A downhole tool includes a tool body and at least one blade coupled to the tool body. Cutting elements are coupled to a forward surface of the blade, and each cutting element may include a flank face and a trailing face to collectively define the width of the cutting element. A cutting edge is formed at the intersection of the flank face and a front face of the cutting element. The trailing and flank faces of adjacent cutting elements may be inclined relative to each other to define a flank angle that may be between greater than 0° and 15°. Adjacent cutting elements may have a gap therebetween, even when there is contact between the adjacent cutting elements.
FIG. 19-1

1988

FIG. 19-2

1990
CUTTING ELEMENTS FOR CASING MILLING
CROSS-REFERENCE TO RELATED APPLICATIONS


BACKGROUND

[0002] Section milling tools include a tubular body having blades coupled to the body. Each of blades has a forward surface facing the direction of rotation of the tool which is dressed with a cutting material. Section milling tools may be used to, for example, remove portions or entire sections of downhole casing.

[0003] The cutting material on the forward surface of the section milling tools may include cutting elements. As the cutting elements cut the downhole casing, “birdnesting” may occur. Birdnesting is the term given to the long spirals of swarf that are cut from a tubular member that form into a conglomerate mass. These materials may restrict the flow of mud about a tool and may reduce the rate of penetration of the tool.

SUMMARY

[0004] Some embodiments of the present disclosure relate to downhole tools. An example downhole tool may include a body with a blade coupled thereto. The blade may have a forward surface and first and second cutting elements coupled to the forward surface. The first and second cutting elements may have flank and trailing faces. The second cutting element may be axially adjacent the first cutting element and the flank face of the second cutting element may define a flank angle greater than 0° relative to the trailing face of the first cutting element.

[0005] According to other embodiments, a cutting element may include a flank face and an opposing trailing face. The trailing face may be non-parallel to the flank face and the distance between the flank and trailing faces may be the width of the cutting element. A front face may extend between the flank face and the trailing face. Cutting and trailing edges may be formed at intersections of the front face with the flank face and trailing face, respectively.

[0006] In accordance with still other embodiments of the present disclosure, a method of milling may include inserting a cutting tool into a wellbore. The cutting tool may include a blade with first and second cutting elements that are adjacent to each other and have a gap therebetween. The casing may be engaged with at least the first cutting element and a portion of the casing may be milled away. In some embodiments, the first and/or second cutting elements may include a flank face, a trailing face, first and second sides, and a front face. The front face may extend between the first and second sides, and between the flank face and the trailing face. A cutting edge may be formed at an intersection of the front and flank faces, and a trailing edge may be formed at an intersection of the trailing and front faces.

[0007] In other embodiments, a downhole tool may include a tool body, at least one blade coupled to the tool body, and a plurality of cutting elements coupled to a forward surface of each blade. Each cutting element may have a flank face, a trailing face opposite the flank face, a front face extending between a first side and a second side and between the flank face and trailing face, a cutting edge formed at an intersection between the front face and the flank face, and a trailing edge formed at an intersection between the front face and the trailing face. A width of the cutting element can be measured between the flank face and the trailing face, and a length of the cutting element can be measured between the first side and the second side. A flank angle of the cutting element can be measured between the flank face of one of the plurality of cutting elements and the trailing face of an adjacent cutting element. The flank angle may range from greater than 0° to 15°.

[0008] In another aspect, embodiments disclose herein relate to a cutting element having a flank face, a trailing face opposite the flank face, a front face extending between a first side and a second side and between the flank face and trailing face, a back face opposite the front face, a cutting edge formed at an intersection of the front face and the flank face, and a trailing edge formed at an intersection between the front face and the trailing face. A width of the cutting element can be measured between the flank face and the trailing face, and a length of the cutting element can be measured between the first side and the second side. A plurality of teeth may be formed in the front face and extend the full length of the cutting element. The teeth may have back-up cutting edges formed at an intersection of a back-up flank face and a rake face. A back-up flank angle may be formed between the rake face of each back-up cutting edge and a line perpendicular to the back face. The width of the cutting element may vary along its length.

[0009] In another aspect, embodiments disclosed herein relate to a cutting element having a flank face, a trailing face opposite the flank face, a front face extending between a first side and a second side and between the flank face and trailing face, and a cutting edge formed at an intersection of the front face and the flank face. A width of the cutting element can be measured between the flank face and the trailing face, and a length of the cutting element can be measured between the first side and the second side. The trailing face may be non-parallel with respect to the flank face.

[0010] In yet another aspect, embodiments disclosed herein relate to milling a downhole casing, and includes inserting a downhole cutting tool into a wellbore. The inserted downhole cutting tool includes first and second cutting elements on a blade of the downhole cutting tool. Each cutting element includes a flank face, a trailing face opposite the flank face, a front face extending between a first side and a second side and between the flank face and trailing face, a cutting edge formed at an intersection of the front face and the flank face, and a trailing edge formed at an intersection between the trailing face and the front face. The trailing edge of the first cutting element may be positioned adjacent the flank face of the second cutting element, such that a gap is formed between trailing face of the first cutting element and the flank face of the second cutting element. The first and second cutting elements of the downhole cutting tool may be engaged with the downhole casing and rotated to mill away a portion of the downhole casing.

[0011] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or
BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a partial cross-sectional view of a downhole cutting tool having cutting elements, according to embodiments of the present disclosure.

FIG. 2 is a side view of cutting elements on a downhole cutting tool, according to embodiments of the present disclosure.

FIG. 3 is a perspective view of adjacent cutting elements, according to embodiments of the present disclosure.

FIG. 4 is a side view of one of the cutting elements of FIG. 3, according to embodiments of the present disclosure.

FIG. 5 is a perspective view of cutting elements, according to embodiments of the present disclosure.

FIG. 6 is a perspective view of cutting elements, according to embodiments of the present disclosure.

FIG. 7 is a perspective view of cutting elements, according to embodiments of the present disclosure.

FIG. 8-1 is a side view of cutting elements on a downhole tool, according to embodiments of the present disclosure.

FIG. 8-2 is a side view of one of the cutting elements of FIG. 8-1, according to embodiments of the present disclosure.

FIG. 9 is a side view of a cutting element, according to embodiments of the present disclosure.

FIG. 10 is a side view of cutting elements on a downhole tool, according to embodiments of the present disclosure.

FIG. 11 is a side view of a cutting element, according to embodiments of the present disclosure.

FIG. 12 is a cross-sectional side view of a coated cutting element, according to embodiments of the present disclosure.

FIG. 13 is a magnified view of a coated cutting element, according to embodiments of the present disclosure.

FIG. 14 is a cross-sectional view of a cutting edge of a cutting element cutting a work piece, according to embodiments of the present disclosure.

FIGS. 15-1 and 15-2 are side view of cutting elements on a downhole cutting tool, according to embodiments of the present disclosure.

FIG. 16-1 is a side view of a cutting element working on a work piece, according to embodiments of the present disclosure.

FIG. 16-2 is a graph of results from lab testing for cutting elements having a flank angle greater than 0°, according to embodiments of the present disclosure.

FIG. 17-1 is a side view of a cutting element working on a work piece, according to embodiments of the present disclosure.

FIG. 17-2 is a graph of results from lab testing for cutting elements having a flank angle of 0°, according to embodiments of the present disclosure.

FIG. 18 is a side view of cutting elements on a downhole cutting tool, according to embodiments of the present disclosure.

FIGS. 19-1 and 19-2 are photographs of cutting element failures.

