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(71) Applicants: **SAINT-GOBAIN ABRASIVES, INC.** [US/US]; One New Bond Street, Worcester, Massachusetts 01615 (US). **SAINT-GOBAIN ABRASIFS** [FR/FR]; Rue de l'Ambassadeur, 78700 Conflans-Sainte-Honorine (FR).

(72) Inventors: **LAFOND, Gregory G.**; 163 Central Street, Boylston, Massachusetts 01505 (US). **SAHLIN, Katherine M.**; 132 Union Ave., Old Orchard Beach, Maine 04064 (US).

(74) Agents: **ABEL LAW GROUP, LLP** et al.; 8911 N. Capital of Texas Hwy, Bldg 4, Suite 4200, Austin, Texas 78759 (US).

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(54) Title: METHOD AND APPARATUS FOR EVALUATING BONDED ABRASIVE ARTICLE PERFORMANCE DURING A CUT-OFF GRINDING OPERATION

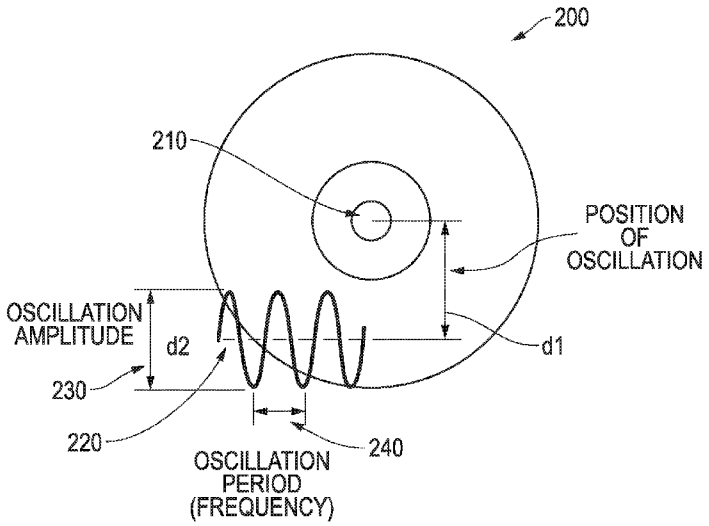


FIG. 2

(57) Abstract: A method and apparatus for evaluating performance of a bonded abrasive article during a cutoff grinding operation including an abrasive assembly holding a bonded abrasive article, a workpiece assembly holding a workpiece and a measuring assembly. The abrasive assembly and the workpiece assembly may be configured to create contact between the bonded abrasive article and the workpiece with an initial contact force. The abrasive assembly and the workpiece are further configured to maintain the initial contact force while varying a size of the initial contact area during the cut-off grinding operation using oscillation.

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METHOD AND APPARATUS FOR EVALUATING BONDED ABRASIVE ARTICLE PERFORMANCE DURING A CUT-OFF GRINDING OPERATION

FIELD OF THE DISCLOSURE

The present invention relates in general to a method and apparatus for evaluating bonded abrasive article performance in a cut-off grinding operation and, in particular, for evaluating cut-off wheel performance in a hand-held cut-off grinding operation.

BACKGROUND

Abrasive wheels are typically used for cutting, abrading, and shaping of various materials, such as stone, metal, glass, and plastics, among other materials. Generally, the abrasive wheels can have various phases of materials including abrasive grains or particles, a bonding agent, and some porosity. Depending upon the intended application, the abrasive wheel can have various designs and configurations. For example, for applications directed to the grinding, finishing and cutting of certain material, some abrasive wheels are fashioned such that they have a particularly thin profile for efficient cutting and are referred to as thin wheeled abrasive cutting systems. In certain applications, such thin wheel grinding systems are designed to be used manually as hand- held tools.

However, given the application of such wheels, the abrasive articles are subject to fatigue and failure. In the case of thin wheel cutting systems, degradation includes a reduction in the amount of cutting that can be achieved before the thin wheeled abrasive wears out. In addition, degradation can include an increase in wear rate of the abrasive article or a reduction in grind rate on a work piece. Some wheels may have a limited time of use of less than a day depending upon the frequency of use. Accordingly, the industry continues to demand improved methods and testing systems for evaluating the performance and providing performance expectations of abrasive wheels. In particular relation to hand-held thin wheel systems, evaluating the performance using people can result in undesirable variation in performance results which can mask true performance differences between wheels.

SUMMARY

According to a first aspect, an apparatus for evaluating performance of a bonded abrasive article during a cut-off grinding operation may include an abrasive assembly holding a bonded abrasive article, a workpiece assembly holding a workpiece and a measuring assembly. The abrasive assembly and the workpiece assembly may be configured to create contact between the bonded abrasive article and the workpiece with an initial contact force. The abrasive assembly and the workpiece are further configured to maintain the initial

contact force while varying a size of a contact area between the bonded abrasive article and the workpiece using oscillation.

According to another aspect, a method for evaluating performance of a bonded abrasive article during a cut-off grinding operation may include creating contact between a bonded abrasive article and a workpiece with a particular initial contact force, maintaining contact between the bonded abrasive article and the workpiece while varying a size of a contact area between the bonded abrasive article and the workpiece using oscillation, maintaining the initial contact force between the bonded abrasive article and the workpiece throughout the grinding operation; and measuring at least one performance parameter of the bonded abrasive article during the grinding operation.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments are illustrated by way of example and are not limited in the accompanying figures.

FIG. 1 includes a flow chart illustrating a process for evaluating a bonded abrasive article's performance during a cut-off grinding operation according to an embodiment;

FIG. 2 includes a diagram illustrating oscillation parameters on a bonded abrasive article for use according to an embodiment;

FIG. 3 includes diagram of an apparatus for evaluating a bonded abrasive article's performance during a cut-off grinding operation according to an embodiment;

FIG. 4 includes a chart showing performance evaluation conducted using conventional testing operations and a testing operation according to an embodiment;

FIG. 5 includes a chart showing performance evaluation conducted using a conventional testing operation and a testing operation according to an embodiment; and

FIGS. 6a, 6b and 6c include charts showing performance evaluations conducted using conventional testing operations and a testing operation according to an embodiment.

Skilled artisans appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the invention.

DETAILED DESCRIPTION

Embodiments disclosed herein are related to a method and apparatus for evaluating a bonded abrasive article's performance during a cut-off grinding operation. In particular, embodiments disclosed herein are related to a method and apparatus for evaluating the performance of a hand-held grinding tool in a cut-off grinding operation.

Referring first to the method for evaluating the performance of a bonded abrasive article in a cut-off grinding operation, FIG. 1 illustrates a testing process 100 that may include steps, 110, 120, 130 and 140. Step 110 of testing process 100 may include creating contact between a bonded abrasive article and a workpiece with a particular initial contact force. Step 120 of testing process 100 may include maintaining contact between the bonded abrasive article and the workpiece while varying a size of a contact area between the bonded abrasive article and the workpiece using oscillation. Step 130 of testing process 100 may include maintaining the initial contact force between the bonded abrasive article and the workpiece throughout the cut-off grinding operation of testing process 100. Finally, step 140 of testing process 100 may include measuring at least one performance parameter during the cut-off grinding operation of testing process 100 to evaluate the bonded abrasive article's performance in the cut-off grinding operation.

The bonded abrasive article that may be evaluated using testing process 100 may be any suitable bonded abrasive article that may be used in a cut-off grinding operation. According to a particular embodiment, the bonded abrasive article may be any bonded abrasive article suitable for use in any hand-held grinding assembly. It will be appreciated that a hand-held grinding assembly may include, but is not limited to, an angle grinder, a side grinder or a disc grinder. It will be further appreciated that a hand-held grinding assembly may utilize, but is not limited to using, a pneumatic driven motor or electrically driven motor. According to certain embodiments that include a hand-held grinding assembly utilizing an electrically driven motor, the electrically driven motor may be a single phase motor or a multi-phase motor.

According to still other embodiments, the hand-held grinding assembly used in testing process 100 may have a particular power rating. For example, the hand-held grinding assembly may have a power rating of at least about 350 Watts, such as, at least about 400 Watts, at least about 450 Watts, at least about 500 Watts, at least about 750 Watts, at least about 1000 Watts, at least about 1500 Watts, at least about 2000 Watts, at least about 2500 Watts, at least about 3000 Watts or even at least about at least about 4000 Watts. According to still another embodiment, the hand-held grinding assembly may have a power rating of not greater than about 5500 Watts, such as, not greater than about 5000 Watts or even not greater than about 4500. It will be appreciated that the hand-held grinding assembly may have a power rating of any value between any of the minimum and maximum values noted above. It will be further appreciated that the hand-held grinding assembly may have a power rating of any value within a range between any of the minimum and maximum values noted above.

According to yet other embodiments, the hand-held assembly used in testing process 100 may have a particular weight. For example, the hand-held grinding tool may have a weight of at least about 3 lbs, such as, at least about 5 lbs, at least about 8 lbs, at least about 10 lbs, at last about 13 lbs or even at least about 15 lbs. According to still other embodiments, the hand-held tool may have a weight of not greater than about 25 lbs, such as, not greater than about 23 lbs, not greater than about 20 lbs or even not greater than about 18 lbs. It will be appreciated that the hand-held grinding assembly may have a weight of any value between any of the minimum and maximum values noted above. It will be further appreciated that the hand-held grinding assembly may have a weight of any value within a range between any of the minimum and maximum values noted above.

According to certain embodiments, the bonded abrasive article may be a cut-off grinding wheel. According to still other embodiments, the bonded abrasive article may be a cut-off grinding wheel mounted in a hand-held grinding assembly using a mounting flange. According to still other embodiments, the bonded abrasive article may be a cut-off grinding wheel mounted in a hand-held grinding assembly using a mounting hub. According to still other embodiments, the bonded abrasive article may be a cut-off grinding wheel mounted in a hand-held grinding assembly using a mounting hub fixed to the cut-off grinding wheel.

According to still other embodiments, the bonded abrasive article may have a particular diameter. It will be appreciated that the particular diameter of the bonded abrasive article may be determined by the requirements of the hand-held grinding assembly utilized in the testing process and any bonded abrasive article diameters provided herein are intended as examples and not to limit every embodiment described herein. According to certain embodiments, the bonded abrasive article may have a diameter of at least about 3.0 inches, such as, at least about 3.3 inches, at least about 3.5 inches, at least about 3.8 inches, at least about 4.0 inches, at least about 4.3 inches, at least about 4.5 inches, at least about 4.8 inches, at least about 5.0 inches, at least about 5.3 inches, at least about 5.5 inches, at least about 5.8 inches, at least about 6.0 inches, at least about 6.3 inches, at least about 6.5 inches, at least about 6.8 inches, at least about 7.0 inches, at least about 7.3 inches, at least about 7.5 inches, at least about 7.8 inches, at least about 8.0 inches, at least about 8.3 inches, at least about 8.5 inches and at least about 8.8 inches. According to still other embodiments, the bonded abrasive article may have a diameter of not greater than about 13 inches, such as, not greater than about 12.5 inches, not greater than about 12 inches, not greater than about 11.5 inches, not greater than about 11.0 inches, not greater than about 10.5 inches, not greater than about 10.0 inches, not greater than about 10.5 inches, not greater than about 9.0 inches, not greater

than about 8.7 inches, not greater than about 8.5 inches, not greater than about 8.2 inches, not greater than about 8.0 inches, not greater than about 7.7 inches, not greater than about 7.5 inches, not greater than about 7.2 inches, not greater than about 7.0 inches, not greater than about 6.7 inches, not greater than about 6.5 inches, not greater than about 6.2 inches, not greater than about 6.0 inches, not greater than about 5.7 inches, not greater than about 5.5 inches, not greater than about 5.2 inches, not greater than about 5.0 inches and not greater than about 4.7 inches. It will be appreciated that the bonded abrasive article may have a diameter of any value between any of the minimum and maximum values noted above. It will be further appreciated that the bonded abrasive article may have a diameter within a range between any of the minimum and maximum values noted above.

