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| United States Patent Application Publication | 20250264125 |
| Kind Code | A1 |
| Publication Date | August 21, 2025 |
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## FASTENER

### Abstract


There is disclosed a hole forming and thread forming fastener (**2**). The hole forming and thread forming fastener (**2**) comprises a head (**4**) and a shank (**10**) that defines a longitudinal axis (L). The shank (**10**) comprises a shank section (**12**) and a tip section (**14**). The shank section (**12**) extends from the head (**4**). The tip section (**14**) extends from the shank section (**12**) and is opposed to the head (**4**). At least part of the shank section (**12**) is threaded. The tip section (**14**) is at least partially tapered and defines a tip angle (α). The tip angle (α) is at least 50 degrees.



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| **Family ID:** | **1000008616588** |
| **Appl. No.:** | **18/863165** |
| **Filed (or PCT Filed):** | **May 03, 2023** |
| **PCT No.:** | **PCT/GB2023/051170** |

### Foreign Application Priority Data

| | | |
|---|---|---|
| GB | 2206685.6 | May. 06, 2022 |

### Publication Classification

**Int. Cl.:** **F16B25/00** (20060101); **F16B25/10** (20060101)

**U.S. Cl.:**

CPC **F16B25/0021** (20130101); **F16B25/0084** (20130101); **F16B25/106** (20130101);

## Background/Summary

FIELD OF INVENTION

[0001] The present invention relates to a thread forming and hole forming fastener. The present invention also relates to methods of inserting a fastener into a workpiece and to a joint.

BACKGROUND

[0002] Fasteners are used to connect components together. Fasteners may be used in isolation or in combination with other connection methods. Thread forming fasteners are a type of fastener that, rather than cutting material from a workpiece to create a thread, form the material of the workpiece such that a thread is created. No material, or a negligible amount of material, is removed from the workpiece when inserting a thread forming fastener. Some thread forming fasteners are also capable of forming a hole in the workpiece in which the fastener is disposed. The hole is formed simultaneously with the thread. Thread forming fasteners that can also form holes may be referred to as thread forming and hole forming fasteners.

[0003] To insert a thread forming and hole forming fastener into a workpiece, the fastener is rotated while in contact with the workpiece such that the workpiece is heated. The fastener is then inserted into the workpiece. The fastener, which is threaded, is rotated whilst it is being inserted into the workpiece. This forms a thread in the workpiece. The quality of the joint formed is a function of, among other factors, the amount of heat supplied to the workpiece.

[0004] It is an object of the present invention to obviate or at least mitigate the problems associated with known thread forming fasteners, whether identified herein or otherwise.

SUMMARY

[0005] In a first aspect of the invention there is provided a hole forming and thread forming fastener. The hole forming and thread forming fastener comprises a head and a shank that defines a longitudinal axis. The shank comprises a shank section and a tip section. The shank section extends from the head, and the tip section extends from the shank section and is opposed to the head. At least part of the shank section is threaded. The tip section is at least partially tapered and defines a tip angle, the tip angle being at least 50 degrees.

[0006] Throughout this document, the term ‘tip angle’ may be understood to refer to the internal angle of the tip of the fastener. The tip angle may be understood to refer to the maximum angle between two tangents that extend through diametrically opposed points of the tip section.

[0007] The shank section may be a cylindrical shank section. The entire shank section may be threaded. The tip section may merge into the shank section by virtue of a radius or chamfer.

[0008] The tip angle may be not 118 degrees.

[0009] In use, the hole forming and thread forming fastener is rotated on a surface of a workpiece so as to heat the workpiece. Once the workpiece has been heated by a predetermined amount, the fastener is threaded into the workpiece by moving the fastener relative to the workpiece in a direction that is parallel to the longitudinal axis of the fastener. Rotation of the fastener continues while the fastener is being threaded into the workpiece. While the fastener is being threaded into the workpiece, the workpiece material forms around the threads of the shank section, thereby threading the fastener into the workpiece. The quality of the joint created using the fastener is a function of the amount by which the workpiece is heated during insertion of the fastener. Under-heating of the workpiece during the insertion process produces a sub-optimal joint. For example, under-heating of the workpiece during the insertion process may result in separation of the layers of the workpiece (where the workpiece comprises multiple layers), and/or inadequate engagement between the threads of the fastener and the workpiece material. Separation of the layers of the workpiece may also be referred to as gapping.

[0010] Since the tip angle of the tip section is at least 50 degrees, the likelihood of under-heating of

a workpiece occurring while inserting the fastener into a workpiece is advantageously reduced. This is at least partly because of the contact area between the tip section and the workpiece that results from a tip angle of at least 50 degrees. Since the likelihood of under-heating of a workpiece occurring while inserting the fastener is reduced, the quality of the joint created using the fastener is improved relative to where a workpiece is under-heated during insertion of a fastener.
[0011] The tip angle may be at least 70 degrees (for example when no bore is provided in the tip).
[0012] Where the tip angle is at least 70 degrees, the likelihood of under-heating of a workpiece occurring is advantageously further reduced.
[0013] The tip section may define a tip section length. The shank section may define a shank section diameter. A ratio of the tip section length to the shank section diameter may be less than or equal to 0.6.
[0014] The ratio of the tip section length to the shank section diameter may be less than or equal to 0.4.
[0015] The tip angle may be less than or equal to 160 degrees.
[0016] Overheating of the workpiece during the insertion process may also produce a sub-optimal joint. For example, overheating of the workpiece during the insertion process may result in separation of the layers of the workpiece (where the workpiece comprises multiple layers), and/or inadequate engagement between the threads of the fastener and the workpiece material.
[0017] The tip angle being less than or equal to 160 degrees reduces the likelihood of overheating of a workpiece occurring while inserting the fastener into a workpiece. This is at least partly as a result of the contact because of the contact area between the tip section and the workpiece that results from a tip angle of less than or equal to 160 degrees. Since the likelihood of overheating of a workpiece occurring while inserting the fastener is reduced, the quality of the joint created using the fastener is improved relative to where a workpiece is overheated during insertion of a fastener.
[0018] In addition, a tip angle of less than or equal to 160 degrees allows the workpiece material to pass around the fastener, instead of being pushed ahead of the fastener. Since the workpiece material is able to pass around the fastener, the likelihood of gapping occurring during insertion of the fastener into a workpiece is advantageously reduced.
[0019] The tip angle may be at least 125 degrees. The tip angle may be less than or equal to 135 degrees.
[0020] Where the tip angle is at least 125 degrees and less than or equal to 135 degrees, the likelihood over overheating or of under-heating is further reduced, thereby further improving the quality of the joint created using the fastener.
[0021] The tip angle may be 130 degrees.
[0022] The head may comprise an internal drive geometry. The head may comprise an external drive geometry. The head may comprise a one-way drive geometry. The head may comprise a frangible drive portion. The frangible drive portion may be separable from the fastener following insertion of the fastener into a workpiece.
[0023] The tip of the fastener may be conical. The tip of the fastener may be frustoconical. The tip of the fastener may be radiused.
[0024] The shank section may comprise a first shank portion that adjoins the head. The shank section may comprise a second shank portion that adjoins the tip section.
[0025] The shank section may comprise a base section. The first shank portion may comprise the base section.
[0026] The first shank portion may not threaded. The second shank portion may be threaded.
[0027] Where the first shank portion is not threaded, the resistance to insertion of the fastener is reduced relative to if the first shank portion were threaded. This reduces the magnitude of the force required to insert the fastener into a workpiece. Reducing the force required to insert the fastener into a workpiece advantageously reduces the magnitude of deflection exhibited by the workpiece during the fastener insertion process, which reduces the likelihood of gapping occurring. Therefore,

where the first shank portion is not threaded and the second shank portion is threaded, a better quality joint is provided.
[0028] The first shank portion may be axisymmetric about the longitudinal axis.
[0029] The first shank portion may comprise one or more retaining features. In use, the one or more retaining features may engage a workpiece into which the hole forming and thread forming fastener is inserted.
[0030] The one or more retaining features may comprise one or more surface irregularities. The one or more surface irregularities may comprise a plurality of projections that project from the first shank portion. The plurality of projections may take the form of, for example, ribs and/or hemispheres. The ribs may extend around and/or along the longitudinal axis of the shank.
[0031] Where the first shank portion comprises one or more retaining features, the likelihood of the fastener loosening in use is advantageously reduced, thereby resulting in a more robust joint.
[0032] The diameter of the first shank portion may be greater than the diameter of the second shank portion.
[0033] The head may define an undercut.
[0034] When inserting the fastener into a workpiece, some of the workpiece material may be extruded out of the aperture formed by the workpiece in a direction that is opposed to the direction of insertion of the fastener. Where the head defines an undercut, this extruded material can advantageously be received by the undercut portion of the head. In the absence of an undercut, the extruded material can prevent full insertion of the fastener. Therefore, the undercut of the head allows full fastener insertion, thereby providing a more robust joint using the fastener.
[0035] The hole forming and thread forming fastener may further comprise a threaded stud that extends from a side of the head that is opposed to the underside.
[0036] Advantageously, a threaded stud allows a component to be affixed to the fastener, thereby making the fastener more versatile as compared to if the threaded stud were not present.
[0037] The tip section may define an undercut that is disposed adjacent the shank section.
[0038] Where the tip section comprises an undercut, the workpiece material deforms into the undercut during the fastener insertion process. This creates a further interlocked region between the fastener and the workpiece. The further interlocked region increases the strength of the connection between the fastener and the workpiece as compared to if the undercut were not provided. Therefore, the undercut allows a more robust joint to be created using the fastener.
[0039] The pitch diameter of the thread of the shank section may be constant along at least 90% of the length of the shank section.
[0040] The pitch diameter of the thread of the shank section may be constant along at least 75% of the length of the shank section. The pitch diameter of the thread of the shank section may be constant along the entire length of the shank section.
[0041] In a second aspect of the invention there is provided a method of inserting a fastener into a workpiece. The method comprises providing a fastener, the fastener being a fastener according to the first aspect of the invention, the fourth aspect of the invention, the fifth aspect of the invention or the sixth aspect of the invention. The method further comprises providing a workpiece. The workpiece comprising a first surface and a second surface. The second surface is opposed to the first surface. The method further comprises rotating the fastener about the longitudinal axis of the fastener and bringing the fastener into contact with the first surface of the workpiece so as to heat the workpiece. The method further comprises threading the fastener into the workpiece by moving the fastener and the workpiece relative to one another in a direction that is parallel to the longitudinal axis of the fastener such that the tip section of the fastener penetrates the first surface. The fastener does not penetrate the second surface of the workpiece.
[0042] The advantages discussed above in relation to the first aspect of the invention apply to the present aspect mutatis mutandis.
[0043] The first surface of the workpiece and the second surface of the workpiece need not form a

part of the same material layer of the workpiece. The first surface may be referred to as an upper or top surface. The second surface may be referred to as a lower or bottom surface.
[0044] Threading the fastener into the workpiece may comprise forming a thread in the workpiece with the fastener.
[0045] The method may further comprise providing a die. While the fastener is being threaded into the workpiece, the second surface may engage the die. The method may comprise deforming workpiece material into the die. The workpiece material may be deformed into the die at the same time that the fastener is being threaded into the workpiece.
[0046] The method may be performed without using a die.
[0047] Where the second workpiece surface engages the die while the fastener is being threaded into the workpiece, the workpiece is advantageously better constrained compared to if the die were not present. The die is able to react the force used to thread the fastener into the workpiece, thereby resulting in reduced workpiece deflection as the fastener is being threaded into the workpiece, as compared to if the die were not provided. Workpiece deflection can, for example, cause gapping. In addition, since the force used to insert the fastener into the workpiece can be reacted by the die, the force used can be increased relative to where no die is provided. Therefore, providing a die that the second workpiece surface of the workpiece engages advantageously provides a better quality joint.
[0048] The die may comprise a die recess. While the fastener is being threaded into the workpiece, the second surface of the workpiece may deform into the die recess.
[0049] Where the second workpiece surface deforms into the die recess, the shape of the second surface of the workpiece can be controlled by virtue of the shape of the die.
[0050] The die recess may be configured such that the workpiece material does not completely fill the die upon completion of insertion of the fastener into the workpiece.
[0051] The die recess being configured such that the workpiece material does not completely fill the die upon completion of insertion of the fastener into the workpiece advantageously allows the die to be used with a variety of different workpiece materials. In addition, the likelihood of the workpiece becoming stuck to the workpiece is reduced.
[0052] The die recess may be in the form of a continuous groove or a continuous channel.
[0053] The die recess may define a die recess volume. A volume of workpiece material may be displaced while the fastener is being threaded into the workpiece. The die volume may be equal to or greater than the volume of workpiece material displaced.
[0054] The workpiece may comprise only a single workpiece layer.
[0055] The single workpiece layer may comprise both the first surface and the second surface of the workpiece.
[0056] The workpiece may comprise a first layer and a second layer.
[0057] The first layer of the workpiece may comprise the first surface of the workpiece. The second layer of the workpiece may comprise the second surface of the workpiece.
[0058] At least one of the layers of the workpiece may be made from a metallic material. At least one of the layers of the workpiece may be made from aluminium.
[0059] Both of the layers of the workpiece may be made from a metallic material. The first layer may be made from aluminium. The second layer may be made from aluminium. The first layer may be made from cast aluminium. The second layer may be made from sheet aluminium. The second layer may be made from cast aluminium. The first layer may be made from sheet aluminium.
[0060] The material of the workpiece may have a tensile strength of at least 300 MPa. The material of the workpiece may have a tensile strength of equal to or less than 550 MPa. The material of the workpiece may have a ductility, measured as percent elongation, of equal to or less than 10%. The material of the workpiece may have a ductility, measured as percent elongation, of equal to or less than 5%.
[0061] The first workpiece layer may comprise an aperture through which the fastener passes before contacting the workpiece.

