United States Patent [19]

Ernsberger et al.

[11] **3,865,293**

[45] **Feb. 11, 1975**

[54] **SUBSURFACE CRACKS**

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[73] Assignee: **PPG Industries, Inc.**, Pittsburgh, Pa.

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[21] Appl. No.: **242,511**

[52] **U.S. Cl.** **225/2**, 161/149

[51] **Int. Cl.** **B26f 3/00**

[58] **Field of Search** 225/2, 103, 96.5, 93.5; 30/164.95; 161/149

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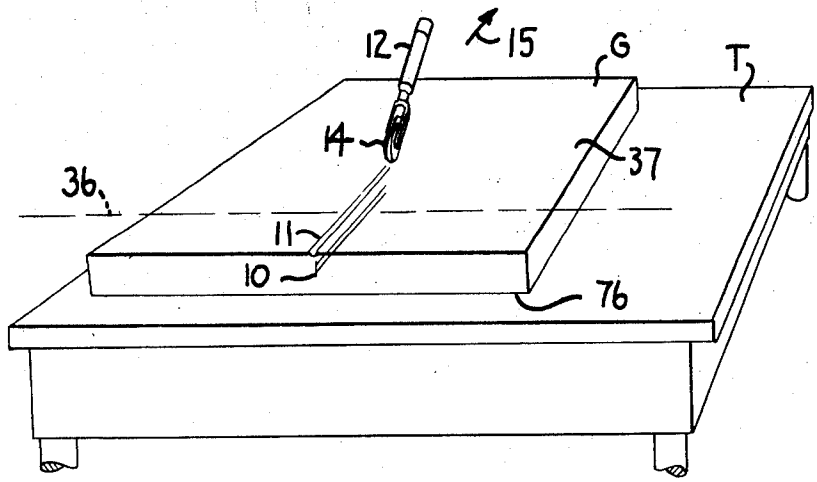
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Assistant Examiner—Leon Gilden
Attorney, Agent, or Firm—Thomas F. Shanahan

[57] **ABSTRACT**

Pieces of flat glass are cut to desired size without the necessity of grinding to size and polishing. Edges of the piece are cut in accordance with a procedure involving the use of a large-diameter scoring wheel at a greater-than-usual applied pressure, to produce a subsurface crack that is substantially free of serrations, followed by the application of a bending moment about the crack to propagate a fracture in the piece of glass. Light seaming of the top and bottom portions of the edges completes the preparation of these edges.

21 Claims, 13 Drawing Figures



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SHEET 1 OF 2

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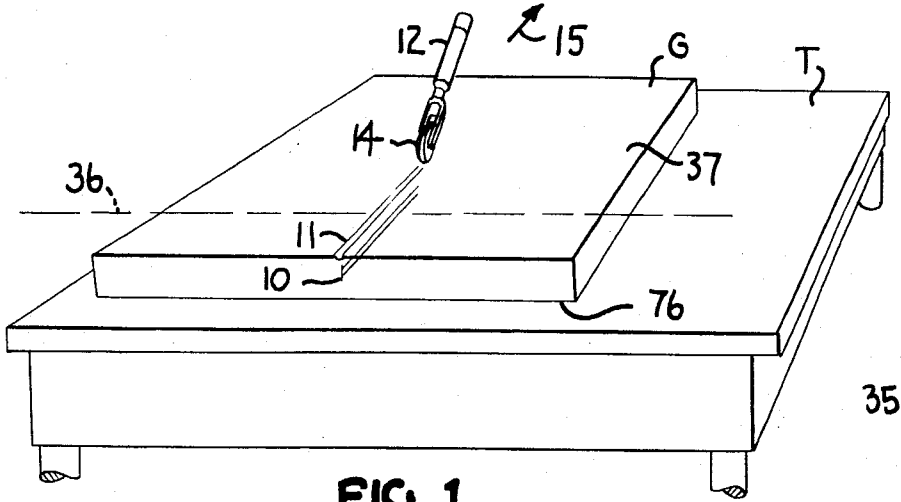


