

**MULTIPLE DIAMOND LAYER
POLYCRYSTALLINE DIAMOND COMPOSITE CUTTERS
AND A METHOD FOR MAKING THE SAME**

Background of the Invention

The present invention relates to polycrystalline diamond composite ("PDC") cutters used in drag bits for drilling bore holes in earth formations.

PDC cutters are well known in the art. They have a cemented tungsten carbide body and are typically cylindrical in shape. The cutting surface of the cutter is formed by sintering a PDC layer to a face of the cutter. The diamond layer serves as the cutting surface of the cutter. The cutters are inserted on a drag bit outer body 8 exposing at least a portion of the cutter body 10 and the diamond cutting surface 14 as shown in FIG. 10. Typically, the cutter makes contact with a formation at an angle, i.e., the diamond cutting layer is at an angle to the formation surface. As the bit rotates, the PDC cutting layer edge makes contact and "cuts" away at the formation. At the same time portions of the exposed cutter body also make contact with the formation surface. This contact erodes the cutter body. As the carbide body of the cutter erodes, less and less carbide material is available to support the diamond cutting layer, resulting in the eventual detachment and loss of the PDC cutting layer. Consequently, the cutter is disabled.

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Furthermore, as the PDC cutter body erodes, the cutter which is tightly fitted into the bit body loosens and falls out. As the cutting process continues, the fallen cutter can come in contact with or lodge against the remaining cutters causing them to also fail.

For improved cutting action it is preferred that the substrate forming the cutter body have high stiffness and hardness. A stiffer substrate tends to better support the cutting PDC surface, resulting in improved cutting action. However, a stiffer, harder substrate is prone to cracking. Cracks typically form on the substrate interface with the PDC layer and propagate toward the cutter base. As the crack approaches the base of the cutter, the cutter tends to split resulting in the failure of the cutter and the eventual failure of the bit.

Accordingly, there is a need for a cutter with increased resistance to body wear and erosion so as to prevent the detachment of the PDC cutting layer and the consequential "fall-out" of the cutter. There is also a need for a cutter which can still function after the diamond cutting layer is detached. Such a cutter will have an enhanced useful life resulting in less frequent cutter changes and in fewer drilling operation stoppages for replacing failed cutters. Moreover, there is a need for a cutter having a stiff, hard substrate supporting the cutter cutting layer to allow for improved cutting but which prevents the propagation of crack growth through the cutter body.

Summary of the Invention

This invention relates to an improved polycrystalline diamond composite ("PDC") drag bit cutter comprising multiple cutting surfaces resulting in an enhanced useful life. The invention also relates to the method for making such an improved PDC cutter. Generally, PDC cutters have a cylindrical shape. The cutting surface of a PDC cutter is formed by sintering polycrystalline diamond to the

PDC cutter face. With the present invention secondary cutting surfaces are formed on the body of the PDC cutter. These cutting surfaces are formed by sintering polycrystalline diamond in grooves formed on the outer surface of the cutter body.

The secondary cutting surfaces take the shape of the formed grooves. Shapes of secondary cutting surfaces can comprise a plurality of spaced rings spanning the whole of a part of the PDC body circumference. These rings can be inter-connected by finger-like members which are also cutting surfaces. Secondary cutting surfaces can be in the shape of rings, curves, dots, triangles, rectangles, squares. Moreover, they can be in the shape of an inverted "V", they can be longitudinal, circumferential, or skewed. The shapes of the cutting surfaces that can be formed is basically unlimited. A combination of cutting surfaces shapes may be incorporated in single cutter.

In a preferred embodiment, the PDC cutter has at least a two-layer substrate. For descriptive purposes, the substrate layers are also referred to herein as "wafers." Each wafer has a top end, a bottom end and a body therebetween.

The cutter body is formed by bonding the wafers of cemented tungsten carbide together, one on top of the other. It is preferred that a stiffer grade cemented tungsten carbide is used to form the uppermost portion of the cutter which interfaces with the primary PDC cutting layer. A stiffer substrate provides better support for the cutting layer which results in enhanced cutting.

