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- **SRINIVASAN, Gajawalli V.**
East Hartford, 06118 (US)
- **FERNANDEZ, Robin H.**
East Hartford, 06118 (US)
- **RIEHL, John D.**
East Hartford, 06118 (US)
- **BARRON, Alan C.**
East Hartford, 06118 (US)
- **ABDI, Ahmed Abdillahi**
East Hartford, 06118 (US)
- **NELSON, Jason**
East Hartford, 06118 (US)
- **LAZUR, Andrew Joseph**
East Hartford, 06118 (US)

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(71) Applicant: **RTX Corporation**
Farmington, CT 06032 (US)

(72) Inventors:

- **WANG, Zhigang**
East Hartford, 06118 (US)
- **KUCZEK, Andrzej E.**
East Hartford, 06118 (US)

(74) Representative: **Dehns**
St. Bride's House
10 Salisbury Square
London EC4Y 8JD (GB)

(54) **SELF-SHARPENING TOOLING DESIGN FOR ULTRASONIC IMPACT GRINDING OF CMCS**

(57) A tool (12; 40; 60; 80) for an ultrasonic impact grinding machine (10) driven to vibrate along a longitudinal axis (A) includes a hollow tool body (20; 42; 62; 82) and a hollow tip (22; 44; 64; 84) extending from an end of the hollow tool body (20... 82). The hollow tip (22... 84) has an outer surface comprising a plurality of grooves (24; 50; 70; 90). The hollow tool body (20... 82) and the hollow tip (22... 84) are disposed about the longitudinal axis (A) and the hollow tip (22... 84) and hollow tool body (20... 82) are each defined in part by a common bore (26; 48; 68; 88) extending along the longitudinal axis (A).

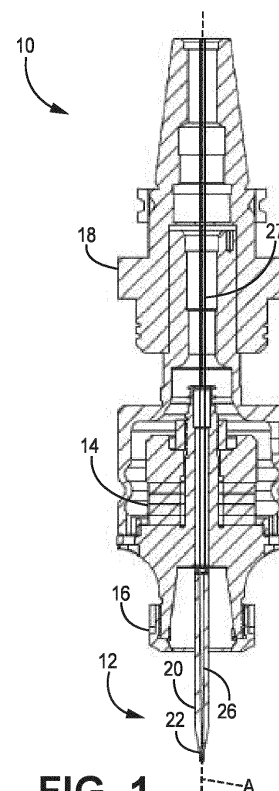


FIG. 1

Description

TECHNICAL FIELD

[0001] The present disclosure relates generally to machining ceramic matrix composites (CMCs) and, more particularly, to ultrasonic impact grinding (UIG).

BACKGROUND

[0002] Lightweight ceramic matrix composites (CMC) are highly desirable materials for gas turbine engine applications. CMCs, and particularly SiC/SiC CMCs (having silicon carbide matrix and fibers) exhibit excellent physical, chemical, and mechanical properties at high temperatures, making them particularly desirable for producing hot section components, including blade outer air seals (BOAS), vanes, blades, combustors, and exhaust structures. Like other materials, it can be critical to the performance, durability, and function of the CMC component to cool the CMC component to maintain appropriate operating temperatures. Features for mitigating thermal stresses can include cooling channels provided through the material. There have been challenges in developing an efficient and cost-effective way to machine CMCs with high quality. SiC/SiC CMCs have a hardness second only to that of diamond tooling and the SiC fiber reinforced phase results in anisotropy and heterogeneity.

[0003] UIG has been used to fabricate complex hole shapes with high aspect ratios on hard and brittle materials, such as CMCs. In UIG, electrical energy input to a transducer is converted to mechanical vibrations along a longitudinal axis at high frequency (usually at 20-40 kHz). The excited vibration is subsequently transmitted through an energy-focusing horn to amplify the vibration amplitude which is delivered to a tool tip. Thus, the tool, which locates directly above a workpiece, can vibrate along its longitudinal axis with a desired amplitude. An abrasive slurry comprising a mixture of abrasive material (e.g., diamond, boron carbide, etc.) suspended in water or oil is provided constantly into the machining area. The vibration of the tool causes the abrasive particles held in the slurry between the tool and the workpiece to impact the workpiece surface causing material removal by microchipping. Since actual machining is carried out by abrasive particles, the tool can be softer than the workpiece.

[0004] The UIG process has matured to offer true three-dimensional machining capability to process a wide variety of engineering materials including ceramics and hard metals. However, its application has been limited due to low material removal rates. Machining speed mainly depends on the vibrational amplitude, applied static pressure, abrasive concentration, and size distribution of the abrasive particles. Machining speed decreases significantly with the depth of cut in hole drilling, which is attributed to a decrease in the abrasive concentration in the working space under the tool. Abrasive par-

ticles are broken down during the UIG process and lose their cutting power and replenishment of new abrasive particles is inefficient. Current methods used to improve the abrasive suspension feed into the machining zone, including periodic lifting of the tool, can provide some improvement in performance, however, they do not change the nature of the dependence of the performance on the cutting depth.