FIG. 1

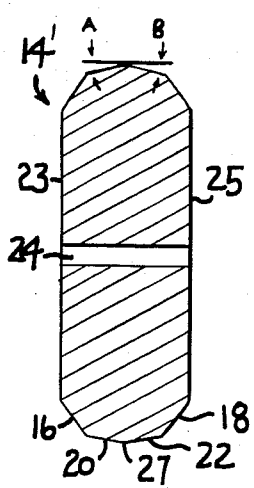


FIG. 2

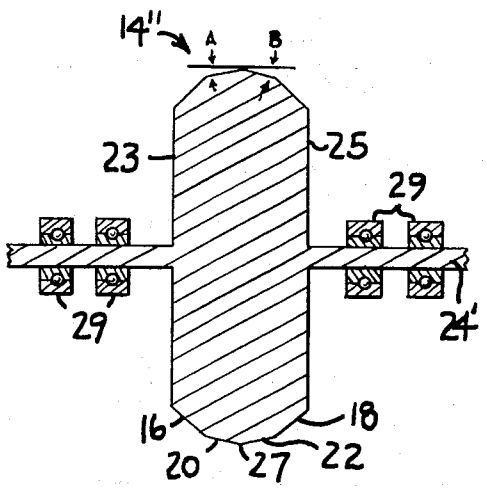


FIG. 2A

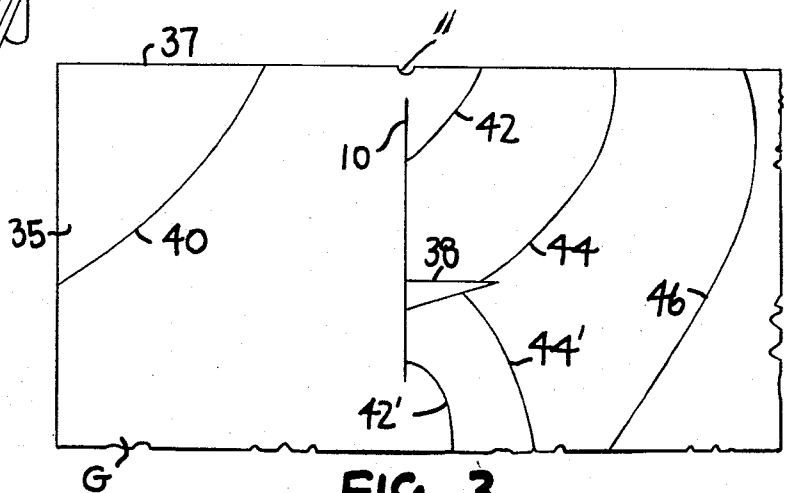


FIG. 3

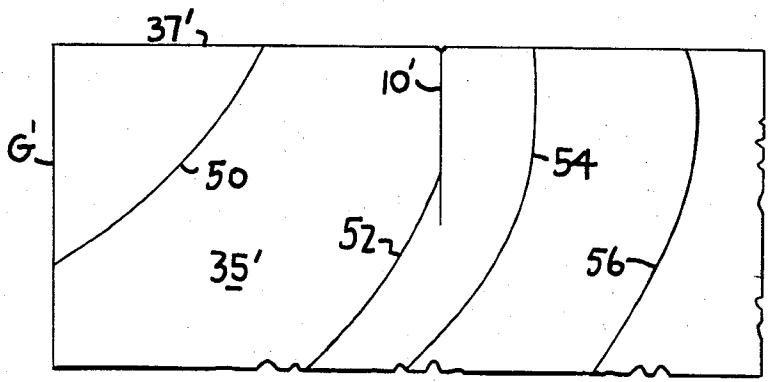


FIG. 4

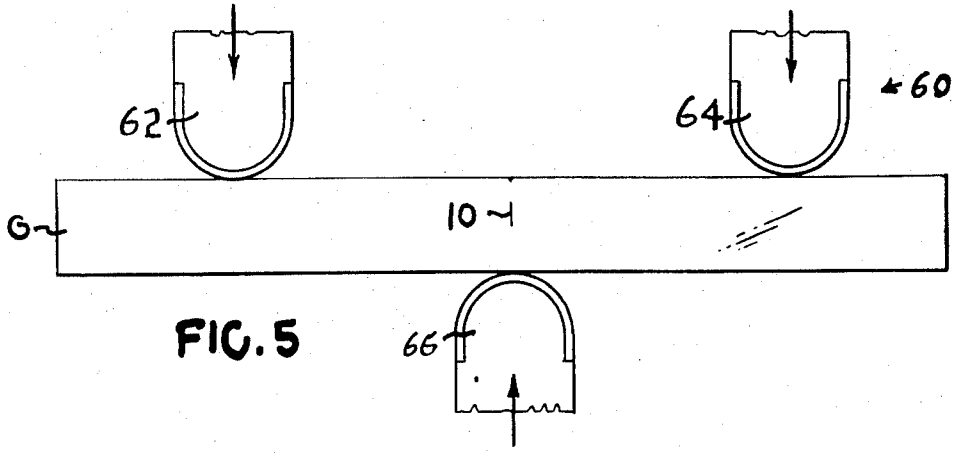


FIG. 5

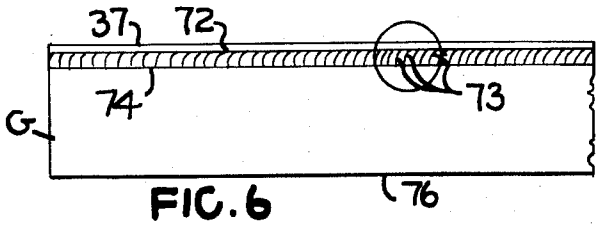


FIG. 6

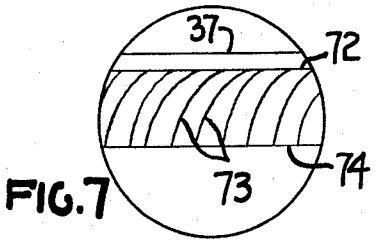


FIG. 7

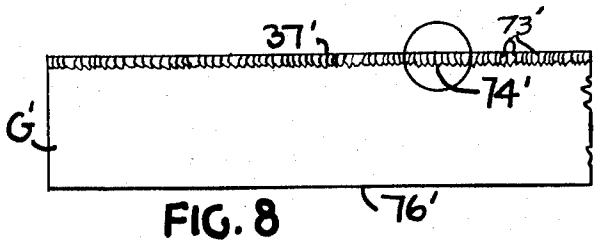


FIG. 8

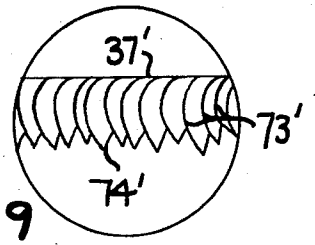


FIG. 9

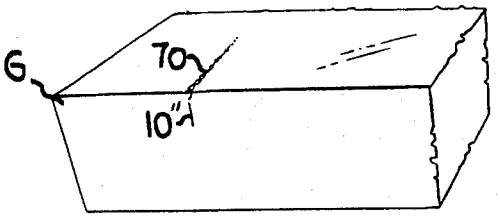


FIG. 10

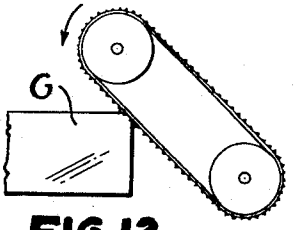


FIG. 12

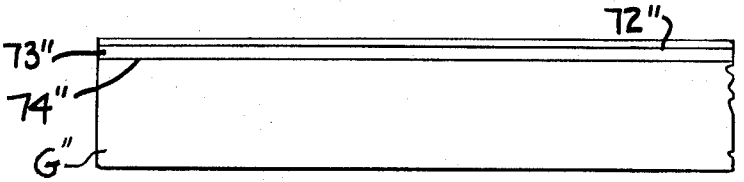


FIG. 11

SUBSURFACE CRACKS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to glass articles and to a method and an apparatus for producing said glass articles, and in particular, for the manufacture of architectural panels, furniture tops and other relatively thick glass articles, for example, in excess of 10 millimeters (especially in the range of 18 to 36 millimeters or above), having dimensions such as 4 meters by 8 meters.

2. Description of the Prior Art

In the manufacture of architectural-glass panels and furniture tops of the kind indicated above, it has hitherto been common to obtain panels of a desired size by hand scoring and mechanical snapping of the edges of the glass to yield a piece somewhat greater in its dimensions than the final size desired, followed by finishing operations, such as the grinding of the cut edges of the piece to the desired size and the polishing of the ground edges. The grinding and polishing are time-consuming and costly operations, but they have hitherto been considered necessary, particularly in cutting glass sheets of substantial thickness.