[0062] Where the first workpiece layer comprises an aperture through which the fastener passes before contacting the workpiece, the second workpiece layer may comprise the first surface of the workpiece. A diameter of the aperture may be greater than a diameter of the threaded shank section of the thread forming and hole forming fastener.
[0063] When inserting the fastener into a workpiece, some of the workpiece material may be extruded out of the aperture formed by the workpiece in a direction that is opposed to the direction of insertion of the fastener. Where the first workpiece layer comprises an aperture through which the fastener passes before contacting the workpiece, this extruded material can advantageously be received between the fastener and the aperture. In the absence of an aperture, the extruded material can prevent full insertion of the fastener. Therefore, the undercut of the head allows full fastener insertion, thereby providing a more robust joint using the fastener.
[0064] Some materials may not be compatible with the fastener. This may be because, for example, the fastener is not able to sufficiently heat the material such that the fastener can be threaded into the material. Providing an aperture through the first workpiece layer through which the fastener passes before contacting the workpiece allows the fastener to connect workpiece layers of different materials, including materials that would otherwise be incompatible with the fastener. Therefore, the method is more versatile as compared to where no aperture is provided.
[0065] The first workpiece layer may be formed of a composite material.
[0066] The first layer may not be provided with an aperture through which the thread forming and hole forming fastener extends.
[0067] The fastener may comprise a threaded stud that extends from a side of the head that is opposed to the shank section of the shank. The method may further comprise securing a component to the threaded stud.
[0068] The rate at which the fastener is rotated relative to the workpiece may be reduced at least once while the fastener is being threaded into the workpiece.
[0069] The rate at which the fastener is rotated relative to the workpiece following the reduction may be a non-zero value.
[0070] Reducing the rate at which the fastener is rotated relative to the workpiece allows the workpiece material to better form around the fastener. Therefore, where the rate at which the fastener is rotated relative to the workpiece is reduced while the fastener is being threaded into the workpiece, the strength of the connection between the fastener and the workpiece is advantageously improved.
[0071] The reduction of the rate at which the fastener is rotated relative to the workpiece may occur while the tip section is disposed in the second workpiece layer.
[0072] The rate at which the fastener is moved relative to the workpiece following the reduction may be a non-zero value. The reduction of rotational speed may occur when the tip section is at least 25% of the way through the second workpiece layer.
[0073] Reducing the rate at which the fastener is rotated relative to the workpiece allows the workpiece material to better form around the fastener. The majority of the connection strength between the fastener and the workpiece is as a result of the connection between the fastener and the second workpiece layer. Therefore, where the rate at which the fastener is rotated relative to the workpiece is reduced while the tip section of the fastener is disposed in the second workpiece layer, the strength of the connection between the fastener and the workpiece is advantageously further improved.
[0074] Following threading the fastener into the workpiece, the second surface of the workpiece may comprise a protrusion in which at least part of the tip section of the shank of the fastener is received.
[0075] In a third aspect of the invention there is provided a joint. The joint comprises a workpiece comprising a first surface and a second surface. The joint further comprises a fastener according to the first aspect of the invention, the fourth aspect of the invention, the fifth aspect of the invention

or the sixth aspect of the invention. The fastener extends through the first surface and does not penetrate the second surface.
[0076] The workpiece may comprise a first workpiece layer. The first workpiece layer may comprise the first surface of the workpiece. The workpiece may comprise a second workpiece layer. The second workpiece layer may comprise the second surface of the workpiece. The fastener may at least partially penetrate the second workpiece layer. The fastener may only partially penetrate the second workpiece layer.
[0077] The fastener may be removable from the workpiece. The fastener may not be removable from the workpiece.
[0078] The advantages discussed above in relation to the first aspect of the invention apply to the present aspect mutatis mutandis.
[0079] The workpiece may comprise a first workpiece layer that comprises the first surface and a second workpiece layer that comprises the second surface.
[0080] The first workpiece layer may comprise an aperture through which the thread forming and hole forming fastener extends.
[0081] A diameter of the aperture may be greater than a diameter of the threaded shank section of the thread forming and hole forming fastener.
[0082] The first workpiece layer may be formed of a composite material.
[0083] The first layer may not be provided with an aperture through which the thread forming and hole forming fastener extends.
[0084] The workpiece may comprise only a single workpiece layer.
[0085] The thread forming and hole forming fastener may further comprise a threaded stud that extends from a side of the head that is opposed to the shank section.
[0086] At least one of the workpiece layers may be made from a metallic material. At least one of the layers of the workpiece may be made from aluminium.
[0087] Both of the workpiece layers may be made from a metallic material. The first workpiece layer may be made from aluminium. The second workpiece layer may be made from aluminium. Both of the workpiece layers may be made from aluminium. The first workpiece layer may be made from cast aluminium. The second workpiece layer may be made from sheet aluminium. The second layer may be made from cast aluminium. The first layer may be made from sheet aluminium.
[0088] The material of the workpiece may have a tensile strength of at least 300 MPa. The material of the workpiece may have a tensile strength of equal to or less than 550 MPa. The material of the workpiece may have a ductility, measured as percent elongation, of equal to or less than 10%. The material of the workpiece may have a ductility, measured as percent elongation, of equal to or less than 5%.
[0089] The head of the thread forming and hole forming fastener may be disposed proud of the workpiece. The head of the thread forming and hole forming fastener may be disposed substantially flush with the workpiece.
[0090] The second surface may comprise a protrusion in which the tip section of the fastener is at least partially received.
[0091] In a fourth aspect of the invention there is provided a hole forming and thread forming fastener. The hole forming and thread forming fastener comprises a head and a shank that defines a longitudinal axis. The shank comprises a cylindrical shank section. The shank comprises a tip section. The cylindrical shank section extends from the head. The tip section extends from the cylindrical shank section. The tip section is opposed to the head. At least part of the cylindrical shank section is threaded. The fastener further comprises a bore that extends into the tip section and at least part way along the longitudinal axis.
[0092] The term ‘thread forming fastener’ is a known term in the art and refers to a fastener that, instead of cutting a thread in a workpiece, forms a thread by deforming the workpiece material.

[0093] The bore may extend from a tip of the tip section and along the longitudinal axis. The bore may be a through bore. The term 'through bore' may be understood to refer to a bore that extends along the whole length of the fastener. The bore may be cylindrical. The bore may be a blind bore.
[0094] The entire shank section may be threaded.
[0095] In the process of inserting a hole forming and thread forming fastener into a workpiece, at least some of the material of the workpiece is displaced by the fastener. The displaced material protrudes from one or more of an upper surface of the workpiece (i.e. the surface into which the fastener is inserted), a lower surface of the workpiece (i.e., the surface opposed to the surface of insertion) and one or more intermediate surfaces (i.e., the surfaces at an interface between workpiece layers). This can result in joint defects such as separation of the workpiece layers, and impartial insertion of the fastener due to interference with the protruded material. Such defects impair the quality of the joint created.
[0096] Since the fastener comprises a bore, at least some of the workpiece material is received by the bore during and following insertion of the fastener into a workpiece. Therefore, the amount of material displaced by the fastener during insertion is reduced relative to where a bore is not provided, thereby reducing the likelihood of material protruding. This advantageously improves joint quality relative to where a bore is not provided.
[0097] The tip section may define a ring leading edge.
[0098] The ring leading edge may define a ring surface.
[0099] Where the tip section defines a ring leading edge, during the process of inserting the fastener into a workpiece, the initial contact area between the tip section and the workpiece is greater than if, for example, the tip section defined a pointed tip. This increase in contact area advantageously heats the workpiece quicker compared to a smaller contact area, thereby making the fastener insertion process quicker.
[0100] In addition, during the fastener insertion process, the contact area between the ring leading edge and the workpiece is further away from the axis of rotation of the fastener than a fastener that comprises a pointed tip section. Because of this, the velocity of the ring leading edge is greater than the tip of a pointed tip section for the same rotational velocity. This increases the heat that is supplied to the workpiece during the fastener insertion process, thereby heating the workpiece quicker compared to a fastener with, for example, a pointed tip section.
[0101] The ring leading edge may be non-coplanar.
[0102] The ring leading edge being non-coplanar may be understood to mean that at least part of the ring leading edge does not lie in the same plane as another part of the ring leading edge.
[0103] The ring leading edge may comprise a plurality of facets such that the ring leading edge is serrated.
[0104] Since the ring leading edge is non-coplanar, the amount of friction generated while inserting the fastener into a workpiece is increased. This reduces the likelihood that the workpiece is under-heated during the fastener insertion process.
[0105] The bore may define a bore internal diameter. The bore may define a tapered surface section. The ring leading edge may merge into the bore internal diameter via the tapered surface section.
[0106] The diameter of the ring leading edge may be greater than the diameter of the bore internal diameter. The tapered surface section may comprise a chamfered surface section and/or a radiused surface section.
[0107] The bore may define a bore depth. The tapered surface section may define a tapered surface section depth. The ratio of the tapered surface section depth to the bore depth may be at least 0.1. The ratio of the tapered surface section depth to the bore depth may be at least 0.25. The ratio of the tapered surface section depth to the bore depth may be at least 0.5.
[0108] Since the ring leading edge merges into the bore internal diameter by means of a tapered surface section, the stress exerted on the fastener both during the fastener insertion process and in

use is more evenly distributed as compared to alternative transition surfaces between the ring leading edge and the bore internal diameter. More even stress distribution reduces the likelihood of fastener failure as a result of, for example, the fastener cracking.
[0109] The bore may define a bore internal diameter. The cylindrical shank section may define a shank diameter. A ratio of the shank diameter to the bore internal diameter may be at least 1.5.
[0110] This ratio of shank diameter to bore internal diameter advantageously provides sufficient shank material such that the fastener is able to withstand the forces required in use, thereby making the fastener more robust.
[0111] The ratio of the shank diameter to the bore internal diameter may be at least 2.
[0112] The shank may define a shank length. The bore may extend along at least 25% of the shank length.
[0113] Where the bore extends along at least 25% of the shank length, the amount of workpiece material that can be accommodated by the bore is sufficient such that the likelihood of gapping occurring during the fastener insertion process is sufficiently reduced.
[0114] The bore may extend along at least 50% of the shank length.
[0115] The bore may extend along up to 25% of the shank length. The bore may extend along up to 10% of the shank length.
[0116] A shallower bore may be desirable for thinner workpieces. Less workpiece material is displaced by the fastener for thinner workpieces because there is less workpiece material to be displaced. The depth of the bore may therefore be chosen based on the thickness of the workpiece. A shallower bore may also be used for harder and/or stronger workpieces. This is because the likelihood of fastener deformation occurring during fastener insertion increases with increasing workpiece hardness and strength. Therefore, a bore that extends along up to 25%, or up to 10%, of the shank length provides the benefits of increasing the heat supplied to the workpiece, discussed above, while reducing the likelihood of fastener deformation.
[0117] The bore may defines a bore surface. The bore surface may defines a plurality of surface irregularities.
[0118] Where the bore defines a plurality of surface irregularities, the surface irregularities interlock with a workpiece into which the fastener has been inserted. This advantageously improves the strength of the connection between the fastener and a workpiece.
[0119] The entirety of the bore may be cylindrical.
[0120] Where the entirety of the bore is cylindrical, the strength of the shank of the fastener is improved relative to a bore that includes a tapered section.
[0121] In a fifth aspect of the invention there is provided a hole forming and thread forming fastener. The hole forming and thread forming fastener comprises a head and a shank that defines a longitudinal axis. The shank comprises a shank section. The shank comprises a tip section. The shank section extends from the head. The tip section extends from the shank section. The tip section is opposed to the head. At least part of the shank section is threaded. The shank section defines a shank section length. The tip section defines a tip section length. A ratio of the shank section length to the tip section length is at least 2.5. The tip section comprises a plurality of surface irregularities.
[0122] The ratio of the shank section length to the tip section length may be calculated by dividing the shank section length by the tip section length.
[0123] The plurality of surface irregularities may be in the form of a plurality of facets.
[0124] The plurality of surface irregularities may be in the form of a plurality of ribs.
[0125] The plurality of surface irregularities may be in the form of a plurality of facets and a plurality of ribs.
[0126] The plurality of facets may comprise at least three facets. The facets may each be in the form of a radiused surface section. The facets may adjoin one another. The facets may be arranged as an array. The facets may be spaced apart from one another.

[0127] The plurality of ribs may comprise at least two ribs. The plurality of ribs may comprise at least three ribs. The plurality of ribs may comprise six ribs. A component of the length of the ribs may extend in a radial direction (i.e., perpendicular to a longitudinal axis of the fastener). A component of the length of the ribs may extend in a circumferential direction (i.e., about the longitudinal axis of the fastener). The ribs may extend radially outwardly from a tip of the tip section. A thickness and/or width of the ribs may be either uniform or non-uniform. The thickness of the ribs may be understood to refer to the distance by which they protrude from a surface of the tip section. The thickness and/or width of the ribs may be at a minimum at or adjacent to the tip of the tip section. The thickness and/or width of the ribs may be at a maximum at or adjacent to the tip of the tip section.
[0128] The tip section may be a tapered tip section. The shank section may be cylindrical. The entire shank section may be threaded.
[0129] Each facet of the plurality of facets, or each rib of the plurality of ribs, may extend from a tip of the tip section towards the shank section. Each facet of the plurality of facets, or each rib of the plurality of ribs, may extend from a tip of the tip section to the shank section. Each facet of the plurality of facets may extend radially outwardly from a tip of the tip section.
[0130] In use, the hole forming and thread forming fastener is rotated on a surface of a workpiece so as to heat the workpiece. Once the workpiece has been heated by a predetermined amount, the fastener is threaded into the workpiece by moving the fastener relative to the workpiece in a direction that is parallel to the longitudinal axis of the fastener. Rotation of the fastener continues while the fastener is being threaded into the workpiece. While the fastener is being threaded into the workpiece, the workpiece material forms around the threads of the shank section, thereby threading the fastener into the workpiece. The quality of the joint created using the fastener is a function of the amount by which the workpiece is heated during insertion of the fastener. Under-heating of the workpiece during the insertion process produces a sub-optimal joint. For example, under-heating of the workpiece during the insertion process may result in separation of the layers of the workpiece (where the workpiece comprises multiple layers), and/or inadequate engagement between the threads of the fastener and the workpiece material. Separation of the layers of the workpiece may also be referred to as gapping.
[0131] Since the tip section comprises a plurality of surface irregularities, the likelihood of under-heating of a workpiece occurring while inserting the fastener into a workpiece is advantageously reduced. The plurality of surface irregularities provide the tip section with a discontinuous profile. The discontinuous profile increases the amount of friction between the tip section of the fastener of the workpiece, thereby increasing the amount of heat generated during the fastener insertion process. Since the likelihood of under-heating of a workpiece occurring while inserting the fastener is reduced, the quality of the joint created using the fastener is improved relative to where a workpiece is under-heated during insertion of a fastener.
[0132] The plurality of facets may comprise six facets.
[0133] Where the plurality of facets comprises six facets, the heating of the workpiece during insertion of the fastener is optimised.
[0134] The plurality of facets may comprise at least two facets. The plurality of facets may comprise at least four facets.
[0135] The facets may each be in the form of a planar surface section. The facets may adjoin one another. The facets may be spaced apart from one another.
[0136] In a sixth aspect of the invention there is provided a hole forming and thread forming fastener. The hole forming and thread forming fastener comprises a head and a shank that defines a longitudinal axis. The shank comprises a shank section. The shank comprises a tip section. The shank section extends from the head. The tip section extends from the shank section. The tip section is opposed to the head. At least part of the shank section is threaded.
[0137] Any features disclosed with respect to the first, fourth or fifth aspects of the invention may

