

LAPPING TOOL

RELATED APPLICATIONS

This application claims priority to U.S. Application Serial No. 17/000,680 filed on August 24, 2020, currently pending and U.S. Provisional Application Serial No. 62/894,198, filed on August 30, 2020, currently pending, the disclosures of which are hereby incorporated by reference in their entirety.

FIELD OF THE INVENTION

[0001] The present technology relates to lapping, and specifically to lapping tools having features on the surface of the lap configured to engage and retain lapping compound.

BACKGROUND

[0002] Lapping is a finishing technique that typically utilizes a lapping compound containing an abrasive for removing material from a surface to achieve a desired finish. In bore lapping, the lapping achieves a desired bore size as well as a desired bore surface finish.

[0003] The lapping compound tends to include loose abrasive with a fluid carrier such as a paste or grease. Traditionally a lapping tool is designed to be made from a material with properties that are conducive to retaining, at least momentarily, the loose abrasive particles that will be the “micro cutting” points that will remove material from the workpiece. These material properties are often a hardness that is softer than the workpiece, and a grain structure that enables temporary grit retention.

[0004] This often requires, or at least is improved by, a “charging” process where some initial load serves to embed the abrasive particles into the surface of the lap. The carrier generally assists in initially adhering the abrasive particles to the surface of the lapping tool. This charging is usually short-lived and must be repeated frequently for best results. The charging process is fairly simple with lapping of flat

surfaces, but it can be challenging for bore lapping, especially if the process is to be automated to remove the dependence on operator skill.

SUMMARY

[0005] The present technology provides lapping tools having features on the surface of the lap configured to engage and retain lapping compound.

[0006] In one aspect, a lapping tool is provided that includes a lapping surface, wherein the lapping surface includes at least one angled feature that forms at least one surface angle with the lapping surface. The at least one angled feature is configured to receive abrasive grit. The at least one surface angle is selected according to a finish type to be imparted onto a workpiece by the lapping tool.

[0007] In another aspect, a lapping tool is provided that includes a circular cross section and an outer surface that is a lapping surface. The lapping surface includes at least one angled feature that forms at least one surface angle with the lapping surface. The at least one angled feature is configured to receive abrasive grit, and the at least one surface angle is selected according to a finish type to be imparted onto a workpiece by the lapping tool.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Specific examples have been chosen for purposes of illustration and description, and are shown in the accompanying drawings, forming a part of the specification.

[0009] Figure 1 illustrates one example of a lapping tool of the present technology.

[0010] Figure 2 illustrates a portion of the lapping tool of Figure 1.

[0011] Figure 3 illustrates a cross section view along line B of Figure 2, which intersects one of the angled features in a perpendicular orientation.

[0012] Figure 4 illustrates a second example of a lapping tool of the present technology.

[0013] Figure 5 illustrates the lapping tool of Figure 4 with a cross sectional line C.

[0014] Figure 6 illustrates a cross section view of the lapping tool of Figure 4 along the line C of Figure 5, which intersects one of the angled features in a perpendicular orientation.

[0015] Figure 7 illustrates a two-dimensional figure showing one example of a surface angle of the present technology.

[0016] Figure 8 illustrates a two-dimensional figure showing a second example of a surface angle of the present technology.

[0017] Figure 9 illustrates a two-dimensional figure showing a third example of a surface angle of the present technology.

[0018] Figure 10 illustrates a two-dimensional figure showing an example of a lapping tool of the present technology having an angled feature with a first surface angle and a second surface angle.

DETAILED DESCRIPTION

[0019] While specific examples are discussed herein in relation to bore lapping, and lapping sleeves, it should be understood that the present technology is applicable in lapping, generally, and is not limited to bore lapping.

[0020] Lapping tools of the present technology generally include features for engaging abrasive grits on the surface of the lap, which may result in the grits remove material from the workpiece efficiently and in a manner appropriate for the application. Features on the surface of the lap are designed to engage and retain the abrasive grits. The design of these features can determine the type of cutting action between the grit and the bore surface, so that cutting can be either aggressive, reducing material remove time, or gentle, improving surface texture to a finer finish. In at least some examples, these features can be constructed in such a way as to provide for both types of cutting action with the same tool and the same abrasive grits.