DETAILED DESCRIPTION

Embodiments of the present disclosure may relate to cutting tools and/or cutting elements. In another aspect, embodiments of the present disclosure may relate to downhole cutting tools and cutting elements. In at least some embodiments, cutting elements of a cutting tool may have a flank angle formed at its flank face. According to some embodiments, the flank angle may be between 0° and 15°.

Referring to FIG. 1, a partial cross-sectional view of a downhole cutting tool 100 is shown in accordance with embodiments of the present disclosure. The downhole cutting tool 100 may have a body 101 extending in a longitudinal/axial direction. The body 101 may have an upper end portion 104 and a lower end portion 106. The body 101 may be generally tubular with an internal bore or axial passage 103 that facilitates fluid circulation in some embodiments. The body 101 may have a circular cross-sectional shape in some embodiments. In other embodiments, the body 101 may have other cross-sectional shapes or configurations. For instance, the body 101 may be hexagonal, square, a rounded square, have some other shape, or have a combination of the foregoing.

According to some embodiments, the upper end 104 of the body 101 may include an internal screw thread 105 (i.e., a box or female thread) for connecting the body 101 to a drill string (not shown). A lower end 106 of the body 101 may optionally have a “bull nose” 108 positioned to stabilize the cutting tool within the wellbore. In other embodiments, other tools or components (e.g., a stabilizer, a taper mill, etc.) may be used in addition to, or instead of, the bull nose 108.

The body 101 may have multiple blades 107 coupled thereto. The blades 107 may extend longitudinally along the body 101. In FIG. 1, two of three blades 107 may be seen, with the third blade being obscured by the body 101. One of ordinary skill in the art will appreciate in view of the disclosure herein that the downhole cutting tool 100 may have a variety of different numbers of blades or even types of blades. Accordingly, the downhole cutting tool 100 may include fewer or more than three blades. Moreover while the blades 107 may be equi-azimuthally spaced around the body 101, such feature is optional as the blades may or may not be equally spaced about tool 100. The blades 107 (or a portion extending from the body 101) may be rectangular, triangular, or have other shapes or configurations.

A plurality of cutting elements 120 may be coupled to a forward surface 111 of each blade 107 (i.e., facing forwardly in the direction of rotation of the downhole cutting tool 100). As shown in FIG. 1, the downhole cutting tool 100 may have cutting elements 120 extending axially along each blade 107, and each radial row 116 may include one or multiple cutting elements 120. In some embodiments, multiple cutting elements may extend axially and radially along a downhole tool surface. For example, cutting elements according to the present disclosure may be positioned along a surface of a mill, and one or more radial rows of cutting elements may include multiple cutting elements. Further, cutting elements 120 may be formed from any material known in the art. For example, cutting elements 120 may be formed wholly or partially of metal carbides (e.g., cemented or un-cemented tungsten carbide, titanium carbide, tantalum carbide, niobium carbide, etc.), synthetic or polycrystalline diamond, tool steel, high speed steel, polycrystalline cubic boron nitride, other materials having high hardness and/or impact resistance, or some
combination of the foregoing. For example, according to embodiments of the present disclosure, the cutting elements 120 may be formed of at least one of WC, TiC, TaC, NbC, diamond, CBN and mixtures thereof, such as WC(TiC)TaC-NbC), with a suitable binder material, such as cobalt.

0040] The cutting elements 120 may be coupled to each blade 107 in rows 116 by any suitable manner, including by brazing, welding, soldering, mechanical fastening, or the like. The downhole cutting tool 100 shown in FIG. 1 has cutting elements 120 extending axially along each blade 107, with each row 116 extending radially along the blades 107. A row 116 may include one cutting element 120 or multiple cutting elements 120. Some embodiments contemplate rows 116 with a single cutting element 120 extending radially along a full or partial length thereof, while other rows 116 may have multiple cutting elements 120 extending radially along a full or partial length thereof. Thus, some downhole cutting tools may have multiple cutting elements positioned axially and/or radially along a blade or other downhole tool surface.

0041] Referring now to FIGS. 2-4, additional embodiments of a cutting element 220 are shown and described in additional detail. In particular, FIG. 2 is a side view of a plurality of cutting elements 220 coupled to a downhole cutting tool 200 according to one or more additional embodiments of the present disclosure. FIG. 3 is a perspective view of two axially adjacent cutting elements 220, and FIG. 4 is a side view of one cutting element 220.

0042] Each cutting element 220 may have a flank face 222 and a trailing face 224 opposite the flank face 222. As shown in FIG. 2, the flank face 222 and trailing face 224 may each extend outwardly from the front face of the downhole cutting tool 200. A front face 226 of each cutting element 220 may extend between a first side 228 and a second side 230 and between the flank face 222 and trailing face 224. The front face 226 may be bounded on one side by a cutting edge 232 formed at an intersection of the front face 226 and the flank face 222, and on an opposing side at a trailing edge 234 formed at an intersection between the trailing face 224 and the front face 226. The front face 226 may include various surface features, including ridges, recesses, relief, contours, other features, or some combination of the foregoing. In FIGS. 2-4, the various features may define multiple teeth 250.

0043] Each cutting element 220 may have a back face 236 opposite the front face 226, and the back face 236 may be coupled to the downhole cutting tool 200 (e.g., the front face of a blade of the downhole cutting tool 200). The cutting elements 220 may be coupled to, or otherwise positioned on, a blade or other portion of the downhole cutting tool 200 such that from a cross-sectional or side view, the cutting edge 232 may be at the lowest axial position of the cutting element 220 (see FIG. 2). A width 238 of the cutting element 220 may be measured between the cutting edge 232 and the trailing edge 234. A length 242 of the cutting element 220 may be measured between the first side 228 and the second side 230. The first side 228 and the second side 230 may be parallel or non-parallel in some embodiments. When non-parallel, the length 242 may be measured as the greatest distance between the opposite first and second sides 228, 230. A thickness 240 of the cutting element 220 may be measured from the back face 236 to the furthest position on the front face 226.

0044] The cutting element 220 may also define a flank angle 246, as shown in FIG. 2. In some embodiments, the flank angle 246 may be measured between the flank face 222 and a line 244. The line 244 in the illustrated embodiment may be perpendicular to the back face 236 of the cutting element 220, although in some other embodiments the line 244 may be perpendicular to a longitudinal axis of the downhole cutting tool 200, a blade, a wellbore, or some other component. For example, in some embodiments, the line 244 may be perpendicular to the back face 236 of the cutting element 220 and may also be perpendicular to a longitudinal or central axis of the downhole cutting tool 200, in which case the flank angle 246 may be measured from either the line 244 perpendicular to the back face 236 of the cutting element 220 or perpendicular to the longitudinal axis of the downhole cutting tool 200. In other embodiments (e.g., embodiments with an inclined or contoured back face 236 and/or with the cutting element 220 at an angle relative to the longitudinal axis of the downhole cutting tool 200), a line perpendicular to the back face 236 of the cutting element may intersect the longitudinal axis of the downhole cutting tool 200 at a non-right angle, in which case the flank angle may be measured between the flank face 222 and a line perpendicular to the back face 236 of the cutting element.

