invention.
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CLAIMS:

1. An outer air seal of the type circumscribing the turbine rotor blades of a gas turbine engine and
5 having a leading edge region forward of the blades, a midregion opposing the blades and a trailing edge region rearward of the blades, characterized in comprising: an abradable ceramic coating having higher surface density at the leading edge region of the seal than at
10 the midregion of the seal.
 2. The outer air seal according to claim 1 characterized in that said coating further has a higher surface density at the trailing edge region of the seal than at the midregion of the seal.
 - 15 3. The outer air seal according to claim 1 or 2 characterized in that said region of higher density extends to a depth of approximately 0.127 - 0.254 mm into the coating.
 4. The outer air seal according to claim 3
20 characterized in that said abradable ceramic coating is zirconium oxide (ZrO_2).
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