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## (54) RMC-Defined tip blowing slots for turbine blades

(57) A process for forming an airfoil portion (42) of a turbine engine component, such as a turbine blade, is described. The process comprises the steps of placing a ceramic core (14) having a configuration of a passageway (15) to be formed in the airfoil portion (42) within a mold (80), attaching a refractory metal core element (10) to the ceramic core (14) to stabilize a tip region (12) of the ceramic core (14), and casting the airfoil portion (42).

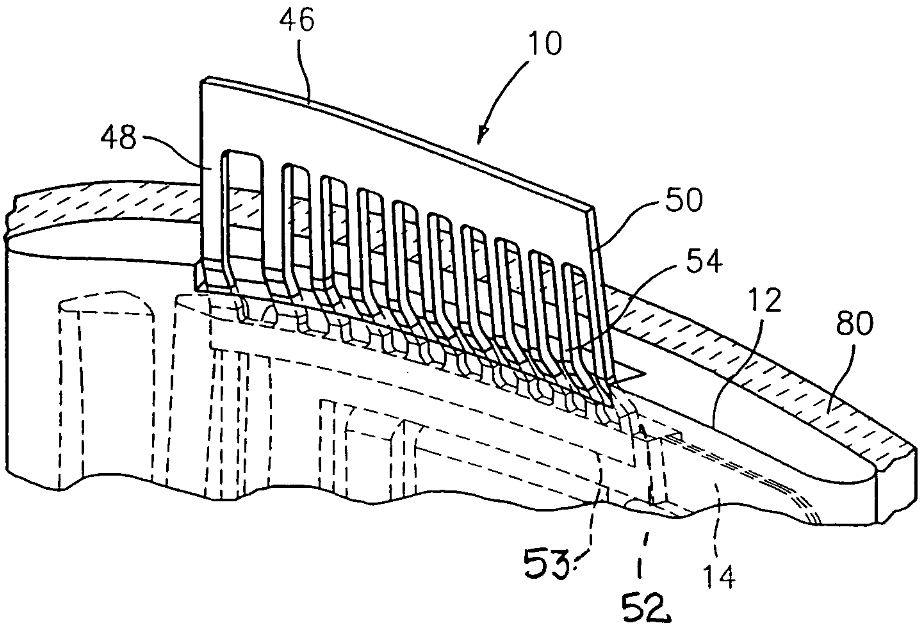


FIG. 2

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## Description

BACKGROUND

(1) Field of the Invention

**[0001]** The present invention relates to a process for forming a turbine engine component, such as a turbine blade, having a plurality of as-cast blowing slots in a tip region using a refractory core element.

(2) Prior Art

**[0002]** One of the typical failure modes for high pressure turbine (HPT) rotor airfoils (blades) is tip distress via oxidation and erosion. It is particularly challenging to design a cooling configuration for a tip region for a variety of reasons. First, it is very difficult to determine the external thermal boundary conditions near the tip due to the highly-three dimensional nature of the gaspath flow. Also, the tip region of a turbine blade is typically the thinnest portion of the airfoil, which makes it more difficult to package the desired cooling features. Furthermore, the tip region of a turbine blade is typically difficult to accurately produce with investment casting processes because the internal ceramic core is thin and weak near the tip. Further, it is cantilevered relatively far from the core-locating fixture at the blade root. Considering these points, it is desirable to have methods to create intricate cooling features near the tip capable of being targeted at specific regions of high heat load, while also allowing for greater control during the investment casting process.

**[0003]** An existing HPT blade tip cooling design is shown in FIG. 1. A radially oriented cavity supplies cooling air to a leading edge impingement cooling scheme as well as a laterally-oriented cavity, known as a tip flag, that helps cool the tip before exiting the blade at the trailing edge near the tip. FIG. 1 also shows a midbody three-pass serpentine cooling arrangement and a trailing edge double-impingement system.