0045] Further, as shown in FIG. 2, the line 244 perpendicular to the back face 236 is optionally also parallel with the trailing face 224 of the cutting element 220, such that the flank angle 246 may also be about equal to the angle measured between the flank face 222 and a line parallel to the trailing face 224. According to some embodiments of the present disclosure, the trailing face 224 of a cutting element 220 may not, however, be perpendicular to the back face 236 of the cutting element 220 or to a line perpendicular to the longitudinal axis of the downhole cutting tool, and the flank angle may be measured between the flank face 222 and a line parallel to the trailing face 224 rather than between the flank face 222 and a line perpendicular to the back face 236. Notwithstanding the method of measuring a flank angle 246, and as shown in FIG. 2, in embodiments having a plurality of cutting elements 220 that are axially adjacent each other on a downhole cutting tool 200, the flank angle 246 formed by a flank face 222 of a cutting element 220 may be at a trailing side of a gap 248 formed between the flank face 222 of the cutting element 220 and a trailing face 224 of an adjacent cutting element 220. According to some embodiments of the present disclosure, a flank angle 246 may range from 0° to 5°. For instance, the flank angle 246 may be within a range having lower and/or upper limits including any of 0°, 2.5°, 5°, 7.5°, 10°, 12.5°, 15°, or values therebetween. More particularly, the flank angle 246 may range from 2.5° to 12.5°, from 5° to 10°, from 7.5° to 15°, or greater than 0°, less than 15°, or the like. In other embodiments, a cutting element 220 may have a flank angle 246 that is negative or that is greater than 15°.

0046] Cutting elements 220 may have a plurality of teeth 250 or other geometries, features, or the like. The teeth 250 illustrated in FIGS. 2-4 may define back-up cutting edges 252 formed in the front face 226. Each back-up cutting edge 252 may be formed at an intersection of a back-up flank face 254 and a rake face 256, and may extend the full or partial length 242 of the cutting element 220. Each tooth 250 may have a tooth width 258 measured between adjacent back-up cutting edges 252 (or between the cutting edge 232 and an adjacent back-up cutting edge 252). According to embodiments of the present disclosure, the ratio of the tooth width 258 to the width 238 of the cutting element may be between 1:1.0 and 1:1.1, between 1:1.0 and 1:2, or between 1:5 and 1:2.5. In some
embodiments, the ratio of the tooth width 288 to the width 238 may be greater than 1:4, or between 1:8 and 1:1.

[0047] One of ordinary skill in the art will appreciate in view of the disclosure herein that the dimensions of a cutting element 220, including width 238, length 242, thickness 240, and tooth width 288 may vary. For example, in some embodiments, the width 238 may be between 0.1 inch (2.5 mm) and 3 inches (75 mm) and/or the length 242 may be between 0.1 inch (2.5 mm) and 6 inches (150 mm). In other embodiments, the width 238 may be between 0.3 inch (7.5 mm) and 0.5 inch (12.5 mm) and/or the length 242 may be between 0.3 inch (7.5 mm) and 1.5 inches (38 mm). According to embodiments of the present disclosure, the width 238 of the cutting element 220 may be less than or greater than 1 inch (25.5 mm). In some embodiments, the width 238 may be between 0.188 inches (5 mm) and 0.375 inches (9.5 mm). In some embodiments, the width 238 may be between 0.188 inches (5 mm) and 0.375 inches (9.5 mm).

[0048] Depending on the width 238 of the cutting element 220, zero or more teeth 250 may be formed on the front face 226 of the cutting element 220. For example, in some embodiments, five or more teeth 250 may be formed on the front face 226 of a cutting element 220. According to some embodiments of the present disclosure, the teeth 250 forming on the front face 226 of a cutting element 220 may have a tooth width 288 ranging from 10% to 100% of the cutting element width 238. Embodiments with a tooth width 288 equal to 100% of the cutting element width 238 may have a ratio of tooth width 288 to cutting element width 238 of 1:1, and may effectively be seen as not having any teeth 250 formed on the front face 226 of the cutting element 220. Cutting elements 220 according to further embodiments of the present disclosure may have a thickness 240 ranging from 0.05 inch (1.5 mm) and 1 inch (25.5 mm). In other embodiments, the thickness 240 may be greater than 0.125 inches (3 mm). For instance, the thickness 240 may range from 0.125 inches (3 mm) to 0.5 inches (12.5 mm).

[0049] Cutting elements 220 according to embodiments of the present disclosure may be arranged in rows (e.g., rows 116 of FIG. 1) axially spaced along a downhole cutting tool 200. On account of the flank angle 246 and the orientation of the trailing face 224, axially adjacent cutting elements 220 may have a gap 248 between the flank face 222 of a downhole cutting element 220 and the trailing face 224 of an axially adjacent, uphole cutting element 220. In some embodiments, at least a portion of a trailing edge 234 at an intersection between the trailing face 224 and the front face 226 of each cutting element 220 may contact the flank face 222 of an adjacent cutting element 220. In some embodiments, however, a gap 248 may be formed such that there is no contact between the adjacent cutting elements 220. As described in greater detail herein, providing a gap 248 between adjacent cutting elements 220 with flank angles 246 and potentially in which no additional material fills the gap 248—may improve cutting efficiency while also reducing crack propagation across cutting elements 220.

[0050] In some embodiments, a back-up flank angle 260 may be defined between the back-up flank face 286 of each back-up cutting edge 252 and the line 244 perpendicular to the back face 230 and intersecting the back-up cutting edge 252. According to embodiments of the present disclosure, the back-up flank angle 260 may be equal to the flank angle 246. In other embodiments, however, the back-up flank angle 260 may be greater than or less than the flank angle 246. Further, a back-up flank angle may have a positive (i.e., greater than 0°) or negative (i.e., less than 0°) angle. For example, according to embodiments of the present disclosure, a back-up flank angle 260 may range from −30° to 45° in some embodiments. For instance, the back-up flank angle 260 may be within a range having lower and/or upper limits including any of −30°, −20°, −15°, −10°, −5°, −2.5°, 0°, 2.5°, 5°, 7.5°, 10°, 12.5°, 15°, 20°, 25°, 30°, 45°; and values therebetween. By way of illustration, a back-up flank angle 260 may be between 0° and 15° in some embodiments, between 0° and 25°, at least 5°, or less than 45°. In other embodiments, the back-up flank angle 260 may be less than −30° or more than 45°.

[0051] FIG. 4 illustrates a positive back-up flank angle 260; however, in yet other embodiments, a back-up flank angle 260 may be negative and less than 0° degrees (i.e., the back-up flank face 254 may extend axially lower than the line 244 intersecting the back-up cutting edge 252). FIG. 10, for instance, illustrates an embodiment in which a blunt angle back-up tooth 1050 forms a negative back-up flank angle.

[0052] Referring now to FIGS. 5-7, cutting elements 520, 620, 720 according to various embodiments of the present disclosure are shown. As shown in FIG. 5, cutting elements 520 may each have a width 538 measured between a cutting edge 532 and a trailing edge 534 of the cutting element 520. The cutting edge 532 may be formed at the intersection of a front face 526 and a flank face 522, while the trailing edge 534 may be formed at the intersection of the front face 526 and a trailing face 524. The cutting element 520 may have a length 542 measured between a first side 528 and a second side 530. A thickness 540 may be measured between the back face 536 and the most distant location of the front face 526.

[0053] The width 538 of each cutting element 520 optionally varies along the length 542. For instance, the width 538 may gradually decrease from a widest point 562 to a narrowest point 564. In the illustrated embodiment, the widest point 562 may correspond to a location at one or more of the first side 528 or the second side 530, and the narrowest point 564 may be generally located between the first and second sides 528, 530 (e.g., near a midpoint of the cutting element length 542). In other embodiments, a cutting element width 538 may gradually decrease from a widest point located at the first and second sides 528, 530 toward a narrowest point located at a point along its length other than the midpoint, or a widest point may be between the first and second sides 528, 530, and one or more of the first or second sides 528, 530 may correspond to a narrowest point 564 or another point having a width less than at the widest point 562. Cutting elements 520 having a gradually decreasing width from a widest point 562 at two outer first and second sides 528, 530 towards a narrowest point 564 located along the cutting element length 542 may have a cross-sectional shape of a “V” or valley when viewed along a plane parallel to the back face 536 of the illustrated embodiment. The back face 536 may be perpendicular to the cutting element thickness 540 and/or the trailing face 524 in some embodiments.