According to yet another embodiment, the workpiece may be any desirable workpiece for evaluating the performance of a bonded abrasive article as described herein. In particular, the workpiece may be any desirable workpiece that may be ground using a hand-held grinding assembly as described herein.

Referring to step 110, creating contact between a bonded abrasive article and a workpiece with a particular initial contact force may include the movement of either the bonded abrasive article towards and into contact with the workpiece or the movement of the workpiece towards and into contact with the bonded abrasive article. For example, according to one particular embodiment, creating contact between a bonded abrasive article and a workpiece with a particular initial contact force may include moving the bonded abrasive article along a first path towards and into contact with the workpiece to create the initial contact force. According to another embodiment, creating contact between a bonded abrasive article and a workpiece with a particular initial contact force may include moving the workpiece along a first path towards and into contact with the bonded abrasive article to create the initial contact force.

According to particular embodiments, the first path may be described as a straight path, meaning that the path extends uniformly in one direction without any curves or bends along the length of the path. It will be appreciated that the first path may have any desirable length sufficient to conduct a cut-off grinding operation on a workpiece. It will be further appreciated that the minimum length of the first path may be any length sufficient for the bonded abrasive article to come into contact with the workpiece, travel through or along the workpiece during the cut-off grinding operation and then exit or separate contact from the work piece on an opposite side of the work piece from where the initial contact occurred.

According to still other embodiments, contact between a bonded abrasive article and a workpiece may be created with a particular initial contact force. For example, the initial contact force created between the bonded abrasive article and the workpiece may be at least about 2 lbs, such as, at least about 3 lbs, at least about 4 lbs, at least about 5 lbs, at least about 6 lbs, at least about 7 lbs, at least about 8 lbs, at least about 9 lbs, at least about 10 lbs, at least about 11 lbs, at least about 12 lbs, at least about 13 lbs, at least about 14 lbs, at least about 15 lbs, at least about 16 lbs, at least about 17 lbs, at least about 18 lbs, at least about 19 lbs, at least about 20 lbs, at least about 21 lbs, at least about 22 lbs, at least about 23 lbs, at least about 24 lbs or even at least about 25 lbs. According to yet another embodiment, the contact force created between the bonded abrasive article and the workpiece may be not greater than about 30 lbs, such as, not greater than about 29 lbs, not greater than about 28 lbs, not greater than about 28 lbs, not greater than about 27 lbs, not greater than about 26 lbs, not greater than about 25 lbs, not greater than about 24 lbs, not greater than about 23 lbs, not greater than about 22 lbs, not greater than about 21 lbs, not greater than about 20 lbs, not greater than about 29 lbs, not greater than about 19 lbs, not greater than about 18 lbs, not greater than about 17 lbs, not greater than about 16 lbs or even not greater than about 15 lbs. It will be appreciated that the contact force created between the bonded abrasive article and the workpiece may be any value between any of the minimum and maximum values noted above. It will be further appreciated that the contact force created between the bonded abrasive article and the workpiece may be within a range between any of the minimum and maximum values noted above.

Referring now back to step 120, maintaining contact between the bonded abrasive article and the workpiece while varying the size of a contact area between the bonded abrasive article and the workpiece using oscillation may include oscillating the bonded abrasive article or the workpiece back and forth along a second path that is distinct from the first path. According to one particular embodiment, maintaining contact between the bonded abrasive article and the workpiece while varying the size of a contact area between the bonded abrasive article and the workpiece using oscillation may include oscillating the bonded abrasive article back and forth along a second path that is distinct from the first path. According to still another embodiment, maintaining contact between the bonded abrasive article and the workpiece while varying the size of a contact area between the bonded abrasive article and the workpiece using oscillation may include oscillating the workpiece back and forth along a second path that is distinct from the first path.

As used in reference to embodiments described herein, "oscillation" or "oscillating" may be defined as moving the bonded abrasive article or the workpiece back and forth along the second path at a particular frequency (i.e., speed) and amplitude relative to a particular oscillation position on the bonded abrasive article or the workpiece. As used in reference to embodiments described herein, the "oscillation position" may be defined as the centerline of the oscillation motion that occurs back and forth along the second path. As used in reference to embodiments described herein, "oscillation amplitude" may be defined as the maximum distance traveled by the bonded abrasive article along the second path away from an "oscillation position" or centerline of the oscillation motion that occurs along the second path. As used in reference to embodiments described herein, "oscillation frequency" may be defined as the speed at which the bonded abrasive article or the workpiece moves back and forth along the full length of the second path (i.e., completing one full cycle of oscillation).

For purposes of illustration, FIG. 2 includes a diagram of a bonded abrasive article 200 having a center point 210. The oscillation position 220 on the bonded abrasive article 210 may be located a distance d1 from the center point 210 of the bonded abrasive article 200. The oscillation amplitude 230 is the maximum distance d2 travel by the bonded abrasive article 210 from the oscillation position 220. The oscillation frequency is the speed at which the bonded abrasive article 210 completes a full cycle of oscillation 240. It will be appreciated that all aspects of oscillation defined herein may be applied to either a bonded abrasive article as illustrated on FIG. 2 or a workpiece.

According to particular embodiments described herein the second path may be a straight path meaning that the path extends uniformly in one direction without any curves or bends along the length of the path. According to still other embodiments, the second path may be an arcuate path meaning that the path extends along a curve or arc.

According to still other embodiments, oscillation of the bonded abrasive article or the workpiece may occur at a particular amplitude. According to a particular embodiment, the oscillation amplitude may be equal to or less than the diameter of the bonded abrasive article. According to particular embodiments, the oscillation amplitude may be at least about 0.04 inches, such as, at least about 0.08 includes, at least about 0.1 inches, at least about 0.2 inches, at least about 0.3 inches, at least about 0.4 inches, at least about 0.5 inches, at least about 0.6 inches, at least about 0.7 inches, at least about 0.8 inches, at least about 0.9 inches, at least about 1.0 inches, at least about 1.1 inches, at least about 1.2 inches, at least about 1.3 inches, at least about 1.4 inches or even at least about 1.5 inches. According to yet another embodiment, the oscillation amplitude may be not greater than about 13 inches, such as, not

greater than about 12.5 inches, not greater than about 12 inches, not greater than about 11.5 inches, not greater than about 11.0 inches, not greater than about 10.5 inches, not greater than about 10.0 inches, not greater than about 10.5 inches, not greater than about 9.0 inches, not greater than about 8.7 inches, not greater than about 8.5 inches, not greater than about 8.2 inches, not greater than about 8.0 inches, not greater than about 7.7 inches, not greater than about 7.5 inches, not greater than about 7.2 inches, not greater than about 7.0 inches, not greater than about 6.7 inches, not greater than about 6.5 inches, not greater than about 6.2 inches, not greater than about 6.0 inches, not greater than about 5.7 inches, not greater than about 5.5 inches, not greater than about 5.2 inches, not greater than about 5.0 inches or even not greater than about 4.7 inches.. It will be appreciated that the oscillation amplitude may be any value between any of the minimum and maximum values noted above. It will be further appreciated that the oscillation amplitude may be within a range between any of the minimum and maximum values noted above.

According to still other embodiments, oscillation of the bonded abrasive article or the workpiece may occur at a particular frequency. According to particular embodiments, the oscillation frequency may be at least about 20 cycles per minute, such as, at least about 30 cycles per minute, at least about 40 cycles per minute, at least about 50 cycles per minute, at least about 60 cycles per minute, at least about 70 cycles per minute, at least about 80 cycles per minute, at least about 90 cycles per minute, at least about 100 cycles per minute, at least about 110 cycles per minute, at least about 120 cycles per minute, at least about 130 cycles per minute or even at least about 140 cycles per minute. According to still other embodiments, the oscillation frequency may be not greater than about 150 cycles per minute, not greater than about 140 cycles per minute, not greater than about 130 cycles per minute, not greater than about 120 cycles per minute, not greater than about 110 cycles per minute, not greater than about 100 cycles per minute, not greater than about 90 cycles per minute, not greater than about 80 cycles per minute, not greater than about 70 cycles per minute, not greater than about 60 cycles per minute, not greater than about 50 cycles per minute, not greater than about 40 cycles per minute or even not greater than about 30 cycles per minute. It will be appreciated that the oscillation frequency may be any value between any of the minimum and maximum values noted above. It will be further appreciated that the oscillation frequency may be within a range between any of the minimum and maximum values noted above.

According to yet another embodiment, the oscillation position of the bonded abrasive article or the workpiece during oscillation may have a particular distance from the center

point of the bonded abrasive article or the workpiece. According to a particular embodiment, the oscillation position may be located any distance along the radius of the bonded abrasive article between the center of the bonded abrasive article and the outer perimeter of the bonded abrasive article.

Referring now back to step 130, maintaining the initial contact force between the bonded abrasive article and the workpiece during the testing process may include ensuring that any variation from the initial contact force during the testing process 100 is less than 150% of the initial contact force and not greater than +or- 5 lbs from the initial contact force during the testing process 100, such as, not greater than +or- 4 lbs, not greater than +or- 3 lbs, not greater than +or- 2 lbs or even not greater than +or- 1 lbs. It will be appreciated that the testing process may include ensuring that any variation from the initial contact force during the testing process 100 is not greater than any value between any of the values noted above.

Referring now back to step 140, measuring performance parameters may include measuring any desired performance parameter used to evaluate the effectiveness of the bonded abrasive article being used in the cut-off grinding operation. According to one particular embodiment, measuring performance parameters may include measuring the G-ratio of the bonded abrasive article, where the G-Ratio is defined as the ratio of the volume of material removed from the workpiece to the volume of material removed from the abrasive wheel. According to other embodiment, measuring performance parameters may include measuring cut duration during the testing process, measuring total number of cuts during the testing process, measuring the change in wheel diameter during the testing process, measuring the average/peak power draw during the testing process or measuring the average/peak current draw during the testing process.

Referring now to the apparatus, FIG. 3 illustrates a testing apparatus 300 for evaluating a bonded abrasive article's performance in a cut-off grinding operation according to methods described herein. Testing apparatus 300 may include an abrasive assembly 310, a workpiece assembly 320 and a measuring assembly 330. The abrasive assembly 310 may be configured for holding a bonded abrasive article 315. The workpiece assembly 320 may be configured for holding a workpiece 325. The measuring assembly may be configured to measure at least one performance parameter during the cut-off grinding operation to evaluate the performance of the bonded abrasive article 315 in grinding the workpiece 325.

The bonded abrasive article 315 that may be evaluated using testing apparatus 300 may be any suitable bonded abrasive article that may be used in a cut-off grinding operation. According to yet another embodiment, the bonded abrasive article 315 may be any bonded

abrasive article suitable for use in any had-held grinding assembly. It will be appreciated that a hand-held grinding assembly may include, but is not limited to, an angle grinder, a side grinder or a disc grinder. It will be further appreciated that a hand-held grinding assembly may utilize, but is not limited to using, a pneumatic driven motor or electrically driven motor. According to certain embodiments that include a hand-held grinding assembly utilizing an electrically driven motor, the electrically driven motor may be a single phase motor or a multi-phase motor.

According to still other embodiments, the hand-held grinding assembly used in testing apparatus 300 may have a particular power rating. For example, the hand-held grinding assembly may have a power rating of at least about 350 Watts, such as, at least about 400 Watts, at least about 450 Watts, at least about 500 Watts, at least about 750 Watts, at least about 1000 Watts, at least about 1500 Watts, at least about 2000 Watts, at least about 2500 Watts, at least about 3000 Watts or even at least about at least about 4000 Watts. According to still another embodiment, the hand-held grinding assembly may have a power rating of not greater than about 5500 Watts, such as, not greater than about 5000 Watts or even not greater than about 4500. It will be appreciated that the hand-held grinding assembly may have a power rating of any value between any of the minimum and maximum values noted above. It will be further appreciated that the hand-held grinding assembly may have a power rating of any value within a range between any of the minimum and maximum values noted above.