It is important architectural panels exhibit adequate edge strength. When tested in accordance with the conventional beam-loading test, the ground-and-polished edges of a 4-meter by 8-meter sheet, approximately 18 millimeters thick, produced by a process including the steps of normal scoring, snapping, grinding and polishing, exhibit strength values such as about 4.6 to 4.9 kilograms per square centimeter. Panels exhibiting values substantially lower than about 4 kilograms per square centimeter are noticeably more susceptible to breakage.

U.S. application Ser. No. 57,574, filed July 23, 1970, and U.S. application Ser. No. 68,735, filed Sept. 1, 1970, both by Robert P. DeTorre, disclose a trimming procedure that involves the application of a surface deep score under relatively high pressure by a large-diameter, blunt scoring wheel, followed by the propagation of the score into a fracture and a light seaming operation on the top and bottom portions of the edges of the glass so cut.

SUMMARY OF THE INVENTION

According to the present invention, a glass article is produced having a top surface, a bottom surface and a cut edge extending therebetween in a direction substantially perpendicular to the top surface and the bottom surface. The cut edge contains two markings, each of which is substantially parallel to the top and bottom surfaces. The area between the markings is substantially free of serrations. The markings are adjacent to one of the surfaces and are indicative of the extent of a subsurface crack that was placed in the glass article to cut the article along the edge. Light seaming removes sharp corners between the edge and each of the major surfaces and it also removes the markings.

As used in this application, the terms "subsurface crack" or "subsurface score" refer to a discontinuity such as a crack or score, respectively, that is within the thickness of the piece of glass and does not extend to a major surface of the piece. The term "subsurface crack" refers to a discontinuity in the piece of glass without substantial serrations. The term "subsurface score" refers to a discontinuity in the piece of glass with serrations. The term "subsurface discontinuity" includes "subsurface cracks" and "subsurface scores."

In accordance with the present invention, a glass article is produced by a process and an apparatus which avoids the use of grinding to size and edge polishing. The process includes the imposition of a subsurface crack along an intended path of cut into the piece of glass and the projection of the crack deeper into the thickness of said piece by a separate, non-simultaneous step, such as the application of a bending moment about the crack. Prior to the creation of the crack, a surface defect is placed in the piece of glass on the intended path of cut at a location where the crack is to initiate. The apparatus for producing the subsurface crack consists of a large-diameter scoring wheel, such as, for example, at least approximately 12 millimeters, and preferably between approximately 19 and 100 millimeters, in diameter, having a blunt cutting angle, such as, for example, between approximately 155° and 170° at high forces, such as, for example, approximately 80 kilograms to approximately 460 kilograms, and even greater. This is at least two to three times the forces used in surface deep scoring. Relatively light seaming of the top and bottom portions of the cut edge yields cut edges that are substantially as strong as conventional ground-and-polished edges and edges produced by a surface deep-scoring process. In addition, less seaming is required in a cut edge that is produced using a subsurface crack than in an edge that is produced by a surface deep score, due to the absence of wing in subsurface cracks.

Accordingly, it is an object of the present invention to produce cut edges that are smooth, strong, straight, pristine and perpendicular to the major surfaces of the piece of glass.

It is a further object of the present invention to produce such edges while avoiding the use of grinding and polishing.

It is a further object of the present invention to provide a method and apparatus for cutting all glass, and in particular, glass in excess of approximately **10** millimeters in thickness by a relatively uncomplicated procedure that involves the application of a subsurface crack, followed by a bending moment about the crack and a small amount of seaming.

It is a further object of the present invention to produce a cut edge that is at least equal in quality to those produced by surface deep scoring, with a lesser amount of seaming.

It is a further object of the present invention to find a practical means for generating a continuous crack that will weaken a sheet of flat glass to the extent necessary so that it may be severed without incurring surface crushing or edge damage.

It is a further object of the present invention to produce a cut edge at relatively high speeds, such as approximately 2 meters per second.

DESCRIPTION OF THE DRAWINGS

A complete understanding of the following invention may be obtained from the foregoing and following description thereof, taken together with the appended drawings, which are not drawn to scale unless noted, and in which:

FIG. 1 is a diagrammatic view of a scoring apparatus applying a subsurface discontinuity to a piece of flat glass;

FIG. 2 is a vertical cross-sectional view of a cutting wheel used to produce subsurface scores;

FIG. 2A is a vertical cross-sectional view of a cutting wheel used to produce subsurface cracks according to the present invention;

FIG. 3 is an enlarged end view of the subsurface discontinuity;

FIG. 4 is an enlarged end view of a surface deep score;

FIG. 5 is an elevation view of a snapping apparatus in position to apply a bending moment about the subsurface discontinuity;

FIG. 6 is an elevation view of an edge of a piece of glass cut in accordance with a procedure that utilizes a wheel with a relatively large amount of friction between the wheel and its holder;

FIG. 7 is an enlarged view of the encircled area in FIG. 6;

FIG. 8 is an elevation view of an edge of a piece of glass cut in accordance with surface deep-scoring techniques;

FIG. 9 is an enlarged view of the encircled area of FIG. 8;

FIG. 10 is a diagrammatic view of a piece of glass with a subsurface score made by a cutting wheel with a relatively large amount of friction between the wheel and its holder;

FIG. 11 is an elevation view of an edge of a piece of glass cut in accordance with the present invention, using a wheel with a relatively small amount of friction between the wheel and its holder; and

FIG. 12 is a schematic view of an edge or corner portion of a piece of glass being seamed.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, an apparatus 12 is shown applying a subsurface discontinuity 10, such as a subsurface crack or score, to a central portion of a piece of glass G along an intended path of cut and in a direction 15 that is substantially parallel to top surface 37 and bottom surface 76, while the glass is supported on a table T. At least a substantial portion of discontinuity 10 is spaced from top surface 37 and bottom surface 76 along the length of discontinuity 10. Apparatus 12, including a scoring or cutting wheel 14, is shown moving from one end of glass G to the other end in the direction of arrow 15 to apply the subsurface discontinuity 10. Wheel 14 may have a central axle hole 24, such as high friction wheel 14' in FIG. 2, or, in accordance with the present invention, it may have an integral shaft 24', such as low friction wheel 14'' in FIG. 2A.

One skilled in the art will appreciate that there are many commercially available devices for housing scoring wheel 14. It is well known, for example, to supply the necessary scoring pressure to a cutting wheel by means of a fluid pressure such as air or hydraulic fluid. Further, U.S. application Ser. No. 128,384, filed on Mar. 26, 1971, by David A. Bier, suggests that a cutting wheel may be actuated by a constant-reluctance motor means. Any suitable means may be used to supply the load to wheel 14.