[0054] As shown in FIG. 6, one or more cutting elements 620 may have a width 638 measured between a cutting edge 632 formed at the intersection of the front face 626 and a flank face 622 and a trailing edge 634 formed at the intersection of the front face 626 and a trailing face 624 of the cutting element 620. A length 642 of the cutting elements 620 may be measured between a first side 628 and a second side 630. The cutting elements 620 may also have a thickness 640. The width 638 of each cutting element 620 may vary along a respective length 642. For instance, the width 638 may decrease from a widest point 662 to a narrowest point 664.
the illustrated embodiment, the widest points 662 are located at or near the first side 628 and the second side 630. As shown, the gradually decreasing width 538 may be the result of the trailing edge 624 having a concave, parabolic, arc, or other shape. For instance, the trailing edge 624 may have a “U” shape, or the like, when viewed along a plane perpendicular to the cutting element thickness 640 or the trailing surface 624 (e.g., a plane parallel to the back face 636). The narrowest point 664 may optionally be located at or near a midpoint of the length 642.

In FIG. 7, the cutting elements 720 may each have a width 738 measured between a cutting edge 732 (formed at the intersection of the front face 726 and flank face 722) and a trailing edge 734 (formed at the intersection of the front face 726 and trailing face 724) of the cutting element 720, a length 742 measured between a first side 728 and a second side 730, and a thickness 740. The width 738 of each cutting element 720 may vary along its length 742, and may thus increase and/or decrease along one or more portions. As shown, the width 738 may decrease from widest points 762 located at one or more of the first side 728, second side 730, or a midpoint 763 along the cutting element length 742, toward narrowest points 764 located along intermediate locations of the length 742 (e.g., a point midway between a first or second side 728, 730 and the midpoint 763). The decreasing and increasing width 738 may form a “W” cross-sectional shape, and a W-shaped trailing edge 734 when viewed along a plane perpendicular to the thickness 740. Although the embodiment shown in FIG. 7 has three widest points 762, 763 and two narrowest points 764, other embodiments may have a varying width and may or may not form other zigzag, serrated, or “W” shapes. For example, some embodiments may have one or more midpoints with a width that is about the same as, less than, or greater than the widths at the first and/or second sides. Such widths may also be greater than the width at the narrowest points. Further, some embodiments may have more or fewer than three widest points and/or more or less than two narrowest points. Moreover, the width at the sides 728, 730 may not be equal. In some embodiments, the trailing edge may have a concave or curved shape, such that the decreasing and increasing width may form an undulating shape or a mixture of undulating and/or zig-zag shapes.

According to embodiments of the present disclosure, cutting elements having a varying width may optionally contact the flank face of an adjacent cutting element. Such contact may, for instance, be at the widest portions of the cutting element trailing edge. For example, as shown in FIG. 5, a trailing edge 534 formed at the intersection of the front face 526 and trailing face 524 may contact the flank face 522 of an adjacent cutting element 520 at the widest points 562, which are optionally located at the first and second sides 528, 530. As shown in FIG. 7, a trailing edge 734 formed at the intersection of the front face 726 and trailing face 724 may optionally contact the flank face 722 of an axially adjacent cutting element 720 at the widest points 762, which are optionally located at the first and second sides 728, 730 and/or at a midpoint 763 or other point along the cutting element length 742, and between the first and second sides 728, 730.

According to embodiments of the present disclosure, widest points of a cutting element having a varying width may be located at one or more points along the length of the cutting element, such as shown in FIGS. 5-7, or may extend a distance (e.g., form a line or surface) along the length of the cutting element. In embodiments having the widest points extending a distance along the length of a cutting element, the portion of the trailing edge of the cutting element at the widest points may contact a flank face of an adjacent cutting element. For example, the portion of the trailing edge at the widest points of a cutting element may contact a flank face of an adjacent cutting element a distance ranging from 0% to 100% of the full length of the cutting element. For example, the portion of the trailing edge of a cutting element which contacts the flank face of an adjacent cutting element may be within a range having lower and/or upper limits including any of 0%, 1%, 2%, 5%, 10%, 25%, 50%, 75%, 90%, 100%, or values therebetween.

Further, cutting elements having a varying width along its length may have a trailing face with various surface geometries. For example, as shown in FIGS. 5 and 7, the trailing face 524, 724 may have a surface geometry with one or more angled, planar surfaces extending a full or partial thickness of the cutting element (forming one or more inverse wedges), or as shown in FIG. 6, the trailing face 624 may have a concave, curved surface geometry. Other trailing face surface geometries may include, for example, grooves extending a full or partial thickness of the cutting element, with the grooves having one or more planar and/or curved surfaces therearound. In the same or other embodiments, various surface geometries may be formed across the thickness of a trailing face of a cutting element in order to form one or more widest points along the trailing edge (or along a line or surface of the trailing face) of the cutting element.

The widest points along the trailing edge optionally contact the flank face of an adjacent cutting element when coupled to a downhole cutting tool. By contacting adjacent cutting elements coupled to a downhole tool between a portion of a trailing edge (e.g., along the widest values of the cutting element) and the flank face of an adjacent cutting element, rather than contacting the full trailing edge to an adjacent cutting element flank face, a larger amount of the gap formed by the trailing face and the flank face may be exposed. Further, different contact profiles (e.g., between a flank face and widest points at a trailing edge) may be used to reduce crack propagation from one cutting element to the adjacent cutting element while also providing an increased amount of cutting edges with flank angles. A gap formed by the flank angle between the flank face of a cutting element and trailing face of an adjacent cutting element may have a volume, for example, ranging between 0% to 90% of the volume of the cutting element. More particularly, the volume of a gap may be within a range having lower and/or upper limits of 0%, 1%, 2%, 5%, 8%, 10%, 15%, 20%, 25%, 35%, 50%, 75%, 90%, 100%, or values therebetween, relative to the volume of the cutting element. In some embodiments, the gap may have a volume between 5% and 50%, between 10% and 35%, or that is less than 30% of the volume of the cutting element.

According to embodiments of the present disclosure, a cutting tool (e.g., a downhole cutting tool) having a gap formed between adjacent cutting elements (e.g., cutting elements 520, 620, 720) may be made by designing or selecting the adjacent cutting elements to have an adjacent flank face and trailing face that are non-mating. For example, according to some embodiments, a cutting tool may be formed by selecting—and potentially forming—first and second cutting elements, each cutting element including a flank face, a trailing face opposite the flank face, a front face extending between a first side and a second side and between the flank face and trailing face, a cutting edge formed at an intersection of the
front face and the flank face, and a trailing edge formed at an intersection between the trailing face and the front face. A distance between the cutting edge and the trailing edge may define a width of the cutting element. The trailing edge of the first cutting element may be positioned adjacent to the flank face of the second cutting element, such that a gap is formed between trailing face of the first cutting element and the flank face of the second cutting element. For example, the trailing face of the first cutting element and the flank face of the second cutting element may be designed to be non-mating surfaces, such that once the trailing face of the first cutting element is positioned next to the flank face of the second cutting element, a gap is formed between the non-mating portions of the flank face and adjacent trailing face. The first cutting element and the adjacent second cutting element may be coupled to a blade of the cutting tool. In some embodiments, the trailing face of the first cutting element may contact the flank face of the second cutting element at one or more points, along one or more lines or surfaces, despite being non-mating.

