ABSTRACT

A method of joining a component, such as a cutting element, to another component or body of an earth-boring tool, according to embodiments of the present disclosure, includes disposing a third-body structure, which may comprise a braze material, between a surface of the component and a surface of the another component of the earth-boring tool. The component to be joined is then rotated relative to the surface of the another component to generate frictional heat in the third-body structure and to at least plasticize material of the third-body structure. After the rotation, the plasticized material of the third-body structure is compressed between the surfaces and then allowed to solidify, which bonds the component to the another component without deforming either the component or the another component.
FIG. 4A
METHODS FOR JOINING CUTTING ELEMENTS OR OTHER COMPONENTS TO EARTH-BORING TOOLS AND RELATED METHODS

FIELD

[0001] Embodiments of the present disclosure generally relate to methods of manufacturing earth-boring drill bits and other tools that may be used to drill subterranean formations. More particularly, embodiments of the present disclosure relate to methods for attaching components of the earth-boring drill bit or other tool.

BACKGROUND

[0002] Earth-boring drill bits, such as rotary drill bits (e.g., a “drag” bit) and roller cone bits, are commonly used for drilling wellbores in earth formations. These drill bits include cutting elements secured to a face of the body of the drill bit, i.e., to the bit body. The cutting elements generally include a cutting surface formed of hard material, such as diamond material, which may be supported by a substrate. In forming a drill bit to include cutting elements, the cutting elements are often formed separately and then secured to the bit body of the drill bit with the cutting surface directed so that it will contact earthen material as the drill bit is being used to form a borehole in the earth.

[0003] In addition to cutting elements, other components of drill bits may also be secured together, or to the bit body, to construct a drill bit. For example, conventionally, in a rotary drill bit configured as a drag bit, the bit body is secured to a shank that has a threaded portion for attaching the drill bit to a drill string. The bit body and the shank may be secured together, e.g., by welding. Also, conventionally, when manufacturing a roller cone earth-boring drill bit, for example, the bit body is formed in a plurality of portions that are then welded together along a seam to form the body.

[0004] Processes used to join components of a drill bit to one another, or to join one component to the bit body, have often risked damage to the materials being joined. For example, conventionally, in manufacturing a drill bit having cutting elements, already formed cutting elements may be secured to the bit body of a drill bit by, for example, welding (e.g., oxyacetylene brazing). In conventional welding, a channel or weld groove is formed along an interface of at least two surfaces to be welded. A metallic material or “filler material” such as, for example, an iron-based alloy, a nickel-based alloy, or a cobalt-based alloy is deposited within the weld groove and melted to weld the at least two surfaces. The filler material may be deposited using, for example, an arc welding process such as submerged arc welding (SAW), gas metal arc welding (GMAW), flux-cored arc welding (FCAW), and other arc welding techniques known in the art. The conventional welding process, however, may have several disadvantages. For example, multiple depositions of the filler material may be required to achieve a desired thickness of filler material in the weld groove, thus making the process time consuming. Similarly, the materials to be welded must be prepared in advance, often requiring pre-heating, which is also time consuming. Moreover, the structure of the components to be joined may be altered, in forming the weld groove in which to apply the filler material, which not only deforms the components, but also requires a timely and potentially expensive preparation.

Additionally, as the melted filler material solidifies, discontinuities may form in the filler material that may result in cracks or differing porosity throughout the material that may weaken the weld and ultimately result in failure along the welded seam. Furthermore, the temperatures used with welding are high and a flame is often applied, which temperatures and flame can cause thermal damage in the diamond table at the cutting surface of the cutting element being joined to a drill bit, or thermal damage in material of such other component being joined to a body by welding. Moreover, the weld processes themselves may release dangerous or toxic fumes and/or may cause the melted filler material to spatter during deposition. Still further, welding is usually performed by a welder who must have appropriate know-how to complete the welding successfully. Therefore, operator skill level is also often a factor in the success of the welding process.

[0005] Another process that may be used to join components of a drill bit is friction stir welding. In friction stir welding, a pin is rotated (i.e., “stirred”) against an interface, and moved along the interface, between the two components. The pin generates frictional heat along the interface, causing the materials of the components to plasticize. The plasticized materials intermix along the interface, forming a solid phase bond of weld along the interface. This friction stir welding process, however, provides a bond along essentially only an outer periphery of the two components and physically deforms, at least in part, the components being joined.

[0006] In view of the above, joining of cutting elements to a bit body, or joining of other components, in manufacturing drill bits, continues to present challenges.

BRIEF SUMMARY

[0007] In some embodiments, the present disclosure includes a method of joining a cutting element to an earth-boring tool. The method comprises disposing a cutting element in a pocket defined in a body of the earth-boring tool with a third-body structure between a surface of the cutting element and a surface of the body within the pocket. Movement, relative between the third-body structure and at least one of the surface of the cutting element and the surface of the body within the pocket, is provided to generate frictional heat within and at least plasticize material of the third-body structure. After providing the relative movement, at least a portion of the material of the third-body structure is compressed and at least plastically deformed between the surface of the cutting element and the surface of the body within the pocket.

[0008] The disclosure also includes embodiments of a method of joining a component of an earth-boring tool to a surface of another component of the earth-boring tool. The method comprises providing a third-body structure having a shape substantially symmetrical about a longitudinal axis of the third-body structure. The third-body structure is abutted against the surface of the another component of the earth-boring tool. Rotational movement, relative between the third-body structure and at least one of the component and the another component of the earth-boring tool, is provided such that material of the third-body structure is heated by friction and at least plasticized. After providing the relative rotational movement, at least a portion of the material of the
third-body structure is compressed and at least plastically 
deformed between the component and the another compo-
ment of the earth-boring tool.