According to yet other embodiments, the hand-held assembly used in testing apparatus 300 may have a particular weight. For example, the hand-held grinding tool may have a weight of at least about 3 lbs, such as, at least about 5 lbs, at least about 8 lbs, at least about 10 lbs, at last about 13 lbs or even at least about 15 lbs. According to still other embodiments, the hand-held tool may have a weight of not greater than about 25 lbs, such as, not greater than about 23 lbs, not greater than about 20 lbs or even not greater than about 18 lbs. It will be appreciated that the hand-held grinding assembly may have a weight of any value between any of the minimum and maximum values noted above. It will be further appreciated that the hand-held grinding assembly may have a weight of any value within a range between any of the minimum and maximum values noted above. According to certain embodiments, the bonded abrasive article 315 may be a cut-off grinding wheel. According to still other embodiments, the bonded abrasive article 315 may be a cut-off grinding wheel mounted in a hand-held grinding assembly using a mounting flange. According to still other embodiments, the bonded abrasive article 315 may be a cut-off grinding wheel mounted in a hand-held grinding assembly using a mounting hub. According to still other embodiments,

the bonded abrasive article 315 may be a cut-off grinding wheel mounted in a hand-held grinding assembly using a mounting hub fixed to the cut-off grinding wheel.

According to still other embodiments, bonded abrasive article 315 may have a particular diameter. It will be appreciated that the particular diameter of the bonded abrasive article 315 may be determined by the requirements of the hand-held grinding assembly utilized in the testing apparatus 300 and any bonded abrasive article diameters provided herein are intended as examples and not to limit every embodiment described herein. According to certain embodiments, the bonded abrasive article may have a diameter of at least about 3.0 inches, such as, at least about 3.3 inches, at least about 3.5 inches, at least about 3.8 inches, at least about 4.0 inches, at least about 4.3 inches, at least about 4.5 inches, at least about 4.8 inches, at least about 5.0 inches, at least about 5.3 inches, at least about 5.5 inches, at least about 5.8 inches, at least about 6.0 inches, at least about 6.3 inches, at least about 6.5 inches, at least about 6.8 inches, at least about 7.0 inches, at least about 7.3 inches, at least about 7.5 inches, at least about 7.8 inches, at least about 8.0 inches, at least about 8.3 inches, at least about 8.5 inches and at least about 8.8 inches. According to still other embodiments, the bonded abrasive article 315 cut-off grinding wheel may have a diameter of not greater than about 13 inches, such as, not greater than about 12.5 inches, not greater than about 12 inches, not greater than about 11.5 inches, not greater than about 11.0 inches, not greater than about 10.5 inches, not greater than about 10.0 inches, not greater than about 10.5 inches, not greater than about 9.0 inches, not greater than about 8.7 inches, not greater than about 8.5 inches, not greater than about 8.2 inches, not greater than about 8.0 inches, not greater than about 7.7 inches, not greater than about 7.5 inches, not greater than about 7.2 inches, not greater than about 7.0 inches, not greater than about 6.7 inches, not greater than about 6.5 inches, not greater than about 6.2 inches, not greater than about 6.0 inches, not greater than about 5.7 inches, not greater than about 5.5 inches, not greater than about 5.2 inches, not greater than about 5.0 inches and not greater than about 4.7 inches. It will be appreciated that the bonded abrasive article 315 may have a diameter of any value between any of the minimum and maximum values noted above. It will be further appreciated that the bonded abrasive article 315 may have a diameter within a range between any of the minimum and maximum values noted above.

According to yet another embodiment, the workpiece 325 may be any desirable workpiece for evaluating the performance of a bonded abrasive article as described herein. In particular, the workpiece 325 may be any desirable workpiece that may be grinded using a hand-held grinding assembly as described herein.

According to one particular embodiment, the abrasive assembly 310 and the workpiece assembly 320 may be configured for creating contact between the bonded abrasive article 315 and the workpiece 325 with a particular initial contact force. According to a particular embodiment, the abrasive assembly 310 may be configured to move the bonded abrasive article 315 along a first path towards and into contact with the workpiece 325, which is held stable by the workpiece assembly 320. According to yet another embodiment, the workpiece assembly 320 may be configure to move the workpiece 325 along a first path towards and into contact with the bonded abrasive article 315, which is held stable by the abrasive assembly 325.

According to particular embodiments, the first path followed by either the abrasive assembly 310 or the workpiece assembly 320 may be described as a straight path meaning that the path extends uniformly in one direction without any curves or bends along the length of the path. It will be appreciated that the first path may have any desirable length sufficient to conduct a cut-off grinding operation on a workpiece 325. It will be further appreciated that the minimum length of the first path may be any length sufficient for the bonded abrasive article 315 to come into contact with the workpiece 325, travel through or along the workpiece 325 during the cut-off grinding operation and then exit or separate contact from the workpiece 325 on an opposite side of the workpiece 325 from where the initial contact occurred.

According to certain other embodiments, the abrasive assembly 310 and the workpiece assembly 320 may be configured to contact the bonded abrasive article 315 and the workpiece 325 with a particular initial contact force. For example, the initial contact force created between the bonded abrasive article 315 and the workpiece 325 may be at least about 2 lbs, such as, at least about 3lbs, at least about 4 lbs, at least about 5 lbs, at least about 6 lbs, at least about 7 lbs, at least about 8 lbs, at least about 9 lbs, at least about 10 lbs, at least about 11 lbs, at least about 12 lbs, at least about 13 lbs, at least about 14 lbs, at least about 15 lbs, at least about 16 lbs, at least about 17 lbs, at least about 18 lbs, at least about 19 lbs, at least about 20 lbs, at least about 21 lbs, at least about 22 lbs, at least about 23 lbs, at least about 24 lbs or even at least about 25 lbs. According to yet another embodiment, the contact force created between the bonded abrasive article 315 and the workpiece 325 may be not greater than about 30 lbs, such as, not greater than about 29 lbs, not greater than about 28 lbs, not greater than about 28 lbs, not greater than about 27 lbs, not greater than about 26 lbs, not greater than about 25 lbs, not greater than about 24 lbs, not greater than about 23 lbs, not greater than about 22 lbs, not greater than about 21 lbs, not greater than about 20 lbs, not

greater than about 29 lbs, not greater than about 19 lbs, not greater than about 18 lbs, not greater than about 17 lbs, not greater than about 16 lbs or even not greater than about 15 lbs. It will be appreciated that the initial contact force created by the abrasive assembly 310 and the workpiece assembly 320 may be any value between any of the minimum and maximum values noted above. It will be further appreciated that the initial force created by the abrasive assembly 310 and the workpiece assembly 320 may be within a range between any of the minimum and maximum values noted above.

According to yet another embodiment, the abrasive assembly 310 and the workpiece assembly 320 may be further configured to maintain contact between the bonded abrasive article 315 and the workpiece 325 while varying the size a contact area between the bonded abrasive article 315 and the workpiece 325 using oscillation. According to particular embodiments, the abrasive assembly 310 or the workpiece assembly 315 may be configured to vary the size of the contact area between the bonded abrasive article 310 and the workpiece 315 by oscillating the bonded abrasive article 310 or the workpiece 315 along a second path that is distinct from the first path. For example, according to one particular embodiment, the abrasive assembly 310 may be configured to oscillate the bonded abrasive article 315 along a second path that is distinct from the first path. According to still another embodiment, the workpiece assembly 320 may be configured to oscillate the workpiece 325 along a second path that is distinct from the first path.

According to particular embodiments described herein, the second path may be a straight path meaning that the path extends uniformly in one direction without any curves or bends along the length of the path. According to still other embodiments, the second path may be an arcuate path meaning that the path extends along a curve or arc.

According to still other embodiments, the oscillation of the bonded abrasive article 315 by the abrasive assembly 310 or the workpiece 325 by the workpiece assembly 320 may occur at a particular amplitude. According to a particular embodiment, the oscillation amplitude may be equal to the diameter of the bonded abrasive article. According to particular embodiments, the oscillation amplitude may be at least about 0.04 inches, such as, at least about 0.8 includes, at least about 0.1 inches, at least about 0.2 inches, at least about 0.3 inches, at least about 0.4 inches, at least about 0.5 inches, at least about 0.6 inches, at least about 0.7 inches, at least about 0.8 inches, at least about 0.9 inches, at least about 1.0 inches, at least about 1.1 inches, at least about 1.2 inches, at least about 1.3 inches, at least about 1.4 inches or even at least about 1.5 inches. According to yet another embodiment, the oscillation amplitude may be not greater than about 13 inches, such as, not greater than about

12.5 inches, not greater than about 12 inches, not greater than about 11.5 inches, not greater than about 11.0 inches, not greater than about 10.5 inches, not greater than about 10.0 inches, not greater than about 10.5 inches, not greater than about 9.0 inches, not greater than about 8.7 inches, not greater than about 8.5 inches, not greater than about 8.2 inches, not greater than about 8.0 inches, not greater than about 7.7 inches, not greater than about 7.5 inches, not greater than about 7.2 inches, not greater than about 7.0 inches, not greater than about 6.7 inches, not greater than about 6.5 inches, not greater than about 6.2 inches, not greater than about 6.0 inches, not greater than about 5.7 inches, not greater than about 5.5 inches, not greater than about 5.2 inches, not greater than about 5.0 inches or even not greater than about 4.7 inches.. It will be appreciated that the oscillation amplitude may be any value between any of the minimum and maximum values noted above. It will be further appreciated that the oscillation amplitude may be within a range between any of the minimum and maximum values noted above.

According to still other embodiments, the oscillation of the bonded abrasive article 315 by the abrasive assembly 310 or the workpiece 325 by the workpiece assembly 320 may occur at a particular frequency. It will be appreciated that, as used in reference to embodiments described herein, "oscillation frequency" may be defined as the speed at which the bonded abrasive article or the workpiece moves back and forth along the full length of the second path (i.e., completing one full cycle of oscillation). According to a particular embodiment, the oscillation frequency may be at least about 20 cycles per minute, such as, at least about 30 cycles per minute, at least about 40 cycles per minute, at least about 50 cycles per minute, at least about 60 cycles per minute, at least about 70 cycles per minute, at least about 80 cycles per minute, at least about 90 cycles per minute, at least about 100 cycles per minute, at least about 110 cycles per minute, at least about 120 cycles per minute, at least about 130 cycles per minute or even at least about 140 cycles per minute. According to still another embodiment, the oscillation frequency may be not greater than about 150 cycles per minute, not greater than about 140 cycles per minute, not greater than about 130 cycles per minute, not greater than about 120 cycles per minute, not greater than about 110 cycles per minute, not greater than about 100 cycles per minute, not greater than about 90 cycles per minute, not greater than about 80 cycles per minute, not greater than about 70 cycles per minute, not greater than about 60 cycles per minute, not greater than about 50 cycles per minute, not greater than about 40 cycles per minute or even not greater than about 30 cycles per minute. It will be appreciated that the oscillation frequency may be any value between any of the minimum and maximum values noted above. It will be further appreciated that the

oscillation frequency may be within a range between any of the minimum and maximum values noted above.

According to yet another embodiment, the oscillation position of the bonded abrasive article 315 or the workpiece 325 during oscillation may have a particular distance from the center point of the bonded abrasive article 315 or the workpiece 325. According to a particular embodiment, the oscillation position of the bonded abrasive article 315 or the workpiece 325 may be located any distance along the radius of the bonded abrasive article between the center of the bonded abrasive article and the outer perimeter of the bonded abrasive article.