10 SUMMARY

[0005] A tool for an ultrasonic impact grinding machine driven to vibrate along a longitudinal axis includes a hollow tool body and a hollow tip extending from an end of the hollow tool body. The hollow tip has an outer surface comprising a plurality of grooves. The hollow tool body and the hollow tip are disposed about the longitudinal axis and the hollow tip and hollow tool body are each defined in part by a common bore extending along the longitudinal axis.

[0006] A method of ultrasonic impact grinding includes applying longitudinal vibration to a tip of a tool in the direction of an axis of the tool, impacting a substrate with the tip, supplying an abrasive slurry to a terminal end of the tip, and evacuating the abrasive slurry and debris from the terminal end of the tip. The abrasive slurry is supplied through a bore extending longitudinally through the tool or the abrasive slurry and debris is evacuated through the bore extending longitudinally through the tool.

[0007] The present summary is provided only by way of example, and not limitation. Other aspects of the present disclosure will be appreciated in view of the entirety of the present disclosure, including the entire text, claims and accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

FIG. 1 is a cross-sectional view of an ultrasonic impact grinding assembly.

FIG. 2 is a simplified cross-sectional view of a tool of the ultrasonic impact grinding assembly of FIG. 1 showing material delivery and removal according to one embodiment.

FIG. 3 is a simplified cross-sectional view of a tool of the ultrasonic impact grinding assembly of FIG. 1 showing material delivery and removal according to another embodiment.

FIG. 4 is a perspective view of one embodiment of a tool tip.

FIG. 5 is a perspective view of another embodiment of a tool tip.

FIG. 6 is a perspective view of yet another embodiment of a tool tip.

[0009] While the above-identified figures set forth em-

bodiments of the present invention, other embodiments are also contemplated, as noted in the discussion. In all cases, this disclosure presents the invention by way of representation and not limitation. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit of the principles of the invention. The figures may not be drawn to scale, and applications and embodiments of the present invention may include features, steps and/or components not specifically shown in the drawings.

DETAILED DESCRIPTION

[0010] The present disclosure is directed to optimizing tooling geometries and slurry circulation to provide continuous removal and replenishment of abrasive particles in the machining zone. Fluted slots or grooves can be provided along the outer surface of a tool tip and a central bore can be provided through the tool tip to improve delivery of abrasive particles and removal of used abrasive particles and workpiece debris.

[0011] FIG. 1 is a cross-sectional view of UIG assembly 10. FIG. 2 is a simplified cross-sectional view of tool 12 of UIG assembly 10 of FIG. 1 showing material delivery and removal according to one embodiment. FIG. 3 is a simplified cross-sectional view of tool 12 of UIG assembly 10 of FIG. 1 showing material delivery and removal according to another embodiment. FIGS. 1-3 are discussed together herein. UIG assembly 10, tool 12, transducer 14, collet 16, tool holder 18, tool body 20, tip 22, grooves 24, bore 26, bore 27, workpiece 28, machining zone 30, used abrasive slurry and debris 32, new abrasive slurry 34, pump 36, reservoir 38, and longitudinal axis A are shown. UIG assembly 10 can include any conventional ultrasonic machining apparatus or variation thereof configured for operation with a tool for ultrasonic impact grinding with a slurry of abrasive particles. Collet 16 is adapted to receive and retain tool 12. Electrical energy input to transducer 14 is converted to mechanical vibrations along longitudinal axis A at high frequency (usually 20-40 kHz). Transducer 14 transmits the vibrational energy to tool 12 when UIG assembly 10 is in use. In some embodiments, tool 12 can be rotated during use via spindle which holds tool holder 18, as known in the art. Machining zone 30 is located between tip 22 and workpiece 28. Tool 12 is disposed along longitudinal axis A and includes tool body 20 and tip 22. Bore 26 extends through tool body 20 and tip 22 along longitudinal axis A. Bore 26 is coupled to bore 27. Bore 27 extends through UIG assembly 10. Tip 22 includes grooves 24 disposed on an outer surface.

[0012] Abrasive slurry 34 comprises a mixture of abrasive material, such as, diamond, boron carbide, etc., suspended in water or oil. An average particle size can vary depending on the application. Typically, abrasive slurry 34 can have an average particle size ranging from 5 to 30 μm .

[0013] During operation of UIG assembly 10, used abrasive slurry and material debris 32 are removed from machining zone 30 and new abrasive slurry 34 is delivered to machining zone 30. The extraction of used abrasive slurry and debris 32 and replenishment of new abrasive slurry 34 can be accomplished by one of two means illustrated in FIGS. 2 and 3.