[0009] In some embodiments of the present disclosure, a 
method of forming an earth-boring tool comprises dispos-
ing a third-body structure between a surface of a compo-
nent and a surface of a body of the earth-boring tool to which 
the component is to be joined. The component is rotated
about a longitudinal axis of the component, and friction is gen-
era ted between the third-body structure and at least one of 
the surface of the component and the surface of the body of 
the earth-boring tool. The friction results in heating and at least 
plasticizing of the third-body structure. After the rotating,
force is applied on the component toward the surface of the 
body of the earth-boring tool.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] While the specification concludes with claims par-
cularly pointing out and distinctly claiming what are 
regarded as embodiments of the disclosure, various features 
and advantages of this disclosure may be more readily 
ascertained from the following description of example 
embodiments provided with reference to the accompanying 
drawings, in which:

[0011] FIG. 1 is a side, partial cross-sectional elevation 
view of an earth-boring rotary drill bit having a component 
joined by third-body friction braze, according to an embodi-
ment of the present disclosure.

[0012] FIGS. 2 through 4A illustrate stages in a method of 
joining a cutting element to a pocket defined in the rotary 
drill bit of FIG. 1, according to an embodiment of the present 
disclosure, wherein:

[0013] FIG. 2 is a side, partial cross-sectional, exploded,
elevation view of a stage in the method;

[0014] FIG. 3 is a side, partial cross-sectional, elevation 
view of another stage following that of FIG. 2;

[0015] FIG. 4 is a side, partial cross-sectional, elevation 
view of another stage following that of FIG. 3; and

[0016] FIG. 4A is a schematic illustration of an industrial 
robot with a rotatable robotic arm that may be used in the 
stage of FIG. 4.

[0017] FIG. 5A is a plan view of a third-body structure 
with a continuous top surface and continuous bottom sur-
face, according to an embodiment of the present disclosure.

[0018] FIG. 5B is an elevation view of the third-body 
structure of FIG. 5A.

[0019] FIG. 6A is a plan view of a third-body structure 
with a discontinuous top surface and discontinuous bottom 
surface, according to an embodiment of the present disclo-
sure.

[0020] FIG. 6B is an elevation view of the third-body 
structure of FIG. 6A.

[0021] FIG. 7A is a plan view of a third-body structure 
with a nonplanar surface, according to an embodiment of 
the present disclosure.

[0022] FIG. 7B is an elevation view of the third-body 
structure of FIG. 7A.

DETAILED DESCRIPTION

[0023] The illustrations presented herein are not actual 
views of any particular component, earth-boring tool, mate-
rial, or method step, but are merely idealized representations 
that are employed to describe embodiments of the present 
disclosure.

[0024] Methods disclosed herein enable joining of a cut-
ing element to a bit body of an earth-boring tool (e.g., a drill 
bit), or joining of other components of the tool, in a manner 
that may not deform the material of the components being 
joined, does not require pre-heating or other time-consum-
ing and costly preparations, may be automated to avoid varia-
tion due to operator skill level, does not involve extreme 
temperatures or flames, and provides a bond that 
may be along essentially an entire interface area between 
the joined materials.

[0025] As used herein, the term “interface” means and 
includes a boundary region between a portion of one com-
ponent and an adjacent portion of another component or 
body.

[0026] As used herein, the term “joined interface” means 
and includes an interface along at least a portion of which 
two components (or one component and a body) are joined 
to one another.

[0027] As used herein, the term “joined” means and 
includes both “directly joined” and “indirectly joined.”

[0028] As used herein, the term “directly joined” means 
and includes at least a portion of at least one surface of one 
component being affixed directly to and in direct physical 
contact with at least a portion of at least one surface of 
another component or body. Therefore, material of the two 
components (or the one component and the body) are in 
direct physical contact where affixed together.

[0029] As used herein, the term “indirectly joined” means 
and includes at least a portion of at least one surface of one 
component being affixed indirectly to at least a portion of 
at least one surface of another component or body, without 
material of the two components (or the one component and 
the body) being in direct physical contact where affixed. 
Therefore, material of a third-body structure may be dis-
posed between the portions of the two components (or the 
one component and the body) that are indirectly joined.

[0030] As used herein, the term “plasticize” means and 
includes converting a material from a solid phase to a 
substantially or completely homogenous, semi-liquid phase. 
For example, but without limitation, to “plasticize” a ma-
terial may include raising the temperature of the material to a 
level of at least about eighty percent (80%) of a melting 
temperature or liquidus temperature of the material (e.g., to 
a temperature within at least about ninety percent (90%) of 
the melting temperature or liquidus temperature of the 
material) but still below the melting temperature or liquidus 
temperature, for the other conditions (e.g., pressure) to 
which the material is subjected.

[0031] As used herein, the term “plasticized,” when used 
to describe a state of a material, means and includes a state 
of the material in which the material is in a semi-liquid 
phase, but not in a liquid phase (i.e., not in a melted state).

[0032] As used herein, the term “at least plasticize” means 
and includes converting a material a solid phase to a 
substantially or completely homogenous, semi-liquid phase, 
and/or from the solid phase to a substantially or completely 
homogenous liquid phase.

[0033] As used herein, the term “at least plasticize,” 
when used to describe a state of a material, means and 
includes a state of the material in which the material is in 
either a semi-liquid phase or in a liquid phase.
[0034] As used herein, the term to “plastically deform” means and includes to alter the shape of a structure while material of the structure is plasticized.

[0035] As used herein, the term to “at least plasticly deform” means and includes to alter the shape of a structure while material of the structure is at least plasticized.

[0036] With reference to FIG. 1, an earth-boring tool (which may also be referred to herein as a “downhole tool”) that may be formed using methods of the present embodiments is illustrated. The downhole tool may be an earth-boring, rotary drill bit 10, as illustrated. The rotary drill bit 10 may be configured as a fixed-cutter bit (which may also be known in the art as a “drag bit”). The rotary drill bit 10 may be a particle-matrix composite material type bit and includes a bit body 12. The bit body 12 comprises a plurality of components that may be joined together during fabrication of the bit body 12.

