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(54) Title: MINIMIZATION OF RE-CRYSTALLIZATION IN SINGLE CRYSTAL CASTINGS

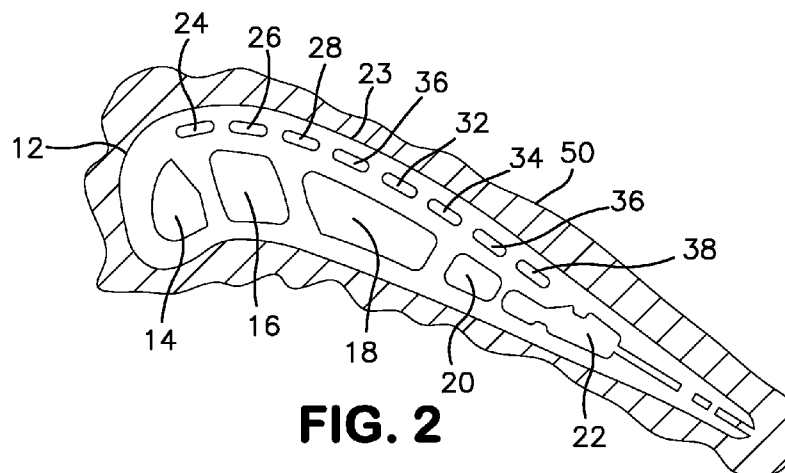


FIG. 2

(57) **Abstract:** A refractory metal core for forming internal features in a turbine engine component has a core formed from a refractory metal material; and the core has at least one blended surface on at least one edge of the core.

MINIMIZATION OF RE-CRYSTALLIZATION IN SINGLE CRYSTAL CASTINGS

BACKGROUND

[0001] The present disclosure is directed to a refractory metal core for minimizing re-crystallization in single crystal castings.

[0002] During the casting solidification process and during subsequent heat treatment operations of hollow single crystal parts, stress/strain may be introduced into the parent material of the casting. This is due to a number of factors including material property mismatch, thermal stress, microstructural behavior, mechanical stress risers, and handling issues. When an area with this stress/strain state reaches a high enough level at a temperature, an energy level is reached that causes the single crystal alloy to re-crystallize at those locations. Re-crystallized regions in a single crystal casting is a defect that can significantly reduce life in an engine component. This problem is prevalent in refractory metal cores due to the more severe difference in specific material properties compared to the parent part material.

SUMMARY

[0003] In accordance with the present disclosure, there is provided a refractory metal core for forming internal features in a turbine engine component, which broadly comprises a core formed from a refractory metal material; and the core having at least one blended surface along at least one edge of the refractory metal core.

[0004] In another and alternative embodiment, the refractory metal core has a longitudinal axis and said at

least one blended surface extends substantially parallel to said longitudinal axis.

[0005] In another and alternative embodiment, the refractory metal core has two opposed edges and each edge has a blended surface.

[0006] In another and alternative embodiment, each edge has a radius and the refractory metal core has a length which forms a radius/length ratio in the range of from 0.0094:1 to 0.156:1.

[0007] In another and alternative embodiment, the radius/length ratio is in the range of from 0.025:1 to 0.156:1.

[0008] In another and alternative embodiment, the refractory metal core has a radius to thickness ratio in the range of 0.28:1 to 0.4:1.

[0009] In another and alternative embodiment, the refractory metal core has two lateral surfaces and said at least one blended surface extends between said two lateral surfaces.

[00010] In another and alternative embodiment, the at least one blended surface comprises a curved surface.

[00011] In another and alternative embodiment, the at least one blended surface extends 180 degrees.

[00012] Further in accordance with the present disclosure, there is provided a molding system for forming a turbine engine component which broadly comprises a mold; at least one ceramic core placed within the mold to form an internal passageway in the turbine engine component; and at least one refractory metal core placed within the mold to form an internal feature in at least one wall of the turbine engine component,

[00013] In another and alternative embodiment, the at least one refractory metal core has at least one edge with at least one blended surface.

[00014] In another and alternative embodiment, a plurality of ceramic cores are placed in the mold.