be combined with the sixth aspect of the invention.
[0138] In a seventh aspect of the invention there is provided a method of inserting a fastener into a workpiece. The method comprises providing a workpiece that comprises a first workpiece layer and a second workpiece layer. The method further comprises applying an adhesive to the first and/or second workpiece layers. The method further comprises bringing the first workpiece and the second workpiece into engagement with one another such that the adhesive is disposed between the first workpiece layer and the second workpiece layer. The method further comprises providing a fastener. The fastener comprising a head and a shank. The shank defines a longitudinal axis The shank comprises a shank section. The shank comprises a tip section. At least part of the shank section is threaded. The shank section extends from the head. The tip section extends from the shank section and is opposed to the head. The method further comprises rotating the fastener about the longitudinal axis and bringing the fastener into contact with the workpiece so as to heat the workpiece. The method further comprises threading the fastener into the workpiece by moving the fastener and the workpiece relative to one another in a direction that is parallel to the longitudinal axis such that the tip section of the fastener penetrates through the first workpiece layer and through the adhesive. The fastener at least partially penetrates the second workpiece layer.
[0139] Since an adhesive layer is provided, the strength of the connection between the first workpiece and the second workpiece is advantageously greater than if the adhesive were not present.
[0140] The fastener may be a fastener according to the first, fourth, fifth or sixth aspect of the invention.
[0141] The fastener may only partially penetrate the second workpiece layer.
[0142] Where the fastener only partially penetrates the second workpiece layer the likelihood of ingress of fluid via the second layer is reduced. Reducing the likelihood of fluid ingress is desirable because the presence of fluid can cause joint defects, such as oxidisation. Therefore, the fastener only partially penetrating the second workpiece layer advantageously provides a more robust joint.
[0143] In addition, where the fastener only partially penetrates the second workpiece layer, the tip section of the fastener is disposed within the second workpiece layer, and does not protrude out of the workpiece. This is desirable because a protruding fastener provides a risk of injury to a user and/or damage to a component. Therefore, the fastener only partially penetrating the second workpiece layer advantageously provides a safer joint.
[0144] In an eighth aspect of the invention there is provided a method for inserting a fastener into a workpiece. The method comprises providing a fastener. The fastener comprises a head and a shank. The shank defines a longitudinal axis. The shank comprises a shank section and a tip section. The shank section is at least partially threaded. The threaded shank section extends from the head. The tip section extends from the shank section and is opposed to the head. The method further comprises providing a workpiece. The workpiece comprises a first surface and a second surface. The second surface is opposed to the first surface. The method further comprises rotating the fastener about the longitudinal axis and bringing the fastener into contact with the first surface of the workpiece so as to heat the workpiece. The method further comprises moving the fastener relative to the workpiece at a rate of at least 0.5 mm/sec. The fastener is moved in a direction that is parallel to the longitudinal axis of the fastener such that the tip section penetrates the first surface of the workpiece and such that the fastener is threaded into the workpiece. The fastener does not penetrate the second surface of the workpiece.
[0145] The first surface of the workpiece and the second surface of the workpiece need not form a part of the same material layer of the workpiece. The first surface may be referred to as an upper or top surface. The second surface may be referred to as a lower or bottom surface.
[0146] The threaded shank may be cylindrical.
[0147] Since the fastener is moved relative to the workpiece at a rate of at least 0.5 mm/sec in a direction that is parallel to the longitudinal axis of the fastener, the likelihood of overheating of the

workpiece occurring is reduced. This is because the rate at which the fastener is inserted into the workpiece is sufficient such that the fastener insertion process can be completed before workpiece overheating occurs. Reducing the likelihood of overheating of the workpiece is desirable because overheating can result in joint defects, such as gapping. Therefore, moving the fastener relative to the workpiece at a rate of at least 0.5 mm/sec in a direction that is parallel to the longitudinal axis of the fastener advantageously produces a better quality joint relative to if the fastener were moved at a rate slower than 0.5 mm/sec.

[0148] In addition, since the fastener does not penetrate the second surface of the workpiece the likelihood of ingress of fluid via the second layer is reduced. Reducing the likelihood of fluid ingress is desirable because the presence of fluid can cause joint defects, such as oxidisation. Therefore, the fastener only partially penetrating the second workpiece layer advantageously provides a more robust joint.

[0149] In addition, since the fastener does not penetrate the second surface of the workpiece, the tip section of the fastener is disposed within the workpiece, and does not protrude out of the workpiece. This is desirable because a protruding fastener provides a risk of injury to a user and/or damage to a component. Therefore, the fastener not penetrating the second surface of the workpiece advantageously provides a safer joint.

[0150] The rate at which the fastener is moved relative to the workpiece may be reduced at least once while the fastener is being threaded into the workpiece.

[0151] The rate at which the fastener is moved relative to the workpiece following the reduction may be a non-zero value.

[0152] Reducing the rate at which the fastener is moved relative to the workpiece allows the workpiece material to better form around the fastener. Therefore, where the rate at which the fastener is moved relative to the workpiece is reduced while the fastener is being threaded into the workpiece, the strength of the connection between the fastener and the workpiece is advantageously improved.

[0153] The workpiece may comprise a first workpiece layer and a second workpiece layer. The first workpiece layer may comprise the first surface of the workpiece. The second workpiece layer may comprise the second surface of the workpiece. The rate at which the fastener is moved relative to the workpiece may be reduced while the tip section of the fastener is disposed in the second workpiece layer.

[0154] The rate at which the fastener is moved relative to the workpiece following the reduction may be a non-zero value.

[0155] Reducing the rate at which the fastener is moved relative to the workpiece allows the workpiece material to better form around the fastener. The majority of the connection strength between the fastener and the workpiece is as a result of the connection between the fastener and the second workpiece layer. Therefore, where the rate at which the fastener is moved relative to the workpiece is reduced while the tip section of the fastener is disposed in the second workpiece layer, the strength of the connection between the fastener and the workpiece is advantageously further improved.

[0156] The fastener may be moved relative to the workpiece in a direction that is parallel with the longitudinal axis of the fastener at a rate of at least 1 mm/sec.

[0157] The fastener may be moved relative to the workpiece in a direction that is parallel with the longitudinal axis of the fastener at a rate of at least 2 mm/sec.

[0158] In a ninth aspect of the invention there is provided a method for inserting a fastener into a workpiece. The method comprises providing a fastener. The fastener comprises a head and a shank. The shank defines a longitudinal axis. The shank comprises a shank section and a tip section. The shank section is at least partially threaded. The threaded shank section extends from the head. The tip section extends from the shank section and is opposed to the head. The method further comprises providing a workpiece. The workpiece comprises a first surface and a second surface.

The second surface is opposed to the first surface. The method further comprises rotating the fastener about the longitudinal axis and bringing the fastener into contact with the first surface of the workpiece so as to heat the workpiece. The method further comprises threading the fastener into the workpiece by moving the fastener and the workpiece relative to one another in a direction that is parallel to the longitudinal axis such that the tip of the fastener penetrates through the first surface of the workpiece. The fastener does not penetrate the second surface of the workpiece. Throughout the method, the workpiece temperature remains below a recrystallisation temperature of the workpiece material.

[0159] The threaded shank section may be cylindrical.

[0160] Since the workpiece temperature remains below the recrystallisation temperature of the workpiece material throughout the method, the fastener is able to better form the threads in the workpiece as compared to if the workpiece temperature were to exceed the recrystallisation temperature of the workpiece material. This is because below the recrystallisation temperature, the ductility of the workpiece material is optimised for the fastener to form the threads. Above the recrystallisation temperature of the material, the ductility of the workpiece material is too great for threads to be correctly formed. Since the threads are better formed, the strength of the connection between the fastener and the workpiece is improved.

[0161] The workpiece may comprise a first workpiece layer and a second workpiece layer. Throughout the method, the material of the first workpiece layer may not mix with the material of the second workpiece layer.

[0162] In a tenth aspect of the invention there is provided a joint. The joint comprises a workpiece. The workpiece comprises a first workpiece layer and a second workpiece layer. The joint further comprises an adhesive layer that is disposed between the first workpiece layer and the second workpiece layer. The joint further comprises a fastener that has formed a hole and a thread in the workpiece. The fastener extends through the first workpiece layer, the adhesive layer, and at least partially through the second workpiece layer.

[0163] The fastener may extend only partially through the second workpiece layer. The fastener may be threaded into the first workpiece layer. The fastener may be threaded into the second workpiece layer.

[0164] The fastener may be threaded into all of the layers of the workpiece. The fastener may be removable from the workpiece. The fastener may not be removable from the workpiece.

[0165] In an eleventh aspect of the invention there is provided a joint. The joint comprises a workpiece. The workpiece comprises a first surface and a second surface. The joint further comprises a hole forming and thread forming fastener. The hole forming and thread forming fastener comprises a head and a shank. The shank comprises a shank section. The shank comprise a tip section. At least part of the shank section is threaded. The shank section extends from the head. The tip section extends from the shank section. The tip section is opposed to the head. The fastener extends through the first surface. The fastener does not penetrate the second surface. The workpiece further comprises a thermomechanically affected zone adjacent an interface between the workpiece and the thread forming and hole forming fastener.

[0166] The workpiece material in the region of the thermomechanically affected zone is harder than the remainder of the workpiece material. Harder workpiece material provides improved connection strength compared to softer workpiece material. Harder workpiece material in the region of the thermomechanically affected zone also improves the ability of the joint to undergo fatigue loading without failing.

[0167] The workpiece may comprise a first workpiece layer. The first workpiece layer may comprise the first surface of the workpiece. The workpiece may comprise a second workpiece layer. The second workpiece layer may comprise the second surface of the workpiece. The fastener may at least partially penetrate the second workpiece layer. The fastener may only partially penetrate the second workpiece layer.

[0168] The workpiece may not comprise a stirred zone. The fastener may be removable from the workpiece. The fastener may not be removable from the workpiece.
[0169] The threaded shank section may be a cylindrical threaded shank section.
[0170] In a twelfth aspect of the invention there is provided a joint. The joint comprises a workpiece. The workpiece comprises only a single workpiece layer. The workpiece layer comprises a first surface and a second surface. The joint further comprises a hole forming and thread forming fastener. The hole forming and thread forming fastener comprises a head and a shank. The shank comprises a shank section. The shank comprises a tip section. The shank section extends from the head. The shank section is at least partially threaded. The tip section extends from the shank section and is opposed to the head. The fastener extends through the first surface and does not extend through the second surface.
[0171] The shank section may be a cylindrical shank section. The fastener may be removable from the workpiece. The fastener may not be removable from the workpiece.
[0172] In a thirteenth aspect of the invention there is provided a hole forming and thread forming fastener. The hole forming and thread forming fastener comprises a head and a shank that defines a longitudinal axis. The shank comprises a shank section. The shank comprises a tip section. The shank section extends from the head. The tip section extends from the shank section. The tip section is opposed to the head. At least part of the shank section is threaded. The head is provided with a cutting edge.
[0173] When inserting the fastener into a workpiece to form a joint, workpiece material can be extruded from the workpiece in a direction that is opposed to the direction that the fastener is being inserted into the workpiece. This is undesirable as the extruded material is susceptible to corrosion, which can lead to joint failure. Advantageously, the cutting feature is able to remove any extruded workpiece material from the workpiece.
[0174] The extruded material may be referred to as excess material.
[0175] The cutting feature may be provided to an underside of the head. The cutting feature may be provided to a circumferential periphery of the head.
[0176] The cutting feature may be in the form of one or more ribs. The one or more ribs may comprise six ribs.
[0177] A component of the length of the ribs of the one or more ribs may extend in the radial direction. A component of the length of the ribs of the one or more ribs may extend in the longitudinal direction.
[0178] The cutting feature may be in the form of one or more teeth. The one or more teeth may comprise four teeth. At least part of each tooth of the plurality of teeth may extend in the radial direction. The one or more teeth may form a part of a radially peripheral surface of the head.
[0179] The one or more teeth may extend from an underside of the head towards a top of the head. The one or more teeth may extend from an underside of the head to the top of the head.
[0180] In a fourteenth aspect of the invention there is provided a method for inserting a fastener into a workpiece. The method comprises providing a fastener according to the thirteenth aspect of the invention. The method further comprises providing a workpiece, the workpiece comprising a first surface and a second surface. The second surface is opposed to the first surface. The method further comprises rotating the fastener about the longitudinal axis of the fastener and bringing the fastener into contact with the first surface of the workpiece so as to heat the workpiece. The method further comprises threading the fastener into the workpiece by moving the fastener and the workpiece relative to one another in a first direction, the first direction being parallel to the longitudinal axis of the fastener. The method further comprises extruding at least some workpiece material from the workpiece in a second direction, the second direction being generally opposed to the first direction. The method further comprises removing the extruded material from the workpiece using the cutting edge of the head of the fastener.
[0181] Features disclosed with respect to one aspect of the invention may be combined with

features of another aspect of the invention. For example, features of any of the first, fourth and/or fifth aspects of the invention may be combined with the sixth aspect of the invention.

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## Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0182] Embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

[0183] FIG. **1***a* shows a cross-sectional side view of a fastener in accordance with an embodiment of the present invention;

[0184] FIG. **1***b* shows a perspective view of the fastener of FIG. **1***a;*

[0185] FIG. **2** shows a fastener insertion apparatus for use with any of the depicted fasteners;

[0186] FIG. **3** shows an enlarged view of a nosepiece of the fastener insertion apparatus of FIG. **2**;

[0187] FIG. **4** shows the nose piece of the fastener insertion apparatus of FIG. **2** during a fastener insertion process;

[0188] FIG. **5** shows a joint formed using the fastener of FIG. **1** and the fastener insertion apparatus of FIG. **2**;

[0189] FIG. **6** shows a joint with a die of a fastener insertion apparatus;

[0190] FIG. **7***a* shows a bottom view of a fastener according to a further embodiment of the present invention;

[0191] FIG. **7***b* shows a cross-sectional side view of the fastener of FIG. **7***a;*

[0192] FIG. **8** shows a cross-sectional view of a fastener according to a further embodiment of the present invention;

[0193] FIG. **9** shows a joint formed using the fastener of FIG. **8**;

[0194] FIG. **10** shows a cross-sectional view of a fastener according to a further embodiment of the present invention;

[0195] FIG. **11** shows a cross-sectional view of a joint formed using a fastener according to a further embodiment of the present invention;

[0196] FIG. **12** shows a cross-sectional view of a joint formed using a fastener according to a further embodiment of the present invention;

[0197] FIG. **13** shows a cross-sectional view of a fastener according to a further embodiment of the present invention;

[0198] FIG. **14** shows a cross-sectional view of a joint formed using a fastener according to a further embodiment of the present invention;

[0199] FIG. **15** shows a cross-sectional view of a fastener according to a further embodiment of the present invention;

[0200] FIG. **16** shows a cross-sectional view of a joint formed using a fastener according to a further embodiment of the present invention;

[0201] FIG. **17** shows a cross-sectional view of a joint formed using a fastener according to a further embodiment of the present invention;

[0202] FIG. **18** shows a cross-sectional view of a fastener according to a further embodiment of the present invention;

[0203] FIG. **19** shows a perspective view of a fastener according to a further embodiment of the present invention;

[0204] FIG. **20** shows a cross-sectional side view of a fastener according to a further embodiment of the present invention;

[0205] FIG. **21** shows a cross-sectional view of a joint formed using a fastener according to a further embodiment of the present invention;

[0206] FIG. **22** shows a cross-sectional side view of a fastener according to a further embodiment

of the present invention;
[0207] FIG. **23** shows a cross-sectional side view of a fastener according to a further embodiment of the present invention;
[0208] FIG. **24** shows a fastener insertion apparatus for use with any of the fasteners disclosed herein;
[0209] FIG. **25** shows a detail view of the fastener insertion apparatus of FIG. **24**;
[0210] FIG. **26** shows a joint with a die of a fastener insertion apparatus;
[0211] FIG. **27** shows a die for use with the fastener insertion apparatus of FIG. **2**;
[0212] FIG. **28** a detail view of a fastener according to a further embodiment of the present invention;
[0213] FIG. **29** shows a cross-sectional view of a fastener and workpiece according to a further embodiment of the present invention;
[0214] FIG. **30** shows a cross-sectional view of a fastener and workpiece according to a further embodiment of the present invention;
[0215] FIG. **31** shows a fastener according to a further embodiment of the present invention;
[0216] FIG. **32** shows a fastener according to a further embodiment of the present invention;
[0217] FIG. **33** shows a fastener according to a further embodiment of the present invention;
[0218] FIG. **34** shows a nosepiece of a fastener insertion apparatus for use with any of the fasteners disclosed herein; and
[0219] FIG. **35** shows a side view of a fastener according to a further embodiment of the present invention.

