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James

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(54) **MECHANICAL JOINING USING ADDITIVE MANUFACTURING PROCESS**

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F01D 5/30	(2006.01)
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B22F 7/06	(2006.01)
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CPC ***F01D 5/30*** (2013.01); ***B22F 3/1055*** (2013.01); ***B22F 7/062*** (2013.01); ***B23K 26/32*** (2013.01); ***B23K 26/342*** (2015.10); ***B23P 15/04*** (2013.01); ***B29C 67/0077*** (2013.01); ***F01D 5/3061*** (2013.01); *B22F 5/106* (2013.01); *B22F 2005/005* (2013.01); *B23K 2201/001* (2013.01); *B29L 2031/7504* (2013.01); *Y02P 10/295* (2015.11)

(58) **Field of Classification Search**
CPC B21D 39/00; F04D 29/24; F04D 29/242; F04D 29/30; F04D 29/324; F04D 29/34; F04D 29/38; F04D 29/388; F01D 9/02; F01D 9/04; F01D 9/042; F01D 9/044; F01D 25/246; F01D 5/3061; F01D 5/30; F01D 25/24; F16B 7/0426; Y10T 403/47; Y10T 403/471; Y10T 403/472; Y10T 403/473; B29C 67/0077; Y02P 10/295; B29L 2031/7504; B23K 2201/001; B23K 26/342; B23K 26/32; B22F 2005/005; B22F 3/1055; B23P 15/04
USPC 219/121.85; 29/527.1; 403/265–268
See application file for complete search history.

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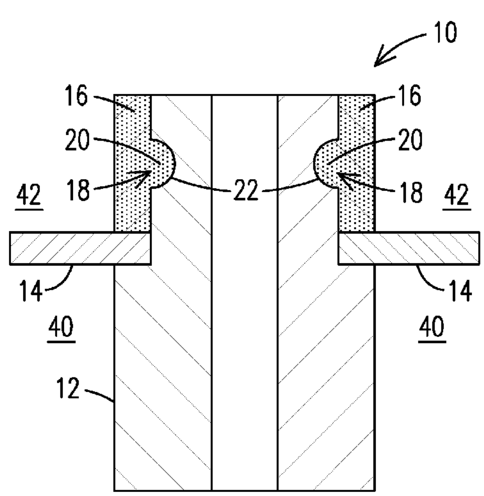
(57) **ABSTRACT**

A method of manufacturing an assembly (**10**), including: positioning a first component (**12**) and a second component (**14**) in a desired positional relationship with each other; and building-up a locking component (**16**) by depositing layer after layer of material onto a surface (**24**, **26**) of the assembly until a completed locking component is formed in-situ that holds the first component and the second component in the desired positional relationship.

12 Claims, 1 Drawing Sheet



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B23K 101/00	(2006.01)
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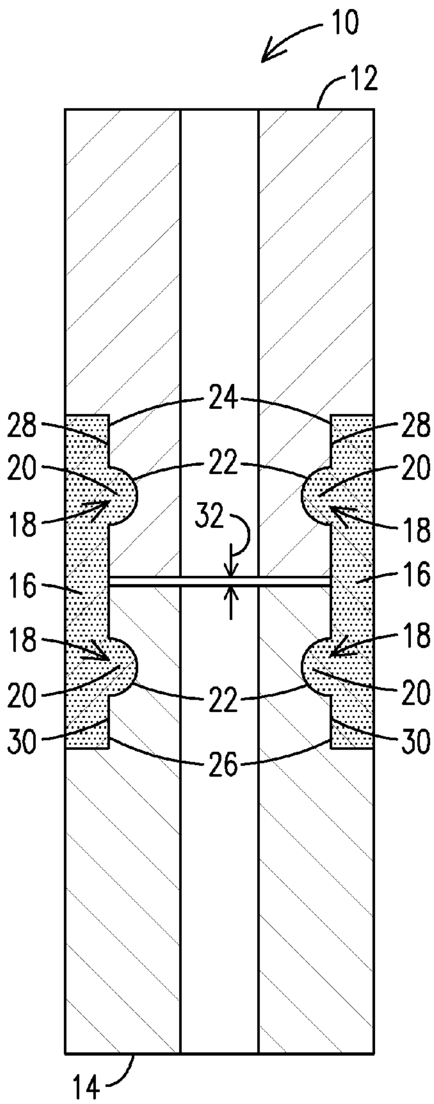

