

[54] COOLED AIRFOIL

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416/229, 231, 232

[56] References Cited

UNITED STATES PATENTS

3,540,810 11/1970 Kercher.....416/90

3,240,468	12/1964	Watts et al.	416/97
3,554,663	1/1971	Helms	416/95
3,560,107	2/1971	Helms	416/95
2,304,259	12/1942	Harrer.....	416/95

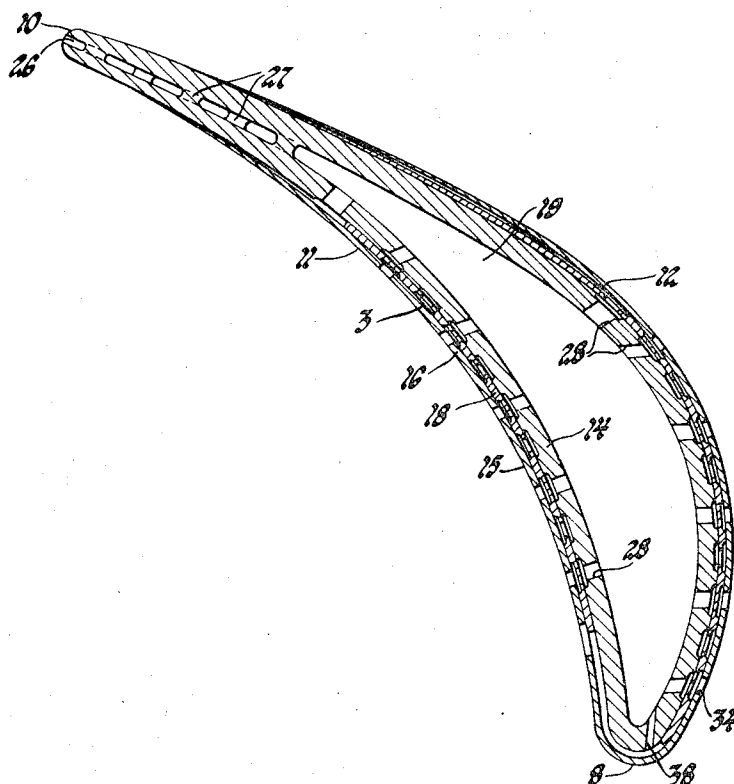