**[0004]** The tip of the core in FIG. 1 includes an appendage that creates a recess blade tip known as a squealer pocket. That appendage is connected to the leading edge and tip flag core by means of two cylindrical connections ("print-outs") that form open holes in the finished casting ("print-out holes"). The core is fixed at the root of the blade during the casting process. The squealer pocket core is located laterally during the casting process, allowing the tip print outs to stabilize the tip region of the core. In order to prevent core breakage during the casting process, these tip print-outs should be as large as possible, especially considering that they are constructed from the brittle ceramic core material. One of the primary purposes of the squealer pocket is to allow for a shorter distance that the tip print-outs must span. However, it is desirable to have the tip print-out holes be smaller so that they do not flow an excessive amount of cooling air in the finished part, which results in inefficiency in the cooling design and, therefore, the turbine performance.

SUMMARY OF THE INVENTION

**[0005]** In accordance with the present invention, there is provided a new tip cooling design that utilizes refractory metal core (RMC) technology in order to create a tip cooling scheme for a turbine engine component that is capable of more efficient use of cooling air and a more reliable casting process.

**[0006]** In accordance with the present invention, a process for forming an airfoil portion of a turbine engine component is provided. The process comprises the steps of placing a ceramic core having a configuration of a passageway to be formed in the airfoil portion within a mold; attaching a refractory metal core element to the ceramic core to stabilize a tip region of the ceramic core during casting; and casting the airfoil portion.

**[0007]** Further, in accordance with the present invention, there is in combination, a ceramic core for forming a passageway in a cast airfoil portion and means for stabilizing a tip region of the ceramic core. The stabilizing means comprises a refractory metal core element.

**[0008]** Still further, in accordance with the present invention, there is provided a refractory metal core element comprising a solid portion and a plurality of spaced apart legs depending from the solid portion. Each of the legs has a first portion adjacent the solid portion, a base portion, and an angled portion intermediate the first portion and the base portion so that the base portion is laterally offset from the solid portion. The base portions of the legs are preferably joined together by a lower portion.

**[0009]** Still further, in accordance with the present invention, there is provided a turbine engine component having an airfoil portion with a tip region, a shelf portion in said tip region, and a plurality of as-cast slots in the shelf portion through which a cooling fluid flows. The slots are located along a pressure side of the tip region.

**[0010]** Other details of the RMC-defined tip blowing slots for turbine blade of the present invention, as well as other advantages attendant thereto, are set forth in the following detailed description and the accompanying drawings, wherein like reference numerals depict like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

**[0011]**

FIG. 1 is a schematic representation of a cooling design used in a prior art turbine blade;
FIG. 2 is an external view of a tip region of a casting;
FIG. 3 is a schematic representation of a tip region of a cast airfoil portion of a turbine blade;
FIG. 4 is a view of a refractory metal core element from the pressure side; and
FIG. 5 is a view of the refractory metal core element from the trailing edge.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

**[0012]** As noted before, a new tip cooling design for a turbine blade is proposed here that utilizes refractory metal core technology in order to help create a tip cooling scheme that is capable of more efficient use of cooling air and a more reliable casting process.

**[0013]** Referring now to FIG. 2, a relatively thin, approximately 0.015" (0.38 mm), refractory metal core element 10 is used to stabilize a tip region 12 of a ceramic core 14 during the casting process. The ceramic core 14 is positioned within a mold 80, only a portion of which has been shown. The ceramic core 14 may have the configuration of a laterally oriented passageway 15 to be formed in the airfoil tip region 34. The refractory metal core element 10 is printed out of the airfoil tip region 34 during casting and is located laterally of the ceramic core 14. Preferably, the refractory metal core element 10 is positioned adjacent a side of the mold which forms the pressure side 40 of the airfoil portion 42. The refractory metal core element 10 is a metal piece which is much more rugged than typically brittle core print-outs. Thus, there is no manufacturing requirement for relatively large core print-out. A core print-out hole (not shown) may still be included if it is required for cooling purposes. In the present case, the core print-out hole can be made smaller than it previously could because it is not required to have as high of a strength. This configuration also allows for multiple ceramic core features to be stabilized by the same refractory metal core element. Furthermore, because this new tip design provides more stability and strength for the ceramic core 14 near the tip, the size of the trailing edge print-out of the tip flag cavity can be reduced, enabling lower cooling air flow out the tip flag exit.