[0021] Figures 1-3 illustrate one example of a lapping tool 100 of the present technology. In the illustrated example, the lapping tool 100 is a bore lapping tool. The lapping tool 100 has a circular cross-section. The tool includes an arbor 102, which is a driven component. A lapping sleeve 104 is mounted on the arbor 102. The

lapping sleeve 104 has a distal end 108 and a proximal end 110, and lapping surface 116. The arbor 102 may have a tapered outer surface 118, and the lapping sleeve 104 may have a corresponding tapered inner surface 120, so that the outer surface 118 of the arbor 102 and the inner surface 120 of the lapping sleeve 104 are in contact along at a portion of, or the entirety of, the length of the lapping sleeve from the proximal end 110 to the distal end 108. Because of the taper of the inner surface 120 of the lapping sleeve 104, the distal end 108 of the lapping sleeve 104 may have a thickness that is greater than the thickness of the proximal end 110 of the lapping sleeve 104. The lapping sleeve 104 may include at least one slit 106, which allows the lapping sleeve 104 to expand or retract in diameter if it is moved axially relative to the arbor 102. Having at least one slit 106, and allowing the lapping sleeve to expand or retract in diameter may allow adjustment, if needed, to match the bore diameter of the workpiece. Expanding the lapping sleeve 104 may also compensate for the normal wear of the outside of the lapping sleeve 104. Each slit 106, may be formed lengthwise along the lapping sleeve 104, and may be straight or helical, to create an open circular cross section at every location along the length of the lapping sleeve 104.

[0022] If the lapping tool 100 is to be used in an automated or semi-automated lapping process, the lapping sleeve 104 may include a retraction feature 112. The retraction feature 112 may be located near the distal end 108 of the lapping sleeve 104. The retraction feature 112 as shown is recessed into the lapping surface 116, and may comprise a deep groove or a plurality of grooves, which can be engaged by some external apparatus configured and operable for applying a retraction force against the sleeve in the direction of convergence of the tapered surfaces for moving the sleeve relative to the arbor in a controlled manner in that direction, for reducing the diametrical extent of the sleeve to a desired extent. Some examples of retraction features that can be used in the present technology are provided in U.S. Patent No. 9,789,581.

[0023] The lapping sleeve 104 also includes at least one angled feature 114. As shown in Figures 1-3, the at least one angled feature 114 is a negative feature. The negative angled feature 114 may be formed by removing material from the lapping

sleeve 104. The negative angled feature 114 may be a helical groove, which may be right-handed or left-handed. In the example shown in Figures 1-3, the lapping sleeve 104 has a first angled feature 114 that is a right-handed helical groove, and a second angled feature 114 that is a left-handed helical groove. Angled features of the present technology may have other geometries and configurations. For example, straight grooves parallel to the bore axis could be suitable. Angled features may also be configured as dimples or another form of depression in the bore surface.

[0024] For example, Figures 4-6 illustrate a second example of a lapping tool 200, in which the at least one angled feature 206 is a positive feature, where material is added and/or created in the form of protrusions, the spaces between the protrusions are the negative spaces that are configured to hold the lapping compound. As shown in Figures 4-6, lapping tool 200 includes lapping sleeve 202, which has an lapping surface 204 that includes angled features 206, and an inner surface 208. The inner surface 208 may be tapered along the length of the lapping sleeve 202, from the proximal end 210 to the distal end 212.

[0025] Angled features of the present technology include one or more surface angles. The term “surface angle” as used herein is the angle between an edge of the angled feature and the lapping surface of the lapping sleeve, which is equivalent to the angle formed between an edge of the angled feature and the workpiece surface of a workpiece.

[0026] Figure 3 shows a cross section of lapping sleeve 104, along line B of Figure 2, which intersects one of the angled features 114 in a perpendicular orientation. As shown, the angled feature 114 forms a first surface angle A1 with the lapping surface 116 of the lapping sleeve 104, and a second surface angle A2 with the lapping surface 116 of the lapping sleeve 104. In this example, first surface angle A1 has a different angle than second surface angle A2. Indeed, in the illustrated example, angle A1 is smaller than angle A2. In some examples, first surface angle A1 may be equal to, less than, or greater than second surface angle A2.

[0027] Similarly, Figure 6 shows a cross section of lapping sleeve 202, along line C of Figure 5, which intersects one of the angled features 206 in a perpendicular orientation. As shown, the angled feature 206 forms a first surface angle D1 with the

lapping surface 204 of the lapping sleeve 202, and a second surface angle D2 with the lapping surface 204 of the lapping sleeve 202. In this example, first surface angle D1 has a different angle than second surface angle D2. In some examples, first surface angle D1 may be equal to, less than, or greater than second surface angle D2.

[0028] Angled features of the present technology are configured to receive lapping compound, and particularly abrasive particles within lapping compound.

[0029] When lapping tools of the present technology are bore lapping tools, the lapping tool both rotates and strokes axially relative to the workpiece bore when in use. The rotation may occur in a clockwise or counter-clockwise direction. The stroking occurs in both a first direction and an opposite second direction, such as down and up, or back and forth, depending upon the orientation of the lapping tool.