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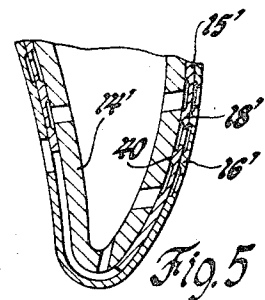
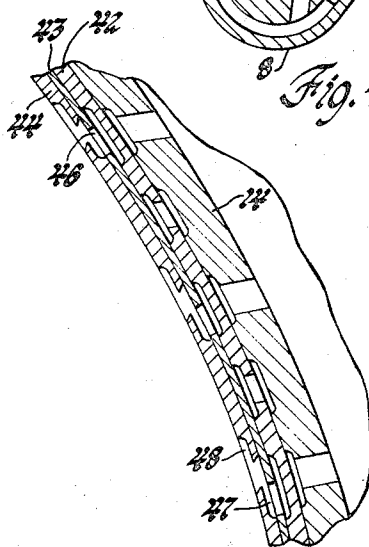
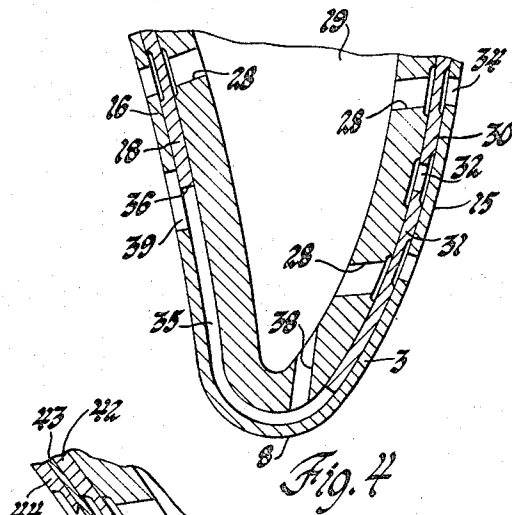
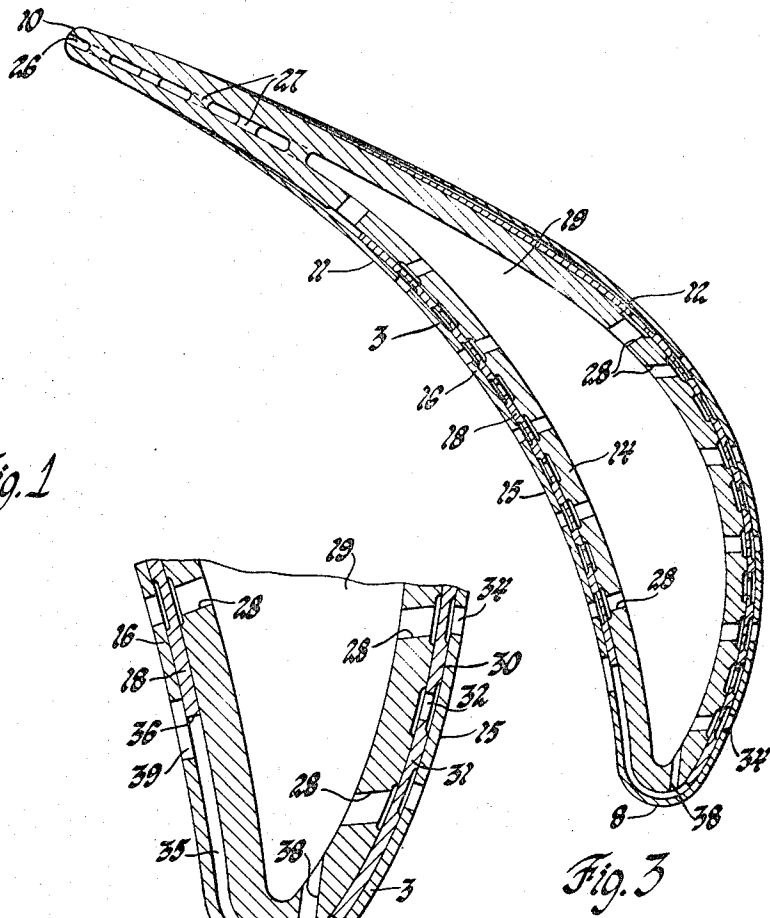
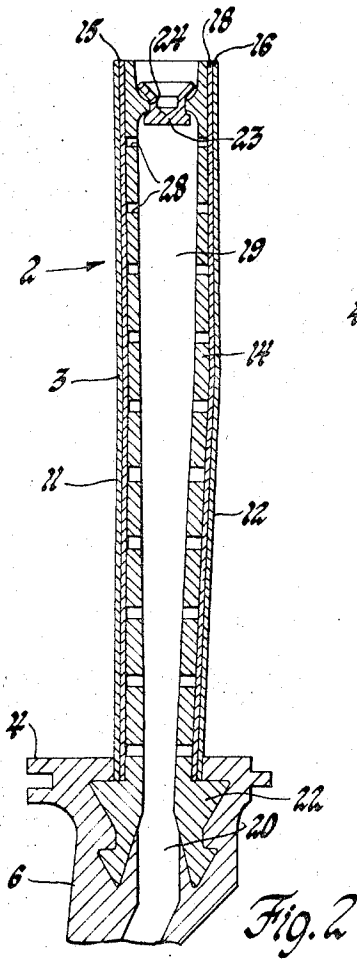
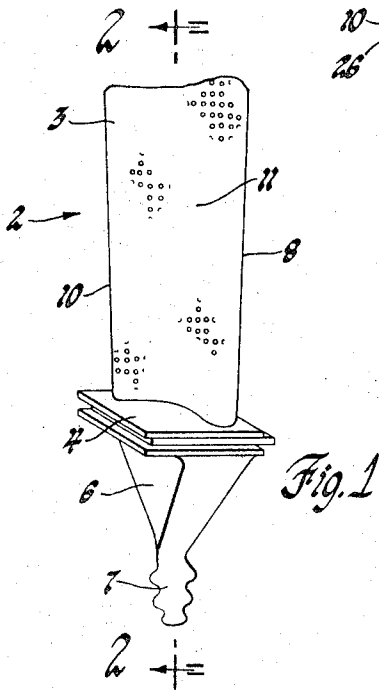
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[57] ABSTRACT