[0014] In a first embodiment, shown in FIG. 2, new abrasive slurry 34 is provided to machining zone 30 through grooves 24 on tip 22. Tip 22 can have a length equal to or exceeding a depth in workpiece 28 or thickness of workpiece 28 through which tip 22 machines. Grooves 24 can extend a full length of tip 22 to ensure grooves 24 remain open to a surface of workpiece 28 during operation of UIG assembly 10. New abrasive slurry 34 can be continuously provided via one or more nozzles (not shown) directed at tip 22 and workpiece 28 during operation of UIG assembly 10. Vibration of tip 22 causes abrasive particles held in abrasive slurry 34 between tip 22 and workpiece 28 to impact the workpiece surface causing material removal by microchipping. The material removed from workpiece 28 forms the debris of used abrasive slurry and debris 32. Used abrasive slurry and debris 32 can be removed through bore 26 opening to a terminal end of tip 22 in machining zone 30. A vacuum can be applied via pump 36 to bore 26 via bore 27 to remove used abrasive slurry and debris 32 from machining zone 30.

[0015] Preferably, UIG assembly 10 and workpiece 28 can be oriented to take advantage of gravitation force. For example, tool 12 can be oriented downward in the direction of the gravitational force such that new abrasive slurry 34 is pulled toward the terminal end of tip 22 and machining zone 30. In some embodiments, such orientation may not be feasible and/or it may be preferable to draw used abrasive slurry and debris 32 from machining zone 30 with the assistance of the gravitational force.

[0016] In a second embodiment, shown in FIG. 3, new abrasive slurry 34 is provided to machining zone 30 through bore 26 via bore 27. New abrasive slurry 34 can be continuously provided from reservoir 38 via pump or gravitational feed. Vibration of tip 22 causes abrasive particles held in abrasive slurry 34 between tip 22 and workpiece 28 to impact the workpiece surface causing material removal by microchipping. The material removed from workpiece 28 forms the debris of used abrasive slurry and debris 32. Used abrasive slurry and debris 32 can be removed through grooves 24 on an outer surface of tip 22. Tip 22 can have a length equal to or exceeding a depth in workpiece 28 or thickness of workpiece 28 through which tip 22 machines. Grooves 24 can extend a full length of tip 22 to ensure grooves 24 remain open to a surface of workpiece 28 during operation of UIG assembly 10.

[0017] Preferably, UIG assembly 10 and workpiece 28 can be oriented to take advantage of gravitation force. For example, UIG assembly can be arranged with a horizontal spindle-tool setup. Tool 12 can be oriented per-

pendicular to the direction of the gravitational force such that used abrasive slurry and debris 32 is pulled down from the terminal end of tip 22 toward a side of tip 22 from which it can be channeled outward toward the surface of workpiece 28 via grooves 24.

[0018] The combined use of grooves 24 and bore 26 make it feasible to provide continuous replenishment of new abrasive slurry 34 in machining zone 30. Use of the methods shown in FIGS. 2 and 3 and described with respect thereto can overcome low material removal rates of the prior art attributed to accumulation of debris and used abrasive particles that have reduced cutting power. Prior art methods have shown that machining speed can decrease significantly with the depth, falling close to zero at 10 mm depth. The disclosed methods can provide continuous replenishment of new abrasive slurry 34 and removal of used abrasive slurry and debris 32 independent of machining depth, resulting in a material removal rate that is substantially unaffected by the penetration depth of tool 12.

[0019] FIG. 4 is a perspective view of one embodiment of a tool tip for use with ultrasonic assembly 10 using the methods shown in FIGS. 2 and 3. FIG. 4 shows a portion of tool 40 with tool body 42, tip 44, terminal end 46, bore 48, grooves 50, longitudinal axis A, and a direction of longitudinal vibration V_L . Tip 44 is disposed at a machining end of tool 40. Terminal end 46 forms an output surface for longitudinal vibration V_L . Bore 48 extends through tip 44 and tool body 42 as discussed with respect to tool 12 shown in FIG. 1. Bore 48 opens to terminal end 46. Grooves 50 are disposed on an outer circumferential or frustoconical surface of tip 44. Grooves 50 open to terminal end 46.

[0020] Tip 44 can be cylindrical. Grooves 50 can extend longitudinally a full length of tip 44. Grooves 50 can extend a length equal to or greater than a depth of a hole machined by tip 44. In some embodiments, a ratio of groove length to hole depth can range from 1:1 to 2:1. Grooves 50 can be uniformly spaced about a circumference of tip 44. The number, width, and depth of grooves 50 can be selected to optimize delivery of new abrasive slurry 34 or removal of used abrasive slurry and debris 32 as discussed with respect to FIGS. 2 and 3. In some embodiments, a ratio of tip diameter to groove depth can range from 5:1 to 10:1. A ratio of groove width to groove depth can range from 2:1 to 1:2.

[0021] Tool 40 is configured for UIG application without rotation. Tool 40 can be designed to provide a desired longitudinal vibration amplitude (e.g., approximately 50 percent of an average abrasive particle size in new abrasive slurry 34) at terminal end 46. Delivery of new abrasive slurry 34 through bore 48 can force used abrasive slurry and debris 32 out of a machining zone through grooves 50. Alternatively, used abrasive slurry and debris 32 can be vacuumed out of the machining zone via bore 48 and new abrasive slurry 34 can be replenished in the machining zone via delivery through grooves 50.