The secondary cutting surfaces are formed by compacting and sintering diamond on grooves formed on the body surface of the wafers. The grooves preferably span the height of the wafers. The grooves can be of any shape. Generally, the shape and orientation of the grooves is dictated by the formation to be cut. In addition, the orientation of the grooves, and hence, of the secondary cutting surfaces, may be varied by rotating

the wafers in relation to each other. For example, the wafers may be oriented such that the grooves on their surfaces are aligned forming grooves that are continuous between the wafers. Moreover different grades of diamond may be compacted and sintered in different grooves.

Brief Description of the Drawings

FIG. 1 is an isometric view of a PDC cutter with a ring-shaped secondary PDC cutting surface.

FIG. 2 is an isometric view of a PDC cutter with a plurality of ring-shaped secondary PDC cutting surfaces.

FIG. 3 is an isometric view of a PDC cutter with a plurality of "dot"-shaped secondary PDC cutting surfaces.

FIG. 4 is an isometric view of a PDC cutter with a cross-shaped secondary PDC cutting surface.

FIG. 5 is an isometric view of a PDC cutter with a plurality of finger-like secondary PDC cutting surfaces.

FIG. 6 is an isometric view of a PDC cutter with a triangular secondary PDC cutting surface.

FIG. 7 is an isometric view of a PDC cutter with a rectangular secondary PDC cutting surface.

FIG. 8 is an isometric view of a PDC cutter with a ring-shaped secondary PDC cutting surface and a plurality of finger-like PDC secondary cutting surfaces positioned cross-wise between the primary cutting surface and the ring-shaped cutting surface.

FIG. 9 is an isometric view of a PDC cutter with a half-ring-shaped secondary PDC cutting surface spanning half of the cutter circumference.

FIG. 10 is an isometric view of a drag bit with installed prior art PDC cutters.

FIG. 11 is an isometric view of a drag bit with installed PDC cutters having a primary and a secondary cutting surface.

FIG. 12 is an isometric view of a PDC cutter with secondary cutting surfaces.

FIG. 13 is an isometric view of five cemented tungsten carbide wafers, three of which have grooves, which when bonded form the PDC cutter body of FIG. 1.

FIG. 14 is an isometric view of a PDC cutter having curve shaped secondary cutting surfaces.

FIG. 15 is an isometric view of a PDC cutter having square shaped secondary cutting surfaces.

FIG. 16 is an isometric view of a PDC cutter having inverted "V" shaped secondary cutting surfaces.

FIG. 17 is an isometric view of a PDC cutter having skewed arc shaped secondary cutting surfaces.

FIG. 18 is an isometric view of a PDC cutter formed from four cemented tungsten carbide wafers where the grooves on the wafers are aligned to form continuous grooves along the cutter body.

FIG. 19 is an isometric view of a PDC cutter with a plurality of square shaped secondary cutting surfaces oriented in a helical pattern.

Detailed Description of the Preferred Embodiment

The present invention is an improved polycrystalline diamond composite ("PDC") cutter comprising multiple PDC cutting surfaces, resulting in enhanced cutter useful life and increased cutter efficiency.

Generally PDC cutters have a carbide body 10 having a cylindrical shape with a cutting face 12 (FIGS. 1-9). A PDC layer 14 is sintered on the cutting face of the cutter (FIGS. 1-9). While the present invention is described herein based on a cylindrical-shaped cutter, the invention is equally applicable to other shapes of cutters. In the present invention, the PDC layer forms a primary cutting surface. Additional cutting surfaces (referred herein as "secondary" cutting surfaces) are formed on the PDC carbide body. These secondary cutting surfaces can span the whole or a portion of the circumference of the cutter body. In many situations, the secondary cutting surfaces span only the portion of the

cutter body exposed to the earth formation during drilling.

To form the secondary cutting surfaces, grooves are formed on the cutter body outer surface. Diamond crystals are compacted into the grooves and the cutter is processed in a high pressure, high temperature press to form polycrystalline diamonds in the grooves. The process of forming the grooves and the subsequent process of sintering and compacting polycrystalline diamond in these grooves is known in the art. For example, U.S. Patent No. 5,031,484 describes a process for fabricating helically fluted end mills with PDC cutting surfaces by sintering and compacting polycrystalline diamond in helically formed grooves in fluted end mills. Generally speaking, the grooves for polycrystalline diamond have a half round cross section without sharp corners. Typically a groove may be 0.060 inch wide and 0.050 inch deep.

