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(54) **TURBINE BLADE WITH COOLING BREAKOUT PASSAGES**

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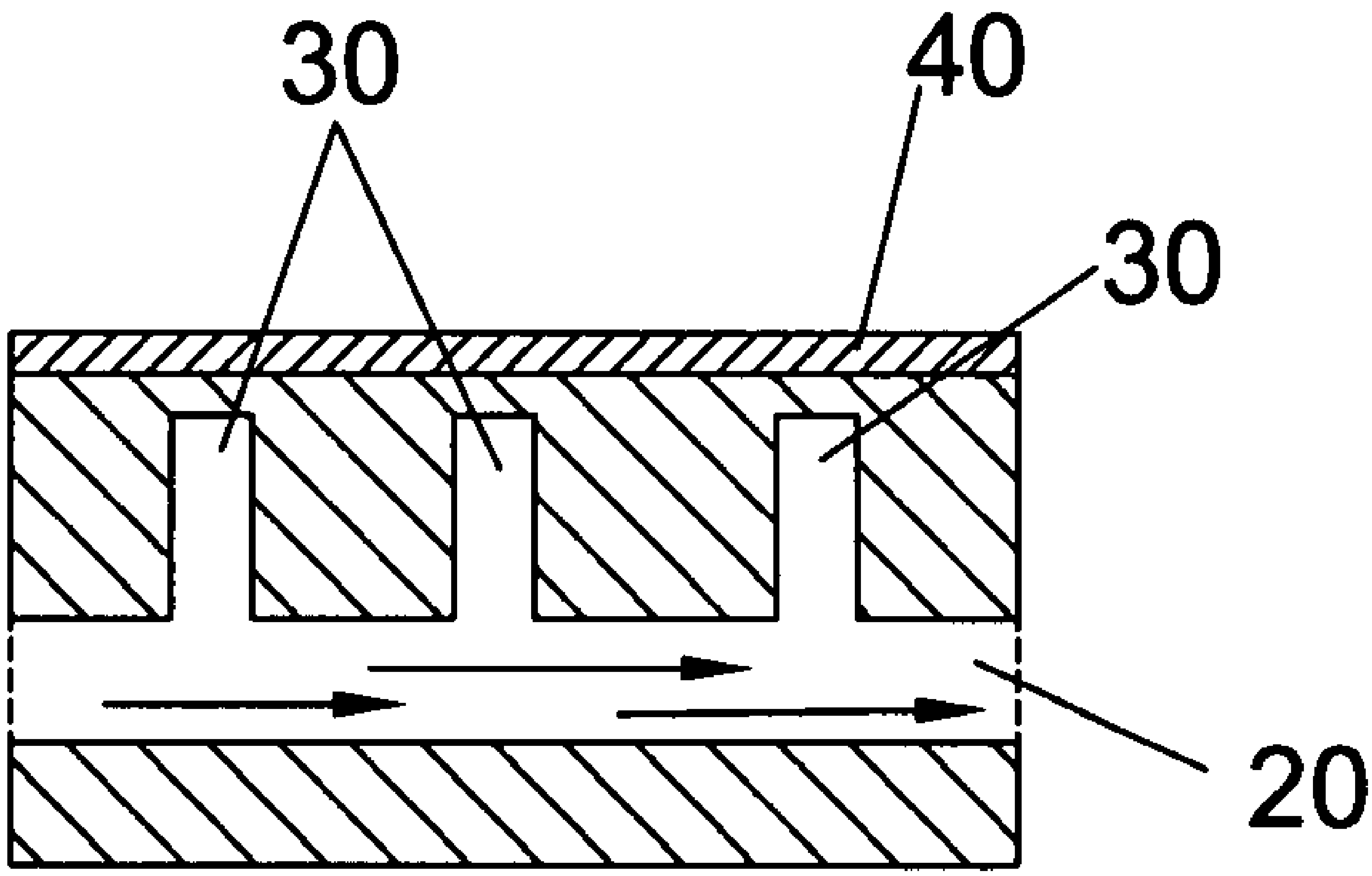
(57) **ABSTRACT**

A turbine airfoil with a plurality of breakout passages located just beneath a thermal barrier coating or just beneath the metal surface of the airfoil. The breakout passages are connected to an internal cooling air passage and allow for film cooling air to flow when a surface over the breakout passage has been chipped or eroded away to provide for additional cooling to the damaged airfoil surface. The breakout passages are formed during the casting process of the airfoil using a plurality of molding pieces. The breakout passages are formed along a direction of the pulling direction of the respective mold piece. This allows for the solidified airfoil to be easily removed from the mold assembly.