[0030] Lapping tools of the present technology may be configured such that at least one angled feature is substantially perpendicular to the direction of relative motion during the first direction of stroking, and the second angled feature is substantially perpendicular to the relative motion during the opposite second direction of stroking. For example, the lapping tool 100 in Figures 1 and 2, which has a first angled feature 114 that is a right-handed helical groove and a second angled feature 114 that is a left-handed helical groove, was selected because under the combined rotation and stroking motion of the lap, the first angled feature 114 will be substantially perpendicular to the direction of relative motion during one direction of stroking, and the second angled feature 114 will be substantially perpendicular to the relative motion during the other direction of stroking. Likewise, the lapping tool 200 shown in Figures 3 and 4 is configured such that a first angled feature 206 will be substantially perpendicular to the direction of relative motion during one direction of stroking, and a second angled feature 206 will be substantially perpendicular to the relative motion during the other direction of stroking.

[0031] Figures 7-9 are two-dimensional figures illustrating examples of the function of angled features of the present technology. Magnified edges of angled features are shown, with the mating surface between the lapping surface of the lapping tool and the workpiece being flat. However, it should be understood that the mating surface between the lapping tool and the workpiece can have any degree of curvature. The

angled features in Figures 7-9 are substantially perpendicular to the direction of relative motion.

[0032] As shown in Figure 7, a lapping tool 300 has an angled feature 302 and a lapping surface 304. Workpiece 306 has workpiece surface 308. The surface angle E1 formed between lapping surface 304, and also the workpiece surface 308 and the angled feature 302 of the lapping tool 300 is relatively large. The surface angle E1 is greater than the optimum angle, discussed below, and may vary depending upon the materials being used, such as the type of abrasive being used and the material that is being lapped. However, in at least some examples the surface angle E1 may be up to about 90°, such as being from about 65° to about 90°. Abrasive grit 310 from the lapping compound may be retained between angled feature 302 and the workpiece surface 308. The direction of the motion of the lapping tool relative to the workpiece is shown as arrow M_L . In this example, there is a first normal force N_L where the abrasive grit 310 contacts the lapping tool and a second normal force N_W where the abrasive grit 310 contacts the workpiece surface 308. There is also a first tangential force T_L where the abrasive grit 310 contacts the lapping tool and a second tangential force T_W where the abrasive grit 310 contacts the workpiece surface 308. Each of the tangential forces are essentially static or dynamic friction, depending on the relative motion or lack thereof between the abrasive grit and the workpiece surface. When there is motion, the tangential forces may also be cutting forces, when the motion results in the removal of material from the workpiece surface 308.

[0033] Lapping tools constructed as shown in Figure 7, with a relatively large surface angle E1, may produce a very fine surface finish, but tend to remove material very slowly. Without being bound by any particular theory, it is believed that a large surface angle may not be able to support any substantial normal force to push the abrasive grit into the workpiece. In such an example, any removal of material may occur substantially by virtue of abrasive grits rolling. This performance may not be substantially affected by changing the size of the abrasive grits. With little or no force to drive the grit into the workpiece, large rolling abrasive grits may have an equivalent effect to small rolling abrasive grits.

[0034] As shown in Figure 8, a lapping tool 400 has an angled feature 402 and an lapping surface 404. Workpiece 406 has workpiece surface 408. The surface angle $F1$ formed between the angled feature 402 of the lapping tool 400 and the lapping surface 404, and also workpiece surface 408, and is relatively small. The surface angle $F1$ is less than the optimum angle, discussed below, and may vary depending upon the materials being used. However, in at least some examples the surface angle $F1$ may be down to about 0° , such as being from about 0° to about 15° . Abrasive grit 410 from the lapping compound may be retained between angled feature 402 and the workpiece surface 408. The direction of the motion of the lapping tool relative to the workpiece is shown as arrow M_L . In this example, there is a first normal force N_L where the abrasive grit 410 contacts the lapping tool and a second normal force N_W where the abrasive grit 410 contacts the workpiece surface 408. There is also a first tangential force T_L where the abrasive grit 410 contacts the lapping tool and a second tangential force T_W where the abrasive grit 410 contacts the workpiece surface 408. Each of the tangential forces are essentially static or dynamic friction, depending on the relative motion or lack thereof between the abrasive grit and the workpiece surface. When there is motion, the tangential forces may also be cutting forces, when the motion results in the removal of material from the workpiece surface 408.