According to still another embodiment, the abrasive assembly 310 and the workpiece assembly 320 may be further configured to maintain the initial contact force between the bonded abrasive article 315 and the workpiece 325 throughout the cut-off grinding operation. According to a particular embodiment, the abrasive assembly and the workpiece assembly may be configured to ensuring that any variation from the initial contact force during the testing by the testing apparatus 300 is less than 150% of the initial contact force and not greater than +or- 5 lbs from the initial contact force, such as, not greater than +or- 4lbs, not greater than +or- 3 lbs, not greater than +or- 2 lbs or even not greater than +or- 1 lbs. It will be appreciated that the testing process may include ensuring that any variation from the initial contact force during the testing process 100 is not greater than any value between any of the values noted above.

According to certain embodiments, the abrasive assembly 310 and the workpiece assembly 320 may be configured to maintain the contact force by using a low friction slide that allows the abrasive assembly 310 or the workpiece assembly 320 to adjust the slide pressure being applied by the bonded abrasive article 315 on the workpiece 325 or being applied by the workpiece 325 on the bonded abrasive article 315 along the first path. According to certain embodiments, the low friction slide may include a particular friction force. For example, the low friction slide may have a friction force of not greater than about 2 lbs, such as, not greater than about 1.5 lbs, not greater than about 1.0 lbs, not greater than about 0.9 lbs, not greater than about 0.8 lbs, not greater than about 0.7 lbs, not greater than about 0.6 lbs, not greater than about 0.5 lbs, not greater than about 0.4 lbs and not greater than about 0.3 lbs.

According to still another embodiment, the measuring assembly 330 may be configured to measure any desired performance parameter used to evaluate the effectiveness of the bonded abrasive article 315 being used in the cut-off grinding operation. According to

one particular embodiment, the measuring assembly 330 may be configured to measure the G-ratio of the bonded abrasive article 315. According to other embodiment, measuring performance parameters may include measuring cut duration during the testing process, measuring total number of cuts during the testing process, measuring the change in wheel diameter during the testing process, measuring the average/peak power draw during the testing process or measuring the average/peak current draw during the testing process.

Many different aspects and embodiments are possible. Some of these aspects and embodiments are described below. After reading this specification, those skilled in the art will appreciate that these aspects and embodiments are only illustrative and do not limit the scope of the present invention. Embodiments may be in accordance with any one or more of the items as listed below.

Embodiment 1. An apparatus for evaluating performance of a bonded abrasive article during a cut-off grinding operation comprising:

an abrasive assembly holding a bonded abrasive article;

a workpiece assembly holding a workpiece; and

a measuring assembly;

wherein the abrasive assembly and the workpiece assembly are configured to create contact between the bonded abrasive article and the workpiece with an initial contact force and maintain the initial contact force while varying a size of the initial contact area using oscillation.

Embodiment 2. The apparatus of embodiment 1, wherein the abrasive assembly is configured to create contact between the bonded abrasive article and the workpiece by moving the bonded abrasive article towards and into contact with the workpiece with the initial contact force.

Embodiment 3. The apparatus of embodiment 1, wherein the workpiece assembly is configured to create contact between the bonded abrasive article and the workpiece by moving the workpiece towards and into contact with the bonded abrasive article with the initial contact force.

Embodiment 4. The apparatus of any one of embodiments 2 and 3, wherein the abrasive assembly is configured to oscillate the bonded abrasive sample along a second path that is different than the first path to vary the size of the initial contact area between the bonded abrasive article and the workpiece.

Embodiment 5. The apparatus of any one of embodiments 2 and 3, wherein the workpiece assembly is configured to oscillate the workpiece along a second path that is

different than the first path to vary the size of the initial contact area between the bonded abrasive article and the workpiece.

Embodiment 6. The apparatus of any one of embodiments 4 and 5, further comprising an oscillation amplitude of 0.04 inches, at least about 0.08 includes, at least about 0.1 inches, at least about 0.2 inches, at least about 0.3 inches, at least about 0.4 inches, at least about 0.5 inches, at least about 0.6 inches, at least about 0.7 inches, at least about 0.8 inches, at least about 0.9 inches, at least about 1.0 inches, at least about 1.1 inches, at least about 1.2 inches, at least about 1.3 inches, at least about 1.4 inches and at least about 1.5 inches.

Embodiment 7. The apparatus of any one of embodiments 4 and 5, further comprising an oscillation amplitude of not greater than about 13 inches, not greater than about 12.5 inches, not greater than about 12 inches, not greater than about 11.5 inches, not greater than about 11.0 inches, not greater than about 10.5 inches, not greater than about 10.0 inches, not greater than about 10.5 inches, not greater than about 9.0 inches, not greater than about 8.7 inches, not greater than about 8.5 inches, not greater than about 8.2 inches, not greater than about 8.0 inches, not greater than about 7.7 inches, not greater than about 7.5 inches, not greater than about 7.2 inches, not greater than about 7.0 inches, not greater than about 6.7 inches, not greater than about 6.5 inches, not greater than about 6.2 inches, not greater than about 6.0 inches, not greater than about 5.7 inches, not greater than about 5.5 inches, not greater than about 5.2 inches, not greater than about 5.0 inches and not greater than about 4.7 inches.

Embodiment 8. The apparatus of any one of claim embodiments 4 and 5, further comprising an oscillation frequency of at least about 20 cycles per minute, at least about 30 cycles per minute, at least about 40 cycles per minute, at least about 50 cycles per minute, at least about 60 cycles per minute, at least about 70 cycles per minute, at least about 80 cycles per minute, at least about 90 cycles per minute, at least about 100 cycles per minute, at least about 110 cycles per minute, at least about 120 cycles per minute, at least about 130 cycles per minute and at least about 140 cycles per minute.

Embodiment 9. The apparatus of any one of embodiments 4 and 5, further comprises an oscillation frequency of not greater than about 150 cycles per minute, not greater than about 140 cycles per minute, not greater than about 130 cycles per minute, not greater than about 120 cycles per minute, not greater than about 110 cycles per minute, not greater than about 100 cycles per minute, not greater than about 90 cycles per minute, not greater than about 80 cycles per minute, not greater than about 70 cycles per minute, not greater than

about 60 cycles per minute, not greater than about 50 cycles per minute, not greater than about 40 cycles per minute and not greater than about 30 cycles per minute.

Embodiment 10. The apparatus of any one of embodiments 4 and 5, wherein the second path comprises a straight path, wherein the second path comprises an arcuate path.

Embodiment 11. The apparatus of embodiment 1, wherein the initial contact force is at least about 3 lbs, at least about 4 lbs, at least about 5 lbs, at least about 6 lbs, at least about 7 lbs, at least about 8 lbs, at least about 9 lbs, at least about 10 lbs, at least about 11 lbs, at least about 12 lbs, at least about 13 lbs, at least about 14 lbs, at least about 15 lbs, at least about 16 lbs, at least about 17 lbs, at least about 18 lbs, at least about 19 lbs, at least about 20 lbs, at least about 21 lbs, at least about 22 lbs, at least about 23 lbs, at least about 24 lbs and at least about 25 lbs.

Embodiment 12. The apparatus of embodiment 1, wherein the initial contact force is not greater than about 30 lbs, not greater than about 29 lbs, not greater than about 28 lbs, not greater than about 28 lbs, not greater than about 27 lbs, not greater than about 26 lbs, not greater than about 25 lbs, not greater than about 24 lbs, not greater than about 23 lbs, not greater than about 22 lbs, not greater than about 21 lbs, not greater than about 20 lbs, not greater than about 29 lbs, not greater than about 19 lbs, not greater than about 18 lbs, not greater than about 17 lbs, not greater than about 16 lbs and not greater than about 15 lbs.

Embodiment 13. The apparatus of any one of embodiments 4 and 5, wherein the abrasive assembly or the workpiece assembly further comprises a low friction slide.

Embodiment 14. The apparatus of embodiment 13, wherein the low friction slide comprises a friction force of not greater than about 2 lbs, not greater than about 1.5 lbs, not greater than about 1.0 lbs, not greater than about 0.9 lbs, not greater than about 0.8 lbs, not greater than about 0.7 lbs, not greater than about 0.6 lbs, not greater than about 0.5 lbs, not greater than about 0.4 lbs and not greater than about 0.3 lbs.

Embodiment 15. The apparatus of embodiment 13, wherein the bonded abrasive sample comprises a bonded abrasive article used in a cut-off grinding operation, a grinding wheel, a cut-off grinding wheel, a cut-off grinding wheel mounted in a hand-held grinding assembly using a mounting flange, a cut-off grinding wheel mounted in a hand-held grinding assembly using a mounting hub, a cut-off grinding wheel mounted in a hand-held grinding assembly using a mounting hub fixed to the cut-off grinding wheel.

Embodiment 16. The apparatus of embodiment 1, wherein the bonded abrasive sample comprises an abrasive wheel.

Embodiment 17. The apparatus of embodiment 16, wherein the abrasive wheel comprises a diameter of at least about 3.0 inches, at least about 3.3 inches, at least about 3.5 inches, at least about 3.8 inches, at least about 4.0 inches, at least about 4.3 inches, at least about 4.5 inches, at least about 4.8 inches, at least about 5.0 inches, at least about 5.3 inches, at least about 5.5 inches, at least about 5.8 inches, at least about 6.0 inches, at least about 6.3 inches, at least about 6.5 inches, at least about 6.8 inches, at least about 7.0 inches, at least about 7.3 inches, at least about 7.5 inches, at least about 7.8 inches, at least about 8.0 inches, at least about 8.3 inches, at least about 8.5 inches and at least about 8.8 inches.

Embodiment 18. The apparatus of embodiment 16, wherein the abrasive wheel comprises a diameter of not greater than about 13 inches, not greater than about 12.5 inches, not greater than about 12 inches, not greater than about 11.5 inches, not greater than about 11.0 inches, not greater than about 10.5 inches, not greater than about 10.0 inches, not greater than about 10.5 inches, not greater than about 10.0 inches, not greater than about 9.0 inches, not greater than about 8.7 inches, not greater than about 8.5 inches, not greater than about 8.2 inches, not greater than about 8.0 inches, not greater than about 7.7 inches, not greater than about 7.5 inches, not greater than about 7.2 inches, not greater than about 7.0 inches, not greater than about 6.7 inches, not greater than about 6.5 inches, not greater than about 6.2 inches, not greater than about 6.0 inches, not greater than about 5.7 inches, not greater than about 5.5 inches, not greater than about 5.2 inches, not greater than about 5.0 inches and not greater than about 4.7 inches.

Embodiment 19. A method for evaluating performance of a bonded abrasive article during a cut-off grinding operation comprising:

creating contact between a bonded abrasive article and a workpiece with a particular initial contact force;

maintaining contact between the bonded abrasive article and the workpiece while varying the size of a contact area between the bonded abrasive article and the workpiece using oscillation;

maintaining the initial contact force between the bonded abrasive article and the workpiece throughout the grinding operation; and

measuring at least one performance parameter of the bonded abrasive article during the grinding operation.

Embodiment 20. The method of embodiment 19, wherein creating contact between the bonded abrasive article and the workpiece comprises moving the bonded abrasive article along a first path towards and into contact with the workpiece.

Embodiment 21. The method of embodiment 19, wherein creating contact between the bonded abrasive article and the workpiece comprises moving the workpiece along a first path towards and into contact with the bonded abrasive article.

Embodiment 22. The method of any one of embodiments 20 and 21, wherein varying the size of the initial contact area between the bonded abrasive article and the workpiece using oscillation comprises oscillating the bonded abrasive article along a second path that is different than the first path.

Embodiment 23. The method of any one of embodiments 20 and 21, wherein varying the size of the initial contact are between the bonded abrasive article and the workpiece using oscillation comprises oscillating the workpiece along a second path that is different than the first path.

Embodiment 24. The method of any one of embodiments 22 and 23, wherein oscillating occurs at an oscillation amplitude of at least about 0.04 inches, at least about 0.08 includes, at least about 0.1 inches, at least about 0.2 inches, at least about 0.3 inches, at least about 0.4 inches, at least about 0.5 inches, at least about 0.6 inches, at least about 0.7 inches, at least about 0.8 inches, at least about 0.9 inches, at least about 1.0 inches, at least about 1.1 inches, at least about 1.2 inches, at least about 1.3 inches, at least about 1.4 inches and at least about 1.5 inches.