**[0014]** The refractory metal core element 10 may be formed from any suitable refractory material known in the art such as molybdenum or a molybdenum alloy. The refractory metal core element 10, as shown in FIGS. 2, 4 and 5 may have a solid portion 46 and a plurality of spaced apart legs 48 depending downwardly from the solid portion 46. Each leg 48 preferably has a first leg portion 50, a base portion 52, and an angled portion 54 between the first portion 50 and the base portion 52. The base portion 52 of the legs may be joined together by a lower portion 53. The refractory metal core element 10 may be attached to the ceramic core 14 using any suitable means known in the art such as an adhesive or a mechanical fit connection. Because the refractory metal core element 10 and the ceramic core 14 are attached, inside the casting, the refractory metal core element can be used to control the location of both the refractory metal core and the ceramic core, relative to the external mold. In an alternative embodiment of the refractory metal core element 10, the angled portion 54 may be omitted. Still further, the legs 48 can be arranged in any way that makes sense for the cooling design. Furthermore, the legs 48 only need to be connected at one end (inside or outside the casting), whichever makes sense for the cooling design and the casting process.

**[0015]** As shown in FIG. 3, the refractory metal core element 10 is printed out in such a way as to produce a row of aligned open slots 30 in the finished casting, along the pressure side edge 32 of the tip 34. Cooling air may be ejected from the slots 30 in whichever direction the slots 30 are oriented. As shown in FIG. 3, the slots 30 may be oriented primarily radially outwards towards an outer circumference of the gaspath. The slots 30 may also be slightly angled towards the pressure side 40 of the turbine blade airfoil portion 42. The slots 30 may be purely radial or leaned in any combination of directions - forward/aft and/or towards pressure/suction side. The' slots 30 may be in fluid communication with the passageway 15. As shown in FIG. 3, the slots 30 may be located in a recessed shelf 36 in the tip 34. The recessed shelf 36 may be a cast feature, or it may be machined into the finished casting in a later process.

**[0016]** When the cooling air exits the RMC defined tip slots 30, the cooling air immediately flows into a tip gap between the blade tip 34 and the blade outer air seal (BOAS)(not shown) due to the strong pressure gradient towards the suction side 60 of the airfoil portion 42. Injecting the cooling air into the tip gap significantly reduces the gaspath temperature in the tip gap downstream of the slots 30, resulting in lower heat load to the tip region of the blade. This is a similar effect to film cooling on the body of an airfoil. Conventional tip print-out holes provide some film cooling benefit on the tip surface, but they are significantly less efficient than this new design because the conventional tip print-out holes are so large that they can only be located at one or two locations along the mid-thickness of the tip.

**[0017]** Another cooling benefit of the RMC-defined tip slots 30 is the substantial convective cooling of the pressure side region of the tip 34 due to the high-velocity cooling air flowing through the tip slots 30. This convective cooling is very effective at preventing oxidation and erosion along the pressure side edge 32 of the tip 34, which is a common location of tip distress. As a result of this increased convective cooling along the pressure side edge 32 of the tip 34, it is feasible to use fewer film cooling holes on the pressure side edge of the airfoil near the tip. In a prior art design, two rows of shaped cooling holes are provided along the pressure side near the tip. The purpose of these holes is to cool the tip region via film cooling and convective cooling. FIG. 3 shows a tip cooling design in accordance with the present invention which has only a single row of shaped cooling holes 70. The reduction of two rows of pressure side film cooling to one row is a benefit of the present invention, but it is not a necessary aspect of it.

**[0018]** The flexibility of the convective and film cooling aspects of the RMC-defined tip slots lends itself well to the challenge of designing a tip cooling configuration when the external boundary conditions are difficult to determine. Furthermore, the inherent strength of the refractory metal core element 10 during the casting process allows for increased design flexibility in the tip region. As a result, this new tip cooling configuration allows for more efficient use of cooling air and more predictable casting yields, resulting in a more cost-effective product.