FIG. 1

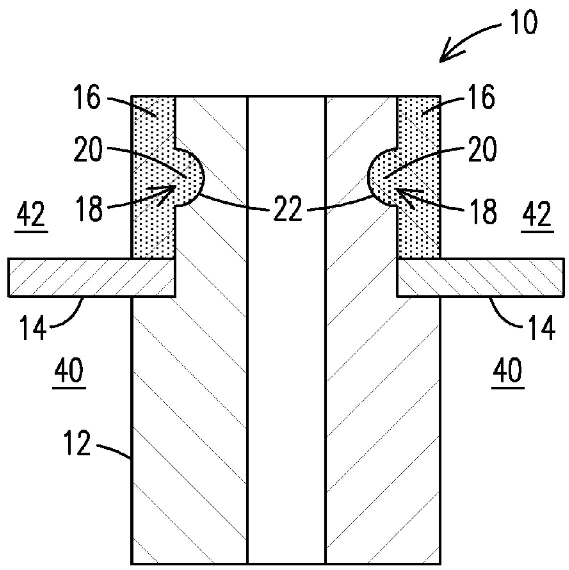

FIG. 2

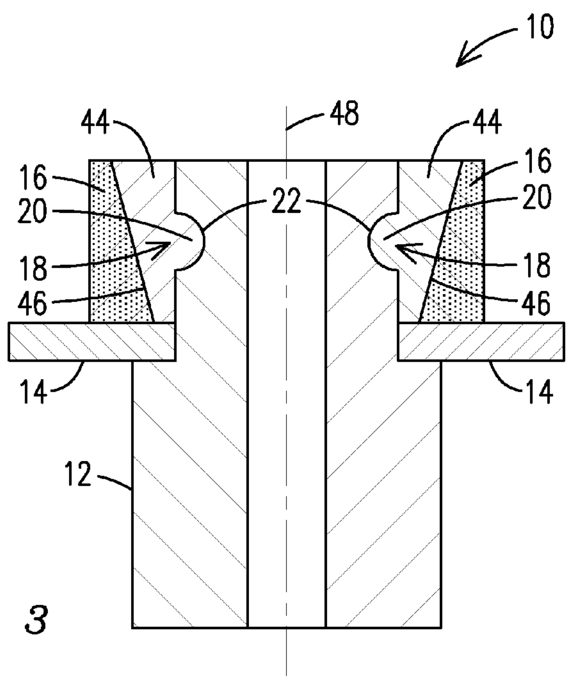

FIG. 3

MECHANICAL JOINING USING ADDITIVE MANUFACTURING PROCESS

FIELD OF THE INVENTION

The present invention relates to mechanical joining of an assembly via a component formed in-situ via a layer-by-layer additive manufacturing process.

BACKGROUND OF THE INVENTION

In the field of gas turbine engines various parts of a single component may have widely varying operational requirements. Certain materials may be well suited for the operating requirements of one of the various parts, while another material may be better suited for the operating requirements of another. Modular components have therefore been used to tailor the materials used to the varying operational requirements. In this manner more expensive or difficult-to-fabricate materials may be limited to those parts of the component where needed, while less expensive or easier-to-fabricate materials can be used elsewhere. Furthermore, this modular approach to manufacturing a component allows for the replacement of individual modules rather than an entire component to extend service life of the component.

Joining of these components conventionally includes metallurgical joining such as welding and brazing. However, there are many high-temperature turbine materials that are very difficult to weld without cracking. This is less of a problem for braze joints, but braze joints are only as strong as the braze material. Mechanical joining offers advantages when joining dissimilar materials or materials that are difficult to weld. However, there are frequently concerns that mechanical joints may fail during service and liberate hardware into the engine. Consequently, there remains room in the art for improvement.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in the following description in view of the drawings that show:

FIG. **1** is a schematic representation of an exemplary embodiment of the assembly.

FIG. **2** is a schematic representation of an alternate exemplary embodiment of the assembly.