A permanent indentation 11 is created in top surface 37 by the wheel 14 directly above discontinuity 10. Indentation 11 may be approximately 0.001 millimeter deep and approximately 0.015 millimeter wide. There are two theories relating to the creation of indentation 11. The first theory is that there is plastic flow of the glass from one area to another without any change in total volume of the glass. The second theory is that the glass is compressed or densified with the total volume of the glass being reduced. Theoretically, if the glass is densified (second theory), the index of refraction of the glass will be altered, but if the glass flows plastically (first theory), the index of refraction will not be altered. Experimental results indicate that the index of refraction, immediately beneath indentation 11, is approximately 5 percent higher than that of normal glass. This tends to favor the theory that densification occurs beneath the indentation 11, but it does not eliminate the possibility that there is a small amount of plastic flow in combination with densification. However, plastic flow requires deformation in shear, which necessarily involves the breaking of interatomic bonds, and those skilled in the art will recognize that this phenomenon cannot occur in a covalent material, such as glass, unless the material is strained at a temperature from one-half to two-thirds of its melting point. In the present case, there is no reason to suspect that the glass is heated to such a degree. In addition, where densification occurs in the glass, tensile stresses are created to assist in severing the glass.

Referring to FIG. 2, there is shown a detailed view of a high friction cutting or scoring wheel 14' that may be used to produce a subsurface score. Wheel 14' is made of tungsten carbide or other suitable material of hardness of about 7 or more on Mohs' scale and having a radius in excess of approximately 6 millimeters, and preferably within approximately 9 to approximately 50 millimeters. The base angle, i.e., the angle between the two sides 16 and 18, if extended, is about 120°, and the angle between the sides 20 and 22 (hereafter referred to as the cutting angle) is between approximately 155° and approximately 170°, with approximately 165° providing best subsurface scores. With cutting angles less than approximately 150°, defects such as spall and wing may occur. The term "spall" may be defined as a chip or flake out of the edge of the piece of glass. The term "wing" may be defined as a lateral crack on either side of a score line, projected outward under the glass surface by the action of a scoring tool. With cutting angles between approximately 150° and approximately 155°, surface deep scores are generally produced. If the cutting angle is greater than approximately 170°, it is extremely difficult to produce any discontinuity beneath the apex 27 of the wheel 14'. If pressure is applied to a wheel 14' having a cutting angle greater than approximately 170°, until the glass fails, the failure will generally occur adjacent to the point where side 16 meets surface 20, or side 18 meets surface 22. This is probably due to the fact that cutting angles in excess of approximately 170° merely place the glass in compression along the entire width of surfaces 20 and 22.

The wheel 14' is shown with a central axle hole 24 which functions as a means for rotatably mounting said wheel on a shaft that is passed through the axle hole 24. Hole 24 may be, for example, 2.4 millimeters in diameter. With such a setup, there may be a relatively large amount of friction between the cutting wheel and its holder, and for this reason, this type of wheel is referred to herein as a "high friction wheel."

Referring to FIG. 2A, there is shown a low friction wheel 14'' for producing subsurface cracks in accordance with the present invention. Wheel 14'' is identical to wheel 14' except that wheel 14'' has an integral shaft 24' instead of a hole 24. The shaft 24' may be mounted in bearings, such as ball bearings 29, to minimize, or even eliminate, friction between the wheel and its holder. For this reason, this type of wheel is referred to herein as a "low friction wheel." As discussed hereinbelow, a low friction wheel has more of a tendency to roll than does a high friction wheel. This reduces the tensile stresses immediately behind the wheel to minimize, or even eliminate, unwanted circular fractures.

Wheel 14'' may be, for example, 19 millimeters in diameter and urged into contact with a piece of glass G that is approximately 19 millimeters thick at a force of approximately 175 kilograms, to produce a subsurface crack that starts approximately 0.01 millimeter from the top surface 37 of glass G and extends for approximately 2 to 2.5 millimeters into the thickness of glass G. Cracks so produced correspond to the intended location of the edge of the finished piece. To guide apparatus 12, a straight-edge member may be secured to the glass G as is conventional in prior-art scoring.

Although a preferred embodiment of the present invention incorporates a cutting wheel or disc, other means will become apparent to carry out the present invention. For example, one may wish to construct a member that comprises a continuous chain forming a curved cutting edge rather than a wheel. It would still be necessary to maintain both the blunt cutting angles and the high pressures described herein. It is also necessary to maintain the effective radius of the continuous chain within the above-mentioned range. For example, continuous chain could take the path of an oval, but the radius of the oval at the point of contact with the chain and the glass (effective radius) should be within the same range as the radius (or effective radius) of a cutting wheel.

It is important to note the importance of orienting wheel 14 such that it is substantially perpendicular to the surface of the glass to be cut. A subsurface discontinuity generally extends in the same direction as the cutting wheel. Therefore, if the cutting wheel is not perpendicular to the glass surface, the resultant subsurface discontinuity will not be perpendicular. Referring to FIGS. 2 and 2A, angles A and B indicate the angles between the cutting wheel and the glass surface. With a cutting wheel having a cutting angle of 165°, it is preferred that angle A and angle B be maintained at 7.5°.

Referring to FIG. 3, there is shown a partial view, greatly magnified, of a surface 35 that is formed when the piece of glass G has been severed along dashed line 36 in FIG. 1 by running a cut. It should be understood that in a normal cutting operation, the glass is not severed along line 36. This is only done to illustrate a means for detecting a subsurface discontinuity. Subsurface discontinuity 10 is located directly beneath the path of wheel 14, starting, for example, at approximately 0.01 millimeter below the top major surface 37 of glass G and extending in a direction that is substantially perpendicular to surface 37 for approximately 2.5 millimeters. Mark 38 is peculiar to the inner section of a severed surface 35 with a subsurface discontinuity. It should be understood that mark 38 is not a crack, but merely a slight ridge, caused by a fracture propagation from two different locations. The term "Wallner lines" is used in the art to describe lines on a severed surface that indicate the direction of fracture propagation as a cut in run. Wallner lines 40, 42, 42', 44, 44' and 46 indicate that discontinuity 10 does not extend entirely to the top major surface 37 of the piece of glass G, as described more fully hereinbelow.