[0022] FIG. 5 is a perspective view of another embod-

iment of a tool tip for use with ultrasonic assembly 10 using the methods shown in FIGS. 2 and 3. FIG. 5 shows a portion of tool 60 with tool body 62, tip 64, terminal end 66, bore 68, grooves 70, longitudinal axis A, a direction of longitudinal vibration V_L , and a direction of torsional vibration V_T . Tip 64 is disposed at a machining end of tool 60. Terminal end 66 forms an output surface for longitudinal vibration V_L . Bore 68 extends through tip 64 and tool body 62 as discussed with respect to tool 12 shown in FIG. 1. Bore 68 opens to terminal end 66. Grooves 60 are disposed on an outer surface of tip 64. Grooves 70 open to terminal end 66.

[0023] Tip 64 can be cylindrical. Grooves 70 can extend a full length of tip 44. Grooves 70 can extend a length equal to or greater than a depth of a hole machined by tip 64. In some embodiments, a ratio of the tip length with grooves to hole depth can range from 1:1 to 2:1. Grooves 70 can be inclined relative to longitudinal axis A. In some embodiments, grooves can extend at an angle ranging from about 30 degrees to 60 degrees relative to longitudinal axis A. Grooves 70 can be helical, extending around a circumference of tip 64. The helical grooves 70 can increase torsional vibration and eliminate excitation of unwanted bending modes. Helical grooves 70 provided on the outer surface of tip 64 result in conversion of the incident longitudinal wave from a vibration source on the input side of tool 60 to a torsional wave (torsional vibration V_T) at the helical grooves 70, while the remainder of the wave progresses longitudinally (longitudinal vibration V_L) through the unslotted bore 68.

[0024] Grooves 70 can be uniformly spaced about a circumference of tip 64. The number, width, and depth of grooves 70 can be selected to optimize delivery of new abrasive slurry 34 or removal of used abrasive slurry and debris 32 as discussed with respect to FIGS. 2 and 3. In some embodiments, a ratio of tip diameter to groove depth can range from 5:1 to 10:1. A ratio of groove width to groove depth can range from 2:1 to 1:2.

[0025] Tool 60 is configured for UIG application with or without rotation. Tool 60 can be designed to provide a desired longitudinal vibration amplitude (e.g., approximately 50 percent of an average abrasive particle size in new abrasive slurry 34) at terminal end 66. Tip 64 can provide a combination of longitudinal vibration in the direction of longitudinal axis A and torsional vibration in the direction of tool rotation about longitudinal axis A. With longitudinal vibration alone, a hemispherical bowl tends to be formed in the workpiece adjacent terminal end 66 of tip 64 until the load reaches a yield strength. The addition of torsional vibration changes a trajectory of the abrasive particles, which can break the material and can result in larger lateral cracks beneficial to material removal. Additionally, torsional vibration can produce a sliding motion of tip 64, which can help smooth the machined area.

[0026] Delivery of new abrasive slurry 34 through bore 68 can force used abrasive slurry and debris 32 out of a machining zone through grooves 70. Alternatively, used

abrasive slurry and debris 32 can be vacuumed out of the machining zone via bore 68 and new abrasive slurry 34 can be replenished in the machining zone via delivery through grooves 70.

[0027] FIG. 6 is a perspective view of yet another embodiment of a tool tip for use with ultrasonic assembly 10 using the methods shown in FIGS. 2 and 3. FIG. 6 shows a portion of tool 80 with tool body 82, tip 84, terminal end 86, bore 88, grooves 90, cutting edges 92 longitudinal axis A, a direction of longitudinal vibration V_L , and a direction of torsional vibration V_T . Tip 84 is disposed at a machining end of tool 80. Terminal end 86 forms an output surface for longitudinal vibration V_L . Bore 88 extends through tip 84 and tool body 82 as discussed with respect to tool 12 shown in FIG. 1. Bore 88 opens to terminal end 86. Grooves 90 are disposed on an outer surface of tip 84. Grooves 90 open to terminal end 86.

[0028] Tool 80 is configured for UIG application with rotation. Tool 80 can be designed to provide a desired longitudinal vibration amplitude (e.g., approximately 50 percent of an average abrasive particle size in new abrasive slurry 34) at terminal end 86. Grooves 90 can be fluted slots having cutting edges 92 configured to smooth workpiece surfaces. Tip 84 can be cylindrical. Grooves 90 can extend a full length of tip 84. Grooves 90 can extend a length equal to or greater than a depth of a hole machined by tip 84. Grooves 90 can be inclined relative to longitudinal axis A. In some embodiments, grooves can extend at an angle ranging from about 30 degrees to 60 degrees relative to longitudinal axis A. Grooves 90 can be helical, extending around a circumference of tip 84. As described with respect to tip 64 shown in FIG. 5, helical grooves 90 provided on the outer surface of tip 84 results in conversion of the incident longitudinal wave from a vibration source on the input side of tool 80 to a torsional wave (torsional vibration V_T) at the helical grooves 90, while the remainder of the wave progresses longitudinally (longitudinal vibration V_L) through the unslopped bore 68.