FIG. **3** is a schematic representation of yet another alternate exemplary embodiment of the assembly.

DETAILED DESCRIPTION OF THE INVENTION

The present inventor has devised an innovative approach for joining components to form an assembly. Specifically, components of the assembly are held relative to each other in a positional relationship that they are to have when they are part of the component. While the components are being held in the desired positional relationship a locking component that completes the assembly is formed in place on one of the other components of the assembly via an additive manufacturing process, where the locking component is formed layer-by-layer. An interlocking relationship within the assembly holds the assembly together, and the locking component ensures that interlocking elements of the interlocking relationship stay engaged with each other. The locking component therefore forms part of the assembly and is effective to ensure the interlocking relationship remains intact, thereby holding the assembly together.

FIG. **1** shows a schematic longitudinal cross-section of an exemplary embodiment of an assembly **10** having an elongated shape similar to an airfoil. The assembly **10** includes a first component **12**, a second component **14**, and a locking component **16**. In this exemplary embodiment the assembly **10** is held together by two interlocking relationships **18** formed by a first interlocking feature **20** and a second interlocking feature **22** that engage each other. So long as the interlocking features **20**, **22** are engaged with each other the interlocking relationship **18** is formed and this holds the assembly **10** together. Thus, the locking component **16** is configured to be part of the component **10** and to simultaneously ensure the interlocking relationship **18** remains intact. In this exemplary embodiment the first interlocking feature **20** for each interlocking relationship **18** is formed as part of the locking component **16**. However, the locking component **16** may or may not include geometry that forms part of the interlocking relationship **18**. Instead, the locking component **16** is formed to ensure the interlocking relationship **18** remain intact, regardless of which components of the assembly **10** actually include the geometric features that form the interlocking relationship **18**.

The locking component **16** may be formed by an additive manufacturing process which can be defined as a process of joining materials to make three dimensional solid objects from a digital model, layer upon layer. This is in contrast to subtractive manufacturing methodologies which rely on the removal of material using techniques such as cutting, drilling, milling and grinding etc. One of many possible examples of an additive manufacturing process envisioned for this method is Laser Engineered Net Shaping (LENS). In this process a metal powder is injected into a molten pool created by a laser beam. The component being formed sits on a surface that may be moved under the laser's focal point, and the laser may be elevated after forming a layer in order to form another layer on top of the formed layer. The component formed is considered to be fully dense (fully sintered) and therefore fully formed when the final shape is reached. Further, the locking component may be ceramic, or as in the exemplary embodiment, it may be metal.

As a result of this layer-by-layer approach, a powder metallurgy component formed via a layer-by-layer additive process has a unique microstructure when compared to components made using other powder metallurgy processes. First, a grain size in the grain structure of the component is limited to a thickness of the deposited layer in which the grain resides because a size of a pool of melted material formed by the process is limited to approximately the thickness of the layer, and the size of the weld pool limits the size of the grain. (The size of the weld pool is, in turn, controlled by the heat input from the laser and the thickness of the powder layer.) The small volume of the molten material and the fast cooling rate effectively prevent grain growth. Therefore, since each layer is essentially fully formed when deposited, any grains within the layer cannot grow to be any thicker than a thickness of the layer itself. While a subsequent layer formed on top of the first layer may melt an upper portion of the first layer in order to bond thereto, any grains present in the first layer do not grow into the second layer.

Second, in the layer-by-layer approach the grains in the component would have a laminar structure as a result of the layering process. In contrast, in conventional powder metallurgy processes the individual powder particles do not melt, rather they join together via inter-diffusion when exposed to high temperatures (below the melting point) in the sintering process. The powder particles have a random orientation to each other and the interfaces between the particles become the grain boundaries. This results in a structure that is more uniformly equiaxed in conventional powder metallurgy processes. The laminar structure that results from the layer-by-layer process can lead to anisotropic properties, (where there may be differences in properties measured parallel to the build direction than properties 90 degrees to the build direction).