FIG. 4 is a view similar to FIG. 3, showing how a severed surface 35' would look if a surface score 10' were placed in a piece of glass G', and the piece were then severed by running a cut along a plane that is perpendicular to score 10'. Wallner lines similar to those shown at 50, 52, 54 and 56 will extend across surface 35'. There is no mark (such as mark 38 in FIG. 3), and this indicates that the severed surface includes a surface score. Note that Wallner lines 50, 52, 54 and 56 bow toward the bottom right of glass G' and the top portion of each Wallner line is farther to the right than the bottom portion. This indicates that a fracture was run from left to right and from top to bottom by a bending moment about the top major surface 37' of the glass G' to place it in tension.

It is apparent that the Wallner line pattern in FIG. 4 is significantly different from the Wallner line pattern in FIG. 3. In FIG. 4, the fracture propagation starts at 50 and moves from left to right. The pattern is similar in FIG. 3 at the start of fracture propagation, as evidenced by Wallner line 40. When the propagation in FIG. 3 reaches subsurface discontinuity 10, the original single Wallner line splits into two independent lines 42 and 42'. This is because some of the propagation occurs between the top major surface 37 of the piece of glass G and the uppermost portion of subsurface discontinuity 10, and some of the propagation occurs between the bottommost portion of subsurface discontinuity 10 and the bottom major surface (not shown in FIG. 3) of the piece of glass G, as illustrated by Wallner lines 42 and 42', respectively. After both fronts have traveled around the subsurface discontinuity, they approach each other, as at 44 and 44', meet at mark 38, and merge to form a single front, as indicated by Wallner line 46. Wallner line 44 is in a plane that is slightly offset from a plane in which Wallner line 44' is located. As a result, where Wallner line 44 meets Wallner line 44', there is a slight protrusion which has been shown as mark 38. By the time the fronts have progressed to Wallner line 46, they have merged into a single front in a common plane. In contrast, the Wallner lines in FIG. 4 do not split at score 10', because score 10' contacts the surface 37' of the glass.

Experience indicates that mark 38 is always present in a subsurface discontinuity, such as a score or crack, pointing in the direction of fracture propagation. This provides a means for establishing whether or not a discontinuity is a subsurface discontinuity or a surface discontinuity. It also provides a method for establishing the direction of fracture propagation where one is severing in a plane that intersects a subsurface discontinuity.

Referring to FIG. 5, there is shown an elevation view of a snapping apparatus 60 in position to apply a bending moment about subsurface discontinuity 10. The apparatus may consist of two top anvils 62 and 64, and a bottom anvil 66. Glass G may be placed upon a table so that a portion of the subsurface discontinuity 10 overlaps the table. A bending moment may be applied at the end of the piece of glass G that overlaps the table

to run a cut along the subsurface discontinuity **10.** It is sometimes difficult, especially with pieces of glass that are relatively long and thick (such as 19-millimeter thick glass in excess of 3 meters in length), to run a cut in a manner described. Under such circumstances, a narrow member or plate, approximately 12 millimeters in width, may be placed between the glass and the table, directly beneath the subsurface discontinuity **10.** This places the top surface of the piece of glass in tension along the discontinuity and reduces the energy necessary to run a cut along the entire length of the piece. Cut edges are produced that are smooth, strong, straight, pristine and perpendicular to the major surfaces of the piece.

After the glass has been snapped, there may be conducted an inspection to determine the quality of the cut that has been opened. In the inspection along the cut edge, looking perpendicularly to the cut edge, it is customary to see a pattern such as that indicated in FIG. **6,** when a high friction wheel **14'** has been used. The top surface of the glass is there designated with the numeral **37** and the bottom designated with the numeral **76.** A short distance below top surface **37** is seen a marking **72** and a marking **74** which indicate the extent of the subsurface score caused by the cutting wheel **14'.** The marking **72** is generally approximately 0.01 millimeter from the top surface of the glass (this has been exaggerated in FIGS. **6** and **7**), and the marking **74** may be approximately 0.5 to 4 millimeters from the marking **72,** or even more. FIG. **7** is a magnified view of the encircled portion of the cut edge shown in FIG. **6,** further illustrating markings **72** and **74** and showing the serrations **73** therebetween. Note that each serration **73** approximates a quarter of a circle and markings **72** and **74** each approximate a straight line that is parallel to top surface **37** and bottom surface **76.**

Referring to FIG. **8,** there is shown a cut edge of the piece of glass G' that was severed with a surface deep score. The piece of glass G' has a top surface **37'** and a bottom surface **76'.** A surface deep score **10'** extends from top surface **37'** to marking **74'.** FIG. **9** is a magnified view of the encircled portion of the cut edge in FIG. **8,** further illustrating marking **74'** and showing serrations **73'.** Each serration **73'** approximates a semicircle. Note that marking **74** is a substantially straight line while marking **74'** is jagged. This is significant since it is often necessary to do additional seaming to remove some of the longer points from marking **74'.** Additionally, with surface deep scoring, the serrations protrude from the glass by approximately 0.25 to 0.5 millimeter, while the serrations in subsurface scores are only about one-half of that amount, or approximately 0.125 to 0.25 millimeter. Finally, as described more fully hereinbelow, long wings develop in surface deep scoring when extremely large-diameter wheels are used, but they do not develop in subsurface scoring. For these reasons, subsurface deep scores require substantially less seaming than do surface deep scores.

It should be emphasized that with wheel **14'** there is a relatively large frictional force between the wheel and its holder. Using a wheel with an integral shaft **24'** and ball bearings **29,** such as wheel **14''** in FIG. **2A,** eliminates most of the frictional force between the wheel and its holder. This produces a subsurface crack that is of even higher quality than a subsurface score, since serrations are substantially eliminated.

Referring to FIG. **10,** there is shown a view of a subsurface score **10''** made with a high friction wheel **14'** in a piece of glass G. Indentation **11** has been omitted, and score **10''** and defects **70** have been exaggerated for the sake of clarity. These defects are caused by the high friction between the wheel **14'** and its holder. With the higher friction, there is a tendency for the wheel to slide rather than roll. This increases the compressive stresses immediately in front of the wheel and the tensile stresses immediately after the wheel. The increased tensile stress causes small circular fractures, such as defects **70,** to be formed. With a wheel, such as wheel **14''**, having a low frictional force between itself and its holder, the tendency for the wheel to slide is minimized. This reduces the tensile stress behind the wheel and defects **70** do not appear. If the speed of advance of the low friction wheel is increased, for example, to at least approximately 1 meter per second for wheels having a diameter of 12.7 millimeters, or 2 meters per second for wheels having a diameter of 100 millimeters, or if forces in excess of those listed in Table B are used, it is likely that a surface score will result from the low friction wheel.