[00015] In another and alternative embodiment, a plurality of refractory metal cores are placed in the mold.

[00016] In another and alternative embodiment, the at least one refractory metal core has a longitudinal axis and the at least one blended surface extends substantially parallel to the longitudinal axis.

[00017] In another and alternative embodiment, the at least one refractory metal core has two opposed edges and each edge has a blended surface.

[00018] In another and alternative embodiment, each edge has a radius and said refractory metal core has a length which forms a radius/length ratio in the range of from 0.0094:1 to 0.156:1.

[00019] In another and alternative embodiment, the radius/length ratio is in the range of from 0.025:1 to 0.156:1.

[00020] In another and alternative embodiment, the refractory metal core has a radius to thickness ratio in the range of 0.28:1 to 0.4:1.

[00021] In another and alternative embodiment, the at least one refractory metal core has two lateral surfaces and the at least one blended surface extends between the two lateral surfaces.

[00022] In another and alternative embodiment, the at least one blended surface comprises a curved surface.

[00023] In another and alternative embodiment, the at least one blended surface extends 180 degrees.

[00024] Still further in accordance with the present disclosure, there is provided a process for casting a turbine engine component, which broadly comprises: providing a mold; placing at least one ceramic core

within the mold to form an internal passageway in the turbine engine component; and placing at least one refractory metal core within the mold to form an internal feature in at least one wall of the turbine engine component, wherein the at least one refractory metal core has at least one edge with at least one blended surface.

[00025] In another and alternative embodiment, the at least one ceramic core placing step comprises placing a plurality of ceramic cores in the mold.

[00026] In another and alternative embodiment, the at least one refractory metal core step comprises placing a plurality of refractory metal cores in the mold.

[00027] In another and alternative embodiment, the process further comprises providing the refractory metal core with a longitudinal axis and the at least one blended surface extending substantially parallel to the longitudinal axis.

[00028] In another and alternative embodiment, the process further comprises providing the refractory metal core with two opposed edges and each edge has a blended surface.

[00029] In another and alternative embodiment, the process further comprises providing each said edge with a radius and providing said refractory metal core with a length which forms a radius/length ratio in the range of from 0.0094:1 to 0.156:1.

[00030] In another and alternative embodiment, the radius/length ratio is in the range of from 0.025:1 to 0.156:1.

[00031] In another and alternative embodiment, the process further comprises providing the refractory metal core with a radius to thickness ratio in the range of 0.28:1 to 0.4:1.

[00032] In another and alternative embodiment, the process further comprises providing the core with two lateral surfaces and the at least one blended surface extending between the two lateral surfaces.

[00033] In another and alternative embodiment, the process further comprises forming the at least one blended surface as a curved surface.

[00034] In another and alternative embodiment, the process further comprises forming the at least one blended surface to extend 180 degrees.

[00035] In another and alternative embodiment, the process further comprises pouring metal in the mold to form the turbine engine component.

[00036] In another and alternative embodiment, the process further comprises removing the at least one ceramic core and the at least one refractory core.

[00037] Other details of the refractory metal core are set forth in the following detailed description and the accompanying drawing wherein like reference numerals depict like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

[00038] FIG. 1 illustrates a turbine engine component having an airfoil portion;

[00039] FIG. 2 illustrates a molding system for forming an airfoil portion of the turbine engine component showing the location of the casting cores;

[00040] FIG. 3 is an enlarged section of Fig. 2;

[00041] FIG. 4 is a sectional view of an airfoil portion of a cast turbine engine component showing a refractory metal core in accordance with the present disclosure;

[00042] FIG. 5 illustrates a refractory metal core in accordance with the present disclosure.

DETAILED DESCRIPTION

[00043] Referring now to FIG. 1, there is shown a cast turbine engine component 10, in particular a turbine blade. The component 10 may be formed to have an attachment portion 11, a platform 13, and an airfoil portion 12.