According to embodiments of the present disclosure, a cutting tool having a gap between adjacent cutting elements may be used to mill a downhole casing. The cutting tool may include first and second cutting elements coupled to a blade at axially adjacent locations (e.g., in axially adjacent rows). Each cutting element may have a flank face and a trailing face opposite the flank face. A front face may extend between first and second sides as well as between the flank and trailing faces, and a cutting edge may be formed at an intersection of the flank face and the front face. The trailing edge of the first cutting element may be coupled to the blade and positioned axially adjacent the flank face on the second cutting element, and a gap may be formed between the trailing face of the first cutting element and the front face of the second cutting element. The cutting tool may be extended into the casing of the wellbore and the first cutting element may engage the casing. By rotating and/or axially moving the cutting tool, the first and second cutting elements may engage the casing, and a portion of the casing may be milled away. Milling away the casing may include wearing down the first cutting element. In wearing down the first cutting element, the cutting edge may be worn away to essentially cause the cutting edge to generally move in an axially up-hole direction until the cutting edge intersects and/or aligns with a back-up flank face. A back-up cutting edge may then become the cutting edge for a cutting element. Continued wearing down of the first cutting element may allow the cutting edge to advance axially the trailing edge, and to the gap between the first and second cutting elements. In such cases, the second cutting element may engage the casing and continue to mill away a portion of the casing.

According to embodiments of the present disclosure, one or more differently shaped cutting elements may be assembled adjacent to each other on a downhole cutting tool such that different shaped gaps are formed between adjacent cutting elements. For example, various combinations of cutting elements having non-planar or other trailing faces, such as shown in FIGS. 5-7, may be positioned adjacent to each other, such that the non-planar or other trailing face of one cutting element may be adjacent the flank face of the adjacent cutting element, in order to form various shaped gaps between the trailing faces and adjacent flank faces.

Referring now to FIGS. 8-1 and 8-2, side views of a downhole cutting tool 800 (FIG. 8-1) and a cutting element 820 (FIG. 8-2) are provided according to embodiments of the present disclosure. As shown, a plurality of cutting elements 820 may be coupled to, or otherwise positioned on or in, a forward face of a blade or other component of the downhole cutting tool 800. Each cutting element 820 may have a flank face 822 and a trailing face 824 opposite the flank face 822. The cutting elements 820 may further include a front face 826 extending between the flank face 822 and trailing face 824, a cutting edge 832 formed at an intersection of the front face 826 and the flank face 822, and a trailing edge 834 formed at an intersection of the front face 826 and the trailing face 824. A plurality of teeth 850 may be formed on the front face 826 and may include or define back-up cutting edges 852. The back-up cutting edges 852 may extend up to the full length of the cutting element, and/or may be formed at an intersection of a back-up flank face 854 and a rake face 856. As shown, transitions 866 between the back-up flank face 854 and an adjacent rake face 856 of the back-up cutting edges 852 may have a radiused or other contoured shape in some embodiments. Using one or more radiused transitions 866 between a back-up flank face 854 and an adjacent rake face 856 of back-up cutting edges 852 may reduce stress concentrations encountered at the back-up cutting edges 852 and may reduce breakage of the cutting elements 820.

According to embodiments of the present disclosure, a transition between a back-up flank face of a tooth and a rake face of an adjacent tooth may include one or more planar and/or curved surfaces. For example, FIG. 9 is a side view of a cutting element 920 according to embodiments of the present disclosure having a flank face 922 and a trailing face 924 opposite the flank face 922. A front face 926 may extend between the flank face 922 and the trailing face 924, and a cutting edge 932 may be formed at an intersection of the front face 926 and the flank face 922. A trailing edge 934 may be formed at an intersection of the front face 926 and the trailing face 924. A plurality of teeth 950 having back-up cutting edges 952 may be formed in the front face 926 and optionally extend the length of the cutting element 920. Each tooth 950 may include a back-up cutting edge 952 formed at an intersection of a back-up flank face 954 and a rake face 956.

Transitions 966 between the back-up flank face 954 and an adjacent rake face 956 of the back-up cutting edges 952 may include one or more planar surfaces intersecting both the back-up flank face 954 and the rake face 956. As shown, the planar surface transition 966 may intersect the back-up flank face 954 at a transition angle 968. In some embodiments, the transition angle 968 may range between 45° and 135°. For instance, the transition angle 968 may range from 70° to 110° and/or may intersect the rake face 956 at an angle greater than the transition angle 968 at the back-up flank face 954. According to other embodiments of the present disclosure, however, one or more planar surfaces may intersect the back-up flank face 954 and/or the rake face 956 at the same or different angles, and such angles may be acute angles, right angles, or obtuse angles. In some embodiments, the transition angle 968 may be less than 45° or more than 135°.

Further, while one planar surface forms the transition 966 in the embodiment shown in FIG. 9 (and one radiused transition 866 in FIG. 8), more than one planar surface may be used to transition from the back-up flank face to the rake face of an adjacent tooth, more than one curved/radiused surface may be used to transition from the back-up flank face
to the rake face of an adjacent tooth, or one or more planar and one or more curved surfaces may be used to transition from the back-up flank face to the rake face of an adjacent tooth. In embodiments using a combination of surfaces to transition from a back-up flank face to a rake face of an adjacent tooth, the transition surfaces may intersect at angled intersections or may intersect at radiused intersections.

As shown in FIG. 10, a plurality of cutting elements 1020 according to embodiments of the present disclosure may be coupled to a forward face of a blade or other component of a downhole cutting tool 1000. Each cutting element 1020 may have a flank face 1022, a trailing face 1024 opposite the flank face 1022, a front face 1026 extending between the flank face 1022 and trailing face 1024, a cutting edge 1032 formed at an intersection of the front face 1026 and the flank face 1022, a trailing edge 1034 formed at an intersection of the front face 1026 and the trailing face 1024, and a plurality of teeth 1050 formed in the front face 1026. The plurality of teeth 1050 may have back-up cutting edges 1052 formed in the front face 1026 and extending the length of the cutting element 1020. Each back-up cutting edge 1052 may be formed at an intersection of a back-up flank face 1054 and a rake face 1056 of each tooth 1050. A transition 1066 between the back-up flank face 1054 of a tooth and the rake face 1056 of an adjacent tooth may include an angled shape or intersection, and the transition angle may be less than, equal to, or greater than 90°. In some embodiments, a transition angle between the back-up flank face 1054 of a tooth 1050 and the rake face 1056 of an adjacent tooth 1050 may range between 95° and 120°. Where the angle between the rake face 1056 and the back-up flank face 1054 is at least 90°, a tooth 1050 may be referred to as a blunt angle tooth.

Referring now to FIG. 11, a side view of a cutting element 1120 is shown. The cutting edge 1132 of the cutting element 1120 may define an axial rake angle 1170 measured between the rake face 1156 and a line parallel to the cutting tool longitudinal axis (or parallel to the back face 1136, perpendicular to the trailing face 1124, etc.). In some embodiments, the rake angle 1170 may be between 0° and 30°, though one having ordinary skill in the art will appreciate in view of the disclosure herein that the rake angle 1170 may vary and may be less than 0° or more than 30°. Additionally, back-up flank face 1154 may extend radially outward from the rake face 1156 by a distance 1172. In some embodiments, the distance 1172 may be between 0.005 in. (0.1 mm) and 1 in. (25.4 mm), depending on, for example, the other dimensions of the cutting element 1120. In a more particular embodiment, the distance 1172 may be between 0.005 in. (0.1 mm) and 0.25 in. (6.5 mm). As shown, the distance 1172 of the rake face extension may include the radial length of any transition 1166 formed between the back-up flank face 1154 and adjacent rake face 1156.