Referring to FIG. **11,** there is shown a cut edge of a piece of glass G'' that was severed with a subsurface crack, using a low friction wheel, such as wheel **14''.** It should be noted that a surface defect, such as a hand nick, should be placed in the glass along the intended path of cut before the subsurface crack is initiated. This functions as a starting point for the subsurface crack.

The edge illustrated in FIG. **11** is similar to the one shown in FIG. **6,** the only difference being that area **73''** is smooth, with little or no serrations between marking **72''** and marking **74''** in FIG. **11.** This is because it is the circular defects **70** appear to cause the serrations, and when circular defects **70** are eliminated, the serrations are also eliminated.

The low friction wheel **14''** would appear to be more desirable than the high friction wheel **14',** since the low friction wheel produces a cut edge with no serrations at a speed approximately four times that of a high friction wheel. However, it should be noted that all subsurface scores and cracks must be initiated at a surface of the glass. With a subsurface score made with high friction wheel **14',** defects **70** function as the starting point for the score. When there are no defects **70,** such as with a subsurface crack, it is necessary to place a surface defect in the glass to initiate the subsurface crack. Since the defects **70** with a high friction wheel may be kept small (and easily removed with light seaming), this type of wheel is preferred unless high scoring speeds are necessary, such as in the "on-line" scoring of a continuous ribbon of glass.

The fact that serrations **73'** protrude from the edge of the piece of glass in FIG. **8** about twice the amount of serrations **73** in FIG. **6** makes the edge shown in FIG. **6** more desirable than the edge shown in FIG. **8.** Further, the lack of serrations **73''** makes the edge in FIG. **11** even more desirable. The fact that cut edges shown in FIGS. **6** and **11** were made with subsurface discontinuities is significant in itself, since cutting oil and healing are eliminated with subsurface discontinuities. But if one obtains a discontinuity having the physical characteristics of the score shown in FIG. **6** or of the crack shown in FIG. **11,** except that the discontinuity intersects the surface of the piece, it is still preferable to the score shown in FIG. **8.** It is important that a score or

crack be of suitable quality such that a fracture may be propagated with little or no edge damage to the piece of glass so that seaming may be minimized. The edges shown in FIGS. **6, 8** and **11** are all of such quality, but serrations **73** require even less seaming than serrations **73'**, and area **73''** requires even less seaming than serrations **73.**

With control of various parameters, such as wheel diameter, cutting angle, force applied to the wheel, etc., it is possible to produce a crack or a score that is beneath the major surfaces of the glass. It should be kept in mind, however, that there may be situations where a crack or a score contacts a major surface of the piece of glass, but retains the physical characteristics of a subsurface crack or score, respectively.

U.S. application Ser. No. 68,305, filed on Aug. 31, 1970, by David A. Bier et al. discloses that in the cutting of blanks, such as windshields, it is advantageous to increase the depth of a score at the corners of the blank. In such a case, subsurface cracks may be used to outline the entire blank except for the corners where a parameter such as speed may be changed to yield a surface score, which weakens the glass to a greater extent, at the corners.

The inspection further comprises viewing the glass vertically, i.e., in a direction perpendicular to the major surfaces of the sheet of glass, to detect wing or undercut defects. A satisfactory cut exhibits no such defects, or, at the worst, ones so minor as to be removed during a subsequent seaming operation.

As used in this application, the term "subsurface score" refers to the area between marking **72** and marking **74** in FIGS. **6** and **7.** The term "subsurface" refers to the area between marking **72''** and marking **74''** in FIG. **11.** The term "fracture" refers to the area marking **74** and the bottom surface **76** in FIG. **6,** or a similar area in FIG. **11.**

As a final step in the process of the present invention, there is conducted a finishing, such as light seaming, of only the upper and bottom portions of the edges of the piece of glass so cut. This leaves a smooth edge with no evidence of markings **72''** and **74''**. There may be used, for example, in FIG. **12** a hand held belt sander using a belt 75 millimeters wide by 600 millimeters long. This is a conventional operation, and it does not require further elaboration or explanation.

The result is that there is produced a finished piece of glass that compares favorably in its edge strength to similar pieces produced by the prior-art method of rough cutting, mechanical snapping, grinding to size, and then polishing. The pieces of the present invention have edge strengths of about 4.4 to about 4.7 kilograms per square centimeter in the conventional beam-loading test, in comparison with strengths such as 4.6 to 4.9 kilograms per square centimeter for the prior-art ground-and-polished pieces. Either will meet specifications on customary glazing installations. In achieving the edge-strength values indicated above, the final limited seaming operation is important. Without the final seaming operation, the edge strength is on the order of 3.8 to 4.0 kilograms per square centimeter.

As the glass becomes thicker, it becomes increasingly difficult to produce with a cutting wheel of a given diameter a subsurface discontinuity of the required depth without causing a development of wing. This means that with thicker glass, a larger cutting wheel should be used, and with thinner glass, the use of a somewhat smaller cutting wheel is permissible.

The present invention utilizes a subsurface crack in a process and an apparatus for cutting a glass article that is, in many circumstances, superior to any known in the prior art. First, in accordance with the present invention, serrations are substantially eliminated to minimize the amount of seaming necessary to finish the edge. Second, the presence of significant wing is eliminated. Third, the presence of glass chips that have heretofore plagued cutting processes is minimized and almost eliminated. This eliminates the necessity of removing these chips and the surface damage to the glass caused by the presence of the chips. Fourth, it has been common to use cutting oil to protect a score from atmospheric moisture. With the present invention, since the subsurface crack does not come in contact with the atmosphere, there is no need to protect it from atmospheric moisture and therefore no need to use cutting oil. This eliminates the problem of removing the cutting oil after the discontinuity has been applied. Fifth, a subsurface discontinuity does not heal when left standing, as does a surface score. When a score heals, the stress produced by the scoring action disappears and the cut is more difficult to open. The present invention allows one to place a subsurface crack in the glass and store it for a period of time before snapping it. Sixth, subsurface cracks may be produced in glass at relatively high speeds. Finally, due to the fact that there is no surface damage to the glass, the scoring wheel is subjected to less of an abrasive action and wheel life is increased.