[0035] As shown in Figure 8, T_L has switched directions as compared to Figure 7. Without being bound by any particular theory, it is believed that the two normal forces N_W and N_L in Figure 8 may provide a moment that balances that of the tangential forces, such that the abrasive grit will tend to get trapped and will not tend to roll. Further, as the surface angle $F1$ is reduced, the value of N_L may approach the value of N_W and the value of T_L may approach the value of T_W . However the lapping tool 400 and the workpiece 406 have different material strengths, and usually the lapping tool 400 is a lower strength material. Experiments using lapping tool 400 have shown that, before T_W gets large enough to cut the workpiece 406, T_L tends to reach a point where the lapping tool material deforms and cuts. Specifically, the workpiece surface 408 became no rougher but the lapping surface 404 of lapping tool 400 did get rougher, showing that the abrasive grit 410 was cutting into the lapping tool 400 rather than the workpiece 406. Accordingly, when the surface angle is too small, undesirable performance may occur, providing no benefit with regard to the

workpiece surface texture or the rate of material removal, and producing faster wear of the lapping tool which diminishes the life of the lapping tool.

[0036] As shown in Figure 9, a lapping tool 500 has an angled feature 502 and an lapping surface 504. Workpiece 506 has workpiece surface 508. Abrasive grit 510 from the lapping compound may be retained between angled feature 502 and the workpiece surface 508. The direction of the motion of the lapping tool relative to the workpiece is shown as arrow M_L . The surface angle $G1$ formed between the angled feature 502 of the lapping tool 500 and the lapping surface 504, and also the workpiece surface 508, has been configured to be an optimum lapping angle. As used herein, an optimum lapping angle is one in which the tangential force of the lapping tool T_L has been minimized, and is zero or substantially zero. The optimum lapping angle can be calculated as: Optimum lapping Angle = $ATAN(TW/NW)$. The optimum angle may vary depending upon materials being used. However, in at least some examples, the optimum angle may be from about 15° to about 65°. Without being bound by any particular theory, it is believed that when the surface angle is an optimum lapping angle, the abrasive grit has neither a tendency to slide away from the workpiece nor to cut the lapping tool. A surface angle having an optimum lapping angle may be able to support fairly large normal forces and force the abrasive grit into the lapping tool surface by yielding of the lapping tool material. With the abrasive grit in a position to be held by the lapping tool, forces high enough to drive larger grits to cut a coarser surface texture may be achieved. Additionally, higher workpiece material removal rates may be achieved.

[0037] Lapping tools of the present technology may be self-charging, in that abrasive grit may be received and retained by the angled features in the normal course of the lapping tool moving relative to the workpiece in the presence of the lapping compound.

[0038] Angled features of the present technology may also serve one or more additional functions or provide one or more additional benefits. For example, in examples where the angled features are negative features, such as lapping sleeve 104, they may act as weakening features, which may reduce the expansion force required for expanding the lapping sleeve, as well as preventing or reducing the tendency for

the lapping sleeve to bulge at some axial location as a result of application of the expansion force. Alternative examples of weakening features are provided in U.S. Patent No. 9,789,581.

[0039] Figure 10 illustrates a lapping tool 600 of the present technology and workpiece 608 having workpiece surface 610. The lapping tool 600 has an angled feature 602 with a first surface angle 604 and a second surface angle 606. The first surface angle 606 is configured as an optimum lapping angle, to provide a coarser finish when the lapping tool 600 is moved in a first direction H. The second surface angle 604 is a large angle configured to allow the abrasive grit to roll and provide a fine finish when the lapping tool 600 is moved in a second direction I. Accordingly, lapping tool 600 can be operated in the first direction H to produce relative fast material removal, or in the second direction I to produce a fine surface finish. When the lapping tool is a bore lapping tool, the first and second directions of movement can be achieved by rotating the lapping tool 600 in a clockwise or counter-clockwise direction.

[0040] A lapping tool such as lapping tool 600 may be used to produce what is known as a plateau finish. A plateau finish is characterized on a micro level by relatively deep valleys in the workpiece surface but very small peaks. Plateau finishes are known to provide tribological benefits and are utilized in various applications where sliding friction and surface wear must be kept to a minimum. A plateau finish is typically produced by honing with a coarse abrasive grit followed by honing briefly with a fine abrasive grit. Lapping tool 600 may produce a plateau finish employing only one size of abrasive grit.

[0041] From the foregoing, it will be appreciated that although specific examples have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit or scope of this disclosure. It is therefore intended that the foregoing detailed description be regarded as illustrative rather than limiting, and that it be understood that it is the following claims, including all equivalents, that are intended to particularly point out and distinctly claim the claimed subject matter.