[0037] For example, in some embodiments, the bit body 12 may include a crown 14 joined to a steel blank 16, with the steel blank 16 at least partially embedded in the crown 14. The crown 14 may include a particle-matrix composite material 15, such as, for example, particles of tungsten carbide embedded in a copper alloy matrix material. In other embodiments (not illustrated), the bit body 12 may be formed by machining a cast or forged steel billet, as known in the art, such that the steel blank 16 and crown 14 portions of the bit body 12, illustrated in FIG. 1, may be integrally formed from steel, rather than from two joined components. However, in those embodiments, such as the embodiment of FIG. 1, in which the bit body 12 is formed by joining the steel blank 16 and the crown 14, the steel blank 16 and the crown 14 may be joined along an interface 17.

[0038] The bit body 12 may be secured to a shank 20 (e.g., a steel shank) that may have a threaded connection portion 28 (e.g., an American Petroleum Institute (API) threaded connection portion) for attaching the rotary drill bit 10 to a drill string (not shown). The bit body 12 may be secured to the shank 20 by way of a threaded connection 22 between the shank 20 and the steel blank 16 of the bit body 12. The bit body 12 may also be secured to the shank 20 along an interface 24. In embodiments, such as that of FIG. 1, in which the bit body 12 comprises the joined crown 14 and steel blank 16, the interface 24 may be between the shank 20 and the steel blank 16 of the bit body.

[0039] The bit body 12 may further include blades 30 (which may also be known in the art as “wings”) that are separated by junk slots 32. Internal fluid passageways (not shown) extend between a face 18 of the bit body 12 and a longitudinal bore 40 that extends through the shank 20 and partially through the bit body 12. Nozzle assemblies 42 also may be provided at the face 18 of the bit body 12 and may communicate with the internal fluid passageways.

[0040] A plurality of cutting elements 34 are attached to the face 18 of the bit body 12, e.g., at an external surface 11 of the rotary drill bit 10. Generally, the cutting elements 34 of a fixed-cutter type drill bit, such as the rotary drill bit 10 of FIG. 1, have either a disk shape or a substantially cylindrical shape, as with the cutting element 34 illustrated in FIG. 2. Each cutting element 34 may have a cutting surface 35 exposed to the exterior environment. The cutting surface 35 comprises a hard, super-abrasive material, such as polycrystalline diamond. Such cutting elements 34 are often referred to as “polycrystalline diamond compact cutting elements” or “PDC cutting elements.”

[0041] The cutting elements 34 may be provided along the blades 30 within pockets 36 formed in the face 18 of the bit body 12 or, in other words, defined in an exterior surface 11 of the rotary drill bit 10. The cutting elements 34 may be supported from behind by buttresses 38 that may be integrally formed with the crown 14 of the bit body 12.

[0042] The cutting elements 34 may be fabricated separately from the bit body 12 and then secured within the pockets 36 defined in the exterior surface 11 of the bit body 12 of the rotary drill bit 10. The cutting elements 34 may be secured within the pockets 36 of the bit body 12 by a solid-state joining process, such as a third-body friction brazing (“TFB/” process) according to embodiments herein.

[0043] With reference to FIGS. 2 through 4, illustrated are stages in a TFB process for joining a cutting element, such as the cutting element 34 of FIG. 1 to a surface of a pocket defined in a bit body, such as the pocket 36 defined in the face 18 of the bit body 12 of FIG. 1. FIG. 2 is a cross-sectional, exploded view of the cutting element 34 to be joined to a floor 37 of the pocket 36. A third-body structure 50 is disposed between the floor 37 of the pocket 36 and a surface (e.g., a bottom surface 33) of the cutting element 34.

[0044] The third body-structure 50 may comprise a braze material, such as a metal braze material or a metal alloy braze material, e.g., silver (Ag), copper (Cu), zinc (Zn), tin (Sn), nickel (Ni), or an alloy of more than one thereof (e.g., a silver-based (Ag-based) braze material, e.g., Ag₅Cu₂Zn₅Sn₅ (commonly known in the industry as a “BAg-7 alloy” or “BAg-7 braze filler material”), Ag₅Cu₂Zn₅Ni₂ (commonly known in the industry as a “BAg-24 alloy” or “BAg-24 braze filler material”), a copper-based (Cu-based) braze material, a zinc-based (Zn-based) braze material, a nickel-based (Ni-based) braze material). Other braze materials may be used, such as a material that at least plasticizes at a temperature below (e.g., about 90% below, about 80% below) a temperature at which material of either component is to be joined plasticizes or otherwise at least plastically deforms.

[0045] With reference to FIG. 3, illustrated is an assembly of the cutting element 34 adjacent the floor 37 of the pocket 36 with the third-body structure 50 disposed between. As illustrated, a bottom surface 52 of the third-body structure 50 may abut the floor 37 of the pocket 36, and the bottom surface 33 of the cutting element 34 may abut a top surface 54 of the third-body structure 50. Thus, the third-body structure 50 is “sandwiched” between a surface (e.g., the floor 37 of the pocket 36 defined in the bit body 12 (FIG. 1) and the bottom surface 33 of the cutting element 34. Therefore, the third-body structure 50 contacts a surface of the bit body 12 (FIG. 1) (i.e., the floor 37 of the pocket 36 in the bit body 12 (FIG. 1)) along interface 60, and the third-body structure 50 contacts a surface of the cutting element 34 along interface 62. In embodiments in which the cutting element 34 comprises a “table” 56 of polycrystalline material (e.g., polycrystalline diamond material) supported on a substrate 58 (e.g., a ceramic-metal composite material, such as, for example, cobalt-cemented tungsten carbide), the bottom surface 33 of the cutting element 34, contacts the top surface 54 of the third-body structure 50.

[0046] In some embodiments, the third-body structure 50 may be a separately-formed structure that is then disposed between the cutting element 34 and the floor 37 of the pocket 36 in the bit body 12 (FIG. 1). Thus, when the third-body
structure 50 is disposed in the pocket 36, the third-body structure 50 is not yet affixed to either the cutting element 34 or the bit body 12 (FIG. 1).