As is the case with surface scores, the depth of a subsurface discontinuity is directly related to the pressure applied to the scoring wheel. As pressure is increased, the depth of the subsurface discontinuity also increases. However, for a wheel of any given diameter, there is a practical limit to the amount of pressure that can be applied. If too much pressure is applied to the cutting wheel, excessive wing appears. By "excessive" or "significant" wing, it is meant that a substantial amount of seaming (more than about 6 millimeters) is necessary to remove the wing. For example, with surface scores, a normal cutting wheel of about 6 millimeters in diameter with a cutting angle of 160° has a maximum score depth of about 1 millimeter in 12-millimeter glass at a force of about 18 kilograms. If the force is increased, a crude fracture and significant wing result without any increase in score depth. In order to increase the depth of the surface score, without producing significant edge defects, it has been necessary to increase the diameter of the wheel. As the diameter of the wheel is increased, it is possible to obtain a score of greater depth by increasing the force applied to the wheel. For example, a high friction cutting wheel having a diameter of 19 millimeters, with a cutting angle of 160°, will produce a surface score depth of about 2.3 millimeters with a force of about 80 kilograms, without significant surface defects, if the wheel is moved at more than about 20 centimeters per second. If the force alone is increased, the depth of the surface score will not increase, and surface defects and perhaps a crude fracture will result.

With a high friction cutting wheel having a diameter of 25 millimeters and a cutting angle of 160°, a 90-kilogram force will produce a maximum surface score depth of 2.5 millimeters with no significant surface defects if the wheel is moved at more than 20 centimeters

per second. With a high friction cutting wheel having a diameter of 32 millimeters and a cutting angle of 160°, a force of 105 kilograms will produce a maximum surface score depth of 3.1 millimeters without any significant surface defects if the wheel is moved at more than 20 centimeters per second. In each of these cases, increasing the applied force beyond the stated maximums creates surface defects that may be removed only with significant amounts of seaming, without any increase in score depth. Note that each example states that the wheel speed should be at least about 20 centimeters per second. At speeds less than this, subsurface scores are produced. This probably occurs because the abrasive forces on the glass are less at lower wheel speeds.

These results seem to indicate that the diameter of the cutting wheel and the force applied thereto should be increased indefinitely. It is to be noted, however, that with surface scoring, as the diameter of the wheel and the force applied thereto are increased, the length of the wings also increases. This increases the amount of seaming necessary to finish the edge. Ordinarily, it is not practical to have to seam more than about 3 millimeters or perhaps, in extreme cases, 6 millimeters in a direction that is transverse to the score. Using a cutting wheel having a diameter of 32 millimeters with a cutting angle of 160°, it is necessary to seam about 3 millimeters from the edge. This is the maximum amount practical.

If a low friction cutting wheel **14''** having a 165° cutting angle and a diameter of 12.7 millimeters applies a force of 115 kilograms to a piece of glass 19 millimeters in thickness, a subsurface crack is produced that begins approximately 0.01 millimeter from the top surface and extends for approximately 2.0 millimeters into the thickness of the glass if the wheel is moved at less than about 1 meter per second. As the force is increased, significant surface defects develop without any increase in crack depth. If a low friction wheel having a diameter of 19 millimeters and a cutting angle of 165° applies a force of 175 kilograms to a piece of glass **19** millimeters in thickness, it is possible to produce a subsurface crack that starts approximately 0.01 millimeter from the glass surface and extends for approximately 2.5 millimeters if the wheel is moved at less than about 1 meter per second. If a low friction wheel having a diameter of 50 millimeters and a cutting angle of 165° applies a force of 275 kilograms to a piece of glass one inch in thickness, a subsurface crack is created that begins approximately 0.01 millimeter from the glass surface and extends for approximately 3 millimeters if the wheel is moved at less than about 1.6 meters per second. With low friction wheels, surface deep scores and sometimes spotty subsurface discontinuities are obtained at speeds above those stated.

As in the case of surface deep scoring, these results seem to indicate that the diameter of the low friction wheel **14''** and the force applied thereto should be increased indefinitely. In this case, unlike surface scoring, it is true. With subsurface cracks, as the scoring wheel diameter increases, it is possible to increase subsurface crack depth, without creating long wings that would necessitate excessive seaming. There does not appear to be any limit, other than the fact that the crack itself must be seamed, and the greater its depth, the more seaming that will be necessary. This is easier, however, than seaming lateral wings.

To summarize, low friction wheel **14''** having a cutting angle of from approximately 155° to approximately 170°, and preferably 165°, and a diameter of at least approximately 12 millimeters, and preferably between approximately 18 and 100 millimeters, may be used to produce a subsurface crack with forces of between approximately 80 and approximately 460 kilograms (or 2 to 3 times surface deep scoring forces). With cutting wheels having cutting angles between 155° and 165°, it is possible to produce both surface and subsurface deep discontinuities by varying either the force that is applied to the cutting wheel, the speed with which the cutting wheel is advanced, or the surface finish of the cutting wheel.

Using a cutting wheel with a perfectly blunt cutting angle (i.e., 180°), the glass being worked upon is in compression throughout its thickness beneath the cutting wheel. If the cutting angle be reduced, the glass will no longer be in compression throughout its entire thickness beneath the wheel, but rather, a tension zone will be created adjacent to the surface of the glass that is opposite the surface being scored. It is known that glass fails more easily in tension than in compression. For a cutting wheel having a given cutting angle, such as 160°, the location of the tension zone (which corresponds to the location of the discontinuity) may be moved by varying the force that is applied to the cutting wheel. For example, if a high friction cutting wheel has a diameter of 19 millimeters and a cutting angle of 160°, it may be used to apply either a surface deep score or a subsurface deep score in a piece of flat glass that is 19 millimeters thick. If a force of approximately 80 kilograms is applied to said wheel, a zone of tension is created adjacent to the top surface of the glass, and a surface deep score will be created at speeds greater than about 25 centimeters per second. At speeds below this, it is likely that a subsurface score will result. If a force of approximately 120 kilograms is applied to the same wheel, the zone of tension is further beneath the glass surface and a surface deep score will result only at wheel speeds in excess of about 30 centimeters per second. This illustrates that the force applied to a cutting wheel and the speed with which it is moved may determine whether a surface or a subsurface deep score results.

The exterior surface of the cutting wheel should preferably be finished so that it has at least a No. 10 finish. If the surface of the wheel is too rough, local stresses may be created in the glass, thereby damaging its surface.