DETAILED DESCRIPTION

[0220] FIGS. **1***a* and **1***b* depict a fastener **2**. The fastener **2** comprises a head **4**. The head **4** comprises an underside **15**. The fastener **2** comprises a shank **10**. The shank **10** extends from the underside **15** of the head **4**. The head **4** comprises a drive geometry **6**, which can be seen in FIG. **1***b*. The periphery of the drive geometry **6** defines a discontinuous profile. In use, the drive geometry **6** is engaged by a fastener insertion apparatus, as will be discussed in more detail below. The drive geometry **6** is an external drive geometry. In some embodiments, the drive geometry **6** may be an internal drive geometry. In some embodiments, the drive geometry **6** may be a snap-off drive geometry.
[0221] The head **4** defines an undercut **8**. The undercut **8** is disposed adjacent to and extends around the shank **10**. The undercut **8** is able to receive material from a workpiece in use, as will be discussed in more detail below. In some embodiments, the undercut **8** need not be present. Where the undercut **8** is not present, the underside **15** of the head **4** may be generally planar.
[0222] The shank **10** comprises a shank section **12**. The shank section **12** comprises a base section **11**. The base section **11** of the shank section **12** extends from the head **4** of the fastener **2**. The shank **10** comprises a tip section **14**. The base section **11** is generally disposed within the undercut **8** of the head **4**. However, in some embodiments, part of the base section **11** may extend beyond the underside **15** of the head **4**. In such embodiments, the base section may taper towards the shank section **12** (as depicted). The shank section **10** defines a shank section diameter SD. The shank section diameter SD may be referred to as the minor diameter. The shank section diameter SD may exclude the diameter of the base section **11**. The shank section diameter SD is determined by, for example, the required connection strength conferred by the fastener. The diameter of the shank section **10** may be at least 2 mm. The diameter of the shank section **12** may be less than or equal to 10 mm. The diameter of the shank section **12** may be at least 3 mm. The diameter of the shank section **12** may be less than or equal to 8 mm. The diameter of the shank section **12** may be 4 mm, such that the fastener **2** is an M4 fastener. The diameter of the shank section **12** may be 5 mm. The diameter of the shank section **12** need not be an integer. For example, the diameter of the shank section **12** may be 4.5 mm. The shank section **12** defines a longitudinal axis L.
[0223] The shank section **12** is threaded. The shank section **12** may therefore be referred to as a

threaded shank section. The thread of the shank section **12** defines a thread diameter TD. The thread diameter TD may be referred to as the major diameter. The thread diameter TD is generally constant along the length of the shank section. In some embodiments, the thread diameter TD of the shank section **12** may be generally constant along at least 50% of the length of the shank section. In some embodiments, the thread diameter TD may be generally constant along at least 75% of the length of the shank section. In some embodiments, the thread diameter TD may be generally constant along at least 90% of the length of the shank section. In some embodiments, the thread of the shank section **12** may comprise a tapered section that adjoins the tip section **14**. The shank section **12** is generally cylindrical. In FIG. **1***a* the entire shank section is shown as being threaded, however, in some embodiments at least part of the shank section **12** may be threaded. The fastener **2** may be made from any suitable material. For example, the fastener **2** may be made from steel. The fastener **2** may be provided with a coating. The coating may be, for example, a zinc nickel coating.

[0224] The tip section **14** extends from the shank section **12**. In some embodiments, the tip section **14** may merge into the shank section **12** by virtue of a radius. In some embodiments, the tip section **14** may merge into the shank section **12** by virtue of a chamfer. The tip section **14** is disposed at an end of the shank section **12** that is opposed to the head **4**. The tip section **14** defines a tip section length TL. In some embodiments, a ratio of the tip section length TL to the thread diameter TD of the shank section **12** may be less than or equal to 0.6. In some embodiments, a ratio of the tip section length TL to the thread diameter TD of the shank section **12** may be less than or equal to 0.4. The ratio of the tip section length TL to the thread diameter TD of the shank section **12** may be calculated by dividing the tip section length TL by the thread diameter TD. The ratio of the tip section length TL to the thread diameter TD may be selected based on, for example, the thickness of the workpiece, as a whole and/or of the individual layers of the workpiece. The ratio of the tip section length TL to thread diameter TD may be proportional to the workpiece thickness.

[0225] The tip section **14** is tapered. The tip section **14** defines a tip angle α. The term tip angle may be understood to refer to the internal angle of the tip of the tip section **14**. The tip angle α is at least 50°. The tip angle α may be at least 70°. The tip angle α may be less than or equal to 160°. The tip angle α may be at least 125° and less than or equal to 135°. The tip angle α may be not 118°. In the depicted embodiment, the tip section **14** is conical. However, in other embodiments, the tip section **14** may be any other tapered shape, such as frustoconical or radiused. Where the tip section **14** is frustoconical, or any other tapered shape, the tip angle α is the angle between diametrically opposed points on the tapered surface of the tip section **14**. Regardless of the shape of the tip section **14**, the tip angle α is the maximum angle defined between two tangents that extend through diametrically opposed points of the tip section **14**. The points through which the tangents extend being disposed at corresponding points along the longitudinal axis L. Where the tip section **14** is radiused, the tip section may be generally dome-shaped. Where the tip section **14** is dome-shaped, the dome may be a pointed dome. Where the tip section **14** is radiused, the radius of the tip section may be at least 2 mm. The radius of the tip section **14** may be equal to or less than 15 mm. The radius of the tip section **14** may be at least 5 mm. The radius of the tip section may be less than or equal to 10 mm. The tip section **14** defines a tip **19**. The tip **19** defines an end point of the tip section **14**. The tip **19** is in the form of a point. In other embodiments, for example where the tip section **14** is frustoconical, the tip **19** may be in the form of a flat surface section.

[0226] The fastener **2** is a hole forming and thread forming fastener. The term thread forming fastener is a term known in the art and refers to a fastener that, instead of cutting a thread in a workpiece, which removes workpiece material, forms a thread by deforming the workpiece material. The fastener **2** forms, rather than cuts, threads in a workpiece by virtue of the geometry of the threads of the shank section **12** and by virtue of the process by which the fastener is inserted into the workpiece, as will be discussed in more detail below. The term hole forming fastener is a term known in the art and refers to a fastener that, instead of cutting a hole in a workpiece, forms a

hole by deforming the workpiece material.
[0227] FIG. **2** shows an insertion apparatus **16** that is capable of inserting a fastener **2** into a workpiece **17**. In some embodiments, the fastener **2** may be inserted into the workpiece **17** using a handheld fastener insertion apparatus. In FIG. **2**, the workpiece **17** comprises a first workpiece layer **18** and a second workpiece layer **20**. The first workpiece layer **18** may be referred to as the top layer of the workpiece **17**. The second workpiece layer **20** may be referred to as the bottom layer of the workpiece **17**. The first workpiece layer **18** defines a first surface **34** of the workpiece **17**. The first surface **34** may be referred to as a top surface of the workpiece **17**. The second workpiece layer **20** defines a second surface **36** of the workpiece **17**. The second surface **36** of the workpiece **17** is opposed to the first surface **34** of the workpiece **17**. The second surface **36** may be referred to as a bottom surface of the workpiece **17**. In some embodiments, the workpiece **17** may comprise only a single workpiece layer. Where the workpiece **17** comprises only a single workpiece layer, the single workpiece layer comprises the first surface **34** and the second surface **36** of the workpiece. In other embodiments, the workpiece **17** may comprise three, four or more workpiece layers. Where the workpiece **17** comprises more than two workpiece layers, the second workpiece layer **20** may still be the bottom workpiece layer. The layer(s) disposed between the first workpiece layer **18** and the second workpiece layer **20** may be referred to as intermediate layer(s).
[0228] The first workpiece layer **18** and the second workpiece layer **20** may be made from any suitable material. The first workpiece layer **18** and the second workpiece layer **20** may be made from a metallic material. In the present embodiment, the first workpiece layer **18** and the second workpiece layer **20** are made from aluminium. The first workpiece layer **18** is made from cast aluminium. The second workpiece layer **20** is made from sheet aluminium. In some embodiments, the first workpiece layer **18** may be made from sheet aluminium. In some embodiments, the second workpiece layer **20** may be made from cast aluminium. Where one or both of the first workpiece layer **18** and the second workpiece layer **20** is made of cast aluminium, the diameter of the shank section **12** may be greater than for other materials. This is because the fastener **2** is typically inserted into a flange portion of a workpiece, and flanges of cast workpieces are typically larger than for, for example, sheet workpieces. Therefore, cast workpieces provide more workpiece material into which the fastener **2** can be inserted. The material of the first and/or second workpiece layers **18**, **20** may have a tensile strength of at least 300 MPa. The material of the first and/or second workpiece layers **18**, **20** may have a tensile strength of equal to or less than 550 MPa. In some embodiments, the material of the first and/or second workpiece layers **18**, **20** may have a tensile strength of at least 100 MPa. In some embodiments, the material of the first and/or second workpiece layers **18**, **20** may have a tensile strength of equal to or less than 1000 MPa. The material of the first and/or second workpiece layers **18**, **20** may have a ductility, measured as percent elongation, of equal to or less than 10%. The material of the first and/or second workpiece layers **18**, **20** may have a ductility, measured as percent elongation, of equal to or less than 5%.
[0229] The insertion apparatus **16** comprises a shaft **22**. The shaft **22** is driven by a first actuator **24** and a second actuator **25**. The first actuator **24** is an electric motor. In some embodiments, the first actuator **24** may be a pneumatic cylinder. In some embodiments, the first actuator **24** may be an air-oil actuator, or an electric-oil actuator. The first actuator **24** is configured to rotate the shaft **22** about a longitudinal axis of the shaft (not depicted in FIG. **2**). The second actuator **25** is a pneumatic cylinder. In some embodiments, the second actuator **25** may be an electric motor. In some embodiments, the second actuator **25** may be an air-oil actuator, or an electric-oil actuator. The second actuator **25** is configured to move the shaft **22** in an axial direction, which is a direction that is parallel to the longitudinal axis of the shaft. The shaft **22** is capable of engaging the drive geometry **6** of the fastener **2** such that rotation of the shaft **22** also results in rotation of the fastener **2**. The insertion apparatus **16** comprises a nosepiece **26**. The fastener **2** is received in the nosepiece **26** prior to insertion of the fastener.
[0230] In some embodiments, the workpiece **17** is not supported on the second workpiece surface

by the fastener insertion apparatus **16** while the fastener is being inserted into a workpiece. This may be referred to as a one-sided insertion. FIG. **2** shows the fastener insertion apparatus **16** carrying out a one-sided insertion. The method of inserting the fastener **2**, or any other fastener disclosed herein, into a workpiece may be a one-sided insertion method.

[0231] The fastener insertion apparatus **16** may comprise a C-frame (not present in FIG. **2**). C-frames may also be referred to as C-clamps. A C-frame may be provided where the workpiece **17** is to be supported on the first workpiece surface and the second workpiece surface while the fastener is being inserted into a workpiece. This may be referred to as two-sided insertion. Therefore, the method of inserting the fastener **2**, or any other fastener disclosed herein, into a workpiece may be a two-sided insertion method. Two-sided insertion allows the force with which the fastener **2** is inserted into the workpiece **117** to be reacted. This results in reduced workpiece deflection as compared to one-sided insertion. Reduced workpiece deflection is advantageous because it reduces the likelihood of damage to the workpiece and/or joint defects, such as gapping, occurring.

[0232] FIG. **2** depicts the insertion apparatus **16** immediately before insertion of the fastener **2** into the workpiece **17**. The insertion apparatus **16** may be any suitable commercially available insertion apparatus. For example, the insertion apparatus **16** may be an Atlas Copco KFLOW® system available from Atlas Copco IAS GmbH of Geretsried, Germany.

[0233] FIG. **3** shows the nosepiece **26** of the fastener insertion apparatus **16** prior to insertion of the fastener **2**. The shaft **22** comprises an end portion **28**. The end portion **28** of the shaft **22** comprises a bore **30**. The bore **30** extends into the end portion **28**. The bore **30** provides the end portion **28** of the shaft **22** with a fastener engaging portion **32**. The geometry of the fastener engaging portion **32** is complementary to the drive geometry **6** of the fastener **2**. The fastener engaging portion **32** is configured to engage the drive geometry **6** of the head **4** of the fastener **2**. In FIG. **3**, the head **4** of the fastener **2** is received within the bore **30** of the end portion **28** of the shaft **22**. Therefore, rotation of the shaft **22** also results in rotation of the fastener **2**. Similarly, movement of the shaft **22** in the axial direction results in movement of the fastener **2** along its longitudinal axis (not depicted in FIG. **3**). When a fastener **2** is received by the fastener engaging portion **32**, the longitudinal axis of the fastener **2** is coaxial with the longitudinal axis of the shaft **22**.

[0234] The method of inserting the fastener **2** into the workpiece **17** will now be described. Although the method will be described with respect to the fastener **2**, the method applies to all embodiments of fasteners described herein. Starting in the position shown in FIG. **3**, the nosepiece **26** is brought into engagement with the first surface **34** of the workpiece **17**. The shaft **22**, and therefore the fastener **2**, is then rotated about its longitudinal axis (not depicted in FIG. **3**) such that the fastener is rotated about its longitudinal axis. The shaft **22** rotates at a speed of e.g. 3000 rpm. In some embodiments, the shaft **22** may rotate at a speed of at least 500 rpm and/or equal to or less than 12000 rpm. In some embodiments, the shaft **22** may rotate at a speed of at least 1000 rpm and/or equal to 6000 rpm. In some embodiments, the shaft may rotate at a speed of equal to or less than 9000 rpm. In some embodiments, the shaft **22** may rotate at a speed of 6000 rpm. In some embodiments, the shaft **22** may rotate at a speed of 9000 rpm. The speed at which the shaft **22** rotates may be determined by, for example, the hardness of the material from which the workpiece **17** is made. The required speed at which the shaft **22** rotates is generally increases with increasing hardness of the material from which the workpiece **17** is made. Although FIG. **3** shows the fastener **2** spaced apart from the workpiece when rotation of the shaft **22** commences, in some embodiments, the fastener **2** may be brought into contact with the workpiece **17** prior to commencement of rotation of the shaft **22** commencing. While the shaft **22** is rotating, the shaft **22** is moved along the axial direction until the tip **19** of the fastener **2** comes into contact with the first surface **34** of the workpiece **17**. Once the tip **19** contacts the first surface **34** of the workpiece **17**, movement of the shaft **22**, and therefore of the fastener **2**, in the axial direction is paused. While the movement of the shaft **22** is paused, the shaft may exert a load on the fastener **2**. The load exerted by the shaft **22** on the fastener **2** may extend in the axial direction. Therefore, the load exerted by the shaft **22** on the fastener **2** may be referred to as an axial load. The load exerted by the shaft **22** on the fastener **2** may be 250 N. Rotation of the shaft **22**, and therefore the fastener **2**, continues, whilst the fastener **2** is in contact with the first surface **34** of the workpiece **17**. This heats the workpiece **17**. This is because of the friction between the tip section **14** of the fastener **2** and the first surface **34** of the workpiece **17**. Where the shaft **22** exerts an axial load on the fastener **2**, the magnitude of the friction generated between the tip section **14** of the fastener **2** and the first surface **34** of the workpiece **17** is greater than where the fastener is not axially loaded.