[0047] In other embodiments, the third-body structure 50 may be formed directly on, or otherwise affixed to, one of the cutting element 34 and the floor 37 of the pocket 36 before the cutting element 34 and third-body structure 50 are disposed over the floor 37 in the pocket 36. For example, the third-body structure 50 may be a film or other structure formed directly on the bottom surface 33 of the cutting element 34. The cutting element 34 with a film of the third-body structure 50 may then be inserted into the pocket 36 with the film of the third-body structure 50 abutting the floor 37 of the pocket 36. As another example, the third-body structure 50 may be a film, or other structure, formed directly on the floor 37 of the pocket 36 or directly on the floor 37 and sidewalls 39 of the pocket 36. The cutting element 34 may then be disposed in the pocket 36 with the third-body structure 50 nonetheless disposed between at least one surface of the cutting element 34 (e.g., the bottom surface 33 and, in some embodiments, also sidewalls 39 (FIG. 2) and at least one surface of the bit body 12 (FIG. 1) (e.g., the floor 37 of the pocket 36 defined in the bit body 12 (FIG. 1)).

[0048] With reference to FIG. 4, after disposing the third-body structure 50 between at least one surface (e.g., the floor 37 of the pocket 36) of the bit body 12 (FIG. 1) and at least one surface of the cutting element 34, the cutting element 34 may be rotated (e.g., in the direction indicated by arrow R) while the bottom surface 33 of the cutting element 34 abuts the top surface 54 of the third-body structure 50 and the third-body structure 50 abuts the floor 37 of the pocket 36 in the bit body 12 (FIG. 1). The rotation of the cutting element 34, which rotational movement may be accompanied by a force exerted against the cutting element 34 (e.g., an initial axial load), generates friction along at least one interface (e.g., one or both of the interfaces 60, 62 in the sandwiched assembly of FIG. 4).

[0049] In embodiments in which the third-body structure 50 is disposed against the floor 37 of the pocket 36 and the bottom surface 33 of the cutting element 34 without yet being affixed to either abutting surface, rotation of force against the cutting element 34 generates friction along the interface 62 between the cutting element 34 and the third-body structure 50. In some embodiments, the force of friction along the interface 62 may be such as to also cause the third-body structure 50 to rotate in the pocket 36 in the direction of arrow R. Therefore, friction will also be generated along the interface 60 between the third-body structure 50 and the floor 37 of the pocket 36. In some embodiments, the force of friction along the interface 62 between the cutting element 34 and the third-body structure 50 may be a static friction force, such that the third-body structure 50 will rotate at the same rate as the cutting element 34 is rotated. In other embodiments, there may be slippage along one or both interfaces 60, 62. Regardless, friction will be generated along at least one of the interfaces 60, 62 shared by a surface of the third-body structure 50.

[0050] The generated friction increases the temperature of the third-body structure 50 along one or both of the interfaces 60, 62 at which the friction is generated. The increased temperature causes the braze material of the third-body structure 50 to soften or at least plasticize at least along the interface or interfaces 60, 62 at which the friction is generated.

[0051] Though friction may be primarily generated, at least initially, along only one of the interfaces 60, 62, depending on which abutting surfaces exhibits the higher static friction coefficient, the third-body structure 50 may be structured to be thin such that the braze material of the third-body structure 50 will at least plasticize essentially throughout the third-body structure 50 from the friction-generating heat along even one of the interfaces 60, 62. For example, the third-body structure 50 may be disc-shaped and define a longitudinal thickness that is significantly less than a thickness of the cutting element 34. For example, the third-body structure 50 may define a thickness of less than about 2.5 mm (0.1 inches) (e.g., less than about 1 mm (0.04 inches), e.g., less than about 0.5 mm (0.02 inches)). However, at least in some embodiments, the third-body structure 50 may define a thickness thick enough that the third-body structure 50 structurally maintains its shape before the material of the third-body structure 50 is at least plasticized. For example, the third-body structure 50 may define a thickness of at least about 0.025 mm (0.001 inches) (e.g., at least about 0.127 mm (0.005 inches)) but less than about 2.5 mm (0.1 inches) (e.g., a longitudinal thickness of between about 0.025 mm (0.001 inches) and about 2.5 mm (0.1 inches) (e.g., between about 0.127 mm (0.005 inches) and about 2.5 mm (0.1 inches)).

[0052] In other embodiments, in which the third-body structure 50 is a film or coating on either the bottom surface 33 of the cutting element 34 or the floor 37 (and/or sidewalls 39) of the pocket 36, the third-body structure 50 may define a thinner thickness, such as a longitudinal thickness of less than about 0.025 mm (0.001 inches).

[0053] In some embodiments, the braze material of the third-body structure 50 may plasticize without reaching the melting point or liquidus temperature of the braze material. For example, the braze material of the third-body structure 50 may plasticize at a temperature that is about eighty percent (80%) or about ninety percent (90%) of its melting temperature or liquidus temperature. Thus, the speed of the rotation (e.g., rotations per minute (rpm)) of the cutting element 34 may be tailored to produce friction that does not raise the temperature along either of interfaces 60 and 62 to above about ninety percent (90%) (e.g., above about eighty percent (80%) of the melting temperature or liquidus temperature of the braze material of the third-body structure 50. In other embodiments, the braze material of the third-body structure 50 may partially or completely melt.

[0054] The increase in temperature, due to the friction, may be below temperatures at which the material of the bit body 12 (FIG. 1) at the floor 37 of the pocket 36 would substantially soften, plasticize, or melt (i.e., below temperatures at which the material of the bit body 12 (FIG. 1) and the floor within the pocket 36 would substantially at least plasticize). Likewise, the temperatures achieved by the friction may be below temperatures at which the material of the cutting element 34 along the bottom surface 33 (e.g., material of the substrate 58) would substantially soften, plasticize, or melt (i.e., below temperatures at which the material of the cutting element 34 along the bottom surface 33 (e.g., material of the substrate 58) would substantially at least plasticize). Therefore, as the braze material of the third-body structure 50 softens or plasticizes, the material of
the abutting components (e.g., the material of the cutting element 34 and the material of the bit body 12 (FIG. 1) defining the pocket 36) may retain its structure.