**[0019]** Another advantage of this tip cooling configuration is that it is complimentary to tip blowing technology for aerodynamic performance benefits. Tip blowing utilizes a row of cooling air jets or holes 30 along the pressure side edge 32 of the blade tip 34, which act to improve aerodynamic efficiency by reducing endwall losses associated with gaspath leakage across the tip gap. The cooling holes 70 may be machined in the pressure side edge 32 after the blade and its airfoil portion have been cast. The cooling holes 70 may be machined using any suitable technique known in the art. The cooling holes 70 are preferably in fluid communication with the passageway 15. The RMC-defined cooling slots 30 may be situated along the recessed shelf 36 along the pressure side of the tip 34. The recessed shelf 36 will prevent the slots 30 from being unexpectedly closed during engine operation when the blade tip 34 rubs against the outer circumference of the gaspath. The recessed shelf 36 also allows for easier masking when applying abradable coating to the tip surface.

**[0020]** The tip portion 34 of the airfoil portion 42 of the turbine engine blade is a cast structure and is formed at the same time as the remainder of the cast portions of the turbine engine blade. For simplicity sake, only a portion of the mold 80 forming the tip region 34 of the airfoil portion 42 is illustrated in the drawings. It should be recognized that the mold 80 has a portion which is in the shape of the pressure side of the airfoil.

**[0021]** The tip portion 34 may be formed by placing the ceramic core 14 into a mold 80. After the ceramic core 14, as well as any other needed ceramic or silica cores, has been positioned, the refractory metal core element 10 may be attached to the ceramic core 14 using any suitable means known in the art, such as an adhesive or pins. The mold 80 is created after the ceramic core 14 and the RMC 10 are assembled. This is preferably done by first assembling the ceramic core 14 and RMC 10, then injecting wax around the cores 10 and 14 using a wax die, so that the external surface of the wax is the same geometry as the external surface of finished casting. Then, a ceramic shell is applied to the external surface of the wax pattern. Then, the wax is melted out, leaving the ceramic core 14, RMC 10 and ceramic shell (not shown). As previously mentioned, the refractory metal core element 10 serves to stabilize the tip region of the ceramic core 14. Thereafter the blade with the airfoil portion may be cast using any suitable technique known in the art. After casting has been completed, the ceramic core 14 may be removed using any suitable technique known in the art to leave the passageway 15. Similarly, the refractory metal core element 10 is removed, thus leaving the slots 30. The RMC 10 may be leached out of the casting using any suitable chemical bath known in the art, very similar to how the ceramic cores are leached. Thereafter, a plurality of cooling holes 70 may be machined into the tip region of the airfoil portion 42.

## Claims

**1.** A process for forming an airfoil portion (42) of a turbine engine component comprising the steps of:

positioning a ceramic core (14) having a configuration of a passageway to be formed in said airfoil portion (42);
attaching a refractory metal core element (10) to said ceramic core (14) to stabilize a tip region (12) of said ceramic core (14);
creating a mold (80) about the ceramic core (14) and refractory metal core element (10); and
casting said airfoil portion (42).

**2.** The process of claim 1, further comprising locating said ceramic core (14) relative to said mold (80) with said refractory metal core element (10).

**3.** The process of claim 2, wherein said locating step comprises providing a refractory metal core element (10) having at least one leg (48).

**4.** The process of claim 3, wherein said refractory metal core element providing step comprises providing a refractory metal core element (10) having a plurality of legs (48).

**5.** The process of claim 3 or 4, further comprising removing said ceramic core (14) so as to form said passageway and subsequently removing said refractory metal core element (10) and thereby leaving at least one cooling slot (30) in a tip region (34) of said airfoil portion (42).

**6.** The process of claim 5, wherein said removing step comprises leaving a plurality of cooling slots (30) in said tip region (34).

**7.** The process of claim 5 or 6, further comprising machining a plurality of film cooling holes (70) in said airfoil portion in the vicinity of said passageway formed by said ceramic core (14).

**8.** In combination, a ceramic core (14) for forming a passageway in a cast airfoil portion (42) and means for stabilizing a tip region (12) of said ceramic core (14), said stabilizing means comprising a refractory metal core element (10).

**9.** The combination of claim 8, wherein said refractory metal core element (10) comprises a solid portion

(46) and a plurality of legs (48) depending from said solid portion (46).

**10.** The combination of claim 9, wherein each said leg (48) has an angled portion (54) and a base portion (52) and said base portion (52) of said legs (48) is joined together by a lower portion (53).