Several advantages can be realized from this method of forming this type of assembly. For example, if the assembly **10** of FIG. **1** is an airfoil used in a gas turbine engine, and if the first component **12** is an airfoil portion while the second component **14** is a tip coupon, (in such an exemplary embodiment the locking component **16** may take the shape of a ring or cylinder), both of these components could benefit from having different compositions. Specifically, the airfoil portion may required to have greater creep resistance in environments such as those created by hot combustion gases in a gas turbine engine, but need not necessarily be particularly abrasive. The tip coupon portion, which may encounter an abradable portion of a shroud or ring segment, may need greater abrasive properties. As often occurs in gas turbine assemblies, the best choice of material for the first component **12** may not be metallurgically compatible with the best choice of material for the second component **14**. This incompatibility makes it very difficult if not impossible to join the components via welding. Any such weld produced may be less than desirable due to cracking etc. Strength requirements may preclude the use of braze, and debris concerns may prevent the use of conventionally mechanically joined assemblies (e.g. bolting). Thus, in some instances it has not been possible to form a metallurgically ideal assembly. This method overcomes this problem by permitting the creation of an assembly that meets the varying metallurgical, cost, and reliability needs etc of the assembly without any worry associated with welding, brazing, and conventional mechanical joining. Another advantage includes the ability to replace an individual component rather than the entire assembly to extend service life. In order to facilitate disassembly of the assembly and replacement of individual components, or for any other reason deemed important, it may be desirable to form the locking component such that there is no metallurgical bond between the locking component and a surface of the component of the assembly onto which the first layer of the locking component is deposited. For example, in the exemplary embodiment of FIG. **1**, the locking component **16** is formed on both a surface **24** of the first component **12** and a surface **26** of the second component **14**. If, on the other hand, a metallurgical bond is to be formed at an interface **28** between the surface **24** of the first component **12** and the locking component **16** and/or an interface **30** between the surface **26** of the second component **14** and the locking component **16**, then the surfaces **24**, **26** may be appropriately cleaned to permit the metallurgical bond to form. Appropriate cleaning is known to those in the art to be similar to the cleaning necessary in welding operations to permit the formation of a proper weld. In contrast, if no metallurgical bond is to be formed at the interface **28** or the interface **30**, then the cleaning step may be eliminated. Alternately, if no bond is to be formed, an oxide layer may be allowed to form on either or both of the surface **24** of the first component **12** and the surface **26** of the second component **14**. The oxide layer may or may not be burned off during the application of the first layer of the additive manufacturing process, but in either case it is likely to prevent the formation of a metallurgical bond between the locking component **16** and any surface used as the base for the first layer.

Gas turbine engine assemblies often experience thermal growth mismatch within the assembly. This may occur when, for example, dissimilar materials wish to respond differently to a thermal change but are forced to respond identically, such as when dissimilar materials are welded together. Using the method disclosed herein, an assembly **10** can be fabricated that reduces or eliminates this problem by strategic positioning of the components. For example, in FIG. **1** the first component **12** and the second component **14** are disposed end-to-end. This allows for each component to respond to thermal changes independently of the other. In addition a gap **32** may be built-in to the assembly **10** such that when the assembly **10** is at an operating temperature any thermal growth of the components toward each other will be accommodated by the gap **32**, thereby eliminating any stresses that may otherwise result.

FIG. **2** shows a schematic longitudinal cross-section of another exemplary embodiment of the assembly **10**. Here again the first component **12** and the second component **14** are held in place by the locking component **16**. However, in this exemplary embodiment the second component **14** is assembled onto the first component **12** and the locking component **16** is then formed. The locking component **16** interlocks only with the first component **12**, while the second component is held in place simply by the presence of the first component **12** and the locking component **16**. In this exemplary embodiment the assembly **10** may be a gas turbine engine vane where the first component **12** is an airfoil component and the second component **14** is a shroud joined to the airfoil component via the locking component **16**. In such an assembly **10** hot gases are usually present on a hot gas side **40** of the second component **14**. By locating the locking component **16** on a relatively cool side **42** of the second component **14**, the material selected to be used in the locking component **16** need not withstand the operating environment created by the hot gases. Consequently, since materials that can withstand that operating environment are often more expensive and more difficult to fabricate, this configuration saves on material costs and assembly costs.