If the glass is supported on a longitudinally extending knife edge directly beneath the intended path of the subsurface discontinuity during the scoring operation, tension within the glass is increased and it becomes easier to create the subsurface discontinuity. It is important that the knife edge be located exactly beneath the intended path of the subsurface discontinuity **10** or the tensile stresses about the path will not be uniform. It is impractical to align a knife edge with the intended path, and often a narrow plate is used, such as aluminum plate approximately 12.7 millimeters in width. This does not provide tensile stresses within the glass of the same magnitude as those produced with a knife edge, but it is relatively simple to align the plate with the intended path of the subsurface discontinuity and the tensile stresses obtained with a narrow plate are often sufficient.

Generally, the depth of a score or crack, whether surface or subsurface, should be such as to weaken the glass sufficiently so that a bending moment applied about the score or crack will cause the glass to fracture with a resultant edge that is smooth, strong, straight and perpendicular to the major surfaces of the piece of glass. Table A shows the preferred minimum depths of scores or cracks for various glass thicknesses.

Table A

Glass Thickness, millimeters	Preferred Minimum Depth of Score or Crack, millimeters
6	.75
12	1.5
19	2.3
25	3

Referring to Table B, there is shown the ranges of force that may be applied to 165° cutting wheels of various diameters, and the depths of subsurface discontinuities that result. The table also indicates the approximate maximum speeds with which a high friction wheel 14' and a low friction wheel 14'' may be advanced to insure that the discontinuity is subsurface.

Table B

Wheel Diameter, millimeters	Range of Force, kilograms	Range of Depth of Subsurface Discontinuity, millimeters	Maximum Speed for Producing Subsurface Score (centimeters/second)	Maximum Speed for Producing Subsurface Crack (meters/second)
12.7	80 - 115	1.5 - 2.0	25	1
19	135 - 175	1.5 - 2.5	25	1
31	180 - 200	1.7 - 2.7	30	1.2
50	200 - 275	2.0 - 3.0	40	1.6
100	300 - 460	2.5 - 4.0	50	2.0

It is anticipated that the present invention may be used to cut edges other than straight edges. Further, bent or other forms of flat glass may also be cut as herein contemplated. In addition, the invention may also be practiced in cutting glass objects such as thick cylinders, rods and tubes.

While the invention has thus far been described in connection with cutting pieces of flat glass, it will be apparent to one skilled in the art that it is not limited to such. For example, the invention may be practiced in a wareroom to cut a continuous ribbon of glass, either longitudinally or transversely.

Having now fully disclosed the invention, what we claim is as follows:

1. A method of producing a cut edge on a piece of glass comprising the steps of:

applying a force to produce an indentation in a major surface of the glass and, concurrently, a subsurface discontinuity therebelow along an intended path of cut, at least a substantial portion of said discontinuity, along its length, being spaced from said major surface by a zone of glass, and

projecting said discontinuity deeper into the thickness of said glass after said discontinuity is produced.

2. A method of producing a cut edge as defined in claim **1,** wherein all of said discontinuity is spaced from the major surfaces of the glass.

3. A method of producing a cut edge as defined in claim **1,** wherein said discontinuity is projected by applying a bending moment about said discontinuity.

4. A method of producing a cut edge as defined in claim **1,** further including the step of:

grinding upper and lower portions of said cut edge.

5. A method of producing a cut edge as defined in claim **1,** further including the step of:

seaming upper and lower portions of said cut edge.

6. A method of producing a cut edge as defined in claim **3,** further including the step of:

grinding upper and lower portions of said cut edge.

7. A method of producing a cut edge as defined in claim **3,** further including the step of:

seaming upper and lower portions of said cut edge.

8. A method of producing a cut edge as defined in claim **1,** wherein said discontinuity is produced by a wheel having a diameter of at least approximately 12 millimeters.

9. A method of producing a cut edge as defined in claim **8,** further including the step of:

placing a surface defect in the glass along the intended path of cut before the discontinuity is produced to initiate the discontinuity.

10. A method of producing a cut edge as defined in claim **9,** wherein said wheel has a cutting angle of approximately 165°.

11. A method of producing a cut edge as defined in claim **9,** wherein said wheel has a cutting angle of from 155° to 170°.

12. A method of producing a cut edge as defined in claim **11,** wherein said wheel has an integral shaft at the center thereof, said shaft being mounted in bearings to reduce friction between said wheel and a holder.

13. A method of producing a cut edge as defined in claim **12,** wherein said wheel produces said discontinuity at a force of at least about 80 kilograms.

14. A method of producing a cut edge as defined in claim **13,** wherein said wheel travels along the intended path of cut at a speed up to approximately 2 meters per second.

15. A method of producing a cut edge as defined in claim **13,** wherein said discontinuity is projected by applying a bending moment about said crack.

16. A method of producing a cut edge as defined in claim **15,** wherein said wheel travels along the intended path of cut at a speed up to approximately 2 meters per second.

17. A glass article having a top surface, a bottom surface and a cut edge extending therebetween in a direction substantially perpendicular to said top surface and said bottom surface, said cut edge having a smooth, strong fracture area, a seamed indentation and subsurface discontinuity area adjacent to one of said top surface and said bottom surface, and a seamed area adjacent to the other of said top surface and said bottom surface.

18. A glass article having a top surface, a bottom surface and an indentation and a subsurface discontinuity

extending along said article along an intended path of cut, a substantial portion of said discontinuity, along its length, being spaced from the top surface and the bottom surface.

19. A glass article having a top surface, a bottom surface and a cut edge extending therebetween in a direction substantially perpendicular to said top surface and said bottom surface, said cut edge containing an indentation area and spaced therebelow two markings with an area therebetween that is substantially free of serrations, each of said markings being substantially parallel to said top surface and said bottom surface, said markings being indicative of the extent of a subsurface discontinuity.

20. A glass article as defined in claim **19,** wherein one of said markings is at least approximately 0.01 millimeter from one of said surfaces and the other of said markings is up to approximately 4 millimeters from said one of said surfaces.

21. A method of producing a cut edge as defined in claim **8,** wherein said wheel has a cutting angle of from about 163° to approximately 170°.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,865,293 Dated February 11, 1975

Inventor(s) Fred M. Ernsberger et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 6, line 4, after "cut", "in" should be —is—.

Column 9, line 34, after "subsurface" insert —crack"—.

Column 9, line 43, after "may be used," insert —as illustrated—.

Column 9, line 44, after "for example," delete the comma (,).

Column 9, line 44, after "in FIG. 12", insert a comma (,).

Signed and sealed this 29th day of April 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

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