According to some embodiments of the present disclosure, a cutting element may have at least one coating on at least a portion of the front face of the cutting element. For example, FIG. 12 shows a cross-sectional view of a cutting element 1220 having a flank face 1222, a trailing face 1224 opposite the flank face 1222, a front face 1226 extending between the flank face 1222 and trailing face 1224, a cutting edge 1232 formed at an intersection of the front face 1226 and the flank face 1222, a trailing edge 1234 formed at an intersection of the front face 1226 and the trailing face 1224, and a plurality of teeth 1250 formed in the front face 1226. A coating 1274 may be on the entire front face 1226 (or a portion thereof) and/or flank face 1222 of the cutting element 1220. In some embodiments, the coating 1274 may be on portions of, or the entire, front face 1226, without covering the leading or trailing face. In some embodiments, the coating 1274 may be on a portion of the front face 1226 and/or a portion of the flank face 1222 (e.g., sufficient to cover the entire cutting edge 1232). In some embodiments, the coating 1274 may be on the entire front face 1226, flank face 1222, and trailing face 1224. Other combinations of portions of a cutting element 1220 may be coated, including potentially the side surfaces, back face, and the like. Such a coating may be used, for example, to protect various portions of the cutting element 1220, to improve the wear resistance of the cutting element 1220, to improve thermal/chemical stability of the cutting element 1220, for other purposes, or for any combination of the foregoing.

One or more coatings may be applied to a cutting element of the present disclosure. Example coating materials may include, for example, TiN, TiAlN, TiCN, Al2O3, other materials, and combinations of the foregoing. For example, according to some embodiments of the present disclosure, a cutting element may be coated with more than one layer of coating material, such as a TiN layer, Al2O3 layer, and TiC layer combination, a TiN layer and TiC layer combination, or other combinations of coating material layers. Further, different portions of a cutting element may have different coatings or coating layers in some embodiments.

A coating layer thickness may vary, for example, depending on the method of coating application, the material being applied, the portion of the cutting element being coated, and the purpose of the coating, to name a few factors. For example, a coating layer thickness may range from less than 1 μm to greater than 1 mm, or even greater than 2 mm in some embodiments. According to embodiments of the present disclosure, a coating may be deposited on a cutting element surface by chemical plating, chemical vapor deposition (CVD), physical vapor deposition (PVD), atomic layer deposition (ALD), vacuum deposition, arc processes, high velocity sprays, other deposition methods, or any combination of the foregoing.

FIG. 13 is a magnified cross-sectional view of a coating 1374 on a cutting element 1320 according to embodiments of the present disclosure. The coating 1374 may have a thickness 1315 between 1 nm and 2 mm, in some embodiments. For instance, the thickness 1315 of the coating 1374 may be within a range having lower and/or upper limits including any of 1 nm, 50 nm, 100 nm, 500 nm, 1 μm, 50 μm, 100 μm, 1 mm, 2 mm, or any values therebetween. In other embodiments, the thickness 1315 may be less than 1 nm or more than 2 mm.

Depending on the work piece to be milled or otherwise cut, downhole tools and cutting tools of the present disclosure may have different configurations with different blade geometries and varying cutting element placement so that the cutting edge of the cutting elements are aligned with the work piece. Work pieces may include, for example, casing, plugs, tubulars, downhole restrictions, broken tool components (e.g., roller cones), and hand tools dropped down a wellbore from the surface. Embodiments of a downhole cutting tool may include a pilot mill, an expandable section mill, a section mill, a taper mill, a junk mill, a casing mill, or the like. A downhole tool may also include a follow mill or a dress mill for cutting or cleaning up a downhole casing window. Further, the lower ends of the blades of a cutting element (e.g.,
blades 107) may extend substantially radially from the tool body, and about perpendicular to the longitudinal axis of the wellbore. Cutting elements 120 of FIG. 1, for instance, may be mounted so that cutting edge may also extend substantially radially from the tool body and about perpendicular to the longitudinal axis of the wellbore. In some embodiments, a downhole cutting tool may be a taper mill and/or the blades may be positioned to cut away casing at an angle relative to the downhole trajectory of the mill. In such a mill, the cutting edge of the cutting elements may be oriented at an angle relative to the trajectory of the mill (e.g., an angle that is neither parallel nor perpendicular to the trajectory of the mill).

During operation of a downhole cutting tool, the downhole cutting tool may be lowered into the wellbore on a drill string, so that a cutting element may contact the work piece and perform a face milling operation. FIG. 14 depicts an example cutting element 1420 contacting a work piece 1478. The cutting element 1420 may have a positive rake angle 1470, with the rake angle 1470 being measured between a rake face 1450 and a line 1457 perpendicular to the work piece 1478. One skilled in the art will understand in view of the disclosure herein that a negative or neutral rake angle may also be used and remain within the scope of this disclosure.

Upon contacting the work piece, the downhole cutting tool may then be rotated and moved axially. A cutting edge 1432 may contact work piece 1478 and shave a chip 1480 from a top layer or exposed surface of work piece 1478. The chip 1480 may continue to grow (i.e., lengthen), as more material from the work piece 1478 is removed. When the chip 1480 grows to a certain length, chip 1480 may contact the back-up flank face 1454 corresponding to the back-up cutting edge 1452 most proximate to the cutting edge 1432. This contact may cause additional stress within the chip 1480, eventually causing the chip 1480 to break from the work piece 1478. The distance 1458 between the cutting edge 1432 and the back-up cutting edge 1452 may determine or correspond to the size of the chip 1480 when it is broken off from the work piece 1478.

Without the back-up cutting edge 1452, the chip 1480 may grow unboundedly into a long, tangled strand. Such birdnesting may result in a strand which may wrap around the drill string, cutting tool, or the like, and may clog the wellbore around the drill string, or even cut caving around the drill string as it rotates. As chips 1480 are removed from the work piece 1478, the controlled size of the chips may allow the downhole cutting tool to be steadily lowered or translated further into the wellbore, and the chips to be reliably moved to the surface.

As the cutting element 1420 slidesly contacts the work piece 1478, a flank face 1422 of the cutting element 1420 may be worn away, reducing the tooth width 1458 between two adjacent teeth, and/or the width of the cutting element 1420. As this occurs, the cutting edge 1432 may continuously move up the face of cutting element 1420. When the cutting edge 1432 meets the back-up flank face 1454, the back-up cutting edge 1452 may become the new cutting edge 1432. Further, as the entire cutting element 1420 is worn away, the adjacent cutting element (not shown) may provide a new cutting edge 1432. By providing adjacent cutting elements 1420 according to embodiments of the present disclosure (e.g., with a flank angle and a gap between the trailing face of a first cutting element and the flank face of an axially adjacent cutting element), cutting/milling performance and/or efficiency may potentially be improved by, for instance, increasing the number of cutting edges, reducing chip size, reducing crack propagation across cutting elements, or the like.

In contrast to a flank angle (e.g., flank angle 246 of FIG. 2) which may be measured relative to a flank face of a cutting element and other features of the cutting element and/or downhole cutting tool (e.g., a line perpendicular to a back face or tool axis), a relief angle 1482 may be measured between a flank face 1422 of a cutting element 1420 and a work piece 1478. For example, FIG. 14 shows a cutting element 1420 having a relief angle 1482 which may be measured between the flank face 1422 and a surface of the work piece 1478. Because cutting element relief angles 1482 may be measured with respect to the work piece surface, the geometry of the cutting element (e.g., flank angle geometry) in addition to the position of the cutting element on a cutting tool or relative to a work piece may affect the size of the relief angle. For example, FIGS. 15-1 and 15-2 show example cutting elements 1520 coupled to example blades 1507 according to embodiments of the present disclosure. The blades 1507 in FIGS. 15-1 and 15-2 are illustrated at different angular oritnations or tilts. The cutting elements 1520 coupled to the blades 1507 at a forward tilt 1584 may have a larger relief angle 1582 formed between the cutting element flank surface 1522 and the surface of the work piece 1578 than the cutting elements 1520 coupled to the blade 1507 at a reverse tilt 1586. Further, a cutting element 1520 having a relatively higher flank angle may also potentially form a higher relief angle 1582 than a similarly positioned cutting element 1520 having a lower flank angle, or no flank angle. In some embodiments, the flank angle may be equal to the relief angle 1582.