[0235] Rotation of the shaft **22**, and therefore the fastener **2**, continues until a pre-determined amount of heat is supplied to the workpiece **17**. Heating of the workpiece **17** softens (reduces the hardness of) the material of the workpiece **17**. The material of the workpiece **17** does not, however, melt. Throughout the fastener insertion process, the workpiece **17** remains below the recrystallisation temperature of the workpiece material. The recrystallisation temperature of a material is typically 40-50% of the melting temperature of the material. The recrystallisation temperature may vary depending on, for example, whether the material has undergone any cold deformation (i.e., deformation of the material without raising the temperature of the material). Aluminium alloys typically have a recrystallisation temperature of 340° C. to 400° C., and magnesium alloys typically have a recrystallisation temperature of 300° C. to 400° C. Since the material of the workpiece **17** remains below the recrystallisation temperature, the fastener insertion process is a warm forming process. Since the material of the workpiece **17** remains below the recrystallisation temperature during the fastener insertion process, the material of the workpiece **17** is less soft than if the material of the workpiece were above the recrystallisation temperature. This advantageously allows the fastener **2** to form threads in the workpiece **17** during the fastener insertion process. Throughout the fastener insertion process, the material of the first workpiece layer **18** and of the second workpiece layer **20** do not mix with one another. However, a small degree of mixing of the material of the first workpiece layer **18** with the material of the second workpiece layer **20** may occur.

[0236] Once the predetermined amount of heat has been supplied to the workpiece **17**, the shaft, and therefore the fastener **2**, is moved in the axial direction such that the fastener **2** enters the workpiece **17**. The load that is applied to the fastener **2** while the fastener enters the workpiece **17** is at least 500 N. In some embodiments, the load that is applied to the fastener **2** while the fastener enters the workpiece **17** is less than or equal to 20 kN. In some embodiments, the load that is applied to the fastener **2** while the fastener enters the workpiece **17** is at least 2 kN. In some embodiments, the load that is applied to the fastener **2** while the fastener enters the workpiece **17** is less than or equal to 15 kN. In some embodiments, the load that is applied to the fastener **2** while the fastener enters the workpiece **17** is less than or equal to 10 kN. In some embodiments, the load that is applied to the fastener **2** while the fastener enters the workpiece **17** is less than or equal to 5 kN. In some embodiments, the load that is applied to the fastener **2** while the fastener enters the workpiece **17** is at least 1 kN. In some embodiments, the load that is applied to the fastener **2** while the fastener enters the workpiece **17** is at least 3 kN. A higher load may be required with an increasing number of workpiece layers. In addition, the load used may be proportional to the hardness of the material from which the workpiece **17** is made. Other factors may be considered when determining the load that is applied to the fastener **2** during this stage of the fastener insertion process. This results in the fastener **2** being threaded into the workpiece **17**. FIG. **4** shows the insertion apparatus **16** and fastener **2** whilst the tip **19** of the fastener **2** is in contact with the first surface **34** of the workpiece **17**. The rate at which the shaft **22**, and therefore the fastener **2**, is moved in the axial direction is at least 0.5 mm/sec. Since the shaft **22** moves at a rate of at least 0.5 mm/sec the likelihood of the workpiece overheating during the fastener insertion process is reduced. This is because moving the fastener **2** at this rate ensures that the fastener insertion process is complete before the workpiece **17** overheats. The workpiece **17** may be considered to have overheated where the temperature of the workpiece exceeds the recrystallisation temperature of the material from which the workpiece is made. In some embodiments, the shaft **22** may move in the axial direction at a rate of at least 1 mm/sec. In some embodiments, the shaft **22** may move in the axial direction at a rate of at least 2 mm/sec. The rate at which the shaft **22** moves in the axial direction may be determined at least in part by the ductility of the material from which the workpiece **17** is made. The rate at which the shaft **22** moves in the axial direction may be higher for a higher ductility workpiece material. The rate at which the shaft **22** moves in the axial direction may be lower with decreasing ductility of the material from which the workpiece **17** is made. The rate at which the shaft **22** moves in the axial direction may also be determined at least in part by the amount of heat the is supplied to the workpiece **17** be the fastener **2**. The more heat that is supplied to the workpiece **17** by the fastener, the quicker the rate at which the shaft **22** moves in the axial direction.

[0237] In some embodiments, the rate at which the shaft **22** is moved in the axial direction may be reduced at least once whilst the fastener **2** is being threaded into the workpiece **17**. The reduction in speed may be such that the speed of the shaft **22** in the axial direction is non-zero following the reduction. The reduction in the rate at which the shaft **22** is moved in the axial direction may be such that after the reduction the speed of the shaft **22** in the axial direction is at least 50% of the speed of the shaft in this direction prior to the reduction. The reduction in the rate at which the shaft **22** is moved in the axial direction may be such that, following the reduction, the shaft moves in the axial direction by a distance that is equal to or less than the pitch distance of the thread of the shank section **12** of the fastener **2** per revolution of the shaft. Advantageously, this reduces the likelihood of the threads formed in the workpiece **17** by the fastener **2** being stripped. The threads being stripped is undesirable because this can cause, for example, poor joint strength. The term ‘pitch distance’ may be understood to refer to the distance between corresponding points of the thread of the shank section. Where the rate at which the shaft **22** moves in the axial direction is such that the shaft moves in the axial direction by a distance that is less than the pitch distance of the thread of the shank **12** of the fastener **2** per revolution of the shaft, the material of the workpiece **17** is preferably sufficiently soft such that the thread is reformed in the workpiece with each revolution of the shaft **22**, and therefore fastener **2**. The reduction of the speed of the shaft **22** in the axial direction may occur when the tip **19** of the fastener **2** is disposed in the second workpiece layer **20**. The reduction in the speed of the shaft **22** in the axial direction may occur when the tip **19** comes into contact with the second workpiece layer **20**. The position of the tip **19** may be determined by, for example, monitoring the position of the shaft **22** and determining the amount by which the shaft has moved in the axial direction.

[0238] As the fastener **2** is moved in the axial direction, the material of the workpiece **17** deforms around the tip section **14** and around the shaft section **12** of the fastener **2**. The material of the workpiece **17** deforms into the threads of the shank section **12**. Therefore, a thread is formed in the material of the workpiece **17** such that the fastener **2** is threaded into the workpiece **17**. In addition, an aperture (or hole), in which the fastener **2** is received, is formed in the workpiece **17**. Movement of the shaft **22**, and therefore of the fastener **2**, in the axial direction continues until the tip section **14** is disposed within the second workpiece layer **20**. Movement of the shaft **22**, and therefore of the fastener **2**, in axial direction ceases prior to the tip **19** of the fastener **2** penetrating the second surface **36** of the workpiece **17**. Therefore, once the fastener insertion process is complete, the tip **19** of the fastener **2** is disposed within the second workpiece layer **20** of the workpiece **17**. In addition, once the fastener insertion process is complete, the underside **15** of the head of the fastener **2** contacts the first surface **34** of the workpiece **17**.

[0239] In some embodiments, the speed at which the shaft **22** is rotated about its longitudinal axis, and therefore the speed at which the fastener **2** is rotated about its longitudinal axis, may be reduced at least once whilst the fastener **2** is being threaded into the workpiece **17**. The reduction in rotational speed may be such that the rotational speed of the shaft **22** is non-zero following the reduction. The reduction in the rate at which the shaft **22** rotates be such that the rotational speed of the shaft **22** following the reduction is at least 50% of the rotational speed of the shaft **22** prior to the reduction. In some embodiments, the reduction in the rate at which the shaft **22** rotates be such that the rotational speed of the shaft **22** following the reduction is at least 30% and/or less than or equal to 70% of the rotational speed of the shaft **22** prior to the reduction. The reduction of the rotational speed of the shaft **22** may occur when the tip **19** of the fastener **2** is disposed in the second workpiece layer **20**. The reduction in the rotational speed of the shaft may occur when the tip **19** contacts the second workpiece layer **20**. The rotational speed of the shaft **22** following the reduction may be, for example, 300 rpm.

[0240] Following the reduction in the rotational speed, the amount of heat that is supplied to the workpiece **17** is reduced relative to the amount of heat that is supplied to the workpiece **17** prior to the reduction. This causes the temperature of the material of the workpiece **17** to also reduce. As the temperature of the material of the workpiece **17** reduces, the torque that is required to rotate the shaft **22** at a constant, or approximately constant, rotational speed increases. In addition, the torque that is required to rotate the shaft **22** at a constant, or approximately constant, rotational speed increases when the underside **15** of the head **4** of the fastener **2** contacts the first surface **34** of the workpiece **17**. The torque that is required to rotate the shaft **22** is monitored throughout the fastener insertion process. When the torque that is required to rotate the shaft **22** reaches a predetermined value, rotation of the shaft **22**, and therefore of the fastener **2**, ceases. The pre-determined torque value at which rotation of the shaft **22** ceases may be at least 3 Nm. The predetermined torque value at which rotation of the shaft **22** ceases may be less than or equal to 30 Nm. The pre-determined torque value at which rotation of the shaft ceased may be at least 10 Nm. The predetermined torque value at which rotation of the shaft **22** ceases may be less than or equal to 20 Nm. The predetermined torque value at which rotation of the shaft **22** ceases may be 10 Nm. The magnitude of the predetermined torque may be determined by, for example, the required connection strength and/or the material from which the workpiece **17** is made.

[0241] FIG. **5** shows a joint **38** resulting from the process of inserting the fastener **2** into the workpiece **17**. The head **4** of the fastener **2** is proud of the workpiece **17**. In other words the head **4** protrudes beyond the first surface **34** of the workpiece **17**. In some embodiments, the head **4** may be flush with the workpiece. The head **4** is flush with the workpiece **17** if the head is generally coplanar with the first surface **34** of the workpiece **17**. The fastener **2** is removable from the joint **38**. In some embodiments, the fastener **2** may not be removable. Whether or not the fastener **2** is removable from the joint **38** is determined by the function of the fastener in use. The underside **15** of the head **4** of the fastener **2** engages the first surface **34** of the workpiece **17**. The tip section **14** of the fastener **2** is disposed within the second workpiece layer **20**. The tip section **14** has not penetrated the second surface **36** of the workpiece **17**. Therefore, the tip section **14** of the fastener **2** has only partially penetrated the second workpiece layer **20**. As a result of the fastener insertion process, the second workpiece layer **20** now comprises a protrusion **40**. This is because the fastener **2** has displaced a volume of material of the workpiece **17**. The protrusion **40** extends from the second surface **36** of the workpiece **17**. The tip **19** of the fastener **2** is disposed within the protrusion **40**. No part of the tip section **14** of the fastener **2** extends through the second surface **36** of the workpiece **17**.

[0242] Since the temperature of the workpiece **17** does not exceed the recrystallization temperature of the material of the workpiece **17** throughout the fastener insertion process, the joint **38** comprises a thermo-mechanically affected zone (TMAZ). The thermos-mechanically affected zone is characterised by the material of the workpiece **17** that is subject to both heating and mechanical shearing during the fastener insertion process. The thermo-mechanically affected zone is disposed adjacent an interface between the workpiece **17** and the fastener **2**.

[0243] The quality of the joint produced using the insertion process is a function of the amount of heat that is supplied to the workpiece **17** during the fastener insertion process. Under heating or overheating of the workpiece during the fastener insertion process can result in joint defects.

Examples of such joint defects are inadequate engagement between the threads of the shank section **12** of the fastener **2** and the workpiece **17**, or separation of the first workpiece layer **18** from the second workpiece **20**. Separation between the first workpiece layer **18** and the second workpiece layer **20** may be referred to as gapping. Gapping is undesirable because environmental substances, such as water, can enter the joint, and can damage the joint. The amount of heat supplied to the workpiece **17** during the fastener insertion process is a function of the tip angle α of the tip section **14** of the fastener **2**. The tip angle α of the fastener **2** of the present embodiment can be optimised within the range of at least 50° such that an optimised amount of heat to the workpiece **17**. The optimum tip angle α is a function of at least the ductility of the material of the workpiece **17**, the hardness of the material of the workpiece **17**, the rate at which the fastener is inserted during the fastener insertion process, and the rate at which the fastener is moved axially during the fastener insertion process. This reduces the likelihood of under heating or over heating of the workpiece **17** occurring during the fastener insertion process relative to where the tip angle α of a fastener falls outside of the range of the tip angle α of the present embodiment.

[0244] In some embodiments the fastener insertion process may include applying an adhesive to the first and/or second workpiece layers **18**, **20**. The adhesive is applied to the first and/or second workpiece layers **18**, **20** prior to the workpiece **17** being provided to the fastener insertion apparatus **16**. The adhesive may be applied as a liquid paste layer or as a film layer. The adhesive is applied in the regions of the first workpiece layer **18** and the second workpiece layer **20** through which the fastener **2** is to be inserted. The first workpiece layer **18** and the second workpiece layer **20** are then brought into engagement with one another. Once the first workpiece **18** and the second workpiece **20** have been brought into engagement with one another the adhesive is disposed between the first workpiece layer **18** and the second workpiece **20**. The fastener insertion process then continues as discussed above, with the fastener passing through the adhesive layer. Where an adhesive is applied, the joint resulting from the fastener insertion process comprises an adhesive layer that is disposed between the first workpiece layer and the second workpiece layer.

[0245] The fastener insertion apparatus **16** does not require a die. Where the fastener insertion apparatus **16** does not include a die, the method of inserting the fastener **2** into a workpiece **17** may be a one-sided insertion or a two-sided insertion. The absence of a die may be particularly useful where, for example, the workpiece **17** is a box section or where the point of the workpiece at which the fastener **2** is to be inserted is not accessible from both sides by the fastener insertion apparatus. In these cases, a one-sided insertion may be appropriate. However, a two-sided insertion method may also be used. The absence of a die may also be beneficial for thicker workpieces (e.g., workpieces having a total thickness of at least 6 mm). This is because thicker workpieces are able to better accommodate the volume occupied by the fastener.