[00044] FIG. 2 illustrates a mold 15 and the various cores which may be used to cast the airfoil portion 12 of the turbine engine component 10. For example, central cooling air conducting passageways and cooling air outlets may be formed in the airfoil portion 12 by placing a plurality of ceramic cores in the mold 15. In one non-limiting embodiment, ceramic cores 14, 16, 18, 20, and 22 may be placed into the mold. It is often desirable to form internal features, such as cooling circuits, within the walls of the airfoil portion, such as the suction side wall 23. To this end, refractory metal cores 24, 26, 28, 30, 32, 34, 36, and 38 may be placed in the mold 15. The refractory metal cores 24, 26, 28, 30, 32, 34, 36, and 38 may be formed from any suitable refractory material such as from molybdenum or a molybdenum alloy.

[00045] After the various ceramic cores 14, 16, 18, 20, and 22 and refractory metal cores 24, 26, 29, 30, 32, 34, 36, and 38 have been placed in the mold 15, molten metal, such as a nickel based superalloy, may be poured into the mold in order to form the cast turbine engine component 10. Often, it is desirable to form the turbine engine component from a single crystal nickel base alloy.

[00046] As can be seen from FIG. 3, the refractory metal cores 24, 26, 28, 30, 32, 34, and 36 may be formed with sharp edges 40 and 42. These sharp edges however can be the source of stress/strains in single crystal

castings that cause re-crystallization sites in the castings. These re-crystallization sites are due to the high levels of stress concentrations created by the use of sharp edges.

[00047] Referring now to FIG. 4, there are shown refractory metal cores 24', 26', 28', 30', 32', 34' and 36' which may be used to reduce or eliminate the re-crystallization sites. Each of these refractory metal cores 24', 26', 28', 30', 32', 34', and 36' may be provided with blended edges 44' and 46'.

[00048] Each refractory metal core 24', 26', 28', 30', 32', 34' and 36' may extend in and have a length in a spanwise direction and may have lateral edges 48' and 50'. The lateral edges 48' and 50' may be substantially linear or may have a slight curve depending upon the location of the respective refractory metal core. The blended edges 44' and 46' extend between the lateral edges 48' and 50'.

[00049] The blended edges 44' and 46' may each be formed by curved or arcuate surfaces of a radius which reduces or eliminates the stress concentrations in the single crystal casting. In other words, the edges 44' and 46' do not have any sharp edges. In a non-limiting embodiment, each blended edge 44' and 46' may be formed by an arcuate surface which extends approximately 180 degrees.

[00050] Each of the blended edges 44' and 46' has a radius which forms a radius/core length ratio in the range of 0.0094:1 to 0.156:1. Each of the refractory metal cores 24', 26', 28', 30', 32', 34' and 36' may have a blended edge radius to rib thickness (T) ratio in the range of from 0.28:1 to 0.4:1. A particularly useful radius to core length ratio is in the range of from

0.025:1 to 0.156:1. The rib thickness (T) to wall thickness (W) ratio should be close to unity.

[00051] Referring now to FIG. 5, the refractory metal core having the blended edges 44' and 46' may have a longitudinal axis 60'. The longitudinal axis 60' may extend in the spanwise direction. The blended edges 44' and 46' may each extend parallel to the longitudinal axis 60'.

[00052] Each of the refractory metal cores 24', 26', 28' 30', 32' 34' and 36' may be formed from a refractory metal or metal alloy having a coefficient of thermal expansion in the range of 2.8×10^{-6} in/in/F to 3.4×10^{-6} in/in/F. Further, each of the refractory cores 24', 26', 28' 30', 32' 34' and 36' may have a Young's Modulus of 3.8×10^7 psi to 4.7×10^7 psi.

[00053] After the turbine engine component 10 has been cast, the ceramic cores 14, 16, 18, 20, and 22 and the refractory metal cores 24', 26', 28' 30', 32' 34' and 36' may be removed using any suitable technique known in the art.

[00054] The cooling microcircuits which are left have curved or arcuate end surfaces which mirror the curvature of the blended edges 44' and 46'.

[00055] The use of the blended edges 44' and 46' provides controlled reduction/elimination of re-crystallization defects in single crystal castings which may otherwise reduce the service life of the cast turbine engine component 10. Refractory metal cores, especially those with very thin cross sections, are important to the production of high performance turbine engine component designs.