[0055] The cutting element may be rotated using, for example and without limitation, a rotatable robotic arm 104 of the industrial robot 100 of FIG. 4A, or another robotic tool, such as a mill, releasably secured to hold, e.g., at a distal end 106 of the rotatable robotic arm 104, the cutting element along, e.g., a periphery of the cutting surface 35 or along the cutting face 35 itself. The rotatable robotic arm 104 may be configured to rotate, e.g., in the direction indicated by arrow R and about a longitudinal axis X of the rotatable robotic arm 104, an object, such as the cutting element 34 (FIG. 4) releasably secured to the distal end 106. The rotation may be carried out for a predetermined time, with many rotations, to achieve the plasticizing (or at least plasticizing) of the braze material of the third-body structure 50, but not plasticizing or melting of the cutting element 34 or the material of the bit body 12 (FIG. 1) at the floor 37 of the pocket 36. The rotatable robotic arm 104, mill, or other robotic tool, used to rotate the cutting element 34 (or other component being joined to the earth-boring tool) may also apply a force (e.g., an axial load) against the cutting element 34 (or other component being joined) during the rotation to promote the generation of friction between the cutting element 34 and the third-body structure 50, or between the third-body structure 50 and the floor 37 (or other surface) within the pocket 36, or both. The rotation may then be halted and an axial load applied to the cutting element 34. For example, the rotatable robotic arm 104, mill, or other robotic tool may apply a mechanical force against the cutting surface 35 of the cutting element 34 in the direction of longitudinal axis X. The axial load applied after the rotation is halted may be a maintained axial load from that applied during the rotation, or may be an altered axial load, such as an increased load. In other embodiments, an axial load applied after the rotation is halted may be less than an axial load applied during the rotation. The load may be varied during application, e.g., decreased, increased, or varied between decreasing and increasing.

[0056] Applying the post-rotational-motion force urges the cutting element 34 against the at least plasticized braze material of the third-body structure 50 and toward the floor 37 of the pocket 36, compressing and at least plastically deforming (e.g., thinning) the at least plasticized braze material. Therefore, the longitudinal thicknesses of the third-body structure 50, discussed above, may be lessened to a minimal thickness as the force (e.g., the axial load) against the cutting element 34 compresses the plasticized material. In some embodiments, the plasticized braze material of the third-body structure 50 may be squeezed to substantially or completely fill otherwise empty space between the bottom surface 33 of the cutting element 34 and the floor 37 of the pocket 36. In some such embodiments, the at least plasticized braze material of the third-body structure 50 may also be squeezed to partially or completely fill otherwise empty space between the sidewalls 59 of the cutting element 34 and the sidewalls 39 of the pocket 36.

[0057] Because the post-rotational-motion axial load may be applied after the rotation has ended, friction, and therefore heat due to friction, may no longer be generated during the later force application stage. Therefore, after at least some compression and deformation and as the axial load is being applied, the at least plasticized braze material of the third-body 50 may begin to solidify and form a strong bond with both the material of the cutting element 34 (e.g., the material of the substrate 58) and the material of the bit body 12 (FIG. 1) in which the pocket 36 is defined.

[0058] The axial load may be steadily applied for another predetermined period of time (e.g., longer than thirty seconds, longer than one minute, longer than three minutes) until such time as the at least plasticized braze material is sufficiently solidified such that cutting element 34 will not slip away from the floor 37 of the pocket 36 when the axial load is removed.

[0059] Though, in some embodiments, the axial load may be held steady during the solidifying time period, in other embodiments, the axial load may be tapered off from an initial level to a minimal level before the axial load is removed.

[0060] After application of the axial load, the axial load may be removed (e.g., the rotatable robotic arm 104, mill, or other robotic tool may release its connection or hold on the cutting element 34), leaving the cutting element 34 bonded to the bit body 12 (FIG. 1) in the pocket 36 without deformation of the material of either the cutting element 34 or the bit body 12. Moreover, because the heat to at least plasticize the braze material of the third-body structure 50 is provided by the friction generated along interfaces 60, 62 that are at the bottom surface 33 of the cutting element 34 or at the sidewalls 59 of the cutting element 34, the heat is largely distant from the cutting surface 35 and the table 56 of the polycrystalline material. Therefore, the heat used in the TBFB process may not significantly risk thermal damage to the table 56 or the cutting surface 35, unlike conventional welding processes that subject heat nearer to these portions of the cutting element 34. Furthermore, because the rotation of the cutting element 34 may be achieved using, for example, a rotatable robotic arm (e.g., the rotatable robotic arm 104 of FIG. 4A), mill, or other robotic tool, the TBFB process may be automated, and the outcomes of the TBFB process may not depend largely on operator skill, unlike conventional welding processes. Still further, because each the TBFB process focuses the friction generation and heat directly on one cutting element 34 being joined, the process may be used to attach one cutting element 34 without impacting or damaging a bond already formed between a neighboring cutting element 34 and its respective pocket 36.

[0061] Accordingly, disclosed is a method of joining a cutting element to an earth-boring tool. The method comprises disposing a cutting element in a pocket defined in a body of the earth-boring tool with a third-body structure between a surface of the cutting element and a surface of the body within the pocket. Movement, relative between the third-body structure and at least one of the surface of the cutting element and the surface of the body within the pocket, is provided to generate frictional heat within and at least plasticize material of the third-body structure without melting the material of the third-body structure. After providing the relative movement, at least a portion of the material of the third-body structure is compressed and at least plastically deformed between the surface of the cutting element and the surface of the body within the pocket.

[0062] With reference to FIGS. 5A through 7B, illustrated are various configurations for a third-body structure 50, 150, 250 according to embodiments of the present disclosure. Because the third-body friction braze (TBFB) process involves rotating one component to be joined (e.g., the
cutting element 34) about a longitudinal axis X and against a third-body structure 50, 150, 250, in some embodiments, the third-body structure 50, 150, 250 may be configured to be substantially symmetrical about the longitudinal axis X and to correspond to at least a portion of each of the surfaces to be joined.