A cooled turbine blade or vane for high-temperature machines. To obtain maximum strength and oxidation resistance and the best cooling characteristics, the airfoil has a core of cast super alloy covered by a porous facing of wrought super alloy sheet, the core providing passages to transmit the cooling fluid to the facing. The effective cooling and resistance to corrosion are due primarily to the facing and the strength and resistance to centrifugal, buffeting, or ballooning loads are contributed primarily by the cast core.

3 Claims, 6 Drawing Figures





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COOLED AIRFOIL

The invention herein described was made in the course of work under a contract or subcontract thereunder with the Department of Defense.

DESCRIPTION

Our invention relates to cooled airfoils, particularly such as are used as vanes or blades in high temperature turbomachines. Our invention is primarily intended for high temperature gas turbines but is applicable to other environments where airfoils having a high degree of resistance to very hot motive fluids and a considerable degree of strength are required.

In the preferred embodiment, a vane or blade (hereafter referred to as an "airfoil") comprises a hollow cast airfoil cross-section core and a formed porous sheet metal facing covering and bonded to the core. A cooling fluid, usually air, is supplied through perforations in the core to the interface between core and facing, one of which is formed to provide passages generally parallel to the outer surface of the airfoil. The facing defines pores through which the cooling fluid emerges from the surface of the airfoil for transpiration cooling.

By virtue of the principles of the invention, the strength characteristics of cast super alloys employed for the core or backbone of the airfoil give it the requisite strength. The superior adaptation to cooling, formability, and resistance to oxidation of the wrought super alloy sheet used for the surface of the airfoil give better cooling and oxidation resistance than can be obtained in an all-cast structure.

The outer facing made of thin sheets with the circulation of air through and from the sheets provides very effective and efficient cooling of a degree of efficiency which cannot be approached in the present state of the art with a cast blade lacking the facing. On the other hand, the materials which are available for the facing do not have the high strength at high temperatures of the materials specified for the core. In prior practice, with a porous sheet metal blade, the maximum temperature of the outer layer has been about 1,650°F. By providing the cast core, the temperature of the facing may be as high as 2,100°F. at the outer surface. This makes possible effective and efficient cooling even with cooling air at a temperature of around 1,300°F., which is the level of cooling air available under some conditions in modern gas turbine engines. By the more efficient cooling and the higher temperature level of the outer surface, the amount of cooling air can be approximately halved with respect to prior technology involving either a cast blade or a formed sheet metal transpiration cooled blade or vane. Viewed another way, the improved cooling and resistance to temperature are capable of providing a turbine blade usable in a gas turbine operating at the very high motive fluid temperatures (about 3,700°F. turbine inlet and about 3,300° at the first rotor stage) resulting from stoichiometric combustion of JP fuels. It will be appreciated by those skilled in the art how significant these facts are and it will also be appreciated from the succeeding detailed description that this advance in the art is made possible by a structure which is feasible to fabricate in the present state of the art.

The principal objects of the invention are to improve the efficiency of turbomachines; to improve the temperature tolerance and life at high temperature of turbomachinery; to provide airfoils for turbomachines which have superior cooling properties; to provide a highly satisfactory cooled airfoil structure which is feasible from the standpoint of manufacture; and to provide an airfoil such as a turbine vane or blade having a porous sheet metal facing and a perforated hollow cast metal core bonded to the facing.