[00056] The blended edges 44' and 46' may be formed using mechanical forming, mechanical grinding/blending, additive manufacturing, electro-chemical

machining/finishing, hybrid electrochemical-mechanical machining/finishing, coating, and chemical/electro-chemical etching. In mechanical forming, an open or closed die forming process is used that would be applied as either (a) part of the RMC blanking and forming operations or (b) a subsequent edge forming operation using dies specific for the edge detail. This process can be accomplished at either room temperature or elevated temperature. In mechanical grinding/blending, a manual or robotic blending operation may use material removal tools such as grinding wheels or other abrasive/cutting tools. In additive manufacturing, the edge geometry can be incorporated as part of an additive manufacturing process for making the RMC, such as direct metal laser sintering or an injection casting process. In electro-chemical machining/finishing, the process may involve immersing the part in an electrolytic bath serving as the anode. A current is passed from the anode to the cathode oxidizing the surface material and dissolving it in the electrolyte. This can be either an ECM or EDM process where there may or may not be contact between the part and the electrode. In hybrid electrochemical-mechanical machining/fabricating, the process may utilize both electrochemical principles in conjunction with a mechanical material removal process. Liquefaction of the surface material using the electrochemical is not necessary with the assistance of the mechanical process. In a coating process, it may be applied to the RMC where the thickness of the material deposited is inherently and/or intentionally thicker at the edges, giving the sharp corners a rounded geometry of a minimum radius. In chemical/electro-chemical etching, the process may involve submersing the part in a chemical bath and relying on the bath alone or charging the bath

with electronic pulses wherein the material is preferentially removed at high spots in the geometry leaving rounded corners or radii.

[00057] There has been provided in accordance with the present disclosure a refractory metal core which minimizes re-crystallization in single crystal castings. While the refractory metal core has been disclosed in the context of specific embodiments thereof, other unforeseen alternatives, modifications, and variations may become apparent to those skilled in the art having read the foregoing disclosure. Accordingly, it is intended to embrace those alternatives, modifications, and variations as fall within the broad scope of the appended claims.

WHAT IS CLAIMED IS:

1. A refractory metal core for forming internal features in a turbine engine component, comprising:

a core formed from a refractory metal material; and
said core having at least one blended surface on at least one edge of said core.

2. The refractory metal core of claim 1, wherein said core has a longitudinal axis and said at least one blended surface extends substantially parallel to said longitudinal axis.

3. The refractory metal core of claim 1, wherein said core has two opposed edges and each said edge has a blended surface.

4. The refractory metal core of claim 3, wherein each said edge has a radius and said refractory metal core has a length which forms a radius/length ratio in the range of from 0.0094:1 to 0.156:1.

5. The refractory metal core of claim 4, wherein said radius/length ratio is in the range of from 0.025:1 to 0.156:1.

6. The refractory metal core of claim 3, wherein said refractory metal core has a radius to thickness ratio in the range of 0.28:1 to 0.4:1.

7. The refractory metal core of claim 1, wherein said core has two lateral surfaces and said at least one blended surface extends between said two lateral surfaces.

8. The refractory metal core of claim 1, wherein said at least one blended surface comprises a curved surface.

9. The refractory metal core of claim 1, wherein said at least one blended surface extends 180 degrees.

10. A molding system for forming a turbine engine component comprising:

 a mold;

 at least one ceramic core placed within the mold to form an internal passageway in said turbine engine component; and

 at least one refractory metal core placed within the mold to form an internal feature in at least one wall of said turbine engine component,

 wherein said at least one refractory metal core has at least one edge with at least one blended surface.

11. The molding system of claim 10, wherein a plurality of ceramic cores are placed in said mold.

12. The molding system of claim 10, wherein a plurality of refractory metal cores are placed in said mold.

13. The molding system of claim 10, wherein said at least one refractory metal core has a longitudinal axis and said at least one blended surface extends substantially parallel to said longitudinal axis.

14. The molding system of claim 10, wherein said at least one refractory metal core has two opposed edges and each edge has a blended surface.

15. The molding system of claim 14, wherein each said edge has a radius and said refractory metal core has a length which forms a radius/length ratio in the range of from 0.0094:1 to 0.156:1.