For example, with reference to FIGS. 5A and 5B, in an embodiment in which a circular bottom surface 33 (FIG. 4) of the cutting element 34 (FIG. 4) is to be joined to a circular floor 37 of the pocket 36 (FIG. 4), the third-body structure 50 may define a corresponding circular shape at, for example, the top surface 54 as well as at the bottom surface 52. (Though FIG. 5A illustrates the top surface 54, a view of the bottom surface 52 would be identical.) According to the embodiment of FIGS. 5A and 5B, the top surface 54 and the bottom surface 52 of the third-body structure 50 may be continuous across a diameter of the third-body structure 50. Thus, the TBFB process may provide the at least plasticized material of the third-body structure 50 along substantially all of the interface 60 (FIG. 4) between the third-body structure 50 and the floor 37 of the pocket 36 and along substantially all of the interface 62 (FIG. 4) between the third-body structure 50 and the cutting element 34. Therefore, the cutting element 34 (FIG. 4) may be joined to the bit body 12 (FIG. 1) along substantially all of the surface of the floor 37 of the pocket 36. With more surface area in the joined interface, as compared to, for example, a friction stir welding bond along only a periphery of a joined interface, the TBFB may provide improved mechanical properties along the bond compared to a peripheral bond provided by conventional welding or braze along a weld groove.

With reference to FIGS. 6A and 6B, in other embodiments, a third-body structure 150 may not providing braze material across the whole of the width (e.g., diameter) of the third-body structure 150. For example, concentric rings 151, 153 of the braze material may be arranged to form a third-body structure 150 with a "target-shaped" top surface 154. Thus, the top surface 154 may be discontinuous. (Though FIG. 6A illustrates the top surface 154, a view of the bottom surface 152 would be identical.) Such third-body structure 150 may nonetheless be disposed between two components to be joined, or one component and a body surface to be joined, such as between the cutting element 34 (FIG. 4) and the floor 37 of the pocket 36. The rotation along the longitudinal axis X may at least plasticize the braze material of each of the rings 151, 153, and the at least plasticized braze material may nonetheless be squeezed to fill all, or part of, the space between the bottom surface 33 (FIG. 4) of the cutting element 4 and the floor 37. In some such embodiments, the at least plasticized braze material may further be squeezed to fill all or a part of space between the sidewalls 59 of the cutting element 34 and the sidewalls 39 of the pocket 36. Thus, the third-body structure 150 of FIGS. 6A and 6B may provide for a strong bond between the cutting element 34 and the bit body 12 (FIG. 1) at the floor 37 of the pocket 36, which bond may be cover more area along the joined interface than would be achieved with conventional welding or friction stir welding along only a periphery of the joined interface.

The third-body structures 50, 150 of FIGS. 5A through 6B define substantially planar top surfaces 54, 154, respectively, and so are conducive for use in bonding the cutting element 34 having a substantially planar bottom surface 33 to a substantially planar floor 37 of the pocket 36. In other embodiments, however, a non-planar third-body structure, such as the third-body structure 250 of FIGS. 7A and 7B may be used to bond components (or a component and a body surface) that are nonplanar. For example, and without limitation, the third-body structure 250 of FIGS. 7A and 7B, having a top surface 254 defined by a conical inner sidewall 253 about a planar, circular inner floor 251 and having a bottom surface 252 defined by a conical outer sidewall 257 about a planar, circular outer floor 256, may be used to join a cutting element having a bottom surface configured as a truncated cone (conical frustum) to a pocket having an upper surface with a correspondingly-receptive shape. Such cutting element may nonetheless be rotated against the third-body structure 250 and about the longitudinal axis X to generate friction at one or more interfaces between the third-body structure 250 and the abutting materials. Thus, even a nonplanar third-body structure may be used in the TBFB process of the present disclosure to join together components (or a component and a body) having corresponding nonplanar surfaces.

The TBFB process of embodiments of the present disclosure may be used to join other components of an earth-boring tool (e.g., the rotary drill bit 10 of FIG. 1) in addition to, on instead of, being used to join cutting elements (e.g., the cutting elements 34 of FIG. 1) to the body of the earth-boring tool (e.g., the floor 37 and/or the sidewalls 39 of the pockets 36 of FIG. 1). For example, the TBFB process may be used to join the bit body 12 and the shank 20 of FIG. 1 along the interface 24. Notably, the interface 24 may be configured as a so-called "butt joint," with flat faces (in this instance annual flat faces) of the shank 20 and the steel blank 16 of the bit body 12 disposed in an abutting relationship. To form a joined interface along the interface 24, a ring-shaped third-body structure (not shown) may be disposed between the flat faces and the friction generated to at least plasticize the braze material of the third-body structure as the two components (i.e., the steel blank 16 and the bit body 12) are rotated, relative to one another, about a longitudinal axis of the rotary drill bit 10 and while the threaded connection 22 is engaged. In other embodiments, however, the interface 24 may be secured by a conventional welding process, a conventional braze process, a friction stir welding process, or the like, while, for example, the cutting elements 34 are secured in the pockets 36 by the TBFB process.

As another example, with returned reference to FIG. 1, in some embodiments, the interface 17 between the crown 14 and the steel blank 16 of the bit body 12 may be joined using the TBFB process described above, but with a third-body structure corresponding to at least a portion of the interface 17. For example, a downwardly pointed conically shaped third-body structure (not shown) may be disposed between adjacent surfaces of the steel blank 16 and the crown 14, e.g., in area 19. Additionally or alternatively, an upwardly pointed conically shaped third-body structure (not shown) may be disposed between adjacent surfaces of the steel blank 16 and the crown 14, e.g., in area 21. Rotation of the crown 14 and the steel blank 16 relative to one another and about the longitudinal axis of the rotary drill bit 10 may generate the friction and heat to at least plasticize the braze material of the third-body structure to join the crown 14 and the steel blank 16 along an area of the interface 17.