Embodiment 25. The method of any one of embodiments 22 and 23, wherein oscillating occurs at an oscillation amplitude of not greater than about 13 inches, not greater than about 12.5 inches, not greater than about 12 inches, not greater than about 11.5 inches, not greater than about 11.0 inches, not greater than about 10.5 inches, not greater than about 10.0 inches, not greater than about 10.5 inches, not greater than about 9.0 inches, not greater than about 8.7 inches, not greater than about 8.5 inches, not greater than about 8.2 inches, not greater than about 8.0 inches, not greater than about 7.7 inches, not greater than about 7.5 inches, not greater than about 7.2 inches, not greater than about 7.0 inches, not greater than about 6.7 inches, not greater than about 6.5 inches, not greater than about 6.2 inches, not greater than about 6.0 inches, not greater than about 5.7 inches, not greater than about 5.5 inches, not greater than about 5.2 inches, not greater than about 5.0 inches and not greater than about 4.7 inches.

Embodiment 26. The method of any one of embodiments 22 and 23, wherein oscillating occurs at an oscillation frequency of at least about 20 cycles per minute, at least about 30 cycles per minute, at least about 40 cycles per minute, at least about 50 cycles per minute, at least about 60 cycles per minute, at least about 70 cycles per minute, at least about

80 cycles per minute, at least about 90 cycles per minute, at least about 100 cycles per minute, at least about 110 cycles per minute, at least about 120 cycles per minute, at least about 130 cycles per minute and at least about 140 cycles per minute.

Embodiment 27. The method of any one of embodiments 22 and 23, wherein oscillating occurs at an oscillation frequency of not greater than about 150 cycles per minute, not greater than about 140 cycles per minute, not greater than about 130 cycles per minute, not greater than about 120 cycles per minute, not greater than about 110 cycles per minute, not greater than about 100 cycles per minute, not greater than about 90 cycles per minute, not greater than about 80 cycles per minute, not greater than about 70 cycles per minute, not greater than about 60 cycles per minute, not greater than about 50 cycles per minute, not greater than about 40 cycles per minute and not greater than about 30 cycles per minute.

Embodiment 28. The method of any one of embodiments 22 and 23, wherein the second path comprises a straight path, wherein the second path comprises an arcuate path.

Embodiment 29. The method of embodiment 28, wherein the abrasive article comprises a grinding wheel, comprises a grinding wheel and a mounting flange, comprises a grinding wheel and a mounting hub, comprising a grinding wheel and a mounting hub fixed to the cut-off grinding wheel.

Embodiment 30. The method of embodiment 19, wherein the contact force is at least about 3 lbs, at least about 4 lbs, at least about 5 lbs, at least about 6 lbs, at least about 7 lbs, at least about 8 lbs, at least about 9 lbs, at least about 10 lbs, at least about 11 lbs, at least about 12 lbs, at least about 13 lbs, at least about 14 lbs, at least about 15 lbs, at least about 16 lbs, at least about 17 lbs, at least about 18 lbs, at least about 19 lbs, at least about 20 lbs, at least about 21 lbs, at least about 22 lbs, at least about 23 lbs, at least about 24 lbs and at least about 25 lbs.

Embodiment 31. The method of embodiment 19, wherein the contact force is not greater than about 30 lbs, not greater than about 29 lbs, not greater than about 28 lbs, not greater than about 28 lbs, not greater than about 27 lbs, not greater than about 26 lbs, not greater than about 25 lbs, not greater than about 24 lbs, not greater than about 23 lbs, not greater than about 22 lbs, not greater than about 21 lbs, not greater than about 20 lbs, not greater than about 29 lbs, not greater than about 19 lbs, not greater than about 18 lbs, not greater than about 17 lbs, not greater than about 16 lbs and not greater than about 15 lbs.

Embodiment 32. The method of embodiment 19, wherein the bonded abrasive sample comprises a hand-held tool, comprises a portable grinder.

Embodiment 33. The method of embodiment 19, wherein the bonded abrasive sample comprises an abrasive wheel.

Embodiment 34. The method of embodiment 33, wherein the abrasive wheel comprises a diameter of at least about 3.0 inches, at least about 3.3 inches, at least about 3.5 inches, at least about 3.8 inches, at least about 4.0 inches, at least about 4.3 inches, at least about 4.5 inches, at least about 4.8 inches, at least about 5.0 inches, at least about 5.3 inches, at least about 5.5 inches, at least about 5.8 inches, at least about 6.0 inches, at least about 6.3 inches, at least about 6.5 inches, at least about 6.8 inches, at least about 7.0 inches, at least about 7.3 inches, at least about 7.5 inches, at least about 7.8 inches, at least about 8.0 inches, at least about 8.3 inches, at least about 8.5 inches and at least about 8.8 inches.

Embodiment 35. The method of embodiment 33, wherein the abrasive wheel comprises a diameter of not greater than about 13 inches, not greater than about 8.7 inches, not greater than about 8.5 inches, not greater than about 8.2 inches, not greater than about 8.0 inches, not greater than about 7.7 inches, not greater than about 7.5 inches, not greater than about 7.2 inches, not greater than about 7.0 inches, not greater than about 6.7 inches, not greater than about 6.5 inches, not greater than about 6.2 inches, not greater than about 6.0 inches, not greater than about 5.7 inches, not greater than about 5.5 inches, not greater than about 5.2 inches, not greater than about 5.0 inches and not greater than about 4.7 inches.

EXAMPLES

The following includes various comparisons between three conventional performance testing procedures for cut-off grinding wheels in cut-off grinding operations and one performance testing procedure carried out according to embodiments described herein. The first conventional testing operation CO1 is a testing operation conducted by a person who manually holds and operates the handheld grinding tool during the evaluation procedure. The second conventional testing operation CO2 is a testing operation conducted using a conventional testing apparatus that includes a constant force tester to mechanically create force between a cut-off grinding wheel and a workpiece. The third conventional testing operation CO3 is a testing operation conducted using a conventional testing apparatus that includes a controlled velocity infeed tester to mechanically create force between a cut-off grinding wheel and a workpiece. Neither conventional testing operation CO2, nor conventional testing operation CO3 include oscillation of the cut-off grinding wheel or the workpiece. The performance testing operation SO1 carried out according to embodiments described herein includes mechanical creation of a contact force between the cut-off grinding

wheel and the workpiece while the contact area between the cut-off girding wheel and the workpiece is varied using oscillation.

FIG. 4 includes a comparison chart showing performance evaluation of two different cut-off grinding wheels (A & B) conducted using testing operations CO1, CO2 and SO1. Performance of both grinding wheels in all three testing operations was measured in G-ratio. As shown in the comparison chart, CO2 showed no difference in the G-ratio between the two different cut-off grinding wheels (A & B) while both CO1 and SO1 showed significant difference in G-ratio between the two different cut-off grinding wheels (A & B). Based on this similarity between performance measurements obtained from CO1 and SO1, performance testing operation SO1 carried out according to embodiments described herein is more representative of manual hand held cut-off grinding (i.e., CO1) than performance testing carried out using conventional testing equipment (i.e., CO2).

FIG. 5 includes a chart showing variation that can occur when using testing operation CO1 depending on the person carrying out the manual testing procedure. As shown in the chart, four different people tested two cut-off grinding wheels (C & D) with each person yielding different results on the testing of each wheel. The chart of FIG. 5 further shows that performance data collected using testing operation SO1 can be adjusted by altering the initial contact force.

FIG. 6a includes a chart comparing average material removal rate versus average wheel wear rate as measured using both conventional testing operation CO1 and performance testing operation SO1. FIG. 6b includes a chart comparing material average removal rate versus average wheel wear rate as measured using both conventional testing operation CO1 and conventional testing operation CO2. FIG. 6c includes a chart comparing average material removal rate versus average wheel wear rate as measured using both conventional testing operation CO1 and conventional testing operation CO3. Material removal rate (MRR) is the volume of material removed per unit time and the wheel wear rate (WWR) is the volume of abrasive wheel lost per unit time. The prime (`) after the MRR and WWR indicates that these parameters have been divided (or normalized) over the contact width (divided by the wheel thickness). Average MRR' is calculated from the number of cuts, the workpiece cross section area and the cumulative grind time. Average WWR' is calculated from the change in wheel diameter and the cumulative grind time. As demonstrated by the charts in FIGS. 6a, 6b and 6c, based on average MMR' and average WWR' performance parameters, performance testing operation SO1 carried out according to embodiments described herein is more representative of manual hand held cut-off grinding operations (i.e.,

CO1) than performance testing carried out using either conventional testing operations CO2 or CO3.

The present application represents a departure from the state of the art. Notably, the embodiments herein demonstrate improved and unexpected performance over conventional and comparative methods and grinding systems for evaluating bonded abrasive article performance in a cut-off grinding operation. While not wishing to be bound to a particular theory, it is suggested that combination of certain features including designs, processes, materials, and the like may facilitate such improvements. The combination of features can include, but is not limited to, the combination of maintaining a contact force between a bonded abrasive wheel and a workpiece while varying a size of the initial contact area using oscillation of the bonded abrasive article or the workpiece. Notably these combinations of features showed improved evaluation performance, for example, in that the performance results were found to eliminate the operator-induced testing variations associated with manual cutoff tests while still being representative of a thin wheel performance in a hand-held cut-off grinding system.

Note that not all of the activities described above in the general description or the examples are required, that a portion of a specific activity may not be required, and that one or more further activities may be performed in addition to those described. Still further, the orders in which activities are listed are not necessarily the order in which they are performed.

In the foregoing specification, the concepts have been described with reference to specific embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of invention.

As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of features is not necessarily limited only to those features but may include other features not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive-or and not to an exclusive-or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

Also, the use of "a" or "an" are employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims.

After reading the specification, skilled artisans will appreciate that certain features are, for clarity, described herein in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features that are, for brevity, described in the context of a single embodiment, may also be provided separately or in any subcombination. Further, references to values stated in ranges include each and every value within that range.

WHAT IS CLAIMED IS:

1. An apparatus for evaluating performance of a bonded abrasive article during a cut-off grinding operation comprising:

an abrasive assembly holding a bonded abrasive article;

a workpiece assembly holding a workpiece; and

a measuring assembly;

wherein the abrasive assembly and the workpiece assembly are configured to create contact between the bonded abrasive article and the workpiece with an initial contact force and maintain the initial contact force while varying a size of the initial contact area using oscillation.

2. The apparatus of claim 1, wherein the abrasive assembly is configured to create contact between the bonded abrasive article and the workpiece by moving the bonded abrasive article towards and into contact with the workpiece with the initial contact force.

3. The apparatus of claim 1, wherein the workpiece assembly is configured to create contact between the bonded abrasive article and the workpiece by moving the workpiece towards and into contact with the bonded abrasive article with the initial contact force.

4. The apparatus of any one of claims 2 and 3, wherein the abrasive assembly is configured to oscillate the bonded abrasive sample along a second path that is different than the first path to vary the size of the initial contact area between the bonded abrasive article and the workpiece.

5. The apparatus of any one of claims 2 and 3, wherein the workpiece assembly is configured to oscillate the workpiece along a second path that is different than the first path to vary the size of the initial contact area between the bonded abrasive article and the workpiece.

6. The apparatus of any one of claims 4 and 5, further comprising an oscillation amplitude of at least about 0.04 inches.

7. The apparatus of any one of claims 4 and 5, further comprising an oscillation frequency of at least about 20 cycles per minute.

8. The apparatus of any one of claims 4 and 5, wherein the second path comprises a straight path.

9. The apparatus of any one of claims 4 and 5, wherein the second path comprises an arcuate path.

10. The apparatus of any one of claims 4 and 5, wherein the abrasive assembly or the workpiece assembly further comprises a low friction slide.