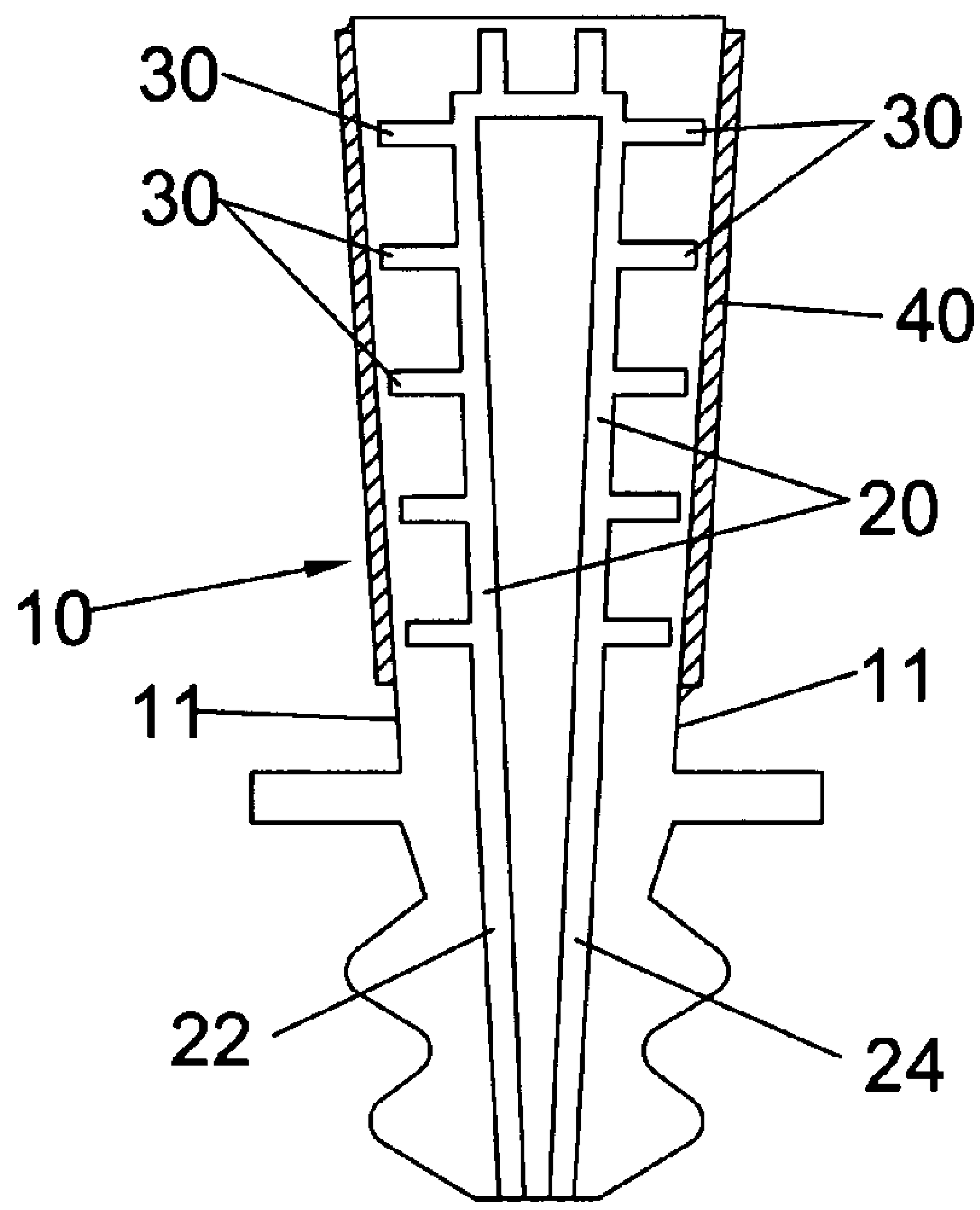


Fig 1

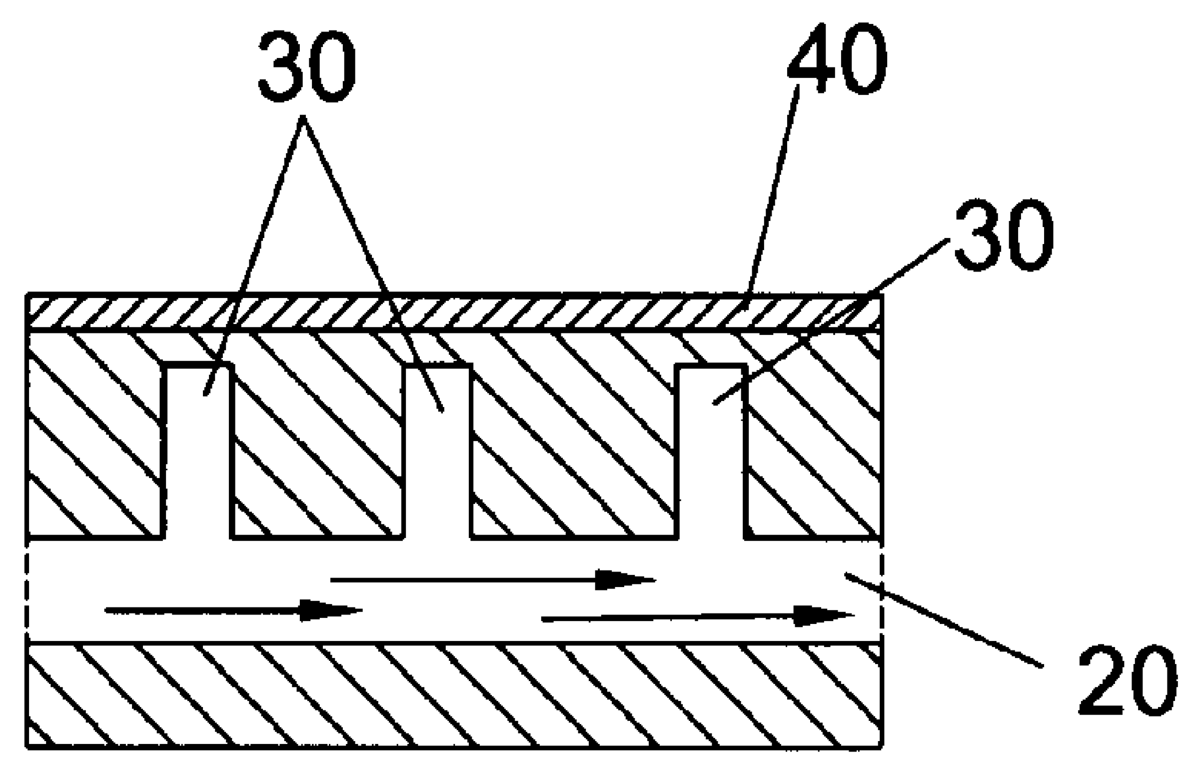


Fig 2

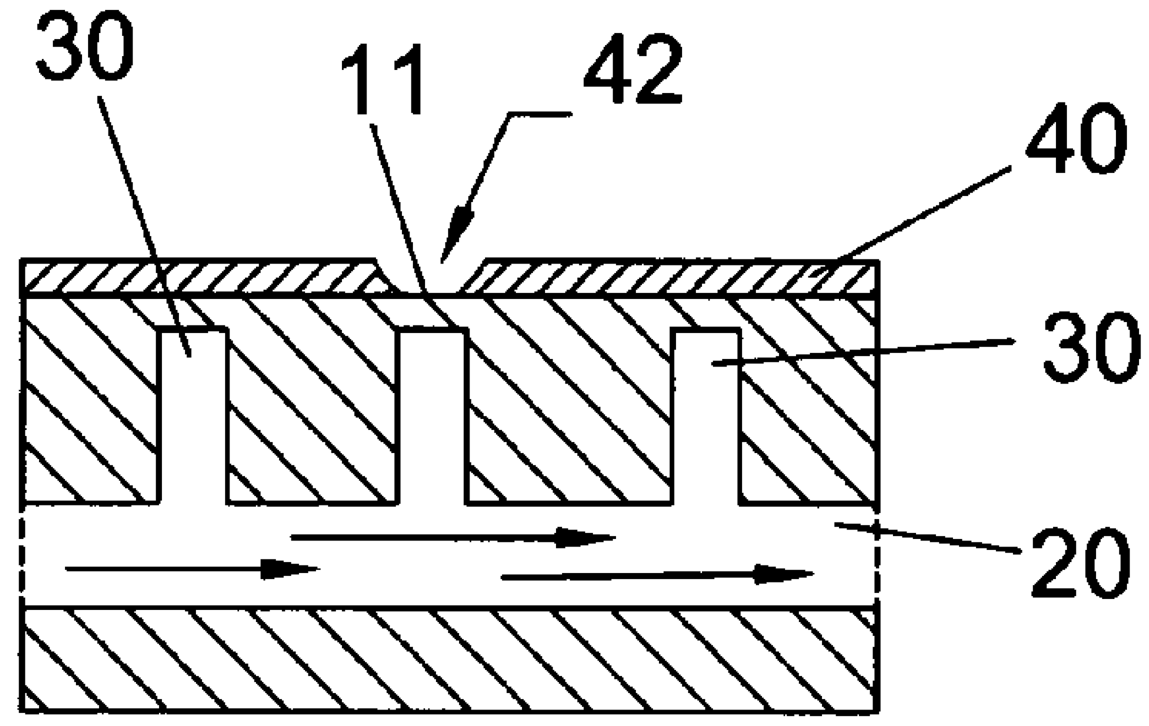


Fig 3

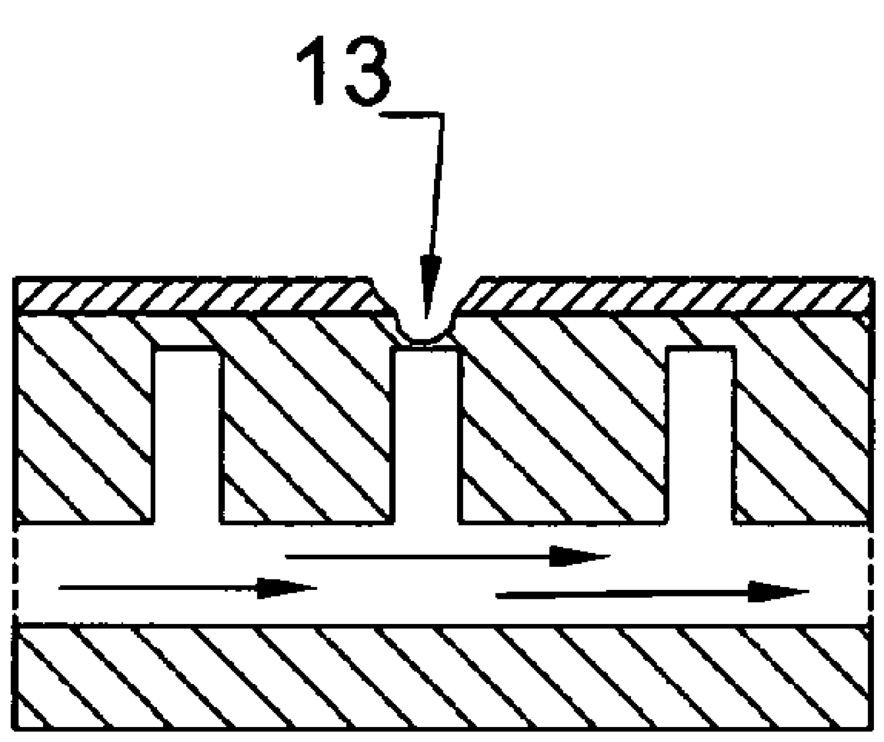


Fig 4

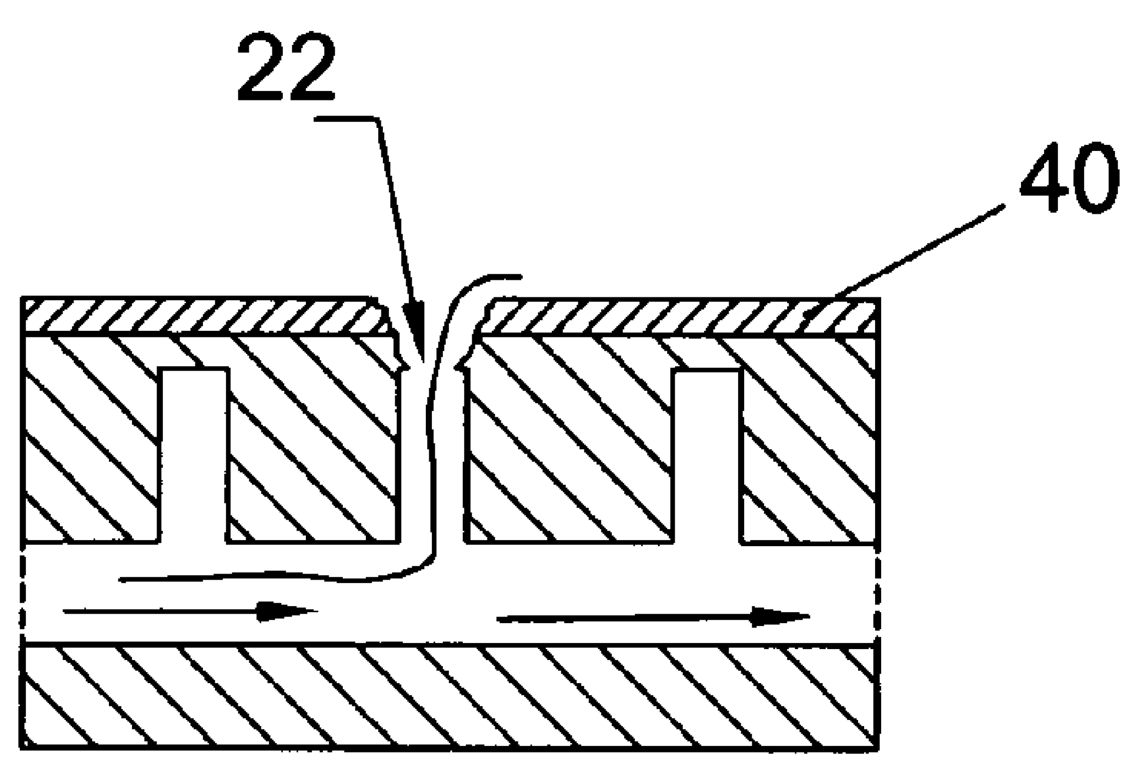


Fig 5

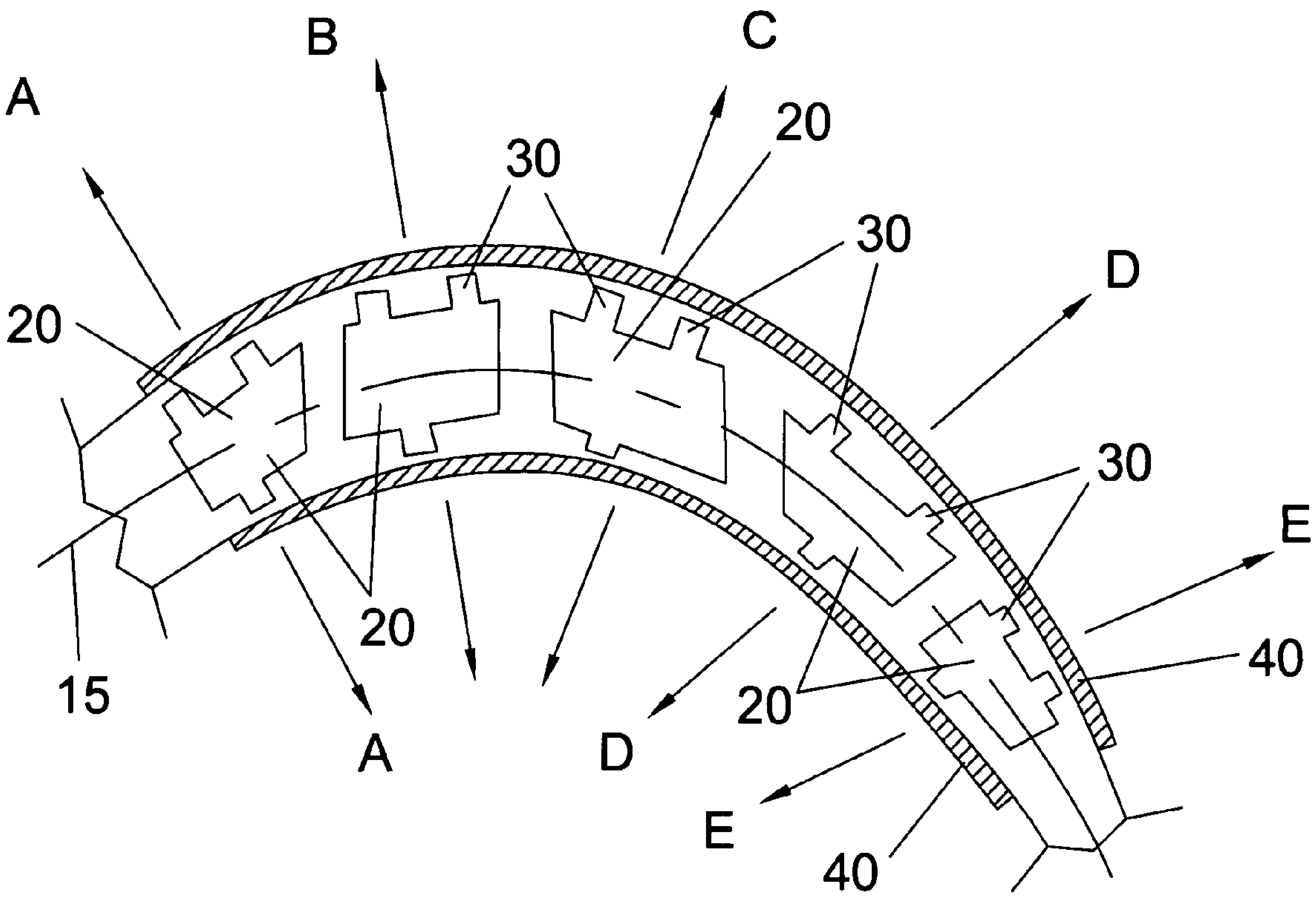


Fig 6

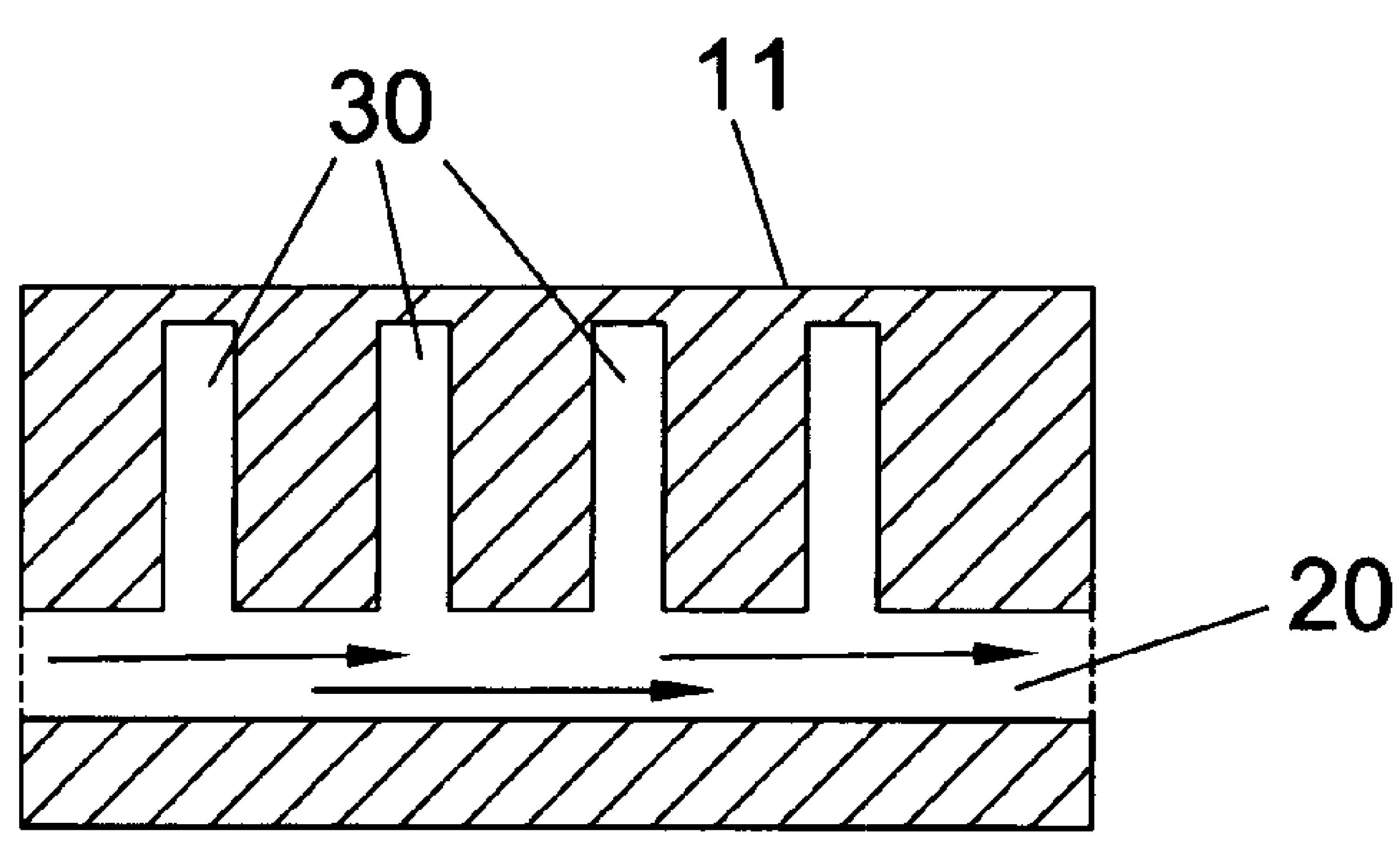


Fig 7

TURBINE BLADE WITH COOLING BREAKOUT PASSAGES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit to an earlier filed Provisional Patent Application 60/794,173 filed on Apr. 20, 2006 and entitled TURBINE BLADE WITH COOLING BREAKOUT PASSAGES.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to gas turbine airfoils, and more specifically to turbine airfoils having a thermal barrier coating and internal cooling passages.

[0004] 2. Description of the Related Art Including Information Disclosed Under 37 CFR 1.97 and 1.98

[0005] In gas turbine engines, airfoils (both moving blades and stationary vanes) include cooling fluid passages within the airfoil that form a closed (or open) cooling passage. A