[0246] FIG. **24** shows a fastener insertion apparatus **16** that does not include a die. With this fastener insertion apparatus **16**, the second surface of the workpiece (not shown) is supported on a lower arm **29** of the C-frame **35**. Therefore, the fastener insertion apparatus **16** of FIG. **24** allows two-sided insertion of a fastener. FIG. **25** shows a detail view of the lower arm **29** of the C-frame **35**. The lower arm **29** of the C-frame **35** comprises a die holder **37**. A stem of a die (not shown) is receivable in the die holder **37**. A two-sided insertion of a fastener may be carried out with or without a die received in the die holder **37**.

[0247] In some embodiments, a die may be provided during the fastener insertion process. FIG. **6** shows a further embodiment of a joint **138** with a die **135**. The die **135** forms a part of a fastener insertion apparatus (not depicted), and may for example be provided on an opposite side of a C-clamp (or other clamp) from a punch of the fastener insertion apparatus. The die is receivable in the die holder of the lower arm of the C-clamp.

[0248] The die **135** defines a die recess **137**. The die recess **137** defines a die recess volume. The die recess **137** comprises a base surface **139**. The die recess **137** comprises a sidewall **141**. In the depicted embodiment, the die recess **137** is generally cylindrical. In other embodiments, the die recess **137** may be any suitable shape. For example, the die recess may be frustoconical.

[0249] During the fastener insertion process, the die **135** engages the second surface **136** of the workpiece **117**. The die **135** engages the second surface of the workpiece **117** throughout the fastener insertion process. The die **135** is brought into contact with the second surface **136** of the workpiece **117** prior to the fastener **2** making contact with the workpiece **117**. As discussed above, as the fastener **2** is inserted into the workpiece **117**, at least some of the material of the workpiece **117** is displaced. Where the die **135** is provided, the material of the workpiece **117** that is displaced deforms into the die recess **137**. The volume of the die recess **137** may be equal to or greater than the volume of workpiece material that is displaced during the fastener insertion process.

[0250] FIG. **26** shows an alternative die **235**. The die **235** is similar to the die **135**. The die **235** differs from the die **135** in that the die recess **237** does not comprise a base surface. The die recess **237** comprises a sidewall **241**. Since the die recess **237** does not comprise a base surface, deformation of the workpiece material in the direction that the fastener is inserted into the workpiece is less restricted as compared to a die recess that does comprise a base surface. Deformation of the workpiece material is moulded by the sidewall **241** of the die recess **237**. The die may comprise a surface that is disposed at or towards a bottom end of the recess, the surface being spaced apart from the second surface of the workpiece, in use. With this arrangement, the second surface does not come into contact with the base surface during a fastener insertion process.

[0251] FIG. **27** shows a further alternative die **335**. The die **335** may be used with the fastener insertion apparatus **2** shown in FIGS. **2** to **4**. The die **335** is in the form of a die table. The die table **335** comprises a plurality of die recesses **337**. When inserting a fastener into a workpiece using the die **335**, the nosepiece of the fastener insertion apparatus (not shown) is positioned above one of the die recesses **337**. The die **337** allows a plurality of fasteners to be inserted at different locations of a workpiece (not shown) without moving the workpiece. In some embodiments, the die recesses **337** of the die table may take the form of a continuous channel or a continuous groove that extends along a length or width of the die table.

[0252] In some embodiments, the fastener may comprise a plurality of surface irregularities. FIGS. **7***a* and **7***b* show such an embodiment of a fastener **102**. Like numerals for the fastener **2** have been used for the fastener **102**. In this embodiment, the tip section **114** is depicted as being frustoconical. However, in other embodiments, the tip section may be conical. Since the tip section **114** is frustoconical, the tip **119** of the tip section defines a planar surface section.

[0253] The fastener **102** differs from the fastener **2** of FIG. **1** in that the tip section **114** of the fastener **102** comprises a plurality of surface irregularities **142** (only one of which is labelled in FIG. **6**). In the depicted embodiment, the surface irregularities are in the form of facets **142**. In the depicted embodiment, the plurality of facets **142** comprises six facets. However, in other embodiments, the plurality of facets **142** can comprise any suitable number of facets. In some embodiments, the plurality of facets **142** may comprise at least two facets. In some embodiments, the plurality of facets **142** may comprise at least four facets. In some embodiments, the plurality of facets **142** may comprise less than or equal to nine facets. In some embodiments, the plurality of facets **142** may comprise less than or equal to eight facets. The optimum number of facets of the plurality of facets **142** may be determined by, for example, the desired fastener insertion time (i.e., the time required to insert the fastener into a workpiece), the material properties of the workpiece into which the fastener **102** is to be inserted. With an increasing number of facets, the amount of heat supplied to the workpiece during the fastener insertion process also increases. Where the workpiece is made from aluminium, the optimum number of facets is preferably six. This is because the likelihood of the workpiece being overheated or under heated is minimised. The plurality of facets **142** are arranged as an array. Therefore, the plurality of facets **142** are distributed around the longitudinal axis of the fastener **2**. In the depicted embodiment, the plurality of facets **142** adjoin one another. However, in other embodiments, the facets of the plurality of facets **142** may be spaced apart from one another. Where the facets of the plurality of facets **142** are spaced apart from one another, radiused surface sections may be disposed between the facets. Each facet of the plurality of facets **142** is in the form of a planar surface section. However, in other embodiments, each facet of the plurality of facets **142** may be in the form of a radiused surface section.

[0254] FIG. **7***b* shows a cross-sectional side view of the fastener **102**. The tip section **114** defines a tip section length TL. The tip section length TL extends along a direction that is parallel to a longitudinal axis L of the fastener **102**. The shank section **112** defines a shank section length SL. The shank section length SL extends along a direction that is parallel to the longitudinal axis L of the fastener **102**. The shank section length SL extends from the underside **115** of the head **104** of the fastener **102** to the tip section **114**. A ratio of the shank section length SL to the tip section length TL is at least 2.5. In some embodiments, the ratio of the shank section length SL to the tip section length TL may be at least 3. In some embodiments the ratio of the shank section length SL to the tip section length TL may be at least 3.5. In some embodiments, the ratio of the shank section length SL to the tip section length TL may be at least 2. The ratio of the shank section length SL to the tip section length TL may be determined by, for example, the required connection strength provided by the fastener **102**, and/or the total thickness of the workpiece into which the fastener **102** is to be inserted. A larger ratio of shank section length SL to tip section length TL increases the connection strength because more thread is provided to be secured to the workpiece **17**. The ratios of the shank section length to the tip section length disclosed herein may apply to all embodiments of fastener disclosed in this document.

[0255] Referring again to FIG. **7***a*, each facet of the plurality of facets **142** extends from the tip **119** towards the shank section **112**. In particular, each facet of the plurality of facets **142** extends from the tip **119** to the shank section **112**. However, in some embodiments, each facet of the plurality of facets **142** may not extend all the way to the shank section **112**, but may, instead, extend from the tip **119** towards the shank section **112**. In which case, a surface section is disposed between the plurality of facets **142** and the shank section **112**. Whether the plurality of facets **142** extend all the way to the shank section **112** or not may be determined by the material from which the workpiece is made. The plurality of facets **142** extending to the shank section **112** provides the workpiece with more heat compared to where the plurality of facets **142** do not extend all the way to the shank section **112**. The tip angle α of the fastener **102** varies around the longitudinal axis L of the fastener. The tip angle α of the fastener **102** is determined by the smallest angle between two diametrically opposed points of the tip section **112**.

[0256] As discussed above, the method of inserting the fastener **2**, as described above, applies to each of the fasteners disclosed in this document. In use, the plurality of facets advantageously reduce the likelihood of the workpiece being under heated while inserting the fastener **102** into a workpiece. The facets of the plurality of facets **142** increase the amount of friction between the tip section **114** and the workpiece (compared with a rotationally symmetric tip section). This increase in friction increases the amount of heat that is generated between the tip section and the workpiece, thereby reducing the likelihood of the workpiece being under heated whilst the fastener **102** is being inserted. Since the likelihood of under heating of a workpiece occurring while inserting the fastener **102** is reduced, the quality of the joint created using the fastener **102** is improved (compared with a joint created using a fastener which does not have a plurality of facets).

[0257] In some embodiments, the plurality of surface irregularities may be in the form of a plurality of ribs. Such an embodiment is shown in FIG. **28**. The plurality of ribs **2142** provide the same benefits as the plurality of facets **142**. The plurality of ribs **2142** comprises four ribs. However, in some embodiments, the plurality of ribs **2142** may comprise at least two ribs and/or up to six ribs. A component of the length of each rib of the plurality of ribs **2142** extends in a radial direction (i.e., perpendicular to a longitudinal axis L of the fastener **2102**). The ribs **2142** extend from the tip **2119** of the tip section **2114**. A component of the length of each rib of the plurality of ribs **2142** extends in a circumferential direction (i.e., about the longitudinal axis L of the fastener

**2102**). A thickness and/or width of the ribs **2142** may be either uniform of non-uniform. The thickness of the ribs **2142** may be understood to refer to the distance by which they protrude from a surface of the tip section **2114**. The thickness and/or width of the ribs **2142** may be at a minimum at or adjacent to the tip **2119** of the tip section **2114**. The thickness and/or width of the ribs **2142** may be at a maximum at or adjacent to the tip **2119** of the tip section **2114**. In some embodiments, the plurality of surface irregularities may include two or more facets and one or more ribs.
[0258] In some embodiments, the fastener may comprise a fixing point. In some embodiments, the fixing point is in the form of a stud. Preferably, where the fastener comprises a stud, the fastener insertion apparatus does not comprise a die. This is because, where the fastener comprises a stud, the point of the workpiece into which the fastener is to be inserted is often inaccessible for a die. However, the fastener insertion apparatus may include a die where the fastener comprises a stud. FIG. **8** shows an embodiment of a fastener **202** which comprises a fixing point. Like numerals for the fasteners **2**, **102** have been used for the fastener **202**. The fastener **202** differs from the fasteners **2**, **102** in that the fastener **202** further comprises a stud **246**. However, the tip angle of the fastener **202** may correspond with the tip angle of the fastener **2**. Similarly, the tip section **214** may comprise a plurality of facets.
[0259] The stud **246** extends from a top side **244** of the head **204** of the fastener **202**. The topside **244** is opposed to the underside **215** of the head **204**. The stud **246** is threaded. The stud **246** is generally cylindrical. The stud **246** extends along the longitudinal axis L of the fastener **202**. The stud **246** allows a component, such as an electrical contact, to be secured to the fastener **202**. The stud **246** defines a diameter. The diameter of the stud **246** need not be the same as the diameter of the shank section **212**. The diameter of the stud **246** may be at least 2 mm. The diameter of the stud **246** may be less than or equal to 10 mm. The diameter of the stud **246** may be at least 3 mm. The diameter of the stud **246** may be less than or equal to 8 mm. The diameter of the stud **246** may be less than or equal to 10 mm. The diameter of the stud **246** may be at least 3 mm. The diameter of the stud **246** may be less than or equal to 8 mm. The diameter of the stud **246** need not be an integer. For example, the diameter of the stud **246** may be 4.5 mm.
[0260] In some embodiments, the fixing point may be in the form of, for example, a loop that extends from the topside **244** of the fastener **202**.
[0261] FIG. **9** shows the fastener **202** inserted into a workpiece **217**, thereby forming a joint **238**. In the depicted embodiment, the workpiece **217** comprises the first workpiece layer **218**. The first workpiece layer **218** is the only workpiece layer of the workpiece **217**. However, in other embodiments, the workpiece **217** may comprise a plurality of workpiece layers. Since the first workpiece layer **218** is the only workpiece layer, the first workpiece layer **218** comprises the first surface **234** of the workpiece and the second surface **236** of the workpiece.
[0262] In some embodiments, the fastener may comprise a bore. FIG. **10** shows such an embodiment of a fastener **302**. Like numerals for the fasteners **2**, **102**, **202** have been used for the fastener **302**. Although not depicted, the fastener **302** may also comprise a stud that extends from the top side **344** of the head **304** of the fastener **302**.
[0263] The fastener **302** comprises a bore **348**. The bore **348** extends into the tip section **314** of the fastener **302**. The bore **348** extends along a direction that is parallel with the longitudinal axis L of the fastener **302**. The shank **310** defines a shank length ZL. The bore **348** defines a bore depth BD. A ratio of the bore depth BD to the shank length ZL may be at least 0.25. In other words, the bore **348** extends along at least 25% of the shank length ZL. The tip section **314** comprises a ring leading edge **350**. The shank length ZL extends from the underside **315** of the head **304** to the ring leading edge **350**. The ring leading edge **350** may define a ring surface. In the depicted embodiment, the ring leading edge **350** is planar. However, in some embodiments the ring leading edge **350** may be non-planar. In such embodiments, the ring leading edge **350** may be serrated. The ring leading edge **350** being serrated reduces the likelihood of the workpiece being under heated during the fastener insertion process. The bore defines a bore surface **355**. In some embodiments,

the bore surface **355** may define a plurality of surface irregularities. The surface irregularities may be in the form of, for example, tabs, ribs and/or protrusions. Where the bore surface **355** defines a plurality of surface irregularities the surface irregularities interlock with the workpiece into which the fastener **302** has been inserted, thereby improving the strength of the connection between the fastener **302** and the workpiece.

[0264] The tip angle α of the tip section **314** is at least 50°. Because the fastener **302** comprises the bore **348**, and so the tip section **314** defines the ring leading edge **350**, the initial contact area between the fastener **302** is greater than if the bore **348** were not present, for a constant tip angle. This allows the tip angle α of the tip section **314** of the fastener **302** to be reduced relative to where no bore is present because the increase in contact area increases the amount of heat that is supplied to a workpiece in use. Thus, when a bore is present the fastener may for example work well when the tip angle is at least 50°, and when no bore is present the fastener may for example work well when the tip angle is at least 70°.

[0265] The bore **348** defines a bore internal diameter d. A ratio of the shank diameter to the bore internal diameter d may be at least 1.5. This advantageously provides sufficient material in the shank section **312** such that the fastener **302** is able to withstand force as required in use. In some embodiments, the ratio of the shank diameter to the bore internal diameter d may be at least two.

[0266] The ring leading edge **350** merges into the bore internal diameter d by virtue of a tapered surface section **352**. The tapered surface section **352** comprises a chamfered surface section **354**. The angle between diametrically opposed points of the chamfered surface section **354** is at least 25 degrees. The angle between diametrically opposed points of the chamfered surface section **354** is less than or equal to 45 degrees. The chamfered surface section **354** adjoins the ring leading edge **350**. The tapered surface section **352** comprises a radius surface section **356**. The radius surface section **356** adjoins the chamfered surface section **354**. The radius surface section **356** adjoins the bore internal diameter d. In some embodiments, the tapered surface section **352** may comprise only one of the chamfered surface section **354** and the radius surface section **356**. In some embodiments, the chamfered surface section **354** may adjoin the bore internal diameter d and the radius surface section **356** may adjoin the ring leading edge **350**. In some embodiments, the entirety of the bore **348** may be cylindrical.