Secondary cutting surfaces can be in the shape of rings 16 which are parallel to the primary cutting surface, and span the circumference of the cutter (FIGS. 1 and 2). A single ring or multiple rings can span the entire circumference of the cutter body or only a portion of it. For example, a further embodiment utilizes a half ring (or band) 28 which spans half of the circumference of the cutter and which is parallel to the primary PDC cutting surface (FIG. 9). In another embodiment, the secondary ring surface and the primary cutting surface are inter-connected with finger-like cutting surfaces 22 which are parallel to each other and perpendicular to the ring and the primary cutting surface 14 (FIG. 8). In embodiments using multiple secondary ring cutting surfaces, the rings can also be inter-connected with finger-like cutting surfaces.

In a further embodiment, the secondary cutting surfaces can be in the form of "dots" 18 which are generally equidistant from the primary diamond layer cutting surface and which are equally spaced (FIG. 3).

These "dots" can span the entire circumference of the cutter or can span only a portion of the cutter circumference.

Another embodiment utilizes longitudinal finger-like cutting surfaces 22 which are parallel to each other and perpendicular to the primary diamond cutting surface 14. These finger-like cutting surfaces can be equally spaced and can span the entire circumference of the cutter body or only a portion of it (FIG. 5).

In yet a further embodiment, the secondary cutting surface has a triangular shape 24 (FIG. 6). Instead of a triangular cutting surface, a rectangular cutting surface 26 (FIG. 7) or a cross-shaped surface 20 (FIG. 4) can also be incorporated. Other shapes of cutting surfaces can also be used.

In another embodiment, the secondary cutting surfaces have an inverted "V" shape (FIG. 16), or may be square (FIG. 15), curved (FIG. 14), longitudinal, circumferential or skewed (FIG. 17). In essence, the secondary cutting surfaces can be of any shape. A secondary cutting surface shapes is typically directed by the shape of the groove on which it is formed.

A secondary cutting surface serves two purposes. First, it serves as an additional cutting surface, increasing the cutting efficiency of the cutter. Second, it delays the erosion and wear of the cutter body that occurs when the cutter body is allowed to make contact with the earth formations during drilling.

PDC cutters are sometimes inserted on a drag bit outer body at an angle exposing the primary cutting surface 14 and a portion 11 of the cutter body 10 (FIG. 10). As the bit rotates during the drilling process, the primary PDC cutting surface 14 makes contact with the formation first, followed by contact of the exposed cutter body portion 11. With the present invention, contact of the primary cutting surface with the earth formations is followed by contact of the secondary

cutting surface (shown as ring 16 in FIG. 11) which is formed on the cutter exposed outer surface. As the secondary cutting surface makes contact with the formations, it prevents the portion of the exposed cutter body surrounding the secondary cutting surface from making contact with the formation and, therefore, slows down the cutter body erosion.

As a result, the period of time it takes for the cutter body to wear down to a point where the primary PDC cutting surface 14 detaches from the cutter is prolonged, resulting in enhanced cutter life. Furthermore, the retardation of cutter body erosion ensures that cutters remain tightly fitted into the cutter bit longer, decreasing the frequency of cutter "fall-out." In addition, with this improved PDC cutter, even if the primary PDC cutting layer detaches or fails, the cutter can still function (i.e., cut) using the secondary cutting surfaces.

In a preferred embodiment, the body of the PDC cutter is formed by bonding together at least two cemented tungsten carbide wafers 116. The wafers are cylindrical having a top 118 and bottom 120 end and a body having a circumferential outer surface therebetween (FIG. 13). To form the cutter body, the wafers are stacked one on top of the other and bonded.

To form the primary PDC cutting layer, typically, diamond is spread over the surface and sintered in a high temperature, high pressure press. To form the secondary cutting surfaces, grooves 126 are formed on the wafers. Preferably, the grooves span the full length of the wafers. Grooves which span the length of the wafer are easier to form since the groove can begin and end at each end face 118, 120 of a wafer. As a result, the grooves can have maximum depth from their onset.

With this embodiment, the groove (and secondary cutting surfaces) orientation may be varied by rotating the wafers in relation to each other prior to bonding.

For example, the wafers may be aligned such that the grooves on their surfaces are aligned forming grooves 130 that are continuous between the wafers 116 (FIG. 18). The secondary cutting surfaces can be oriented along the cutter body, as necessary, to accommodate the task at hand. For example, the secondary cutting surfaces can be oriented in a helical pattern along the length of the cutter (FIG. 19).