thermal barrier coating (TBC) can also be applied to an outer surface of the airfoil to provide a heat shield and prevent damage to the airfoil due to high temperatures.

[0006] Spallation of the TBC is a very common in gas turbine engines. When the TBC spalls, a small portion of the coating is broken off from the airfoil, exposing the substrate metal or airfoil surface below the TBC to extremely high gas temperatures of the gas turbine. Usually, the high gas temperature is higher than the melting temperature of the airfoil, especially in the first and second stages of the turbine. Thus, when spallation—or other means such as erosion or oxidation or foreign object damage—removes a piece of the TBC, the metal substrate is exposed to the high gas temperature and will melt away with time.

[0007] U.S. Pat. No. 6,039,537 issued to Scheurlen on Mar. 21, 2000 shows a gas turbine blade with internal cooling passages and a thermal barrier coating (TBC) applied to the outer surface. Smaller cooling air passages are located between the internal cooling passages and the TBC. Some of the smaller cooling air passages are covered up by the TBC such that the passage is closed to cooling air flow. When the TBC above the opening of a smaller cooling air passage is broken away (or, eroded or oxidized), the passage becomes open and cooling air flows through the passage from the internal cooling air passage out onto the surface of the airfoil around the removed section of substrate, allowing for additional cooling of the airfoil. As disclosed in the Scheurlen patent, "in the event of a failure of the heat insulating layer system in the effected region of the turbine blade, provision is made for additional cooling by virtue of the fact that the heat insulating system which breaks off opens the closed bore and enables a coolant, which is operationally admitted to the interior space anyway, to flow through the opened bore and thus intensify the cooling of the affected region. The heat insulating layer system is constructed in such a way that the use of the closed bore for cooling the turbine blade is not necessary