**11.** A refractory metal core element (10) comprising a solid portion (46) and a plurality of spaced apart legs (48) depending from said solid portion (46), each of said legs having a first portion (50) adjacent said solid portion (46), a base portion (52), and an angled portion (54) intermediate said first portion (50) and said base portion (52) so that said base portion (52) is laterally offset from said solid portion (46).

**12.** A refractory metal core element according to claim 11, further comprising a lower portion (53) connecting each base portion (52).

**13.** A turbine engine component having an airfoil portion (42) with a tip region (34), a recessed shelf (36) in said tip region (34), and a plurality of slots (30) in said recessed shelf (36) through which a cooling fluid flows, said slots (30) being located along a pressure side (40) of said tip region (34).

**14.** The turbine engine component according to claim 13, further comprising said slots (30) being oriented primarily radially outwards and being angled towards said pressure side (40).

**15.** The turbine engine component according to claim 13 or 14, further comprising a passageway (15) within said tip region (34) and each of said slots (30) communicating with said passageway (15).

**16.** The turbine engine component according to claim 15, further comprising a plurality of cooling holes (70) machined in said pressure side (40) and communicating with said passageway (15).

**17.** The turbine engine component according to claim 15 or 16, wherein said passageway (15) comprises a laterally-oriented cavity.

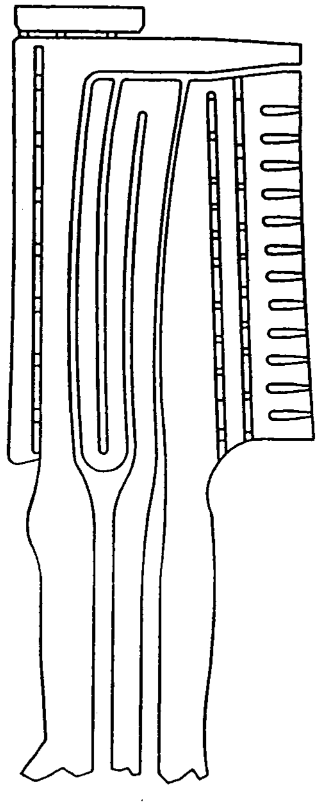

*FIG. 1*
(PRIOR ART)