According to some embodiments, a method of milling or otherwise cutting with a downhole tool is described, and may include providing or accessing a downhole tool such as a downhole cutting tool. A blade may be coupled to a body of the downhole tool and may have a forward surface. A plurality of cutting elements may be coupled to the forward surface of the blade. Each cutting element may have a front face extending fully or partially between a first side and a second side. A flank face of the cutting element may extend fully or partially between the first and second side, and a cutting edge may be formed at the intersection of the front face and the flank face. A flank angle of the cutting element may be measured using the flank face. The flank face may also be positioned adjacent a trailing face of an adjacent cutting element. Each cutting element may optionally include one or more back-up cutting edges formed in the front face, and which extend fully or partially from the first side to the second side. A back-up cutting edge may be located at an intersection of a back-up flank face and a rake face. In the method of cutting with a downhole tool, the cutting edge of the cutting element may be contacted with a work piece, and the downhole tool may be rotated and/or translated (e.g., moved axially downward) within the wellbore.

By providing multiple cutting elements with flank angles adjacent to each other on a downhole cutting tool, such that a gap is formed between the flank face forming the flank angle and a trailing face of an adjacent cutting element, multiple cutting edges may be provided on the downhole cutting tool to increase cutting effectiveness and/or extend the amount of cutting that may be performed by a single downhole cutting tool. For example, referring now to FIGS. 16-1 to 17-2, lab testing was performed to compare the performance
of a downhole tool having a cutting element with a 0° relief angle formed at the cutting edge (cutting element 1720 of FIG. 17-1) and a cutting element with a relief angle greater than 0° (cutting element 1620 of FIG. 16-1). Lab testing was performed by securing the cutting elements 1620, 1720 to a holder and replicating the cutting action within a casing 1678, 1778. The cutting elements 1620, 1720 that were tested included cutting elements 1620, 1720 with a 19° rake angle on a casing 1678, 1778 with an outer diameter of 9.5 in. (24 cm). The cutting element 1620 was tested with a relief angle 1682 of 5° and was able to cut a length of a casing 1678 up to 6 in. (15.2 cm) using a 0.006 in./rev (0.15 mm/rev) feed rate and 100 rpm. The cutting elements 1720 tested with a relief angle 1782 of 0° were unable to cut the casing 1778, even using a lower depth of cut of 0.001 in./rev (0.03 mm/rev) as the load exceeded the limit of the testing machine. FIGS. 16-2 and 17-2 show graphical representations of the cutting performance of the tested cutting elements 1620, 1720. In particular, the x-axis measures time and the y-axis measures distance. The various lines shown in FIG. 16-2 represent cutting performance with various feed rates, while the line in FIG. 17-2 also corresponds to attempts to cut the casing 1778 at multiple feed rates. As shown in FIG. 16-2 and FIG. 17-2, cutting elements 1620 having a relief angle 1682 of greater than 0° showed higher cutting performance when compared with cutting elements 1720 having a 0° relief angle 1782.

[0081] As described herein, downhole cutting milling tools of the present disclosure may include a plurality of cutting elements, and some or each of the cutting elements may have a flank angle greater than 0° at the flank face, and gaps may be formed between flank faces of cutting elements and trailing faces of axially adjacent cutting elements. Thus, once one cutting element (e.g., a more downhole cutting element) is worn away, the cutting edge having a flank angle greater than 0° formed in an adjacent cutting element (e.g., a more uphole cutting element) may be exposed and may continue cutting milling. In contrast, a downhole tool having a plurality of adjacent cutting elements without flank angles (and/or potentially without gaps between cutting elements as shown in FIG. 18) may cut at a flank angle of 0° once a first cutting edge or cutting element is worn away.

[0082] In particular, referring to FIG. 18, a blade of a downhole tool 1800 may have a plurality of cutting elements 1820 coupled thereto. Each cutting element 1820 may have a flank face 1822, a trailing face 1824, and a front face 1826 extending from the flank face 1822 to the trailing face 1824. The cutting elements 1820 may be adjacent to each other such that the flank face 1822 of a cutting element 1820 may optionally be in full contact with the trailing face 1824 of an adjacent cutting element 1820. During cutting, once the first cutting edge 1832 of the axially lowermost or first cutting element 1820-1 is worn away, the cutting element 1820-1 may be worn flat, and the remaining cutting action may be performed at a 0° flank angle (or potentially 0° relief angle), with the full thickness of the cutting element 1820-1 scraping the work piece. Cutting along a wear flat, or at a 0° flank angle, may reduce cutting efficiency, require higher loads, generate increased amounts of heat, result in other cutting characteristics, or have some combination of the foregoing. Further, by having adjacent cutting elements 1820 in full contact (e.g., with a flank face 1822 in full contact with a trailing face 1824 of the adjacent cutting element 1820), cracks may propagate across multiple cutting elements 1820 as there is increased contact between the cutting elements 1820. FIG. 19-1 shows pictures of an example of a wear flat 1988 formed during milling and FIG. 19-2 shows an example of a crack 1990 propagating across multiple cutting elements.

[0083] In the description and claims herein, various relational terms may be used to facilitate an understanding of various aspects of some embodiments of the present disclosure. Relational terms such as “bottom,” “below,” “top,” “above,” “back,” “front,” “left,” “right,” “rear,” “forward,” “up,” “down,” “horizontal,” “vertical,” “clockwise,” “counterclockwise,” “upper,” “lower,” “uphole,” “downhole,” and the like, may be used to describe various components, including their operation and/or illustrated position relative to one or more other components. Relational terms do not indicate a particular orientation for each embodiment within the scope of the description or claims. For example, a component of a downhole that is described as a lower element may be further from the surface relative to an upper element while within a vertical wellbore, but may have a different orientation during assembly, when removed from the wellbore, or in a lateral or other deviated borehole. Accordingly, relational descriptions are intended solely for convenience in facilitating reference to various components, but such relational aspects may be reversed, flipped, rotated, moved in space, placed in a diagonal orientation or position, placed horizontally or vertically, or similarly modified. Certain descriptions or designations of components as “first,” “second,” “third,” and the like may also be used to differentiate between identical components or between components which are similar in use, structure, orientation, or operation. Such language is not intended to limit a component to a singular designation. As such, a component referenced in the specification as the “first” component may be the same or different than a component that is referenced in the claims as a “first” component.

[0084] Furthermore, while the description or claims may refer to “an additional” or “other” element, feature, aspect, component, or the like, it does not preclude there being a single element, or more than one, of the additional or other element. Where the claims or description refer to “a” or “an” element, such reference is not be construed that there is just one of that element, but is instead to be inclusive of other components and understood as “at least one” of the element. It is to be understood that where the specification states that a component, feature, structure, function, or characteristic “may,” “might,” “can,” or “could” be included, that particular component, feature, structure, or characteristic is provided in some embodiments, but is optional for other embodiments of the present disclosure. The terms “couple,” “coupled,” “connect,” “connection,” “connected,” “in connection with,” and “connecting” refer to “in direct connection with,” or “in connection with via one or more intermediate elements or members.” Components that are “integral” or “integrated” formed include components made from the same piece of material, or sets of materials, such as by being commonly molded or cast from the same material, or machined from the same one or more pieces of material stock. Components that are “integral” should also be understood to be “coupled” together.