In yet another exemplary embodiment that is a variation of FIG. **2**, FIG. **3** depicts a longitudinal cross-section of the assembly **10**, having a third component **44**. The third component **44** may be modular in construction, for example a split ring, and the third component **44** and the first component have the first interlocking feature **20** and the second interlocking feature **22** respectively and hence form the interlocking relationship **18**. The locking component **16** holds the third component **44** in place, and hence the locking component **16** effectively ensures the interlocking relationship **18** of the first component **12** and the third component **44** is maintained. As shown an interface **46** between the locking component **16** and the third component **44** is angled with respect to a longitudinal axis **48** of the assembly **10**. This configuration is advantageous if there is no metallurgical bond at the interface **46**, since the geometry of the assembly **10** will hold the locking component **16** in place. Alternately, should there be no angle desired between the interface **46** and the longitudinal axis **48** of the assembly **10**, a metallurgical bond may be allowed to form at the interface such that the locking component **16** is metallurgically bonded to the third component **44**. This metallurgical bond would hold the locking component **16** in place and thereby hold the interlocking relationship **18** in place. Further, in this configuration the locking component **16** is isolated from the first component **12** and the second component **14**, which may prevent compatibility problems were they not isolated from each other.

From the foregoing it is evident that the present inventor has created a unique way of fabricating assemblies and that this unique method can produce assemblies that solve known problems in the art. However, the solution uses technologies that can be readily applied, and so the implementation can be fast and inexpensive. Consequently, this represents an improvement in the art.

While various embodiments of the present invention have been shown and described herein, it will be obvious that such embodiments are provided by way of example only. Numerous variations, changes and substitutions may be made without departing from the invention herein. Accordingly, it is intended that the invention be limited only by the spirit and scope of the appended claims.

The invention claimed is:

1. A gas turbine engine assembly, comprising:

a first component and a second component of the gas turbine engine assembly; and

a locking component formed via a layer-by-layer additive manufacturing process, wherein each layer of the locking component is fully formed when deposited, and wherein the locking component secures the first component, the second component, and the locking component together in an interlocking relationship.

2. The assembly of claim **1**, wherein the layer-by-layer additive manufacturing process comprises laser engineered net shaping.

3. The assembly of claim **1**, wherein the locking component interlocks with the first component, and wherein the second component is held in place relative to the first component at least by the locking component.

4. The assembly of claim **3**, wherein the locking component further interlocks with the second component.

5. The assembly of claim **1**, wherein the first component comprises an airfoil component, wherein the second component comprises a shroud component assembled onto the airfoil component, and wherein the locking component interlocks with the airfoil component and holds the shroud component in place.

6. The assembly of claim **1**, wherein the first and the second component are held together by an interlocking arrangement maintained by the locking component.

7. The assembly of claim **6**, wherein the assembly further comprises a third component, wherein the interlocking arrangement is positioned between the first component and the third component, and wherein the locking component is arranged so as to prevent the third component from disengaging from the first component.

8. The assembly of claim **7**, wherein the first component comprises an airfoil component, wherein the second component comprises a shroud component assembled onto the airfoil component, wherein the third component comprises a modular construction that interlocks with the airfoil component, and wherein the locking component holds the modular construction in place.

9. The assembly of claim **1**, wherein the assembly comprises no metallurgical bond to the locking component.

10. The assembly of claim **1**, wherein the first component and the second component are assembled in a manner that permits differential thermal expansion.

11. A gas turbine engine assembly comprising:

a first component and a second component; and

a locking component formed via a layer-by-layer additive manufacturing process and comprising a laminar grain structure, wherein each layer of the locking component is fully formed when deposited, and wherein the locking component secures the first component, the second component, and the locking component together in a mechanically interlocking relationship,

wherein the first and the second component are held together by an interlocking arrangement maintained by the locking component, wherein the interlocking arrangement is between the first component and a third component;

wherein the locking component prevents the third component from disengaging from the first component; and wherein:

the first component comprises an airfoil component;

the second component comprises a shroud component assembled onto the airfoil component; and

the third component comprises a modular construction that mechanically interlocks with the airfoil component, and wherein the locking component holds the modular construction in place.

12. The gas turbine engine assembly of claim **11**, wherein the locking component and the third component comprise abutting and corresponding beveled surfaces.

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