Moreover, the cutting surfaces can be arranged on the cutter body so as to vector the cutting forces applied by the cutter as needed for the cutting to be accomplished. Additionally, grooves, and thereby secondary cutting surfaces, of various shapes may be formed in a single wafer. Similarly, each wafer may have grooves of different shapes.

The wafers can be made of different grades of cemented tungsten carbide. For example, a stiff (i.e., hard) substrate is desired to support the primary PDC cutting layer so as to prevent breakage of the PDC layer. A stiff support also enhances the cutting performance of the PDC layer by preventing flexing of the layer. However, a stiff, hard substrate is prone to cracking. The cracks typically form at the cutting face 12 of the substrate which interfaces with the primary PDC cutting layer. These cracks eventually grow the length of the substrate resulting in the splitting of the substrate and failure of the cutter.

To provide the desired stiffness for prolonging the life of the PDC cutting layer and for enhancing its cutting performance, at least a stiff wafer and a tough wafer are bonded to form the substrate (body) of the cutter. A typical stiff wafer is one made of a grade of cemented tungsten carbide having a particle size of 3 microns and a cobalt content of approximately 13%. A typical tougher wafer is one made of a grade of cemented tungsten carbide having a particle size of 5 microns and a cobalt content of approximately 14%.

The stiffer cemented tungsten carbide wafer forms the top of the cutter for supporting the primary PDC cutting layer. The tougher cemented tungsten carbide wafer is bonded to the stiffer wafer to form the lower portion of the cutter body. The stiffer wafer provides the desired support to the PDC layer. The tougher cemented tungsten carbide wafer which is not as prone to cracking as the stiffer wafer, serves as a crack arrestor. Thus, a crack that propagates through the stiffer wafer should be arrested once it reaches the tougher wafer, preventing the failure of the cutter.

As it will become apparent to one skilled in the art, multiple layers of various grades of cemented carbide may be used to form cutters tailored to the task at hand. By varying the grades of cemented tungsten carbide, the peak stress magnitude on the cutter may be decreased and the stress distribution along the cutter body may be optimized so as to yield a cutter with an enhanced operating life. In addition, each secondary cutting surface may be formed from different grades of diamond to optimize the cutting efficiency of the cutter.

Since the grooves formed on the wafers can have a full depth at their onset, the cutting surfaces formed within such grooves will have a full thickness throughout their length. Consequently, as the substrate around a secondary cutting surface wears, a cutting surface of significant thickness will always be exposed reducing the risk of cutter cracking or breakage.

A preferred embodiment of this invention, therefore, provides a modular approach to cutter design. The approach allows for the formation of a cutter with various shapes of secondary cutting surfaces, with secondary cutting surfaces of different diamond grades, and with substrates of multiple grades of cemented tungsten carbide, allowing for the optimization of the stress distribution within the cutter and for the vectoring of

cutting forces applied by the cutter which result in enhanced cutter performance and life.

In the preferred embodiment, the wafers are stacked together, the grooves are compacted with the appropriate grade of diamond, and diamond is spread on the top end of the uppermost wafer, forming an assembly. The assembly is then pressed together under high temperature, high, pressure, bonding the wafers together and forming a cutter body and sintering the diamond to form a PDC layer in the cutter body top end and secondary PDC cutting surfaces on the grooves. After pressing, the carbide may be ground away, exposing additional portions of the secondary cutting surfaces to allow for enhanced cutting.

In alternate embodiment, the wafers are diffusion bonded together to form the cutter body such as by HIPing. In yet a further embodiment the wafers are brazed together using conventional methods. As it would be apparent to one skilled in the art, the wafers may be bonded with any of the aforementioned methods prior or after the compacting and sintering of the diamond material in the grooves. Similarly, the primary PDC cutting layer may be sintered prior or after the bonding of the wafers.

In another embodiment, the wafers used may be in a green state prior to bonding with the other wafers or prior to the sintering of the PDC material. In such a case, the wafers themselves are sintered during the bonding process or during the sintering of the PDC process.

Having now described the invention as required by the patent statutes, those skilled in the art will recognize modifications and substitutions to the elements of the embodiment disclosed herein. For example, a secondary cutting surface may be employed on a cylindrical compact brazed to a cutter stud as used in some types of rock bits. Such modifications and substitutions are within the scope of the present invention as defined in the following claims.