16. The molding system of claim 15, wherein said radius/length ratio is in the range of from 0.025:1 to 0.156:1.

17. The molding system of claim 15, wherein said refractory metal core has a radius to thickness ratio in the range of 0.28:1 to 0.4:1.

18. The molding system of claim 13, wherein said at least one refractory metal core has two lateral surfaces and said at least one blended surface extends between said two lateral surfaces.

19. The molding system of claim 10, wherein said at least one blended surface comprises a curved surface.

20. The molding system of claim 19, wherein said at least one blended surface extends 180 degrees.

21. A process for casting a turbine engine component, comprising:

providing a mold;

placing at least one ceramic core within the mold to form an internal passageway in said turbine engine component; and

placing at least one refractory metal core within the mold to form an internal feature in at least one wall of said turbine engine component,

wherein said at least one refractory metal core has at least one edge with at least one blended surface.

22. The process of claim 21, wherein said at least one ceramic core placing step comprises placing a plurality of ceramic cores in said mold.

23. The process of claim 21, wherein said at least one refractory metal core step comprises placing a plurality of refractory metal cores in said mold.

24. The process of claim 21, further comprising providing said refractory metal core with a longitudinal axis and said at least one blended surface extending substantially parallel to said longitudinal axis.

25. The process of claim 21, further comprising providing said refractory metal core with two opposed edges and each edge has a blended surface.

26. The process of claim 25, further comprising providing each said edge with a radius and providing said refractory metal core with a length which forms a radius/length ratio in the range of from 0.0094:1 to 0.156:1.

27. The process of claim 26, wherein said radius/length ratio is in the range of from 0.025:1 to 0.156:1.

28. The process of claim 25, further comprising providing said refractory metal core with a radius to thickness ratio in the range of 0.28:1 to 0.4:1.

29. The process of claim 21, further comprising providing said core with two lateral surfaces and said at least one blended surface extending between said two lateral surfaces.

30. The process of claim 21, further comprising forming said at least one blended surface as a curved surface.

31. The process of claim 21, further comprising forming said at least one blended surface to extend 180 degrees.

32. The process of claim 21, further comprising pouring metal in said mold to form said turbine engine component.

33. The process of claim 32, further comprising removing said at least one ceramic core and said at least one refractory core.

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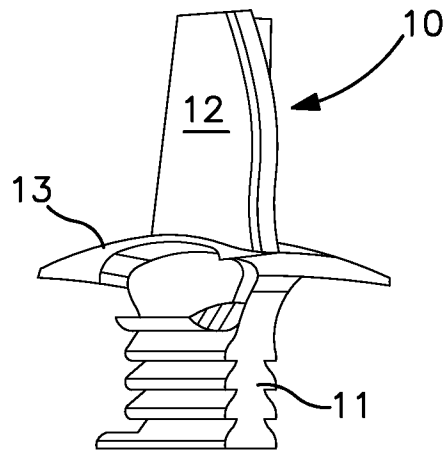