[0267] During the fastener insertion process a volume of workpiece material is displaced by the fastener **304**. The presence of the bore **348** advantageously reduces the amount of workpiece material that is displaced during the fastener insertion process. This is because a volume of workpiece material is received by the bore, thereby reducing the amount of workpiece material that is displaced by the fastener **302**. Since the bore **348** extends along at least 25% of the shank length, the amount of material displaced by the fastener **302** during the fastener insertion process is sufficient such that the likelihood of the workpiece layer separating is reduced. The tapered surface section **352** advantageously encourages deformation of the material of the workpiece into the bore **348**. The geometry by which the ring leading edge **350** merges into the bore internal diameter advantageously distributes the stress that the fastener **302**, in particular the shank **310**, is subject to during the fastener insertion process more evenly.

[0268] The bore **348** defines a bore depth. The bore depth extends from the ring leading edge **350** and towards the head **304** in a direction that is parallel to the longitudinal axis L of the fastener **302**. The tapered surface section **352** defines a tapered surface section depth. The tapered surface section depth extends from the ring leading edge **350** towards the head **304** of the fastener **302** in a direction that is parallel to the longitudinal axis L of the fastener **302**. A ratio of the tapered surface section depth to the bore depth is at least 0.1. In some embodiments, the ratio of the tapered surface section depth to the bore depth is preferably at least 0.2. The ratio of the tapered surface section depth to the bore depth being at least 0.2 provides gradual transition between the ring leading edge **350** and the bore internal diameter d. This provides more even stress distribution in the tip section **314** during the fastener insertion process, thereby reducing the likelihood of a defect occurring while inserting the fastener **302** into a workpiece. In some embodiments, the ratio of the tapered surface section depth to the bore depth may be at least 0.5.

[0269] In some embodiments, the fastener may not be removable from the workpiece into which it has been inserted. FIG. **11** shows such an embodiment of a fastener **402**. Like numerals for the fasteners **2**, **102**, **202**, **302** have been used for the fastener **402**. The fastener **402** may comprise a bore, a stud, a plurality of facets, and/or a tip angle in accordance with the previous embodiments described herein.

[0270] The shank section **412** comprises a first thread portion **458**. The first thread portion **458** adjoins the tip section **414**. The shank section **412** comprises a second thread portion **460**. The shank section **412** comprises a plain portion **462**. The plain portion **462** may be referred to as a horizontal thread gap. The plain portion **462** is disposed between the first thread portion **458** and the second thread portion **460**. FIG. **11** shows the fastener **402** inserted into a workpiece **417**, thereby forming a joint **438**. The plain portion **462** spaces the first thread portion **458** and the second thread portion **460** apart from one another. Because of this, it is not possible to remove the fastener **402** from the workpiece **417** by rotating the fastener **402** in an opposite direction to the threads of the shank section **412**. This is because the material of the workpiece **417** interferes with the second thread portion **460**, thereby preventing rotation of the fastener. During the fastener insertion process, the material of the workpiece **417** is softened due to the heat supplied to it. The material of the workpiece **417** being softened allows the material of the workpiece to deform around the first thread portion **458** and the second thread portion **460**. In some embodiments, the pitch distance, the thread angle, and/or the diameter of the first thread portion **458** may be greater than or equal to that of the second thread portion **460**. In some embodiments, the pitch distance and/or diameter of the first thread portion **458** may be less than or equal to that of the second thread portion **460**.

[0271] In some embodiments, at least part of the shank section of the shank of the fastener is not threaded. FIG. **12** shows an embodiment of such a fastener **502** that is inserted into a workpiece **517**, thereby forming a joint **538**. Like numerals for the fasteners **2**, **102**, **202**, **302**, **402** have been used for the fastener **502**. In this embodiment, the drive geometry **506** of the head **504** of the fastener **502** is an internal drive geometry. However, the drive geometry **506** may be an external drive geometry, or otherwise. The fastener **502** may comprise any of the features disclosed in relation to the previous embodiments described herein.

[0272] The shank section **512** comprises a first shank portion **570**. The shank section **512** comprises a second shank portion **572**. The first shank portion **570** adjoins the head **504** of the fastener **502**. The first shank portion **570** comprises the base section **511** of the shank section **512**. The second shank portion **572** adjoins the first shank portion **570** and the tip section **514**. The first shank portion **570** is not threaded. The second shank portion **572** is threaded. Since only part of the shank section **510** is threaded, the force that is required to insert the fastener **502** into a workpiece is reduced relative to where the entire shank section is threaded. This is because the resistance to insertion of the fastener is reduced relative to where the entire shank section **510** is threaded (this is because less surface area is in contact with the workpiece).

[0273] In some embodiments, the fastener may comprise one or more retaining features that, in use, engage a workpiece into which the fastener is inserted. FIG. **13** depicts an embodiment of such a fastener **602**. Like numerals for the previous embodiments of the fastener described herein have been used for the fastener **602**. The first shank portion **670** of the fastener **602** is not threaded. The second shank portion **672** is threaded. The first shank portion **670** comprises a plurality of protrusions **674** (only one of which is labelled in FIG. **13**). The plurality of protrusions **674** are arranged as an array. Disposed alternatively between the plurality of protrusions **674** are a plurality of cavities **675**. The plurality of protrusions **674** comprises six protrusions. However, in other embodiments, the plurality of protrusions may comprise any suitable number of protrusions. The plurality of protrusions **674** do not extend radially beyond the threads of the second shank portion

**672**. In some embodiments, the plurality of protrusions **674** may project radially beyond the threads of the second shank portion **674**. In the depicted embodiment, the protrusions of the plurality of protrusions **674** extend parallel to the longitudinal axis L of the fastener **602**. In other embodiments, the protrusions of the plurality of protrusions may be twisted about the longitudinal axis L of the fastener **602**. Where the plurality of protrusions twist about the longitudinal axis L of the fastener **602**, the protrusions of the plurality of protrusions **674** extend around the longitudinal axis L of the fastener **602** and in a direction parallel to the longitudinal axis L of the fastener.

[0274] When inserted into a workpiece (not shown in FIG. **13**), the material of the workpiece deforms around the plurality of protrusions **674** and into the cavities of the plurality of cavities **675**. The material of the workpiece at least partially fills the cavities of the plurality of cavities **675**. Therefore, in use, the plurality of protrusions **674** engage the workpiece into which the fastener is inserted. Rotation of the fastener **602** following insertion is therefore prevented by virtue of the interaction between the plurality of protrusions **674** and the material of the workpiece. Therefore, the plurality of protrusions **674** can be referred to as retaining features. In some embodiments, only one protrusion need be provided. Therefore, the fastener **602** comprises one or more retaining features. In some embodiments, the one or more retaining features may be in the form of, for example, ribs that extend around, or in a direction parallel to, the longitudinal axis L of the fastener **602**.

[0275] In some embodiments, the tip section of the fastener may define an undercut. Such an embodiment is shown in FIG. **14**. Like numerals for the previous fasteners disclosed herein have been used for the fastener **702**. FIG. **14** shows the fastener **702** inserted into a workpiece **717**, thereby creating a joint **738**. The maximum diameter of the tip section **714** of the shank **710** is greater than the diameter of the shank section **712** of the shank **710**. Therefore, an undercut **776** is defined by the tip section **714**. The undercut **776** is disposed adjacent to the shank section **712**. Because of the undercut **776**, the amount of interference between the fastener **702** and the workpiece **717** is increased relative to where the undercut **776** is not provided. This increase in interference between the fastener **702** and the workpiece **717** increases the connection strength between the fastener **702** and the workpiece **717**.

[0276] In some embodiments, the fastener may comprise a washer. Such an embodiment is shown in FIG. **15**. Like numerals for the previous embodiments disclosed herein have been used for the fastener **802**. The fastener **802** may comprise any of the features described with reference to the previous embodiments. The fastener **802** comprises a washer **878**. The washer **878** engages the underside **815** of the head **804** of the fastener **802**. Providing the washer **878** reduces the likelihood of the fastener rotating during use (i.e. after the joint has been formed). Rotation of the fastener **802** in use is undesirable because this can result in loosening of the fastener. Therefore, providing the washer **878** provides a more robust joint. The washer **878** may be configured such that, in use, the washer seals against the head **804** of the fastener **802** and against the workpiece (not shown in FIG. **15**). The seal may be a watertight seal such that water, or other liquids, cannot pass under the head **804** of the fastener in use. The presence of water under the head **804** of the fastener is undesirable because this can lead to corrosion. The washer **878** may be made from aluminium. The washer **878** being formed of aluminium may be particularly advantageous where the fastener **802** is formed of steel and the workpiece is formed of magnesium. The washer **878** being formed of aluminium prevents the formation of a galvanic corrosion cell.

[0277] In some embodiments, the diameter of the shank of the fastener need not be uniform along the length of the shank. Such a fastener **902** is shown in FIG. **16**. Like numerals for the fasteners of the previous embodiments have been used for the fastener **902**. FIG. **16** shows the fastener **902** inserted into a workpiece **917**, thereby creating a joint **938**. The fastener **902** may comprise any of the features described with reference to the previous embodiments. In this embodiment, the diameter of the first shank portion **970** is greater than the diameter of the second shank portion **972**. In other embodiments, the diameter of the second shank portion **972** may be greater than the diameter of the first shank portion **970**. The geometry of the shank section **912** of this embodiment displaces less material of the workpiece **917** as compared to a fastener having a shank of constant diameter. Furthermore, the axial load applied to the fastener **902** during the fastener insertion process can be reduced as compared to a fastener having a shank of constant diameter. This advantageously reduces the likelihood of the workpiece **917** cracking as a result of the fastener insertion process. Since the likelihood of the workpiece **917** cracking is reduced, the fastener **917** advantageously may produce more robust joints. In addition, since less material is being displaced by the fastener **917**, the resistance to deformation by the workpiece **917** is reduced relative to a fastener having a shank of constant diameter. Therefore, the time taken to insert the fastener into the workpiece **917** is reduced, where the axial load applied to the fastener **902** is equal to an axial load applied to a fastener having a shank of constant diameter. This therefore results in a more efficient fastener insertion process.

[0278] In some embodiments of the method of inserting the fastener, the method may comprise providing an aperture in the first workpiece layer. This may be particularly advantageous where the workpiece includes layers of different materials. In particular where the workpiece layer or layers to which the aperture or apertures is provided is not readily formable. Where the workpiece comprises one or more intermediate layers, the method may also comprise providing an aperture in at least one or more of the intermediate layers. The method may comprise providing an aperture in all of the intermediate layers. The aperture provided in the first workpiece layer may be referred to as a pre-hole. FIG. **17** depicts a joint **1038** resulting from such a method. As can be seen the first workpiece layer **1018** comprises an aperture **1090**. The aperture **1090** may be provided using any known method, such as machining. In this embodiment, the second workpiece layer **1020** comprises the first surface **1034** of the workpiece **1017**. The material from which the first workpiece layer **1018** is made may be, for example, a composite material. The material from which the first workpiece layer **1018** is made may be any other low ductility material.

[0279] The shape of at least part of the aperture may correspond to the shape of the fastener. FIG. **29** shows an embodiment in which the shape of the aperture **1990** corresponds with the shape of the head **1904** of the fastener **1902**. FIG. **30** also shows an embodiment in which the shape of the aperture **2090** corresponds with the shape of the head **2004** of the fastener **2002**. In FIGS. **29** and **30**, the shape of a part of the apertures **1990**, **2090** each correspond with the shape of the underside **1915**, **2015** of the head **1904**, **2004** of the respective fastener **1902**, **2002**. The aperture may be sized with respect to the fastener that is to be inserted into the workpiece **1917**, **2017**. The size of the aperture **1990**, **2090** with respect to the fastener **1902**, **2002** may be chosen based on, for example, the material from which the workpiece **1917**, **2017** is made. For example, a larger aperture may be used for harder and/or stronger workpieces. In FIG. **29**, the size of the aperture **1990** corresponds with the size of the portion of the fastener **1902** that is to be received in the first workpiece layer **1918**. That is to say, a ratio of the size of the aperture **1990** to the size of the portion of the fastener **1902** that is to be received in the first workpiece layer **1918** is 1:1. In FIG. **30**, the size of the aperture **2090** is 25% of the size of the portion of the fastener **2002** that is to be received in the first workpiece layer **2018**. That is to say, a ratio of the size of the aperture **2090** to the size of the portion of the fastener **2002** that is to be received in the first workpiece layer **2018** is 1:4. In general, the ratio of the size of the aperture to the size of portion of the fastener that is to be received by the first workpiece layer may be at least 1:4 and/or up to 1:1, and/or up to 2:1.

[0280] In some embodiments, where the method comprises providing an aperture in the first workpiece layer **1018**, the method may additionally comprise centring the fastener **1002** with respect to the aperture **1090**. Centring of the fastener **1002** with respect to the aperture **1090** may be performed with a machine vision system. The machine vision system may form a part of the fastener insertion apparatus (not shown in FIG. **17**). The machine vision system is configured to identify the aperture **1090** and determine a centre of the aperture. This information is then provided to the fastener insertion apparatus. The fastener insertion apparatus then adjusts the position of the fastener **1002** such that the fastener is centred with respect to the aperture **1090**. Following the centring of the fastener **1002** with respect to the aperture **1090**, the longitudinal axis L of the fastener is generally coaxial with a centre axis (not shown in FIG. **17**) of the aperture. The centre axis of the aperture **1090** being the axis that extends along a centre of the aperture.

[0281] Centring the fastener **1002** with respect to the aperture **1090** advantageously reduces the likelihood of the fastener contacting a surface of the aperture during the fastener insertion process. Contact between the fastener **1002** and the surface of the aperture is undesirable because this can result in an improperly inserted fastener. By centring the fastener **1002**, consistently formed joints are provided.

[0282] The method for inserting a fastener into the workpiece **1017** is otherwise identical to the method described above. Providing the aperture **1090** allows a fastener to be used to connect a first workpiece layer **1018** to a second workpiece layer **1020** where the first workpiece layer **1018** is made from a material that is not readily formable.

[0283] In some embodiments, the drive geometry of the fastener may be an internal drive geometry. FIG. **18** depicts a fastener **1102** in which the drive geometry **1106** is an internal drive geometry. This allows the fastener **1102**, following insertion into a workpiece (not shown in FIG. **18**) to be generally flush with the first surface of the workpiece. An internal drive geometry may be hexagonal, or may have some other suitable shape (the same applies to an external drive geometry) Because the drive geometry **1106** is an internal drive geometry, the diameter of the head **1104** is reduced compared to a fastener having an external drive geometry. This allows the fastener **1102** to be used on narrower workpieces (not shown in FIG. **18**), as compared to a fastener having an external drive geometry, without the head **1104** overhanging from the workpiece. This drive geometry, and other internal drive geometries, may be used in combination with other fastener embodiments.

[0284] In some embodiments, the fastener may comprise one or more retaining features. FIG. **19** shows a further embodiment of a fastener **1202** that comprises one or more retaining features. In this embodiment, the one or more retaining features are in the form of a plurality of recesses **1292** (only one of which is labelled in FIG. **19**). In some embodiments, only at least one recess need be provided. In the depicted embodiment, the plurality of recesses **1292** comprises four recesses. In other embodiments, the plurality of recesses **1292** may comprise any suitable number of recesses. For example, the plurality of recesses **1292** may comprise at least two recess. In some embodiments, the plurality of recess **1292** may comprise equal to or less than 4 recesses. In some embodiments, the plurality of recess **1292** may comprise equal to or less than 6 recesses. The recesses **1292** extend into the shank section **1212** of the fastener **1202**. The recesses **1292** extend towards the longitudinal axis L of the fastener **1202**. The plurality of recesses **1292** extend in a direction that is parallel to the longitudinal axis L of the fastener **1202**. In some embodiments, the plurality of recesses **1292** may extend at least partially around the longitudinal axis L of the fastener **1202**.