[0085] Although various example embodiments have been described in detail herein, those skilled in the art will readily appreciate in view of the present disclosure that many modifications are possible in the example embodiments without materially departing from the present disclosure. Accordingly, any such modifications are intended to be included in the scope of this disclosure. Likewise, while the disclosure herein contains many specifics, these specifics should not be
construed as limiting the scope of the disclosure or of any of the appended claims, but merely as providing information pertinent to one or more specific embodiments that may fall within the scope of the disclosure and the appended claims. Any described features from the various embodiments disclosed may be employed in any combination. Features and aspects of methods described herein may be performed in any order.

[0086] A person having ordinary skill in the art should realize in view of the present disclosure that equivalent constructions do not depart from the spirit and scope of the present disclosure, and that various changes, substitutions, and alterations may be made to embodiments disclosed here without departing from the spirit and scope of the present disclosure. Equivalent constructions, including functional “means-plus-function” clauses are intended to cover the structures described herein as performing the recited function, including both structural equivalents that operate in the same manner, and equivalent structures that provide the same function. It is the express intention of the applicant not to invoke means-plus-function or other functional claiming for any claim except for those in which the words “means for” appear together with an associated function. Each addition, deletion, and modification to the embodiments that falls within the meaning and scope of the claims is to be embraced by the claims.

[0087] While embodiments disclosed herein may be used in oil, gas, or other hydrocarbon exploration or production environments, such environments are merely illustrative. Systems, tools, assemblies, methods, cutting elements, milling tools, downhole cutting tools, and other components of the present disclosure, or which would be appreciated in view of the disclosure herein, may be used in other applications and environments. In other embodiments, cutting elements, cutting tools, systems, methods, and components, or other embodiments discussed herein or which would be appreciated in view of the disclosure herein, may be used outside of a downhole environment, including in connection with other systems, including within automotive, aquatic, aerospace, hydroelectric, manufacturing, other industries, or even in other downhole environments. The terms “well,” “wellbore,” “borehole,” and the like are therefore also not intended to limit embodiments of the present disclosure to a particular industry. A wellbore or borehole may, for instance, be used for oil and gas production and exploration, water production and exploration, mining, utility line placement, or myriad other applications.

[0088] Certain embodiments and features may have been described using a set of numerical values that may provide lower and/or upper limits. It should be appreciated that a range may be defined by an upper limit, a lower limit, or between a combination of any two values. Numbers, percentages, ratios, measurements, or other values stated herein are intended to include the stated value as well as other values that are about or approximately the stated value, as would be appreciated by one of ordinary skill in the art encompassed by embodiments of the present disclosure. A stated value should therefore be interpreted broadly enough to encompass values that are at least close enough to the stated value to perform a desired function or achieve a desired result. The stated values include at least experimental error and variations that would be expected by a person having ordinary skill in the art, as well as the variation to be expected in a suitable manufacturing or production process. Values, orientations, features, and the like that are “about,” “approximately,” or “substantially” a stated value, orientation, or feature encompass the stated value orientation, or feature, as well as those that are within 10%, within 5%, within 1%, within 0.1%, or within 0.01% thereof.

[0089] The Abstract included with this disclosure is provided to allow the reader to quickly ascertain the general nature of some embodiments of the present disclosure. The Abstract is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

What is claimed is:

1. A downhole tool comprising:
   a body;
   a blade coupled to the body, the blade having a forward surface;
   a first cutting element coupled to the forward surface of the blade, the first cutting element having a flank face and a trailing face; and
   a second cutting element coupled to the forward surface of the blade, the second cutting element being axially adjacent the first cutting element and having a flank face and a trailing face, the flank face of the second cutting element defining a flank angle greater than 0° relative to the trailing face of the first cutting element;

2. The downhole tool of claim 1, the flank face of the second cutting element defining a flank angle up to 15° relative to the trailing face of the first cutting element.

3. The downhole tool of claim 1, each of the first and second cutting elements including:
   first and second sides;
   a front face between the first and second sides and between the flank and trailing faces; and
   a cutting edge at an intersection of the front and flank faces.

4. The downhole tool of claim 3, each of the first and second cutting elements further including:
   a plurality of back-up cutting edges formed in the front face at an intersection of a back-up flank face and a rake face; the back-up cutting edge extending across a full length of the front face of the cutting element.

5. The downhole tool of claim 4, a back-up flank angle being formed between the rake face of each back-up cutting edge and a line perpendicular to the front face.

6. The downhole tool of claim 5, the back-up flank angle being equal to the flank angle.

7. The downhole tool of claim 1, each of the first and second cutting elements further including:
   a trailing edge at an intersection between the trailing face and the front face, at least a portion of the trailing edge of the first cutting element contacting the flank face of the second cutting element.

8. The downhole tool of claim 7, the trailing edge of the first cutting element being in full contact with the second cutting element.

9. The downhole tool of claim 1, the first and second cutting elements defining a gap between the flank face of the second cutting element and the trailing face of the first cutting element.

10. The downhole tool of claim 1, a width of the cutting element varying along a length of the cutting element.

11. The downhole tool of claim 1, the first and second cutting elements each including a front face extending between the flank face and the trailing face, at least a portion of the front face of the first or second cutting element having at least one coating applied thereto.
12. The downhole tool of claim 1, each of the first and second cutting elements having a width of 1 inch or less as measured from the flank face to the trailing face.

13. A cutting element, comprising:
   a flank face;
   a trailing face opposite the flank face and non-parallel to the flank face, a distance between the flank face and the trailing face defining a width of the cutting element;
   a front face extending between the flank face and the trailing face;
   a cutting edge at an intersection of the front face and the flank face; and
   a trailing edge at an intersection of the trailing face and the front face.

14. The cutting element of claim 13, a flank angle of the flank face being greater than 0° to 15°.

15. The cutting element of claim 13, further including:
   a plurality of teeth defining back-up cutting edges in the front face, each back-up cutting edge being at an intersection of a back-up flank face and a rake face, and having a back-up flank angle.

16. The cutting element of claim 15, the back-up flank angle being equal to a flank angle of the flank face.

17. The cutting element of claim 15, a transition between the back-up flank face and the rake face having at least one of a curved, angled, or planar shape.

18. The cutting element of claim 15, a ratio of a tooth width of the plurality of teeth to the width of the cutting element being between 1:8 and 1:2.

19. The cutting element of claim 12, the width of the cutting element being between 5/16 inch and 3/8 inch, and a thickness of the cutting element being between 1/8 inch and 1/2 inch.

20. A method of milling, comprising:
   inserting a cutting tool into a wellbore, the cutting tool including a blade with a first and second cutting elements coupled thereto, the first and second cutting elements being axially adjacent with a gap therebetween, each of the first and second cutting elements including:
   a flank face;
   a trailing face;
   first and second sides;
   a front face extending between the first and second sides, and between the flank and trailing faces;
   a cutting edge at an intersection of the front face and the flank face; and
   a trailing edge at an intersection of the trailing face and the front face;
   engaging a casing with at least the first cutting element of the cutting tool; and
   milling away a portion of the casing with at least the first cutting element.

21. The method of claim 20, the gap being formed between the trailing face of the first cutting element and the flank face of the second cutting element.

22. The method of claim 20, each of the first and second cutting elements further including one or more back-up teeth, wherein milling away the portion of the casing includes wearing down the flank face such that the cutting edge moves toward the one or more back-up teeth.

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