[0029] Grooves 90 can be uniformly spaced about a circumference of tip 84. FIG. 6 shows four grooves 90 with four cutting edges 92. The number, width, and depth of grooves 90 can be selected to optimize delivery of new abrasive slurry 34 or removal of used abrasive slurry and debris 32 as discussed with respect to FIGS. 2 and 3. A ratio of tip diameter to groove depth can range from 5:1 to 10:1. Additionally, torsional motion of cutting edges can produce a sliding and cutting on the workpiece, which can help smooth the machined area and improve the material removal rate.

[0030] Delivery of new abrasive slurry 34 through bore 88 can force used abrasive slurry and debris 32 out of a machining zone through grooves 90. Alternatively, used abrasive slurry and debris 32 can be vacuumed out of the machining zone via bore 88 and new abrasive slurry 34 can be replenished in the machining zone via delivery through grooves 90.

[0031] Any relative terms or terms of degree used here-

in, such as "substantially", "essentially", "generally", "approximately" and the like, should be interpreted in accordance with and subject to any applicable definitions or limits expressly stated herein. In all instances, any relative terms or terms of degree used herein should be interpreted to broadly encompass any relevant disclosed embodiments as well as such ranges or variations as would be understood by a person of ordinary skill in the art in view of the entirety of the present disclosure, such as to encompass ordinary manufacturing tolerance variations, incidental alignment variations, transient alignment or shape variations induced by thermal, rotational or vibrational operational conditions, and the like. Moreover, any relative terms or terms of degree used herein should be interpreted to encompass a range that expressly includes the designated quality, characteristic, parameter or value, without variation, as if no qualifying relative term or term of degree were utilized in the given disclosure or recitation.

Discussion of Possible Embodiments

[0032] The following are non-exclusive descriptions of possible embodiments of the present invention.

[0033] A tool for an ultrasonic impact grinding machine driven to vibrate along a longitudinal axis includes a hollow tool body and a hollow tip extending from an end of the hollow tool body. The hollow tip has an outer surface comprising a plurality of grooves. The hollow tool body and the hollow tip are disposed about the longitudinal axis and the hollow tip and hollow tool body are each defined in part by a common bore extending along the longitudinal axis.

[0034] In an embodiment of the foregoing tool, the plurality of grooves can be angled with respect to the longitudinal axis.

[0035] In an embodiment of any of the foregoing tools, the plurality of grooves can be angled 30 to 60 degrees relative to the longitudinal axis.

[0036] In an embodiment of any of the foregoing tools, the plurality of grooves can be helical.

[0037] In an embodiment of any of the foregoing tools, the plurality of grooves can extend longitudinally.

[0038] In an embodiment of any of the foregoing tools, the plurality of grooves can form a plurality of blades having cutting edges.

[0039] In an embodiment of any of the foregoing tools, the common bore can be configured to receive a slurry of abrasive particles.

[0040] In an embodiment of any of the foregoing tools, grooves of the plurality of grooves can be uniformly spaced

[0041] In an embodiment of any of the foregoing tools, the grooves can have a uniform size and shape.

[0042] In an embodiment of any of the foregoing tools, each of the plurality of grooves can extend a full length of the hollow tip.

[0043] In an embodiment of any of the foregoing tools,

the common bore can be connected to a vacuum configured to evacuate an abrasive slurry and debris from the terminal end through the hollow tip and the hollow tool body.

[0044] In an embodiment of any of the foregoing tools, the common bore can be connected to an abrasive slurry source and configured to deliver the abrasive slurry through the terminal end of the hollow tip and the plurality of grooves can be configured to evacuate the abrasive slurry and debris during operation of the ultrasonic impact grinding machine.

[0045] A method of ultrasonic impact grinding includes applying longitudinal vibration to a tip of a tool in the direction of an axis of the tool, impacting a substrate with the tip, supplying an abrasive slurry to a terminal end of the tip, and evacuating the abrasive slurry and debris from the terminal end of the tip. The abrasive slurry is supplied through a bore extending longitudinally through the tool or the abrasive slurry and debris is evacuated through the bore extending longitudinally through the tool.

[0046] In an embodiment of the foregoing method, the abrasive slurry can be supplied through the bore extending longitudinally through the tool and the abrasive slurry and debris can be evacuated through grooves disposed on an outer surface of the tip.

[0047] In an embodiment of any of the foregoing methods, the abrasive slurry is supplied through grooves disposed on an outer surface of the tip and the abrasive and debris is evacuated through the bore extending longitudinally through the tool.

[0048] An embodiment of any of the foregoing methods can further include applying torsional vibration to the tip.

[0049] In an embodiment of any of the foregoing methods, the torsional vibration can be provided by grooves disposed on an outer surface of the tip and angled with respect to the axis.

[0050] In an embodiment of any of the foregoing methods, the grooves can be helical.

an embodiment of any of the foregoing methods can further include rotating the tip.