Thus, at least one component of an earth-boring tool (e.g., the rotary drill bit 10 of FIG. 1) may be joined to
another component or to a body of the tool using the TFBF process disclosed herein. Other components may be joined using conventional processes. For example, the bit body 12 may be joined to the shank 20 using the TFBF process while the cutting elements 34 are joined to the pockets 36 in the bit body 12 using a conventional bonding material and a conventional welding process. Alternatively, any two joined components that have aligned longitudinal axis and that are essentially symmetrical about the longitudinal axis may be joined by the TFBF process of the present disclosure.

Accordingly, also disclosed is a method of forming an earth-boring tool, the method comprising disposing a third-body structure between a surface of a component and a surface of a body of the earth-boring tool to which the component is to be joined. The component is rotated about a longitudinal axis of the component, and friction is generated between the third-body structure and at least one of the surface of the component and the surface of the body of the earth-boring tool. The friction results in heating and at least plasticizing of the third-body structure. After the rotating, force is applied on the component toward the surface of the body of the earth-boring tool.

Though FIG. 1 illustrates a rotary drill bit 10, it should be noted that the TFBF process of embodiments of the present disclosure is not limited to use with earth-boring tools configured as the rotary drill bit 10 of FIG. 1. For example, the TFBF process may also be used to form a roller cone earth-boring drill bit to secure, for example, inserts comprising a polycrystalline diamond compact insert mounted to a substrate into recesses in the cones of the drill bit. A roller cone earth-boring drill bit typically comprises at least two, and generally three, cones with the inserts protruding from the surface of each cone for engaging and crushing the rock, and these inserts may be joined to the cones using the TFBF process.

Accordingly, disclosed is a method of joining a component of an earth-boring tool to a surface of another component or body of the earth-boring tool. The method comprises providing a third-body structure having a shape substantially symmetrical about a longitudinal axis of the third-body structure. The third-body structure is abutted against the surface of the another component of the earth-boring tool. Rotational movement, relative between the third-body structure and at least one of the component and the another component of the earth-boring tool, is provided such that material of the third-body structure is heated by friction and at least plasticized. After providing the relative rotational movement, at least a portion of the material of the third-body structure is compressed and at least plastically deformed between the component and the another component of the earth-boring tool.

[0072] Additional non-limiting example embodiments of the disclosure are described below.

Embodiment 1

[0073] A method of joining a cutting element to an earth-boring tool, the method comprising: disposing a cutting element in a pocket defined in a body of the earth-boring tool with a third-body structure between a surface of the cutting element and a surface of the body within the pocket; providing relative movement between the third-body structure and at least one of the surface of the cutting element and the surface of the body within the pocket to generate frictional heat within and at least plasticize material of the third-body structure; and after providing the relative movement, compressing and at least plastically deforming at least a portion of the material of the third-body structure between the surface of the cutting element and the surface of the body within the pocket.

Embodiment 2

[0074] The method of Embodiment 1, wherein the surface of the body within the pocket comprises a floor of the pocket.

Embodiment 3

[0075] The method of any one of Embodiments 1 and 2, wherein the material of the third-body structure comprises a braze material.

Embodiment 4

[0076] The method of Embodiment 3, wherein the braze material comprises a silver-based braze material, a copper-based braze material, a zinc-based braze material, or a nickel-based braze material.

Embodiment 5

[0077] The method of any one of Embodiments 1 through 4, further comprising disposing the third-body structure in the pocket adjacent a floor of the pocket before disposing the cutting element in the pocket, the third-body structure having a disc shape.

Embodiment 6

[0078] The method of any one of Embodiments 1 through 4, further comprising forming the third-body structure on the surface of the cutting element before disposing the cutting element in the pocket.

Embodiment 7

[0079] The method of any one of Embodiments 1 through 5, further comprising forming the third-body structure on the surface of the bit body within the pocket before disposing the cutting element in the pocket.

Embodiment 8

[0080] A method of joining a component of an earth-boring tool to a surface of another component of the earth-boring tool, the method comprising: providing a third-body structure having a shape substantially symmetrical about a longitudinal axis of the third-body structure; abutting the third-body structure against the surface of the another component of the earth-boring tool; providing relative rotational movement between the third-body structure and at least one of the component and the another component of the earth-boring tool such that material of the third-body structure is heated by friction and at least plasticized; and after providing the relative rotational movement, compressing and at least plastically deforming at least a portion of the material of the third-body structure between the component and the another component of the earth-boring tool.
Embodiment 9

0081 The method of Embodiment 8, wherein providing the third-body structure comprises providing a third-body structure having a non-planar shape.

Embodiment 10

0082 The method of any one of Embodiments 8 and 9, wherein providing relative rotational movement between the third-body structure and at least one of the component and the another component comprises rotating the component and generating frictional heat along an interface between the third-body structure and at least one of the component and the another component of the earth-boring tool, and raising a temperature of the material of the third-body structure without exceeding a melting point temperature of the material of the third-body structure.

Embodiment 11

0083 The method of any one of Embodiments 8 through 10, wherein the method is carried out without melting material of the component and without melting material of the another component.

Embodiment 12

0084 The method of any one of Embodiments 8 through 11, further comprising: selecting the component to comprise a cutting element; and selecting the another component to comprise a body of the earth-boring tool.

Embodiment 13

0085 The method of any one of Embodiments 8 through 12, wherein providing relative rotational movement between the third-body structure and at least one of the component and the another component of the earth-boring tool comprises rotating the component using a rotatable robotic arm.

Embodiment 14

0086 A method of forming an earth-boring tool, the method comprising: disposing a third-body structure between a surface of a component and a surface of a body of the earth-boring tool to which the component is to be joined; rotating the component about a longitudinal axis of the component and generating friction between the third-body structure and at least one of the surface of the component and the surface of the body of the earth-boring tool, the friction resulting in heating and at least plasticizing of the third-body structure; and after the rotating, applying force on the component toward the surface of the body of the earth-boring tool.

Embodiment 15

0087 The method of Embodiment 14, wherein disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined comprises disposing the third-body structure between a bottom surface of the component and a floor within a pocket defined in the body of the earth-boring tool to which the component is to be joined.