FIG. 1

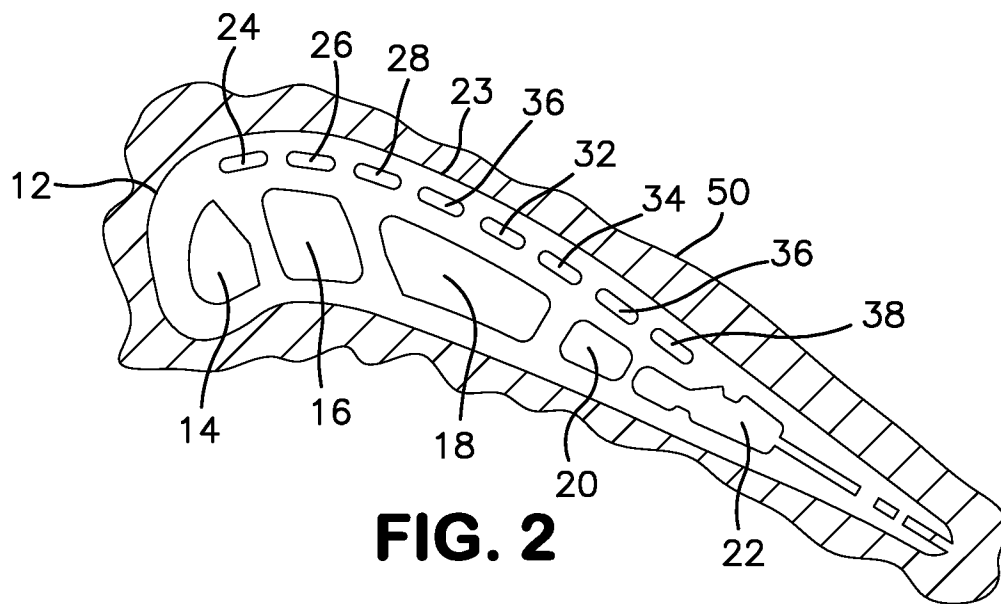


FIG. 2

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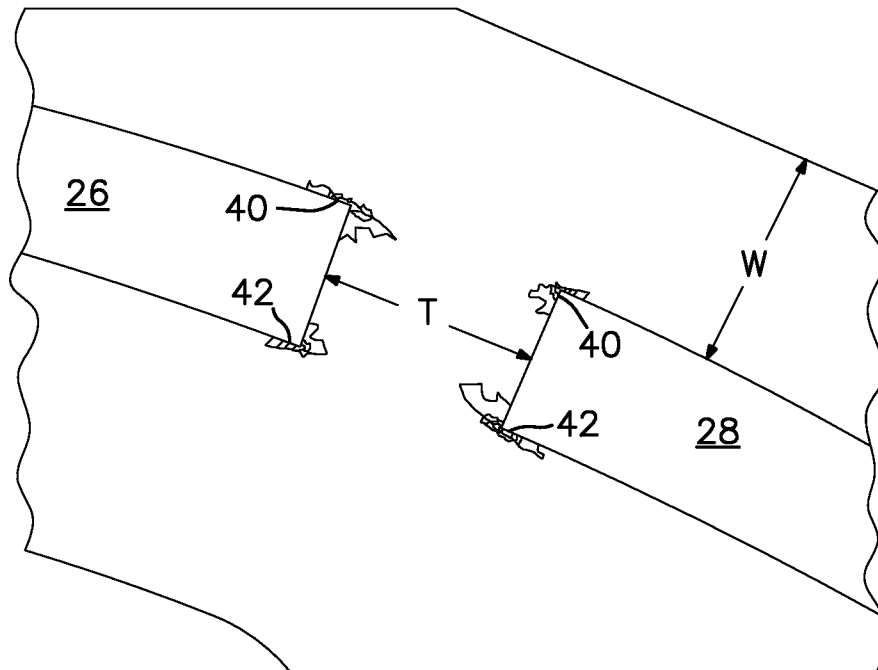