[0051] While the invention has been described with reference to an exemplary embodiment(s), it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. A tool (12; 40; 60; 80) for an ultrasonic impact grind-

ing machine (10) driven to vibrate along a longitudinal axis (A), the tool (12; 40; 60; 80) comprising:

a hollow tool body (20; 42; 62; 82); and
a hollow tip (22; 44; 64; 84) extending from an end of the hollow tool body (20... 82), the hollow tip (22... 84) having an outer surface comprising a plurality of grooves (24; 50; 70; 90);
wherein the hollow tool body (20... 82) and the hollow tip (22... 84) are disposed about the longitudinal axis (A); and
wherein the hollow tip (22... 84) and hollow tool body (20... 82) are each defined in part by a common bore (26; 48; 68; 88) extending along the longitudinal axis (A).

2. The tool of claim 1, wherein the grooves (70; 90) are angled with respect to the longitudinal axis (A), optionally wherein the grooves (70; 90) are angled 30 to 60 degrees relative to the longitudinal axis (A).
3. The tool of claim 1 or 2, wherein the plurality of grooves (70; 90) is helical.
4. The tool of claim 1, wherein the plurality of grooves (40) extends longitudinally.
5. The tool of any preceding claim, wherein the plurality of grooves (24... 90) forms a plurality of blades having cutting edges.
6. The tool of any preceding claim, wherein grooves (24...90) of the plurality of grooves (24... 90) are uniformly spaced.
7. The tool of any preceding claim, wherein the grooves (24... 90) have a uniform size and shape.
8. The tool of any preceding claim, wherein the plurality of grooves (24... 90) extends to a terminal end (46; 66; 86) of the hollow tip (22...84).
9. The tool of claim 8, wherein the common bore (26... 88) is connected to a vacuum (36) configured to evacuate an abrasive slurry and debris (32) from the terminal end (46; 66; 86) through the hollow tip (22... 84) and the hollow tool body (20... 82), or wherein the common bore (26... 88) is connected to an abrasive slurry source (38) and configured to deliver the abrasive slurry (34) through the terminal end (46; 66; 86) of the hollow tip (22... 84) and wherein the plurality of grooves (24... 90) is configured to evacuate the abrasive slurry and debris (32) during operation of the ultrasonic impact grinding machine (10).
10. The tool of any preceding claim, wherein each of the plurality of grooves (24... 90) extends a full length of the hollow tip (22... 84).

11. A method of ultrasonic impact grinding comprising:

applying longitudinal vibration to a tip (22... 82)
 of a tool (12... 80) in the direction of an axis (A)
 of the tool (12... 80); 5
 impacting a substrate (28) with the tip (22... 82);
 supplying an abrasive slurry (34) to a terminal
 end (46; 66; 86) of the tip (22... 82); and
 evacuating the abrasive slurry and debris (32)
 from the terminal end (46; 66; 86) of the tip (22... 10
 82);
 wherein the abrasive slurry (34) is supplied
 through a bore (26... 88) extending longitudinally
 through the tool (12... 80) or the abrasive slurry
 and debris (32) is evacuated through the bore 15
 (26... 88) extending longitudinally through the
 tool (12... 80).

12. The method of claim 11, wherein the abrasive slurry
 (34) is supplied through the bore (26... 88) extending 20
 longitudinally through the tool (12... 80) and the abra-
 sive slurry and debris (32) is evacuated through
 grooves (24... 90) disposed on an outer surface of
 the tip (22... 82).

13. The method of claim 11, wherein the abrasive slurry
 (34) is supplied through grooves (24... 90) disposed
 on an outer surface of the tip (22... 82) and the abra-
 sive slurry and debris (32) is evacuated through the 30
 bore (26... 88) extending longitudinally through the
 tool (12... 80).

14. The method of claim 11 and further comprising ap-
 plying torsional vibration to the tip (22... 82). 35

15. The method of claim 14, wherein the torsional vibra-
 tion is provided by grooves (24... 90) disposed on an
 outer surface of the tip (22... 82), the grooves (24...
 90) angled with respect to the axis (A), optionally
 wherein the grooves (24... 90) are helical, and op- 40
 tionally further comprising rotating the tip (22... 82).

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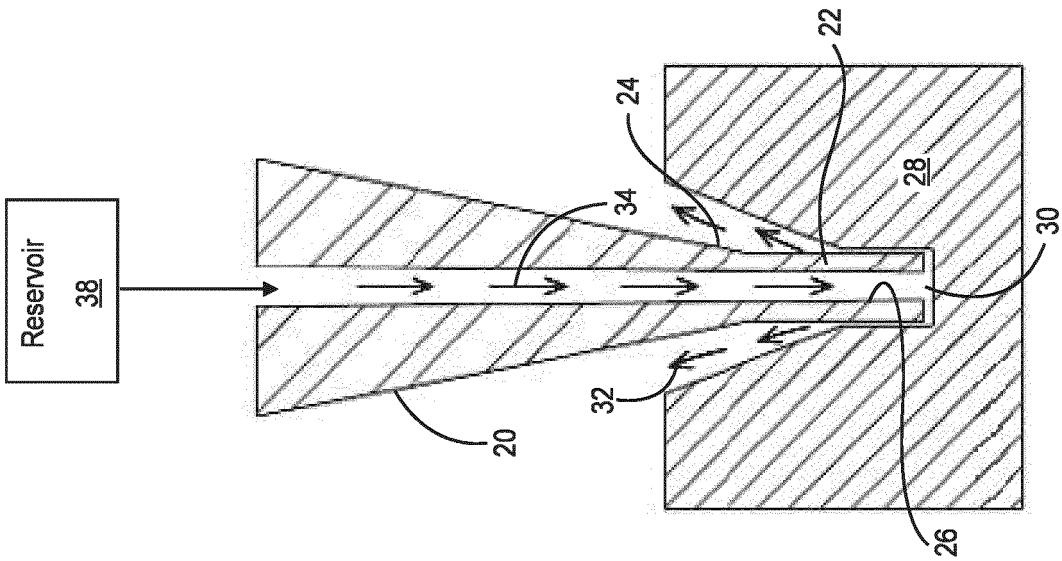