in the case of an undamaged heat insulating layer system. The demand for coolant can therefore be adapted to the protective properties of the heat insulating layer system and be kept at a correspondingly low level. In addition, the provision of corresponding bores to be closed by the heat insulating layer system enables the turbine blade to be reliably cooled by repeated discharge of coolant from the interior space, and thus protected against undesirable failure even in the event of a loss of the heat insulating layer system", and "all of the bores are disposed in the substrate in such a way that the substrate is uniformly cooled when the hot gas flow flows around it, if the heat insulating layer system is open previously closed bores when a cooling fluid drawn off through the bores into the gas flow is fed to the interior space", and "such a structure also permits monitoring of the turbine blade with regard to the integrity of the heat insulating layer system by the inflow of the coolant being measured and compared with a value which must appear when the heat insulating layer system is intact, with all corresponding bores being closed".

[0008] U.S. Pat. No. 5,269,653 issued to Evans on Dec. 14, 1993 and entitled AEROFOIL COOLING discloses a turbine airfoil with a leading edge having a row of spaced blank passages (# 30 is the Evans patent) having blank ends that end just below the leading edge airfoil surface. When a piece of the TBC erodes away, the hot gas will erode away the blank ends of a passage and open the passage so that cooling air will flow through the passage and out onto the leading edge surface.

[0009] U.S. Pat. No. 6,749,396 B2 issued to Barry et al on Jun. 15, 2004 and entitled FAILSAFE FILM COOLED WALL discloses a gas turbine engine with cooling where a number of failsafe film cooling holes are located below a TBC in areas of high risk of thermal barrier coating spallation and that do not permit cooling flow through the holes unless the thermal barrier coating has eroded by spallation for opening the outlet ends of the holes during normal operation of the engine.