More specifically, the primary objective of the invention is to combine the high temperature strength of a cast super alloy as a supporting core with the extremely high cooling efficiency of a laminated porous material outer skin. Thus, one can use the inherent 200° to 300°F. temperature gradient which is found across the wall from outside to inside to advantage. Allowing the inner fibers of the blade (cast core) to operate at their stress rupture limit (approximately 1,800°F.) and letting the outside sheet operate at its oxidation limit (approximately 2,100°F.) one can achieve a maximum allowable temperature at around 1,950°F. which is 100° to 150° better than the present day state of the art.

The nature of our invention and its advantages will be better appreciated by reference to the succeeding detailed description of preferred embodiments of the invention and the accompanying drawings thereof.

Referring to the drawings, FIG. 1 is an axonometric view of a turbine blade of known overall configuration.

FIG. 2 is a sectional view of the same taken on the spanwise extending plane indicated by the line 2—2 in FIG. 1.

FIG. 3 is a transverse section of a turbine airfoil.

FIG. 4 is an enlarged view of the leading edge portion of FIG. 3.

FIG. 5 is a sectional view similar to FIG. 4 of a modified form of the invention.

FIG. 6 is a fragmentary cross sectional view of a still further form of the invention.

Referring now to the drawings, the rotor blade 2 illustrated in FIGS. 1 and 2 includes an airfoil or flow-directing portion 3, a platform 4, a stalk 6, and a root 7 of multiple dovetail configuration. Such a blade is mounted by the root in a mating slot in the turbine rotor rim and the platforms 4 of adjacent blades meet to define an annular inner boundary of the motive fluid flow path through the turbine rotor stage. The airfoil may be of any suitable cross section; FIG. 3 illustrates a typical section of the type normally employed in turbomachinery. It may have a leading edge 8, a trailing edge 10, a concave face 11, and a convex face 12. As will be particularly apparent from FIG. 3, the airfoil (blade or vane) is a composite structure made up of a core 14 overlaid by a facing 15 which covers the core, the facing being a laminated structure made up of an outer layer 16 and an inner layer 18. The core is hollow so as to define a spanwise extending air passage 19 through the airfoil, this passage connecting with a passage 20 in the blade stalk which is supplied from externally of the blade through any suitable opening, as is well known to those skilled in the art. The core 14 is a casting of a nickel base super alloy, such alloys being known to those skilled in the art under such trade names as Mar M 246, Udimet 710, and Inco 713C. These are high strength materials well adapted to sup-

port the loads from blade stresses. In the structure illustrated, the platform, stalk and root portion of the blade is bicast to the airfoil portion 3, the airfoil portion having a ribbed base 22 which is interlocked with the platform and stalk when the latter is cast around the airfoil.

The outer end of the blade core as cast has holes 24 which provide for core location and removal of the core by leaching. After this is done, the holes are closed in any suitable way. As illustrated, a plug 23 in the form of a rivet is inserted and is retained by flaring out the outer end of the plug. At the trailing edge 10 of the airfoil, the air passage 19 discharges through a narrow slot 26 extending generally from end to end of the airfoil. Adjacent the trailing edge, the two faces of the cast core 14 are close together and are joined by unitary cast pins or spacers 27.

The blade, including the pins 27, may be cast by known techniques of the type described in British Pat. No. 872,705 of Hamilton L. McCormick, published July 12, 1961. Preferably, the leading and trailing edge portions of the core are substantially a single crystal as described in U.S. Pat. No. 3,008,855 of Swenson, Nov. 14, 1961.

Referring now to FIGS. 3 and 4 for a more detailed explanation of one variety of blade structure according to our invention, it will be seen that the core 14 defines a multitude of perforations 28 disposed preferably in a generally rectangular two-dimensional array over the major part of the concave face 11 and roughly the first half of the chord of the convex face 12 in the specimen illustrated. These perforations may be formed as part of the airfoil casting process or may be formed by machining, as desired. The outer surface of the core 14 may be formed with a surface relief so that the facing is partly spaced from the core, this relief being preferably in the form of a two-dimensional array of bosses 30 on the outer surface of the core distributed over the area through which the perforations 28 extend. These bosses might be cast on the core or could be the result of some machining process such as photochemical etching to cut away the core surface to a desired depth between the bosses 30, but preferably the core outer surface would be left smooth and the spacers would be etched on the facing.