FIG. 3

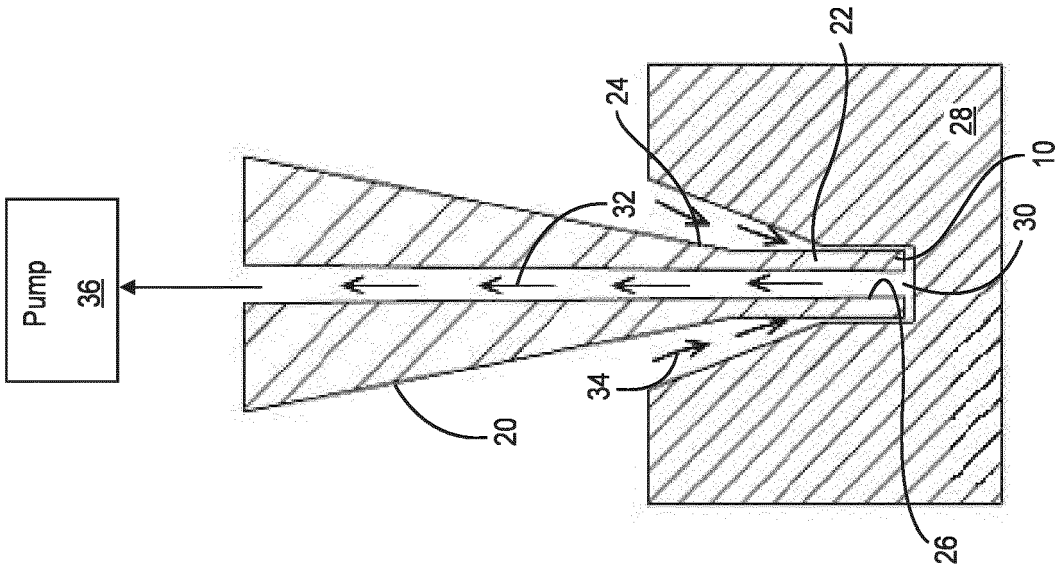


FIG. 2

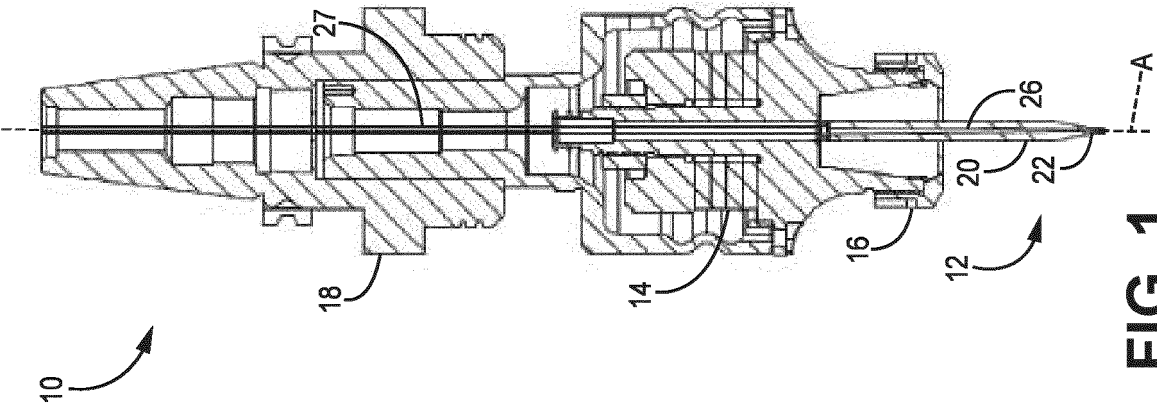
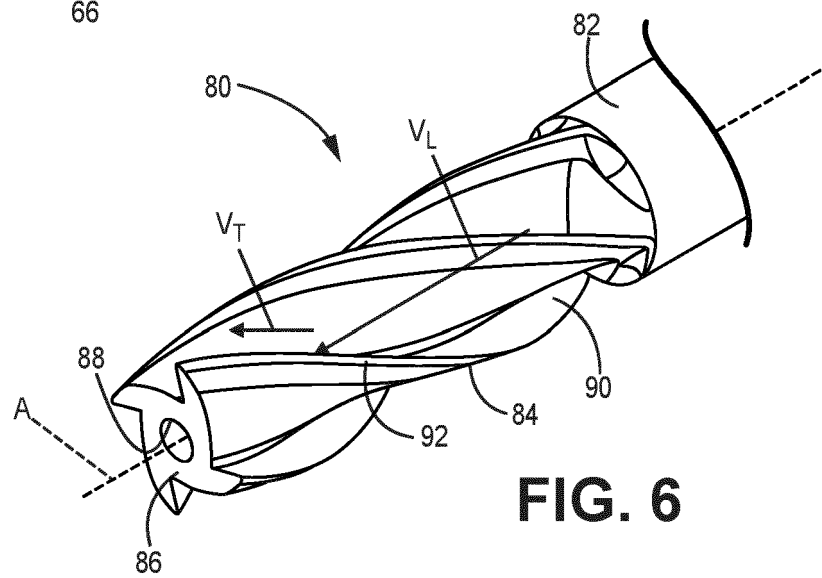
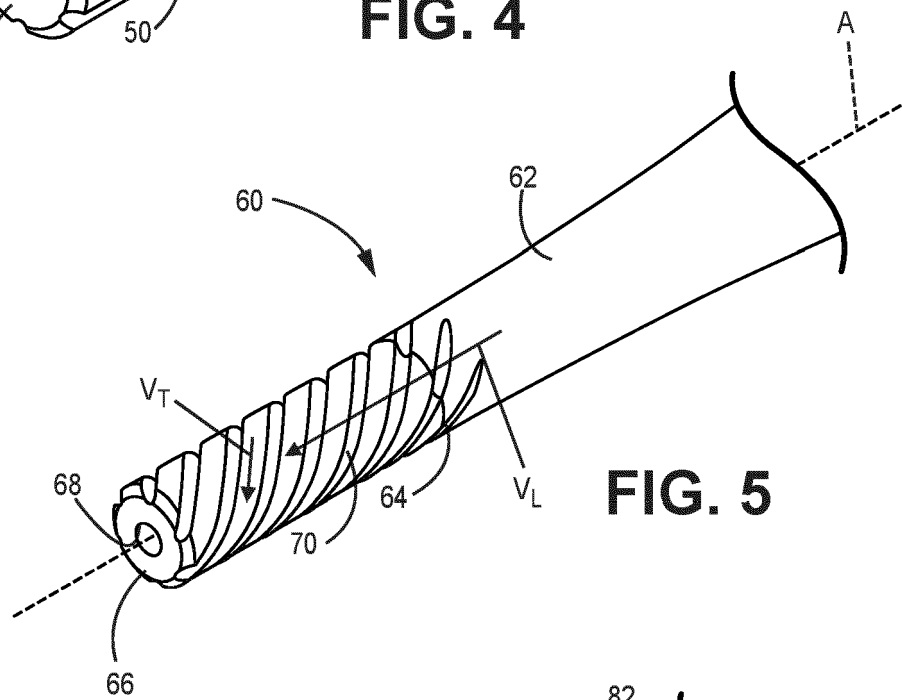
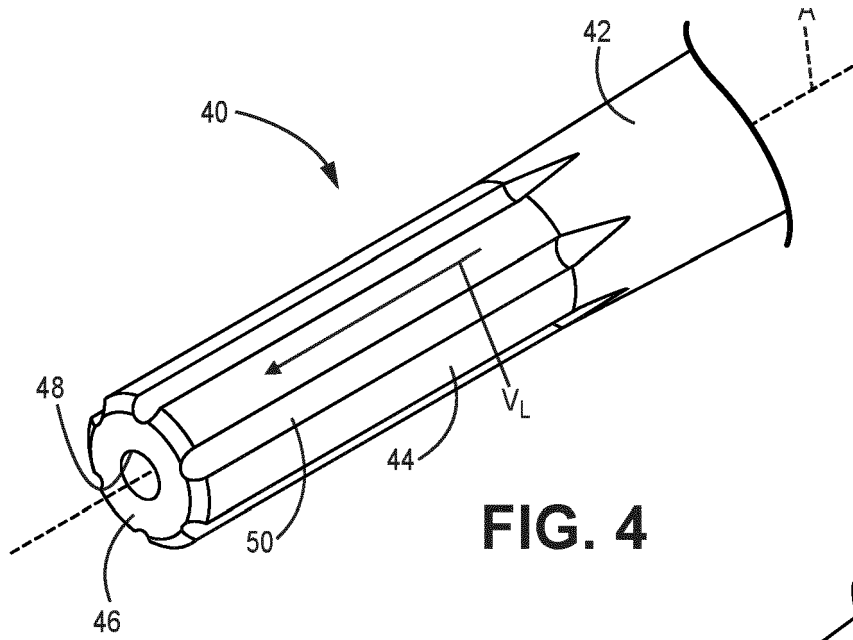


FIG. 1





EUROPEAN SEARCH REPORT

Application Number

EP 23 21 9486

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EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	WO 2009/022712 A1 (OHNISHI KAZUMASA [JP]) 19 February 2009 (2009-02-19)	14	INV. B24B1/04
A	* figures 1, 2 *	1-13,15	ADD. B24B39/02
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