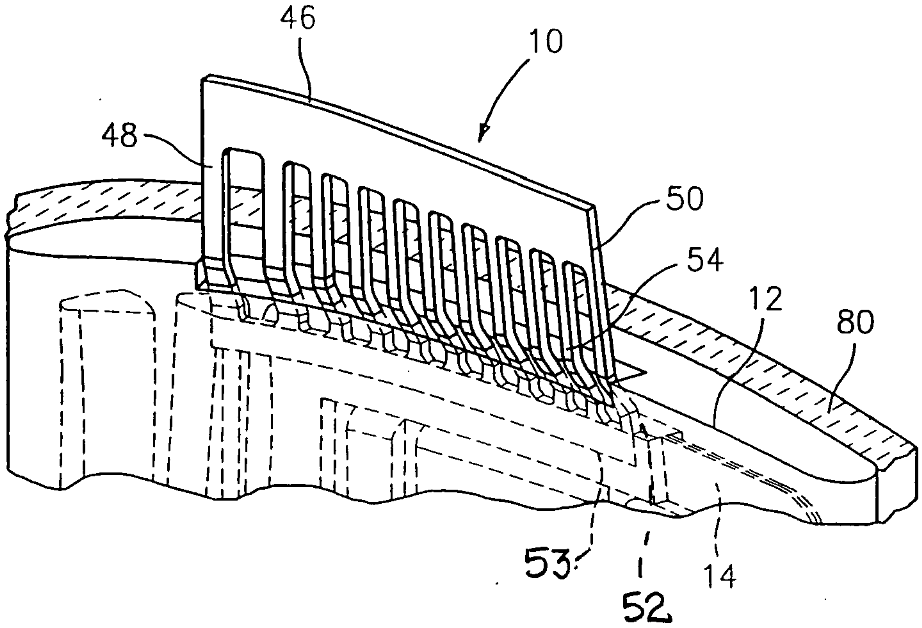


*FIG. 2*

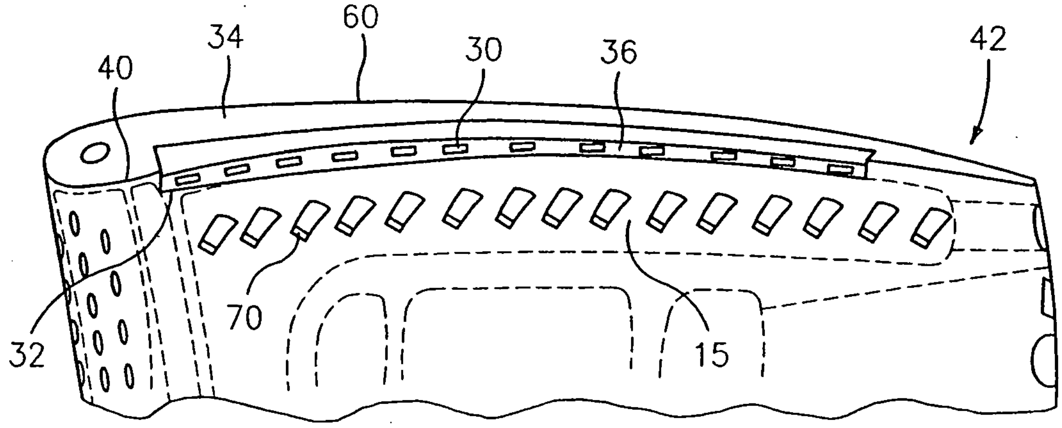


*FIG. 3*

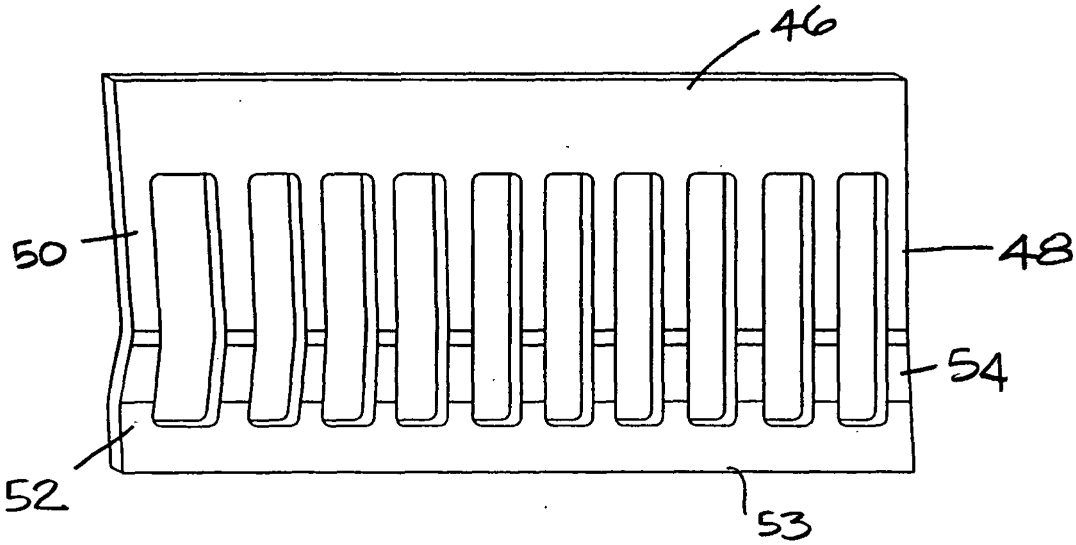


*FIG. 4*

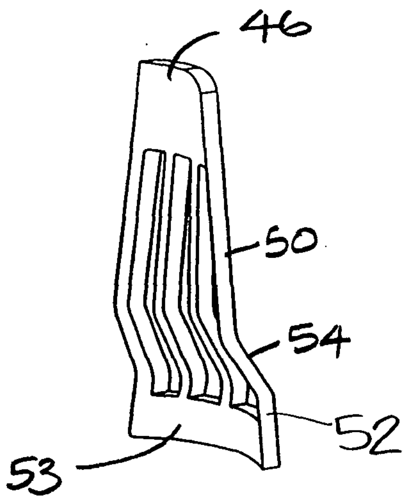


*FIG. 5*