In the structure of FIGS. 3 and 4 the facing 15, as previously pointed out, comprises an outer layer 16 and an inner layer 18. The inner layer 18 is formed with the surface relief on its outer surface by a two-dimensional array of bosses 31 and with an array of pores 32 through the layer. The outer layer also has a two-dimensional array of pores identified as 34. The pores 34 are out of register with pores 32, which in turn are out of register with perforations 28. Because of the arrangement of pores and the surface relief at each interface between the core and layer 18 and between layer 18 and layer 16, cooling air can flow from the air passage 19 through perforations 28, pores 32, and pores 34 to the exterior surface of the airfoil. This provides for transpiration cooling of a considerable part of the surface of the airfoil. The trailing edge portion may be cooled through convection by cooling air escaping from passage 19 through the slot 26 scrubbing the inside surfaces of the core and the spacers 27.

While transpiration cooling might be employed at the leading edge of the blade, it is preferred to adopt an

impingement mode of cooling involving a modification of the facing structure. As shown clearly in FIG. 4, the inner layer 18 is removed locally to provide a series of chordwise channels adjacent the leading edge of the blade and over the forward portion of the concave face 11 so as to define a series of cooling air ducts 35 extending from the forward edge of the convex face around to the edge 36 of the inner layer on the concave face of the airfoil. The cooling air is delivered from the passage 19 through a spanwise-extending row of nozzles 38 defined by holes through the core which direct the cooling fluid against the leading edge and causes it to flow between the outer layer and the core through the channels 35 to a row of outlets 39 adjacent the edge 36. The direction of flow is such as particularly to scour the leading edge portion of the facing and increase the effectiveness of convection cooling of the facing at this point.

Referring particularly to FIG. 3, it may be seen that the facing 15 tapers toward the trailing edge of the blade past the perforations 28 and this part of the facing may be imperforate. Relative distribution of the cooling air to various areas of the facing may be controlled by size and spacing of the pores and perforations and the depth of surface relief.

While the facing as shown comprises two layers, it could comprise more, and could consist of a single layer, with other means than that shown in FIG. 4 employed for cooling the leading edge. As will be apparent, if the outer layer 16 is omitted, cooling air may flow from the perforations 28 under the layer 18 and out the pores 32 for transpiration cooling. Thus it is possible to have a single outer protective layer over the core.

FIG. 5 illustrates a modification of the cooled airfoil of the previously described figures. It may be the same as the structure shown in FIGS. 3 and 4 except for the changes noted below. The core 14' has a smooth outer surface and the relief between the core and the facing 15' is provided by photoetching or otherwise relieving the inner surface of the inner facing layer 18' to provide bosses 40 on this layer. In connection with this, it is also preferred to provide the relief on the inner surface of the outer layer 16' rather than the outer surface of the inner layer of the facing. There is an advantage to this modification in that it is not necessary to relieve the surface of the core and, assuming the perforations and nozzles in the core are provided during the casting operation, the photoetching or other machining may be accomplished only on the layers or layer of the facing.

FIG. 6 is an enlarged sectional view comparable with those of FIGS. 4 and 5, except showing a portion of the concave face of a still further modification of the cooled airfoil of our invention.