11. The apparatus of claim 10, wherein the low friction slide comprises a friction force of not greater than about 2 lbs.

12. A method for evaluating performance of a bonded abrasive article during a cut-off grinding operation comprising:

creating contact between a bonded abrasive article and a workpiece with a particular initial contact force;

maintaining contact between the bonded abrasive article and the workpiece while varying the size of a contact area between the bonded abrasive article and the workpiece using oscillation;

maintaining the initial contact force between the bonded abrasive article and the workpiece throughout the grinding operation; and

measuring at least one performance parameter of the bonded abrasive article during the grinding operation.

13. The method of claim 12, wherein creating contact between the bonded abrasive article and the workpiece comprises moving the bonded abrasive article along a first path towards and into contact with the workpiece.

14. The method of claim 12, wherein creating contact between the bonded abrasive article and the workpiece comprises moving the workpiece along a first path towards and into contact with the bonded abrasive article.

15. The method of any one of claims 13 and 14, wherein varying the size of the initial contact area between the bonded abrasive article and the workpiece using oscillation comprises oscillating the bonded abrasive article along a second path that is different than the first path.

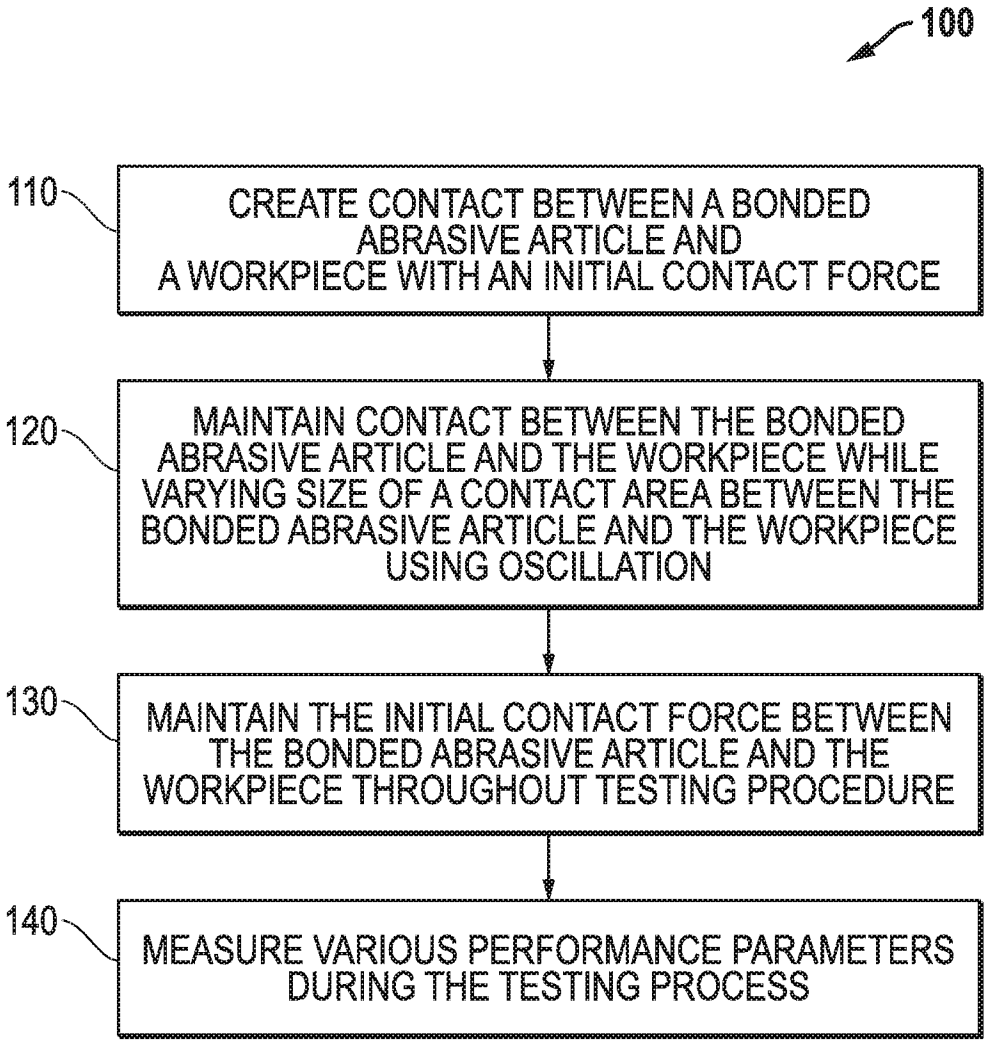

100
110
CREATE CONTACT BETWEEN A BONDED ABRASIVE ARTICLE AND A WORKPIECE WITH AN INITIAL CONTACT FORCE
120
MAINTAIN CONTACT BETWEEN THE BONDED ABRASIVE ARTICLE AND THE WORKPIECE WHILE VARYING SIZE OF A CONTACT AREA BETWEEN THE BONDED ABRASIVE ARTICLE AND THE WORKPIECE USING OSCILLATION
130
MAINTAIN THE INITIAL CONTACT FORCE BETWEEN THE BONDED ABRASIVE ARTICLE AND THE WORKPIECE THROUGHOUT TESTING PROCEDURE
140
MEASURE VARIOUS PERFORMANCE PARAMETERS DURING THE TESTING PROCESS

FIG. 1

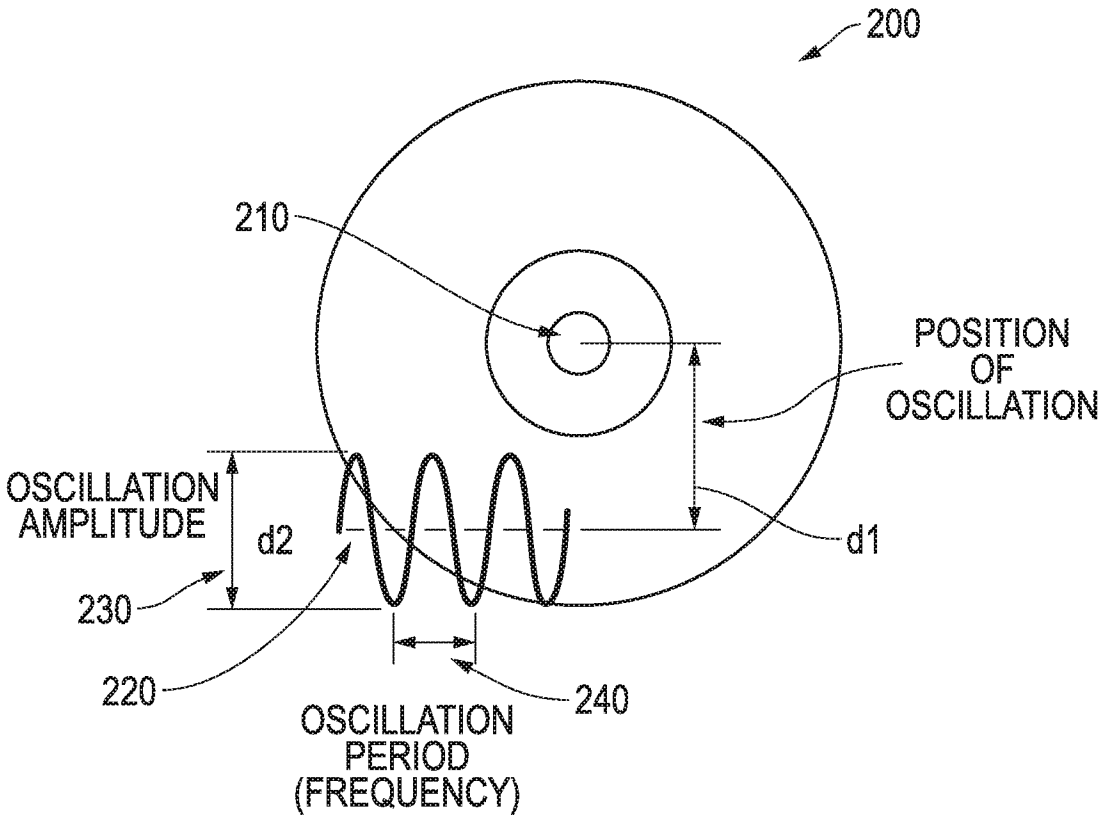

200
210
POSITION
OF
OSCILLATION
OSCILLATION
AMPLITUDE
d2
d1
230
220
240
OSCILLATION
PERIOD
(FREQUENCY)

FIG. 2

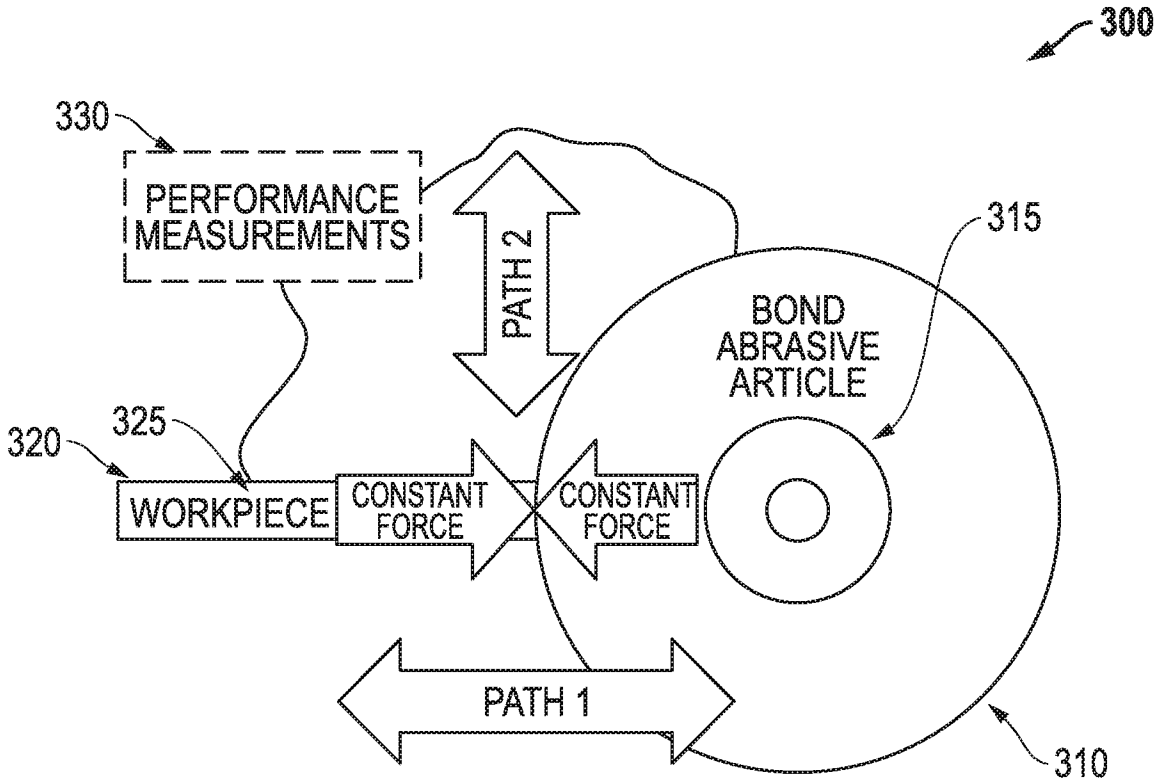

300
330
PERFORMANCE MEASUREMENTS
PATH 2
315
BOND ABRASIVE ARTICLE
325
320
WORKPIECE
CONSTANT FORCE
CONSTANT FORCE
PATH 1
310