[0010] An object of the present invention is to provide for an air cooled airfoil with small film cooling holes that are normally closed to air flow but are opened when the portion of the airfoil around the hole becomes too hot.

[0011] Another object of the present invention is to provide for an air cooled airfoil with film cooling holes aligned with a pulling direction of the mold.

SUMMARY OF THE INVENTION

[0012] The present invention is an air cooled turbine blade for a gas turbine engine, the turbine blade having a cooling air passage therethrough for channeling cooling air through the blade, and a thermal barrier coating (TBC) or oxidation coating (or no coating at all) applied to the exterior of the blade to protect the metal substrate of the blade form damage due to a high temperature of the gas. Located between the internal cooling air passage and the TBC are small cooling air passages that form a closed cooling air path and extend from the internal cooling air passage to a point below the surface of the metal substrate on which the TBC is applied, forming a closed cooling air channel in the blade metal substrate.

[0013] When a piece of the TBC is broken away from the airfoil, the metal substrate below the TBC is then exposed to the high gas temperature. The high gas temperature then begins to melt away the metal substrate around the exposed TBC-less area. Eventually, the metal substrate melts to the point where the resulting hole joins the small cooling air passage just below the substrate such that cooling air flowing through the internal passage is also allowed to flow through the smaller cooling air passage and out onto the exposed surface of the metal substrate. The original closed cooling air passage now becomes an open cooling air passage as cooling air from inside the blade is directed out of the blade through the small cooling air passage to cool the newly exposed area of the metal substrate. Thus, further damage to the metal substrate of the airfoil due to the missing TBC is prevented while allowing the turbine engine to continue under full operating load until a later time when the damage can be discovered and the TBC repaired.

[0014] The turbine airfoil having the breakout passages is formed from a casting process with a mold formed from multiple pieces. Each mold piece has a distinct pulling direction in which the mold pieces are pulled away after the airfoil has been cast. The breakout passages are formed during the casting process. Each mold piece forms the breakout passages along a direction parallel to the pulling direction of the mold piece. This allows for the easy removal of the solidified airfoil after the molding process.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. **1** shows a turbine blade with an internal closed cooling air passage and smaller cooling air passages extending from the internal passage to a point near the surface of the metal substrate and TBC.

[0016] FIG. **2** shows a cross sectional view of the airfoil with a metal substrate and an undamaged TBC on the exterior surface of the metal, and several smaller cooling air passages extending from the internal cooling passage towards the outer surface of the metal substrate.

[0017] FIG. **3** shows the turbine blade of FIG. **2**, but with a small piece of the TBC missing and, thus, forming an exposed surface on the metal substrate on which the high temperature gas can act.

[0018] FIG. **4** shows the turbine blade of FIG. **2**, but with a small hole formed in the metal substrate due to melting of the metal from exposure to the high temperature gas.

[0019] FIG. **5** shows the turbine blade of FIG. **2**, but with a completed hole formed through the metal substrate and joining the small cooling air passage, forming an open cooling air passage and allowing for cooling air to flow through the smaller cooling air passage and onto the exposed portion of the metal substrate in order to prevent further melting of the metal substrate.

[0020] FIG. **6** shows a cross-sectional view of the airfoil with a serpentine internal cooling air passage separated by ribs joining the pressure side airfoil surface and the suction side airfoil surface, where the axial direction of the smaller cooling air passages are aligned with a pulling direction A-E of a multiple piece mold used to form the airfoil passages.

[0021] FIG. **7** shows an airfoil section with smaller cooling air passages extending to just under the surface of the airfoil exposed to high temperature gas, but without the use of a thermal barrier coating (TBC).

DETAILED DESCRIPTION OF THE INVENTION

[0022] Gas turbine engines include moving blades and stationary vanes (both considered to be an airfoil) with an internal cooling passage to direct a cooling fluid (such as air) through the airfoil for cooling purposes. FIG. **1** shows an airfoil **10** having cooling passage **20** within the airfoil, and smaller cooling air passages **30** extending from the internal cooling air passage **20** toward an outer surface **11** of the airfoil **10** on which the high temperature gas is exposed. These smaller cooling air passages **30** stop short of the outer surface **11** of the airfoil to a point just under the TBC **40**, thereby forming a closed cooling air passage such that cooling air from the internal cooling air passage **20** does not flow through the smaller cooling air passages **30**. These cooling air passages **30** can be referred to as failsafe film cooling holes or breakout passages or breakout film cooling holes. Also, the failsafe or breakout film cooling holes can extend just under the surface of the metal substrate as shown in FIG. **2**, or they can extend all the way to the TBC as in the Barry et al U.S. Pat. No. 6,749,396 B2 described above.

[0023] The smaller cooling air passages **30** are spaced apart on the airfoil such that any spallation of the TBC **40** (or, any erosion or oxidation or other means to remove a portion of the TBC) will expose one or more of the smaller cooling air passages **30** when the metal substrate **11** melts away due to exposure to the hot gas temperature.