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WHAT IS CLAIMED IS:

1. A PDC cutter comprising:
a cylindrical body of cemented tungsten carbide;
a polycrystalline diamond composite layer on one end face of the cylindrical body;
a groove in the body spaced apart from the polycrystalline diamond composite layer; and
polycrystalline diamond in the groove.
2. A PDC cutter as recited in claim 1 wherein the groove and polycrystalline diamond are in a circumferentially extending band parallel to the layer.
3. A PDC cutter as recited in claim 2 wherein the band extends around only a portion of the circumference of the body.
4. A PDC cutter as recited in claim 2 further comprising a plurality of fingers of polycrystalline diamond extending between the layer and the polycrystalline diamond in the groove.
5. A PDC cutter as recited in claim 2 wherein the groove and polycrystalline diamond in the groove have a shape on the cylindrical surface of the body selected from the group consisting of a ring extending circumferentially around the body, a band extending circumferentially part way around the body, finger-like shapes extending longitudinally on the body, a plurality of dots, a cross, a triangle, and a rectangle and combinations thereof.
6. A cylindrical PDC cutter having a cutting face and an outer surface and comprising a PDC layer forming a primary cutting surface and a secondary non-abutting PDC cutting surface.



7. A PDC cutter as recited in claim 6 wherein the secondary cutting surface comprises a ring-shaped PDC strip on the outer surface of the PDC cutter parallel to the primary cutting surface.

8. A PDC cutter as recited in claim 6 wherein the PDC strip spans only a portion of the PDC cutter circumference.

9. A PDC cutter as recited in claim 2 further comprising a plurality of polycrystalline finger-like PDC strips sintered perpendicularly between the primary and secondary cutting surfaces forming additional cutting surfaces.

10. A PDC cutter as recited in claim 6 wherein the secondary cutting surface comprises a circular PDC surface formed on the PDC cutter outer surface.

11. A PDC cutter as recited in claim 10 comprising a plurality of circular PDC cutting surfaces on the PDC cutter outer surface.

12. A PDC cutter as recited in claim 6 wherein the secondary cutting surface comprises a triangular PDC surface formed on the PDC cutter outer surface.

13. A PDC cutter as recited in claim 6 wherein the secondary cutting surface comprises a rectangular PDC surface formed on the PDC cutter outer surface.

14. A PDC cutter as recited in claim 6 wherein a secondary cutting surface comprises a cross-shaped PDC surface formed on the PDC cutter outer surface.



15. A PDC cutter recited in claim 6 comprising a plurality of finger-like PDC secondary cutting surfaces arranged longitudinally on the outer surface of the PDC cutter.

16. A PDC cutter as recited in claim 6 wherein the secondary cutting surfaces are parallel to each other and perpendicular to the primary cutting surface.

17. A PDC cutter having a cylindrical cutter body comprising a plurality of PDC cutting surfaces formed on the cutter body, wherein at least two of the cutting surfaces are non-abutting.

18. A drag bit comprising a plurality of cylindrical cemented tungsten carbide PDC cutters having two end faces, wherein the PDC cutters are inserted on the bit outer body so that a portion of each PDC cutter including an end face is exposed, wherein each PDC cutter comprises a primary PDC cutting surface on the exposed end face and a secondary PDC cutting surface formed on a groove on the exposed portion of the cutter body, wherein the secondary cutting surface is spaced apart from the primary cutting surface.

19. A drag bit as recited in claim 18 wherein the secondary cutting surface of each PDC cutter can have a shape selected from the group consisting of a ring extending circumferentially around the body, a band extending circumferentially part way around the body, finger-like shapes extending longitudinally on the body, a plurality of dots, a cross, a triangle, and rectangle and combinations thereof.



20. A PDC cutter comprising:
a cylindrical body comprising at least two grades of cemented tungsten carbide and an end face;
a polycrystalline diamond layer on the end face of the cylindrical body;
a groove in the body; and
polycrystalline diamond in the groove.

21. A cutter as recited in claim 20 wherein the groove has a shape selected from the group consisting of and inverted "V"s, squares, curves and skewed arcs.