[0285] The plurality of recesses **1292** extend along the entire length of the shank section **1212**. In some embodiments, the plurality of recesses may extend part way along the shank section **1212**. In some embodiments, the plurality of recesses **1292** may only extend along the first shank portion **1270**. In some embodiments, the plurality of recesses **1292** may only extend along the second shank portion **1272**. The plurality of recesses **1292** may be referred to as vertical thread gaps. Because of the plurality of recesses **1292**, the fastener **1202** cannot be removed from a workpiece into which the fastener is inserted. This is because of the interference between the plurality of recesses and the material of the workpiece.

[0286] In some embodiments, the fastener may comprise one or more secondary securing features. The one or more secondary securing features may be in the form of one or more surface irregularities. FIG. **20** shows an embodiment of a fastener **1302** that comprises one or more secondary securing features. In the depicted embodiment, the one or more secondary securing features are in the form of a thread **1394** that is provided to the underside **1315** of the head **1304** of the fastener **1302**. The direction of the thread **1394** is the same as the direction of the thread of the shank section **1312**. In some embodiments, the direction of the thread **1394** may be opposed to the direction of the thread of the shank section **1312**. In other embodiments, the one or more retaining features may be in the form of any other type of surface irregularity, such as protrusions and/or ribs. When inserted into a workpiece (not shown in FIG. **20**), the thread **1394** engages the workpiece, thereby further securing the fastener **1302** to the workpiece. The one or more secondary securing features advantageously reduce the likelihood of the fastener **1302** becoming loose when subjected to vibrational loading. Therefore, the one or more secondary securing features advantageously produce a more robust joint.

[0287] In some embodiments, where a die is provided during the fastener insertion process, the die may be a ring die. Such an embodiment is shown in FIG. **21**. In FIG. **21**, the fastener **702** is secured to the workpiece **1417**. However, any of the fasteners described in this document may be used in combination with a ring die. FIG. **21** shows a joint **1438** in combination with a ring die **1495**. The ring die **1495** comprises a cavity **1496**. The ring die **1495** comprises a projection **1497**. The projection **1497** is ring-shaped, and is provided as a lip round the cavity **1496**. During the fastener insertion process, the projection **1497** urges the material of the workpiece **1417** into the threads of the fastener **702**. In addition, where the fastener comprises an undercut **776**, the projection **1497** urges the material of the workpiece **1417** into the undercut **776** of the fastener **702**. Advantageously, this improves the engagement between the fastener **702** and the material of the workpiece **1417**. Improved engagement between the fastener **702** and the material of the workpiece **1417** advantageously improves the strength of the connection between the fastener **702** and the workpiece **1417**.

[0288] As discussed above, in some embodiments, the tip section of the shank may be radiused. Such an embodiment is shown in FIG. **22**. As can be seen, the tip section **1514** is radiused. The tip **1519** of the tip section **1514** is pointed. In some embodiments, the tip **1519** of the tip section **1514** may be radiused. The tip section **1514** defines a tip angle α. The tip angle α is the angle between a first tangent line T**1** and a second tangent line T**2**. The first tangent line T**1** and the second tangent line T**2** extend through diametrically opposed points of the tip section **1514**. The point through which the first tangent line T**1** extends is at the same position along the longitudinal axis L of the fastener **1502** as the point through which the second tangent line T**2** extends. The position of the points through which the first and second tangent lines T**1**, T**2** extend are such that the angle between the first and second tangent lines T**1**, T**2** is a maximum value.

[0289] As discussed above, the fastener may be provided with a bore that is entirely cylindrical. Such an embodiment is shown in FIG. **23**. As can be seen, the entirety of the bore **1648** of the fastener **1602** is cylindrical. The tip angle α of the tip section **1614** is the angle between diametrically opposed points of the tip section **1614**. The tip angle α in FIG. **23** is measured between a first tangent line T**1** and a second tangent line T**2**. The first tangent line T**1** and the second tangent line T**2** extend through diametrically opposed points of the tip section **1614**.

[0290] FIG. **31** shows a further embodiment of a fastener **1802**. The fastener **1802** comprises a bore **1848**. The bore **1848** is conical. In other, non-depicted, embodiments, the bore **1848** may be frustoconical, cylindrical, or any other suitable shape. A ratio of the bore depth BD to the shank length ZL may be up to 0.25. That is to say, the bore depth BD may be up to 25% of the shank length ZL. In some embodiments, the bore depth may be up to 10% of the shank length ZL. The bore depth BD may be chosen based on, for example, the hardness of the workpiece into which the fastener **1802** is to be inserted, the strength of the workpiece, and/or the thickness of the workpiece. A shallower bore depth BD as a ratio of the shank length ZL may be particularly suited for harder, stronger, and/or thinner workpieces. The provision of a bore results in a ring-shaped initial contact area between the fastener **1802** and the workpiece. This increases the velocity of the portion of the fastener **1802** contacting the workpiece as compared a point contact area. Increasing this velocity increases the heat supplied to the workpiece by the fastener **1802**, which decreases the time taken to heat the workpiece.

[0291] In some embodiments, the fastener may be able to remove excess, or extruded, workpiece material. When inserting a fastener into a workpiece, workpiece material may be extruded from the workpiece in a direction opposed to the direction of insertion of the fastener. When extruded, the material of the workpiece is in a softened state, but is not in a liquid state. This excess material is undesirable because it is susceptible to corrosion, which can lead to joint failure. FIG. **32** shows an embodiment of a fastener **2202** that is able to remove excess workpiece material. In this embodiment, the head **2204** of the fastener **2202** is provided with a plurality of cutting edges **2297** (only one of which is labelled in FIG. **32**). Generally, the cutting edge(s) need not be sharp because the extruded material is softened when it is to be cut by the cutting edge(s) of the fastener. The cutting edges **2297** each form a part of a respective tooth **2298** (only one of which is labelled in FIG. **32**). The teeth **2298** extend from the circumferential periphery **2299** of the head **2204**. The plurality of teeth **2298** comprise four teeth **2298**, and so four cutting edges **2297** are provided. However, in some embodiments, the head **2204** may comprise at least one tooth, and/or up to six teeth, each being provided with a respective cutting edge. FIG. **33** shows an alternative embodiment of a fastener **2302** that includes a plurality of cutting edges **2397**. The cutting edges **2397** each form a part of a respective rib of a plurality of ribs **2398**. The ribs **2398** are provided to the underside **2315** of the head **2304**. The plurality of ribs **2398** comprises five ribs, and so five cutting edges **2397** are provided. However, in some embodiments, the head **2304** may comprise at least one rib, and/or up to six ribs, each being provided with a respective cutting edge. The number of teeth **2298** or ribs **2398**, and therefore the number of cutting edges **2297**, **2397**, may be chosen based on, for example, the hardness of the material from which the workpiece into which the fastener **2202** is to be inserted.

[0292] Where the cutting edges **2297**, **2397** are present, which may be the case for any of the embodiments disclosed herein, the method of inserting the fastener into a workpiece may further include cutting extruded, or excess, material from the workpiece using the cutting edge(s). Cutting of the excess workpiece material may take place after the fastener has been threaded into the workpiece. However, the thread need not be fully formed before cutting of the excess workpiece material begins.

[0293] In FIG. **33**, the ribs of the plurality of ribs **2398** are provided with a radius. The ribs of the plurality of ribs are generally rounded. The ribs **2398** are able to cut extruded material from the workpiece during a fastener insertion process because the extruded material is softened. In some, non-depicted, embodiments, the ribs of the plurality of ribs **2398** may each define a respective apex. Where provided, the apexes define the cutting edge of each rib.

[0294] In some embodiments, the nosepiece of the insertion apparatus used to insert any of the above fasteners may be able to remove excess workpiece material. FIG. **34** shows an embodiment of such a nosepiece **2426**. The nose comprises a plurality of cutting edges **2497** (only one of which is visible in FIG. **34**). The plurality of cutting edges **2497** comprise two cutting edges. The two cutting edges are diametrically opposed to one another. In some embodiments, the nosepiece **2426** may comprise at least one, and/or up to four cutting edges.

[0295] Although numerous specific embodiments of the present invention have been described above, features of each embodiment can be combined. For example, the fastener may comprise a bore, as for the fastener **302**, and a stud, as for the fastener **202**. FIG. **35** shows an embodiment of a fastener **1702** that combines features of the embodiments described above. The fastener **1702** comprises a first thread portion **1658** and a second thread portion **1760**. The fastener **1702** further comprises retaining features in the form of a plurality of protrusions **1774**. The plurality of protrusions are disposed between the first thread portion **1558** and the second thread portion **1760**. The pitch distance of the thread of the first thread portion **1758** is less than the pitch distance of the thread of the second thread portion **1760**.

[0296] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The descriptions above are intended to be illustrative, not limiting. Thus, it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

## Claims

**1**. A hole forming and thread forming fastener comprising: a head and a shank that defines a longitudinal axis, the shank comprising a shank section and a tip section, wherein the shank section extends from the head and the tip section extends from the shank section and is opposed to the head; wherein at least part of the shank section is threaded; and wherein the tip section is at least partially tapered and defines a tip angle, the tip angle being at least 50 degrees.
**2**. The hole forming and thread forming fastener of claim 1, wherein the tip angle is at least 70 degrees.
**3**. The hole forming and thread forming fastener of claim 1, wherein the tip section defines a tip section length and the shank section defines a shank section diameter, and where a ratio of the tip section length to the shank section diameter is less than or equal to 0.6.
**4**. The hole forming and thread forming fastener of claim 1, wherein the tip angle is less than or equal to 160 degrees; and/or wherein the tip angle is at least 125 degrees, and less than or equal to 135 degrees.
**5**. (canceled)
**6**. The hole forming and thread forming fastener of claim 1, wherein the shank section comprises a first shank portion that adjoins the head and a second shank portion that adjoins the tip section.
**7**. The hole forming and thread forming fastener of claim 6, wherein the first shank portion is not threaded and the second shank portion is threaded; and/or wherein, the first shank portion comprises one or more retaining features, and wherein, in use, the one or more retaining features engage a workpiece into which the hole forming and thread forming fastener is inserted; and/or wherein the diameter of the first shank portion is greater than the diameter of the second shank portion.
**8**. (canceled)
**9**. (canceled)
**10**. The hole forming and thread forming fastener of claim 1, wherein the head defines an undercut; and/or wherein the hole forming and thread forming fastener further comprises a threaded stud that extends from a side of the head that is opposed to the underside; and/or wherein the tip section defines an undercut that is disposed adjacent the shank section; and/or wherein the pitch diameter of the thread of the shank section is constant along at least 90% of the length of the shank section.
**11-13**. (canceled)
**14**. A method of inserting a fastener into a workpiece, the method comprising: providing a fastener, the fastener a head and a shank that defines a longitudinal axis, the shank comprising a shank section and a tip section, wherein the shank section extends from the head and the tip section extends from the shank section and is opposed to the head; wherein at least part of the shank section is threaded; and wherein the tip section is at least partially tapered and defines a tip angle, the tip angle being at least 50 degrees; providing a workpiece, the workpiece comprising a first surface and a second surface, the second surface being opposed to the first surface; rotating the fastener about the longitudinal axis of the fastener and bringing the fastener into contact with the first surface of the workpiece so as to heat the workpiece; threading the fastener into the workpiece by moving the fastener and the workpiece relative to one another in a direction that is parallel to the longitudinal axis of the fastener such that the tip section of the fastener penetrates the first surface; wherein the fastener does not penetrate the second surface of the workpiece.

**15**. The method of claim 14, wherein threading the fastener into the workpiece comprises forming a thread in the workpiece with the fastener.
**16**. The method of claim 14, further comprising providing a die, and wherein, while the fastener is being threaded into the workpiece, the second surface engages the die; wherein optionally the die comprises a die recess, and wherein while the fastener is being threaded into the workpiece, the second surface of the workpiece deforms into the die recess; wherein optionally the die recess defines a die recess volume, and wherein a volume of workpiece material is displaced while the fastener is being threaded into the workpiece, and wherein the die volume is equal to or greater than the volume of workpiece material displaced.
**17**. (canceled)
**18**. (canceled)
**19**. The method of claim 14, wherein the workpiece comprises only a single workpiece layer.
**20**. The method of claim 14, wherein the workpiece comprises a first layer and a second layer.
**21**. The method of claim 20, wherein at least one of the layers of the workpiece is made from a metallic material, optionally wherein at least one of the layers of the workpiece is made from aluminium; and/or wherein the first workpiece layer comprises an aperture through which the fastener passes before contacting the workpiece; wherein optionally the first workpiece layer is formed of a composite material; and/or wherein the fastener further comprises a threaded stud that extends from a side of the head that is opposed to the shank section of the shank, and wherein the method further comprises securing a component to the threaded stud.
**22-24**. (canceled)
**25**. The method of claim 14, wherein the rate at which the fastener is rotated relative to the workpiece is reduced at least once while the fastener is being threaded into the workpiece; and/or wherein following threading the fastener into the workpiece, the second surface of the workpiece comprises a protrusion in which at least part of the tip section of the shank of the fastener is received.
**26**. The method of claim 14, wherein the workpiece comprises a first layer and a second layer and wherein the reduction of the rate at which the fastener is rotated relative to the workpiece occurs while the tip section is disposed in the second workpiece layer.
**27**. (canceled)
**28**. A joint comprising: a workpiece comprising a first surface and a second surface; a fastener comprising: a head and a shank that defines a longitudinal axis, the shank comprising a shank section and a tip section, wherein the shank section extends from the head and the tip section extends from the shank section and is opposed to the head; wherein at least part of the shank section is threaded; and wherein the tip section is at least partially tapered and defines a tip angle, the tip angle being at least 50 degrees; wherein the fastener extends through the first surface and does not penetrate the second surface.
**29**. The joint of claim 28, wherein the workpiece comprises a first workpiece layer that comprises the first surface and a second workpiece layer that comprises the second surface.
**30**. The joint of claim 29, wherein the first workpiece layer comprises an aperture through which the thread forming and hole forming fastener extends; and/or wherein the first workpiece layer is formed of a composite material.
**31**. (canceled)
**32**. The joint of claim 28, wherein the workpiece comprises only a single workpiece layer.
**33**. The joint of claim 28, wherein the thread forming and hole forming fastener further comprises a threaded stud that extends from a side of the head that is opposed to the shank section; and/or wherein at least one of the workpiece layers is made from a metallic material, optionally wherein at least one of the layers of the workpiece is made from aluminium; and/or wherein the head of the thread forming and hole forming fastener is disposed proud of the workpiece, or wherein the head of the thread forming and hole forming fastener is disposed substantially flush with the workpiece;

and/or wherein the second surface comprises a protrusion in which the tip section of the fastener is at least partially received.

**34-36**. (canceled)