FIG. 3

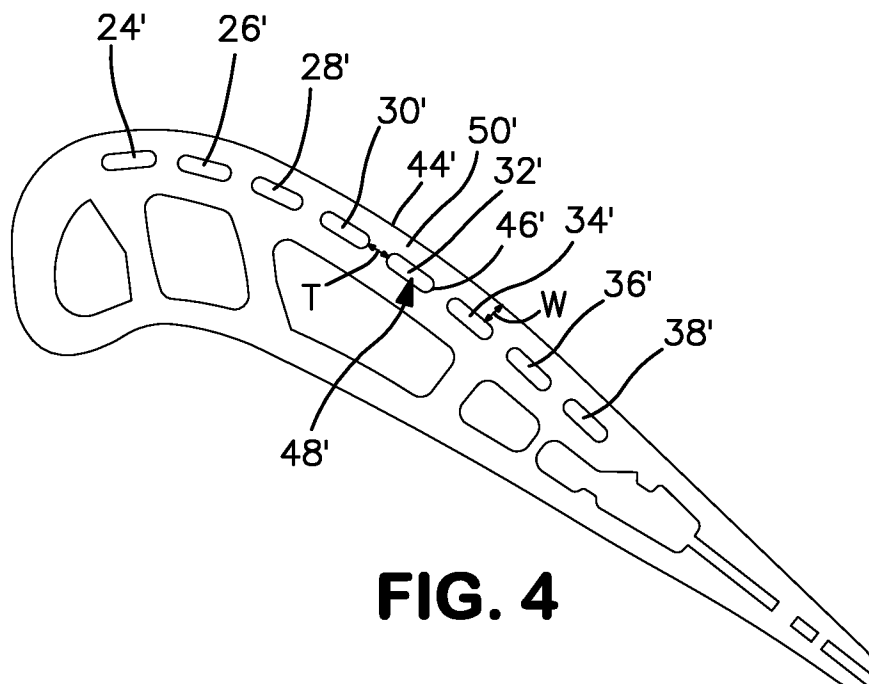


FIG. 4

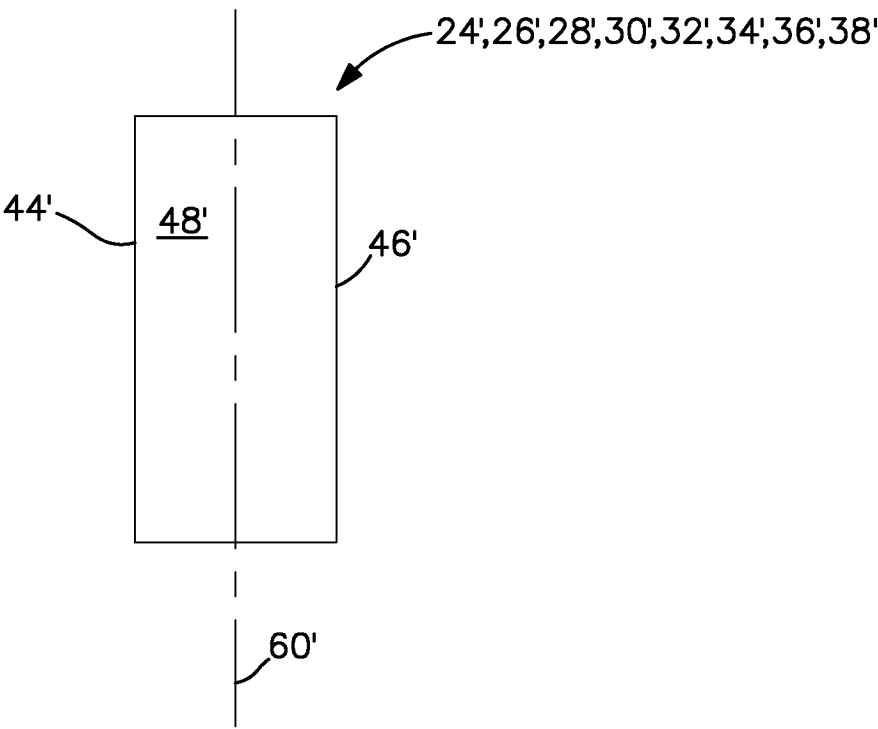


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/067395**A. CLASSIFICATION OF SUBJECT MATTER****B22C 9/10(2006.01)i, B22C 9/22(2006.01)i, B22D 17/00(2006.01)i, B22D 17/22(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B22C 9/10; B22C 9/04; F01D 5/18; B32B 5/16; B22C 7/00; B22D 25/00; B22C 9/00; B22C 9/22; B22D 17/00; B22D 17/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: turbine, mold, core, ceramic, refractory metal, and blended surface

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004-0020629 A1 (SHAH et al.) 05 February 2004	1-10, 13-21, 24-31
Y	See paragraphs [0013]-[0016], [0041], [0046] and figure 5.	11-12, 22-23, 32-33
Y	US 2010-0129217 A1 (CHEROLIS et al.) 27 May 2010	11-12, 22-23, 32-33
	See paragraphs [0029], [0031].	
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A	US 2012-0291983 A1 (GRAHAM et al.) 22 November 2012	1-33
	See claims 1-5 and figures 14-15.	
A	US 5705266 A (KEELAN et al.) 06 January 1998	1-33
	See column 3, line 6 - column 4, line 16.	



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

24 February 2014 (24.02.2014)

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/067395

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