[0024] FIG. **2** shows a cross-sectional view of the airfoil with a TBC **40** on the outer surface **11** of the airfoil **10** on which the high temperature gas is exposed. The internal cooling air passage **20** forms a closed cooling air passage through the airfoil (although an open cooling air passage in which cooling air is exhausted into the working fluid). A plurality of smaller air passages **30** extends from the internal cooling air passage **20** and toward the outer surface **11** of the airfoil **10** on which the TBC **40** is applied. The smaller cooling air passages can be used below TBCs or on an airfoil substrate that does not contain a TBC.

[0025] When a piece of the TBC is removed—for example, such as spallation, chipping, erosion, and oxidation—the metal substrate surface **11** of the airfoil **10** exposed to the high temperature gas of the turbine. Without protection from the TBC, the metal substrate **11** can melt away, damaging the airfoil **10** and therefore reducing the efficiency of the gas turbine engine. FIG. **3** shows a portion **42** of the TBC removed from the airfoil **10**, therefore exposing the metal substrate **11** to the hot gas.

[0026] With a piece of the TBC missing, the metal substrate is now exposed to the high temperature gas. The metal substrate begins to melt away, and eventually will melt a hole **13** to the point in the airfoil **10** where a small cooling air passage ends as shown in FIG. **4**. Thus, the small cooling air passage will open into the melted hole, forming an open cooling air passage **22** (see FIG. **5**). Then, cooling air from the internal cooling air passage **20** will flow through the smaller cooling air passage **30** an out of the hole exposed surface of the airfoil **10**, providing cooling air to the airfoil surface **11** to prevent further damage to the airfoil **10**.

[0027] A hollow airfoil like that used in this invention can be formed by a molding process in which the mold is made up of multiple pieces joined together at a line **15** forming the midpoint of the cross-section of the airfoil. FIG. **6** shows an airfoil with a line **15** along the midpoint of the cross section. The mold pieces are separated from each other in a respective pulling direction. In FIG. **6**, five pulling directions are show and labeled as A through E. The pulling direction would be the direction in which the mold pieces are separated in order to remove the solidified airfoil after a molding process.

[0028] The smaller cooling passages **30** formed in the airfoil **10** are directed along an axis parallel to the pulling direction of the mold piece in which the passage **30** is formed. This makes it easier to form the smaller cooling air passages **30** in the molding process and to separate the solidified airfoil from the mold.

[0029] FIG. **7** shows an embodiment of this invention in which no TBC is used on the airfoil substrate **11**. The smaller cooling air passages **30** are located just below the surface of the airfoil **11**. In this embodiment, the cooling air passing through the internal cooling air passage **20** cools the airfoil. If this cooling fails on a portion of the airfoil substrate **11**, then a hole will be melted away such that the smaller cooling air passage **30** is exposed to the airfoil surface **11** and cooling air flows through the passage **30** to cool the airfoil and prevent additional melting.

[0030] This invention has been disclosed for use in a blade or vane of a gas turbine engine. However, areas other than gas turbine engines can make use of the inventive concept of smaller cooling air passages located between an internal cooling passage and a heated surface. When the heated surface is overexposed to the high temperature, the surface starts to melt away and expose the smaller cooling air passage to the internal cooling air. Additional melting away of the substrate is reduced or prevented by the cooling air flowing through the melted away hole and out through the opening formed in the melted substrate.

I claim the following:

1. A turbine airfoil for use in a gas turbine engine, the airfoil comprising:

An airfoil surface for exposure to a hot gas flow through the turbine;

An internal cooling air supply passage to channel cooling air through the airfoil and provide cooling;

A plurality of cooling breakout passages connected to the cooling air supply passage on an upstream end and extending toward the airfoil surface on the downstream end, the cooling breakout passages being closed to cooling air flow when the airfoil surface is intact and open to cooling air flow when the airfoil surface has eroded away; and,

The turbine airfoil being formed from a molding process that uses a plurality of mold pieces and the plurality of breakout passages are aligned with a pulling direction of the mold piece in which the breakout passages are formed.

2. The turbine airfoil of claim **1**, and further comprising:

The airfoil surface above the breakout passages includes a thermal barrier coating; and,

The breakout passages extend through the airfoil wall and to the thermal barrier coating such that when the thermal barrier coating spalls the breakout passage below the spallation will open to cooling air flow.

3. The turbine airfoil of claim **1**, and further comprising:

The breakout passages extend to a point just under the airfoil metal surface such that erosion of the metal airfoil surface just above the breakout passage must occur before the breakout passage is open to cooling air flow.

4. The turbine airfoil of claim **3**, and further comprising:

A thermal barrier coating is applied to the airfoil surface over the breakout passages.

5. A process of casting a turbine airfoil having an internal cooling air supply passage and a plurality of cooling breakout passages, the process comprising the steps of:

Casting the airfoil using a multiple piece mold assembly in which each mold piece has a pulling direction; and,

Casting the breakout passages along a direction substantially parallel to the pulling direction of the respective mold piece in which the passages are cast.

6. The process of casting a turbine airfoil of claim **5**, and further comprising the step of:

Casting the airfoil in a mold assembly in which the mold pieces are joined together along a line forming a midpoint of the cross section of the airfoil.

7. The process of casting a turbine airfoil of claim **5**, and further comprising the step of:

Casting the breakout passages so that the passages end at a point just below the metal airfoil surface.

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