Embodiment 16

0088 The method of any one of Embodiments 14 through 15, wherein disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined comprises disposing the third-body structure at least partially between a sidewall of the component and a sidewall of a pocket defined in the body of the earth-boring tool to which the component is to be joined.

Embodiment 17

0089 The method of any one of Embodiments 14 through 16, wherein disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined comprises disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined, the third-body structure not being affixed to the component or to the body of the earth-boring tool prior to the rotating.

Embodiment 18

0090 The method of any one of Embodiments 14 through 17, further comprising, forming the third-body structure to have a longitudinal thickness of between about 0.025 mm and about 2.5 mm prior to disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined.

Embodiment 19

0091 The method of any one of Embodiments 14 through 18, wherein disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined comprises disposing, between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined, a third-body structure having a top surface and a bottom surface continuous across a diameter of the surface of the component.

Embodiment 20

0092 The method of any one of Embodiments 14 through 18, wherein disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined comprises disposing, between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined, a third body structure having a discontinuous top surface.

0093 Although the foregoing description contains many specifics, these are not to be construed as limiting the scope of the present disclosure, but merely as providing certain embodiments. Similarly, other embodiments of the methods herein may be devised that do not depart from the scope of the present disclosure. For example, features described herein with reference to one embodiment also may be provided in others of the embodiments described herein. The scope of the invention is, therefore, indicated and limited only by the appended claims and their legal equivalents, rather than by the foregoing description. All additions,
deletions, and modifications to the embodiments, as disclosed herein, which fall within the meaning and scope of the claims, are encompassed by the present disclosure.

What is claimed is:

1. A method of joining a cutting element to an earth-boring tool, the method comprising:
   - disposing a cutting element in a pocket defined in a body of the earth-boring tool with a third-body structure between a surface of the cutting element and a surface of the body within the pocket, and
   - providing relative movement between the third-body structure and at least one of the surface of the cutting element and the surface of the body within the pocket to generate frictional heat within and at least plasticize material of the third-body structure; and
   - after providing the relative movement, compressing and at least plasticity deforming at least a portion of the material of the third-body structure between the surface of the cutting element and the surface of the body within the pocket.

2. The method of claim 1, wherein the surface of the body within the pocket comprises a floor of the pocket.

3. The method of claim 1, wherein the material of the third-body structure comprises a braze material.

4. The method of claim 3, wherein the braze material comprises a silver-based braze material, a copper-based braze material, a zinc-based braze material, or a nickel-based braze material.

5. The method of claim 1, further comprising disposing the third-body structure in the pocket adjacent a floor of the pocket before disposing the cutting element in the pocket, the third-body structure having a disc shape.

6. The method of claim 1, further comprising forming the third-body structure on the surface of the cutting element before disposing the cutting element in the pocket.

7. The method of claim 1, further comprising forming the third-body structure on the surface of the body within the pocket before disposing the cutting element in the pocket.

8. A method of joining a component of an earth-boring tool to a surface of another component of the earth-boring tool, the method comprising:
   - providing a third-body structure having a shape substantially symmetrical about a longitudinal axis of the third-body structure;
   - abutting the third-body structure against the surface of the another component of the earth-boring tool;
   - providing relative rotational movement between the third-body structure and at least one of the component and the another component of the earth-boring tool such that material of the third-body structure is heated by friction and at least plasticized; and
   - after providing the relative rotational movement, compressing and at least plasticity deforming at least a portion of the material of the third-body structure between the component and the another component of the earth-boring tool.

9. The method of claim 8, wherein providing the third-body structure comprises providing a third-body structure having a non-planar shape.

10. The method of claim 8, wherein providing relative rotational movement between the third-body structure and at least one of the component and the another component comprises rotating the component and generating frictional heat along an interface between the third-body structure and at least one of the component and the another component of the earth-boring tool, and raising a temperature of the material of the third-body structure without exceeding a melting point temperature of the material of the third-body structure.

11. The method of claim 8, wherein the method is carried out without melting the material of the component and without melting material of the another component.

12. The method of claim 8, further comprising:
   - selecting the component to comprise a cutting element; and
   - selecting the another component to comprise a body of the earth-boring tool.

13. The method of claim 8, wherein providing relative rotational movement between the third-body structure and at least one of the component and the another component of the earth-boring tool comprises rotating the component using a rotatable robotic arm.

14. A method of forming an earth-boring tool, the method comprising:
   - disposing a third-body structure between a surface of a component and a surface of a body of the earth-boring tool to which the component is to be joined;
   - rotating the component about a longitudinal axis of the component and generating friction between the third-body structure and at least one of the surface of the component and the surface of the body of the earth-boring tool, the friction resulting in heating and at least plasticizing of the third-body structure; and
   - after the rotating, applying force on the component toward the surface of the body of the earth-boring tool.

15. The method of claim 14, wherein disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined comprises disposing the third-body structure between a bottom surface of the component and a floor within a pocket defined in the body of the earth-boring tool to which the component is to be joined.

16. The method of claim 14, wherein disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined comprises disposing the third-body structure at least partially between a sidewall of the component and a sidewall of a pocket defined in the body of the earth-boring tool to which the component is to be joined.

17. The method of claim 14, wherein disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined comprises disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined, the third-body structure not being affixed to the component or to the body of the earth-boring tool prior to the rotating.

18. The method of claim 14, further comprising, forming the third-body structure to have a longitudinal thickness of between about 0.025 mm and about 2.5 mm prior to disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which the component is to be joined.

19. The method of claim 14, wherein disposing the third-body structure between the surface of the component and the surface of the body of the earth-boring tool to which
the component is to be joined comprises disposing, between
the surface of the component and the surface of the body of
the earth-boring tool to which the component is to be joined,
a third-body structure having a top surface and a bottom
surface continuous across a diameter of the surface of the
component.

20. The method of claim 14, wherein disposing the
third-body structure between the surface of the component
and the surface of the body of the earth-boring tool to which
the component is to be joined comprises disposing, between
the surface of the component and the surface of the body of
the earth-boring tool to which the component is to be joined,
a third body structure having a discontinuous top surface.