FIG. 3

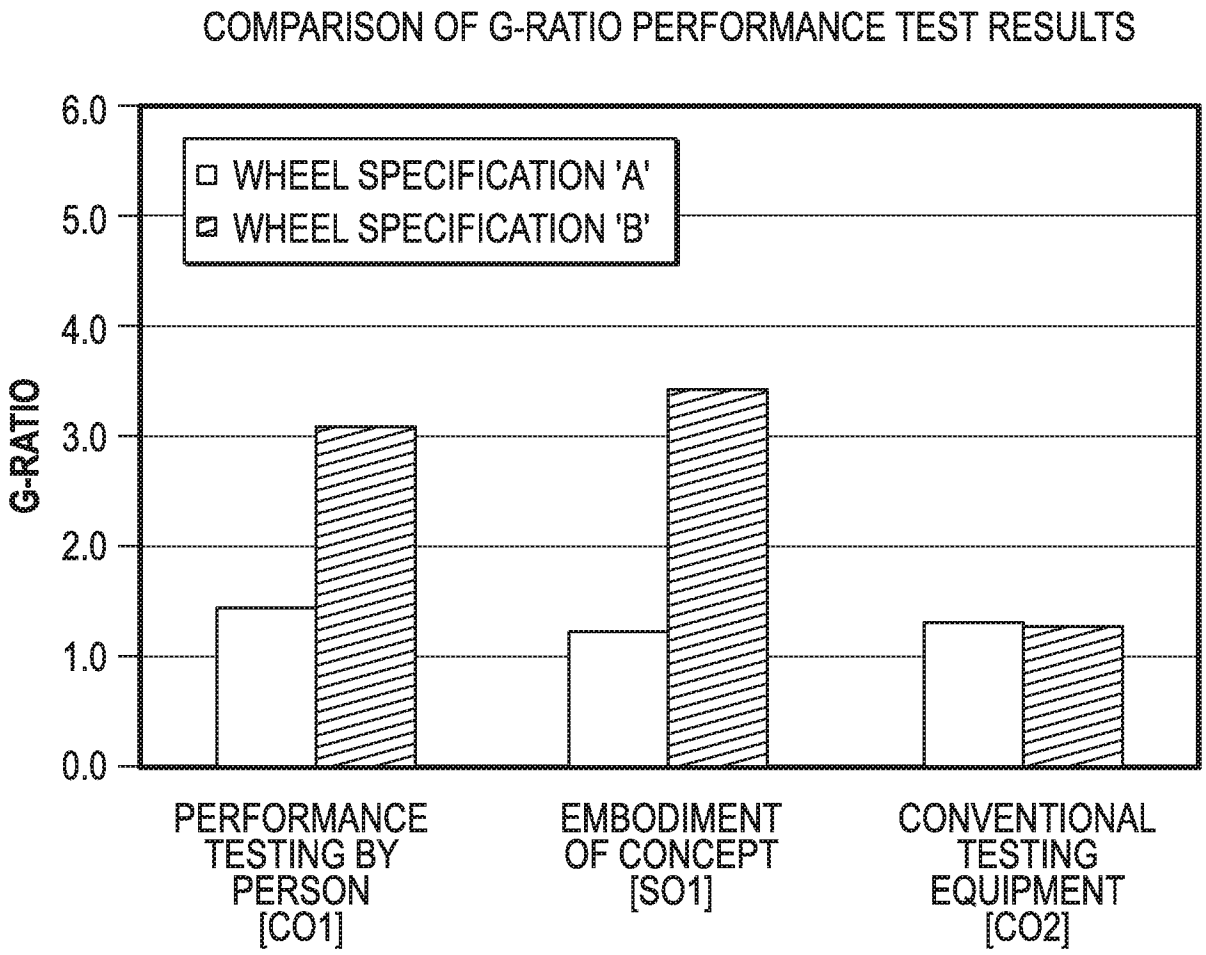

COMPARISON OF G-RATIO PERFORMANCE TEST RESULTS
G-RATIO
6.0
5.0
4.0
3.0
2.0
1.0
0.0
WHEEL SPECIFICATION 'A'
WHEEL SPECIFICATION 'B'
PERFORMANCE TESTING BY PERSON [CO1]
EMBODIMENT OF CONCEPT [SO1]
CONVENTIONAL TESTING EQUIPMENT [CO2]

FIG. 4

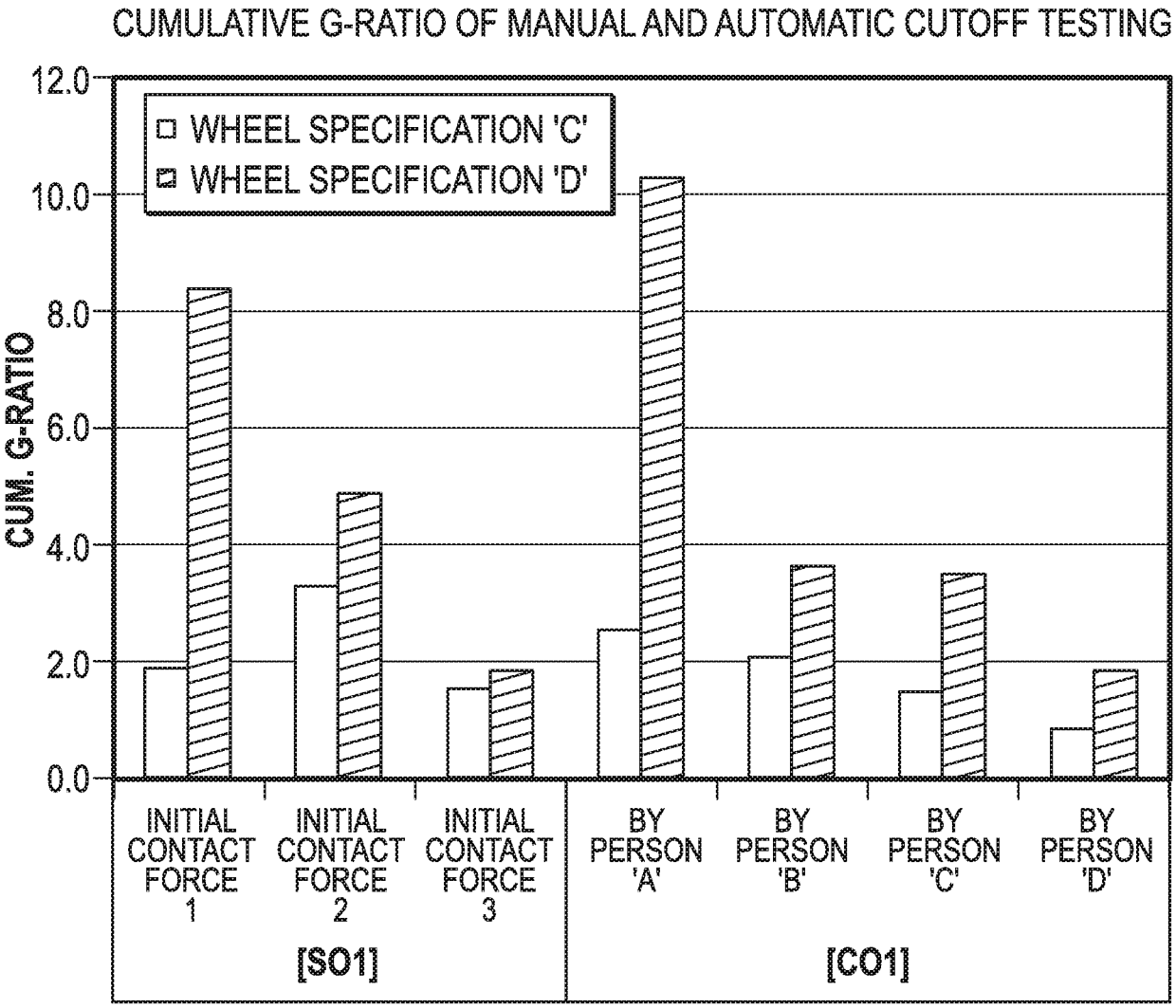

CUMULATIVE G-RATIO OF MANUAL AND AUTOMATIC CUTOFF TESTING
WHEEL SPECIFICATION 'C'
WHEEL SPECIFICATION 'D'
CUM. G-RATIO
12.0
10.0
8.0
6.0
4.0
2.0
0.0
INITIAL CONTACT FORCE 1
INITIAL CONTACT FORCE 2
INITIAL CONTACT FORCE 3
BY PERSON 'A'
BY PERSON 'B'
BY PERSON 'C'
BY PERSON 'D'
[SO1]
[CO1]

FIG. 5

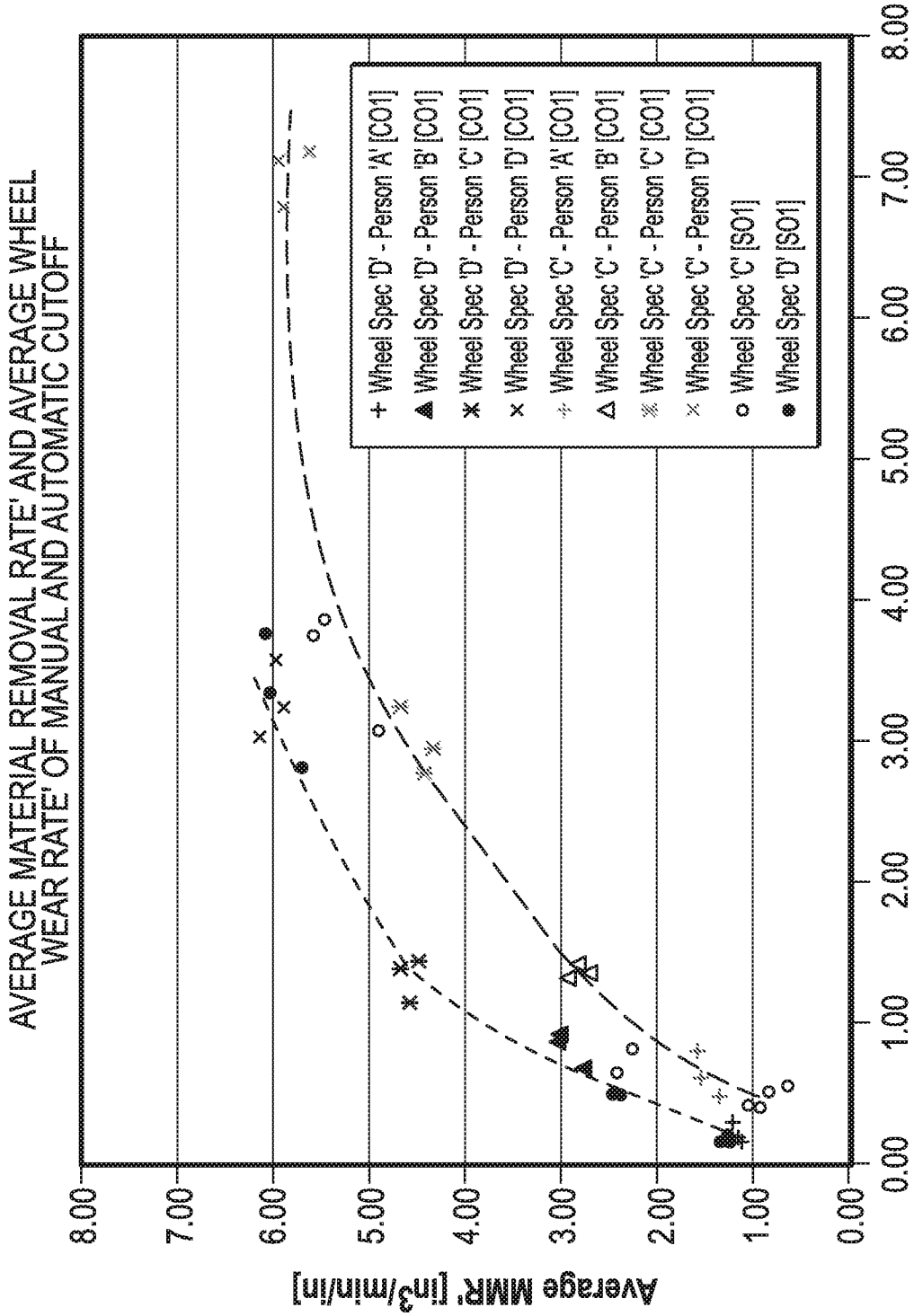

AVERAGE MATERIAL REMOVAL RATE' AND AVERAGE WHEEL WEAR RATE' OF MANUAL AND AUTOMATIC CUTOFF
Average MMR' [in3/min/in]
Average WWR' [in3/min/in]
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
+ Wheel Spec 'D' - Person 'A' [CO1]
▲ Wheel Spec 'D' - Person 'B' [CO1]
✱ Wheel Spec 'D' - Person 'C' [CO1]
× Wheel Spec 'D' - Person 'D' [CO1]
Wheel Spec 'C' - Person 'A' [CO1]
Δ Wheel Spec 'C' - Person 'B' [CO1]
Wheel Spec 'C' - Person 'C' [CO1]
Wheel Spec 'C' - Person 'D' [CO1]
○ Wheel Spec 'C' [SO1]
● Wheel Spec 'D' [SO1]