22. A cutter as recited in claim 20 wherein a first grade of cemented carbide is located nearest the polycrystalline diamond layer and wherein the first grade of cemented carbide is stiffer than a second grade of cemented carbide remote from the polycrystalline diamond layer.

23. A cutter as recited in claim 22 wherein the second grade of cemented carbide is tougher than the first grade of cemented carbide.

24. A cutter as recited in claim 22 wherein the first grade of cemented carbide has a particle size of 3 microns and a cobalt content of approximately 13%

25. A cutter as recited in claim 22 wherein the second grade of cemented carbide has a particle size of 5 microns and a cobalt content of approximately 14%.

26. A cutter as recited in claim 20 comprising a plurality of grooves packed with polycrystalline diamond, wherein the grade of diamond in a first groove is different from the grade of diamond in a second groove.



27. A PDC cutter comprising:
- a cylindrical body comprising at least two coaxial cylindrical wafers of cemented tungsten carbide bonded together;
 - a polycrystalline diamond composite layer on an end face of a first wafer of cemented tungsten carbide;
 - a groove in a cemented tungsten carbide wafer surface; and
 - polycrystalline diamond in the groove.
28. A cutter as recited in claim 27 wherein the groove spans the length of the wafer.
29. A cutter as recited in claim 27 wherein the first wafer is stiffer than a second wafer.
30. A cutter as recited in claim 27 wherein a second wafer is tougher than the first wafer.
31. A cutter as recited in claim 27 wherein the first wafer of cemented carbide has a particle size of 3 microns and a cobalt content of approximately 13%
32. A cutter as recited in claim 27 wherein a second wafer of cemented carbide has a particle size of 5 microns and a cobalt content of approximately 14%.
33. A cutter as recited in claim 27 comprising a plurality of grooves packed with polycrystalline diamond, wherein the grade of diamond in a first groove is different from the grade of diamond in a second groove.
34. A cutter as recited in claim 27 wherein the groove has a shape selected from the group consisting of inverted "V"s, squares, curves and skewed arcs.



35. A method for forming a PDC cutter comprising the steps of:

forming a plurality of cemented tungsten carbide wafers having a pair of opposite end faces and a body therebetween, each wafer having a length;

forming a groove in a circumferential surface of a wafer;

bonding the wafers to each other at their end faces forming a cutter body wherein one of the wafer end faces forms the cutter body primary cutting end face; and

bonding polycrystalline diamond in the groove for forming a secondary cutting surface.

36. A method as recited in claim 35 wherein the step of bonding polycrystalline diamond in the groove comprises the steps of:

compacting diamond particles in the groove; and

pressing the wafer with diamond particles in a high temperature high pressure press for forming a polycrystalline diamond cutting surface.

37. A method as recited in claim 35 further comprising the step of bonding a layer of polycrystalline diamond on the body primary cutting end face for forming a primary cutting surface.

38. A method as recited in claim 37 wherein the step of bonding a layer comprises the step of bonding a layer of polycrystalline diamond on end face of a wafer prior to the step of bonding the wafers.



39. A method as recited in claim 35 wherein the steps of bonding the polycrystalline diamond and bonding the wafer comprise the steps of:

compacting diamond particles in the groove; and
pressing the wafers and the compacted diamond in the groove in a high temperature, high pressure press for forming a cutter body with a polycrystalline diamond cutting surface in the groove.

40. A method as recited in claim 39 wherein the pressing step further comprises the step of simultaneously pressing a layer of diamond material applied to the wafer end forming the body primary cutting end face for forming a primary diamond cutting surface on the PDC cutter body.

41. A method as recited in claim 35 wherein the step of forming a groove comprises the step of forming a groove that spans the length of the wafer.

42. A method as recite in claim 35 wherein the step of forming a groove further comprises the step of forming another groove on a wafer and wherein the bonding step comprises the step of bonding a first grade of diamond in one groove and bonding a second grade of diamond in the other groove.

43. A method as recited in claim 35 wherein the step of forming a groove comprises the step of a forming a groove on at least two wafers.

44. A method as recited in claim 43 wherein the bonding the wafers step further comprises the step of helically orienting the grooves relative to each other prior to bonding.



45. A method as recited in claim 35 further comprising the step of grinding a portion of the cemented tungsten carbide around the secondary cutting surface to expose an additional portion of the secondary cutting surface.