The structure of FIG. 6 involves a core of the same nature as that illustrated in FIG. 4 but a facing which embodies the principle described and claimed in the copending patent applications, of common ownership with this application, of Thomas H. Mayeda, Ser. No. 879,094 [U.S. Pat. No. 3,700,418] and George B. Meginnis, Ser. No. 879,110, both filed Nov. 24, 1969. The particular structure illustrated is similar to one illustrated in the Meginnis application. The facing is such as to cause the air flowing from the facing to flow at an acute angle to the face of the blade in a direction

downstream with respect to the flow of motive fluid so as to minimize interference between the cooling air flow and the motive fluid flow. Specifically, the core 14 is overlaid by an inner layer 42, an intermediate layer 43, and an outer layer 44, these being bonded together and bonded to the core. The inner layer may have the same configuration as the inner layer 18 described in connection with FIGS. 3 and 4. The intermediate layer 43 is a thin sheet having no surface relief but having pores 46 communicating with the air space defined by the relief on the face of the inner layer 42. The outer layer 44 has pores defined by intersecting staggered pits 47 on the inner surface of the layer and 48 on the outer surface of the layer disposed so that the flow through the pores 46 is deflected in a downstream direction; that is, upwardly as illustrated in FIG. 6.

In general, it is desired that the facing in any of the forms described be relatively thin and, in the case of a typical turbine airfoil having a chord of about one or two inches, it is contemplated that the facing have a total thickness of about fifteen to twenty thousandths of an inch. Suitable materials for the facing include various wrought high temperature resistant nickel alloy sheets, specifically, materials known as Haynes alloy 188 and Hastelloy X. The layers of the facing may be bonded together by processes of diffusion bonding after the surface relief and pores have been machined by photoetching or otherwise. The facing is preferably diffusion bonded to the core, which may be accomplished by heat and pressure exerted through a suitable pad to allow the pressure to be distributed over the curved face of the core during the bonding operation. The bonding operation may take place in connection with a creep forming operation by which the contour of the facing is completed. It is preferred to effect the diffusion bonds between facing layers and between facing and core simultaneously. It should be understood that other modes of attachment of the facing to the core are contemplated but that in general welding is not suitable in the present state of the art for the materials specified and brazing is not regarded as being as satisfactory as diffusion bonding. Explosive welding might be feasible. The core is ordinarily cleaned and polished and nickel plated before diffusion bonding the facing to it.

While reference has been made to suitable known commercial high temperature alloys in the preceding specification, it is to be understood that the invention is applicable to such alloys as have the desired properties, either present or as discovered in the future. The prin-

cipal characteristic of the cast material is high strength at high temperatures to resist centrifugal, side, or ballooning loads, and the principal characteristics of the facing are its ductility and its resistance to oxidation and sulfidation at extremely high temperatures, the highest temperature in the airfoil being at the surface.

In a rotor blade, the facing will be running in compression and will unload all its weight onto the load-carrying core because of the greater thermal expansion of the facing resulting from its higher temperature.

The detailed description of preferred embodiments of the invention for the purpose of explaining the principles thereof is not to be considered as limiting or restricting the invention, as many modifications may be made by the exercise of skill in the art.

We claim

1. A cooled flow-directing member for use in a high-temperature turbomachine comprising, in combination, a rigid hollow core of airfoil configuration and a porous facing of corresponding airfoil configuration bonded to and covering the core and defining the exterior of the member, the core having distributed perforations to conduct cooling fluid from within the core to the facing, the core having a smooth outer surface and the facing having an inner surface abutting the core outer surface, the said facing bearing a two-dimensional array of spaced bosses extending from its inner surface abutting the outer surface of the core so as to provide passages for flow of the cooling fluid between the bosses generally parallel to the said surfaces, the perforations communicating with the said passages, the core reinforcing and supporting the facing against loads imposed on the facing and the facing being effective to shield the core from the working fluid of the turbomachine and to cool the core, the facing defining pores distributed over a substantial portion of the area of the airfoil out of register with the said perforations, the said pores connecting the said passages to the exterior of the facing for transpiration cooling of the member, the core being of a cast super alloy having greater strength than the facing at high temperature and the facing being of a ductile wrought super alloy sheet having greater resistance to corrosive attack by high temperature gases than the core.

2. A member as defined in claim 1 in which the facing is a laminated structure of more than one layer.

3. A member as defined in claim 1 in which the core and facing are of nickel base or cobalt base alloys.

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