FIG. 6A

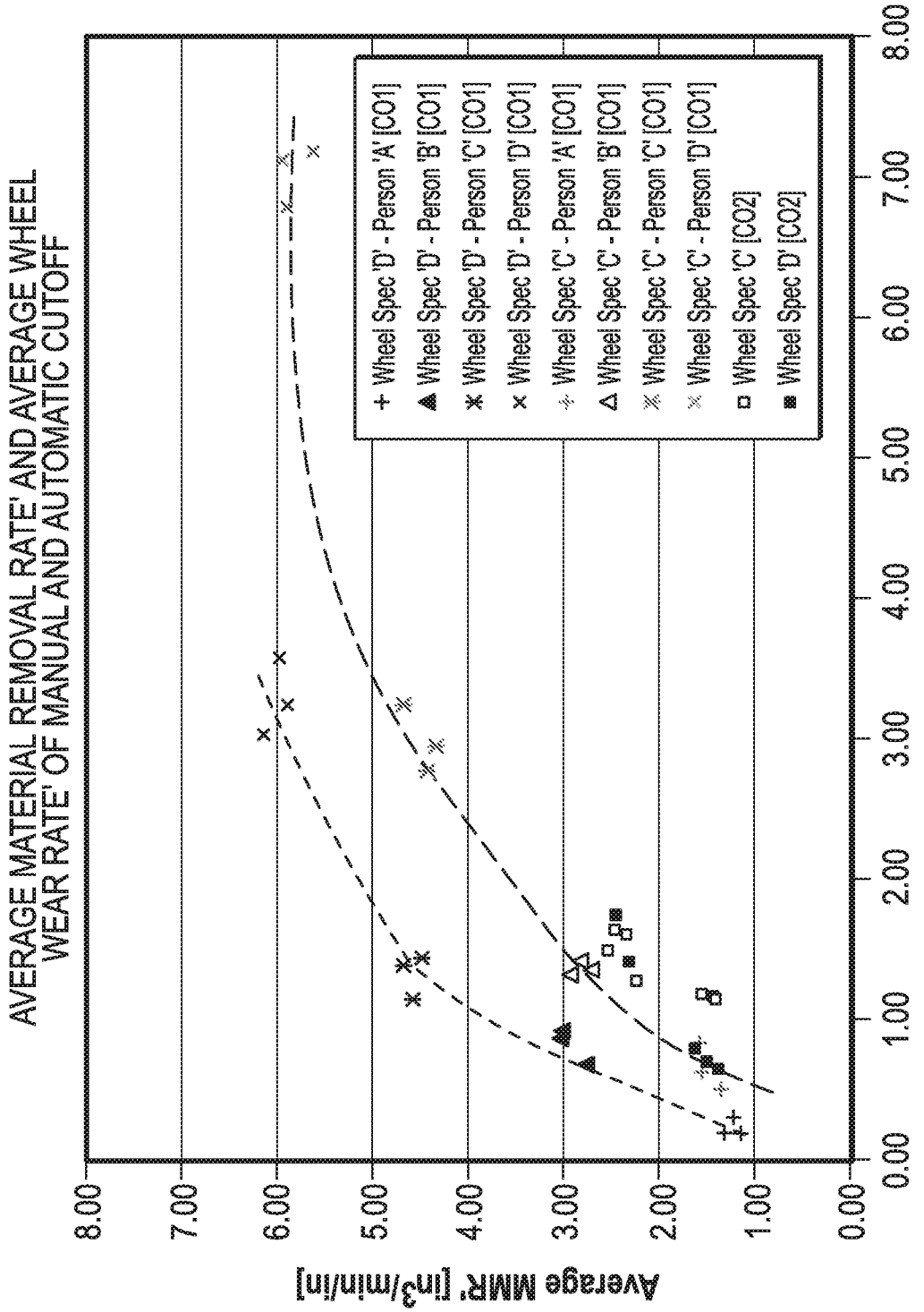

AVERAGE MATERIAL REMOVAL RATE' AND AVERAGE WHEEL WEAR RATE' OF MANUAL AND AUTOMATIC CUTOFF
Average MMR' [in³/min/in]
Average WWR' [in³/min/in]
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
+ Wheel Spec 'D' - Person 'A' [CO1]
▲ Wheel Spec 'D' - Person 'B' [CO1]
✱ Wheel Spec 'D' - Person 'C' [CO1]
× Wheel Spec 'D' - Person 'D' [CO1]
Wheel Spec 'C' - Person 'A' [CO1]
Δ Wheel Spec 'C' - Person 'B' [CO1]
Wheel Spec 'C' - Person 'C' [CO1]
Wheel Spec 'C' - Person 'D' [CO1]
▫ Wheel Spec 'C' [CO2]
■ Wheel Spec 'D' [CO2]

FIG. 6B

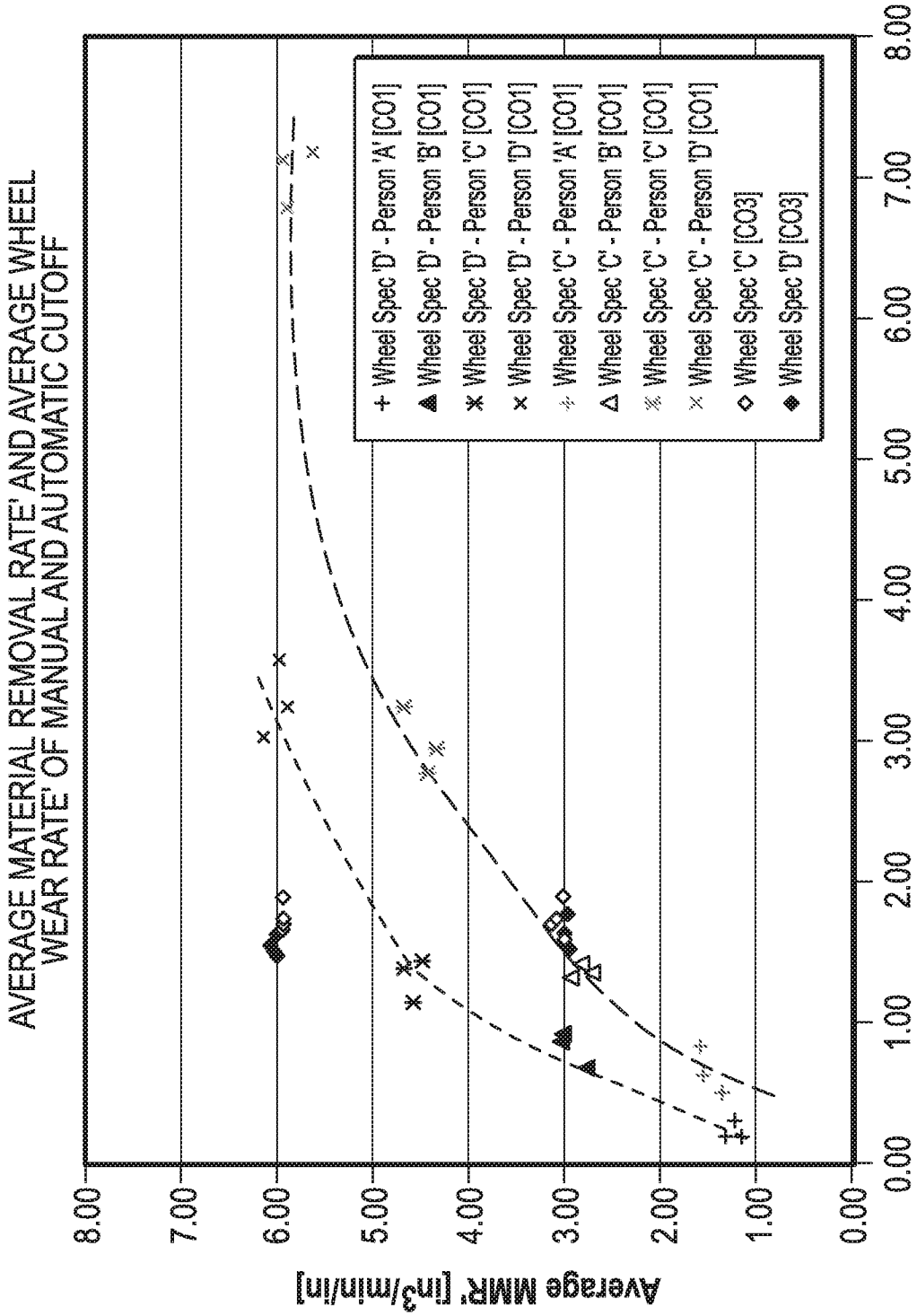

AVERAGE MATERIAL REMOVAL RATE' AND AVERAGE WHEEL WEAR RATE' OF MANUAL AND AUTOMATIC CUTOFF
Average MMR' [in3/min/in]
Average WWR' [in3/min/in]
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
+ Wheel Spec 'D' - Person 'A' [CO1]
▲ Wheel Spec 'D' - Person 'B' [CO1]
✱ Wheel Spec 'D' - Person 'C' [CO1]
× Wheel Spec 'D' - Person 'D' [CO1]
Wheel Spec 'C' - Person 'A' [CO1]
Δ Wheel Spec 'C' - Person 'B' [CO1]
Wheel Spec 'C' - Person 'C' [CO1]
Wheel Spec 'C' - Person 'D' [CO1]
◇ Wheel Spec 'C' [CO3]
◆ Wheel Spec 'D' [CO3]

FIG. 6C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/053924

A. CLASSIFICATION OF SUBJECT MATTER

B24B 49/00(2006.01)i, B24B 1/04(2006.01)i, B24B 23/04(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B24B 49/00; B24B 27/00; H01L 21/304; B24D 5/00; B24D 3/02; B24D 3/20; B24D 7/02; B24B 1/04; B24B 23/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: evaluate, abrasive, article, workpiece, measure, contact, oscillation and friction

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007-0044384 A1 (LARSON, ERIC G.) 01 March 2007 See paragraphs [0020]-[0025].	1-9,12-15
Y		10-11
Y	WO 2014-106157 A1 (SAINT-GOBAIN ABRASIVES INC.) 03 July 2014 See page 16, lines 1-24, page 22, line 21 - page 23, line 6 and figures 1-3.	10-11
A	US 2010-0190424 A1 (FRANCOIS et al.) 29 July 2010 See paragraphs [0029]-[0110] and figures 1A-9.	1-15
A	KR 10-2010-0044011 A (SEJIN CONTROL CO., LTD.) 29 April 2010 See paragraphs [0017]-[0046] and figures 1-3.	1-15
A	JP 2015-060985 A (SHIN ETSU HANDOTAI CO., LTD.) 30 March 2015 See paragraphs [0020]-[0038] and figures 1-8.	1-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 January 2017 (06.01.2017)	**09 January 2017 (09.01.2017)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
BAE, Geun Tae
Telephone No. +82-42-481-3547

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2016/053924

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