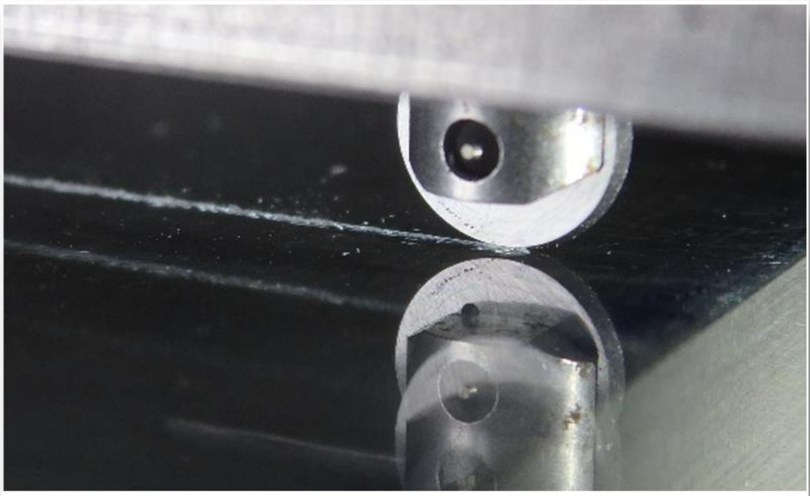
Fachverband Konstruktiver Glasbau e.V.

Technical Note FKG 02/2019

Edge Strength



Date: November 2019

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Fachverband Konstruktiver Glasbau e.V.
Wüllnerstraße 113 | 50931 Köln | Tel.: +49 (0)221.94887.14 | Fax: +49 (0)221.94887.15

www.glas-fkg.org | info@glas-fkg.org

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1. Introduction

Float glass and its applications are key players in today's architecture. Designs are becoming ever more complex and the glazing dimensions ever larger. This results in new and additional loads on the materials used for windows and façades. The glass edge is of crucial importance here because glass is a flaw-sensitive brittle material which will fail immediately when exposed to a critical stress concentration. It is therefore essential to determine not just the surface strength of the "normally cooled" (annealed) float glass (without edge effect) but also the edge strength so as to include it in the engineering evaluation, e.g. in the case of thermally induced glass breakage.

In 2009 the Fachverband Konstruktiver Glasbau (FKG) therefore set up the "Edge strength" working group. Since 2013, over 1,000 test specimens measuring 8 mm x 125 mm x 1,100 mm have been tested for the strong axis (Figure 1) using the four-point bending test based on DIN EN 1288-3 and the edge strength was determined. When determining the bending tensile strength in accordance with DIN EN 1288-3, the 360 mm x 1,100 mm test specimens are normally bent about the weak axis in the four-point bending test. This causes maximum tensile stresses at the two glass edges (labelled "cut edge line" in Figure 2) and on the glass surface. Depending on the location of the breakage origin, either the edge strength or the surface strength of the glass is tested. On the other hand, in the modified "FKG" test set-up, the cut edge line is exposed to a maximum tensile stress over a length of 200 mm. The four-point bending test about the strong axis is therefore better suited to obtaining information on the edge strength. Exposure about the strong axis means that the load is applied over the height of the glass pane (see Figure 1). Exposure about the weak axis, on the other hand, means that the load is applied over the thickness of the glass pane.

As part of the edge strength tests conducted by the FKG, the lateral and median cracks were also measured microscopically [1] in some of the test series. Figure 3 shows the definition of lateral and median cracks.

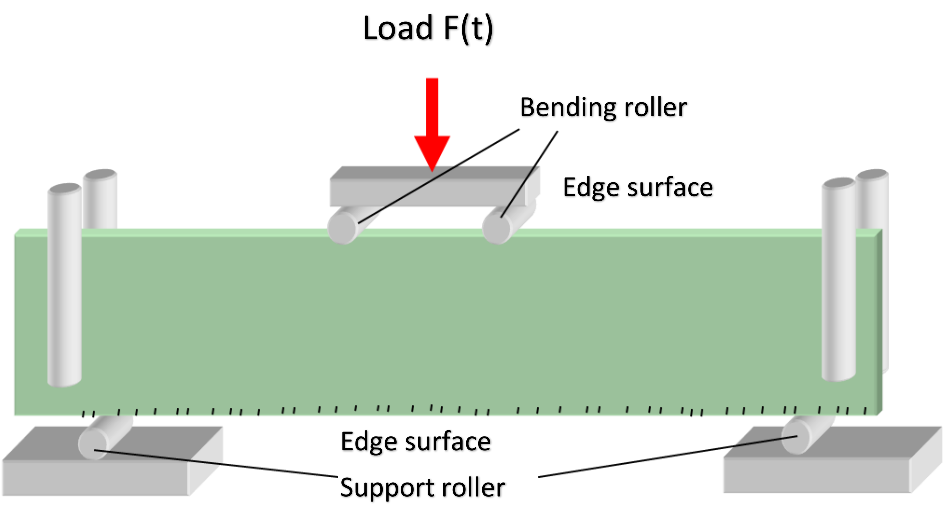


Figure 1 Diagrammatic representation of the four-point bending test about the strong axis (Source: Weißmann, Erlangen)

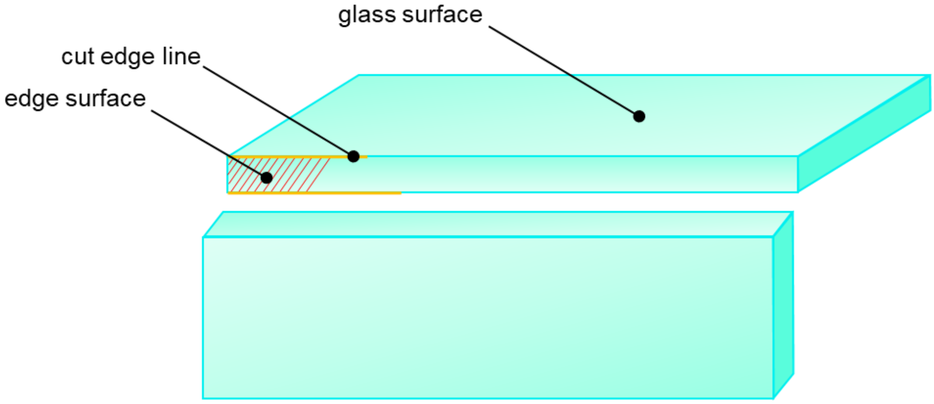


Figure 2 Names of geometries used in edge strength based on DIN 1249-11:2017

2. Cutting Process and Crack System

Cutting glass is in principle a manual process where the glass surface is scratched with a material harder than glass and then broken. Up to the mid-20th century this was done using a diamond as the glass cutter. It was either an industrially automated process or the diamond was guided along a cutting bar using a manual cutter. Over the course of time the diamond tip was replaced by cutting wheels made of hardened steel. Glass cutting is therefore a mechanical process and the result is the cut edge (KG as per DIN 1249-11). Over recent decades industrial cutting processes have been developed which enable a more precise specification of the parameters and therefore improved reproducibility of the edge quality in terms of strength and visual appearance. Scribing the glass surface is usually done using different types of cutting wheel.

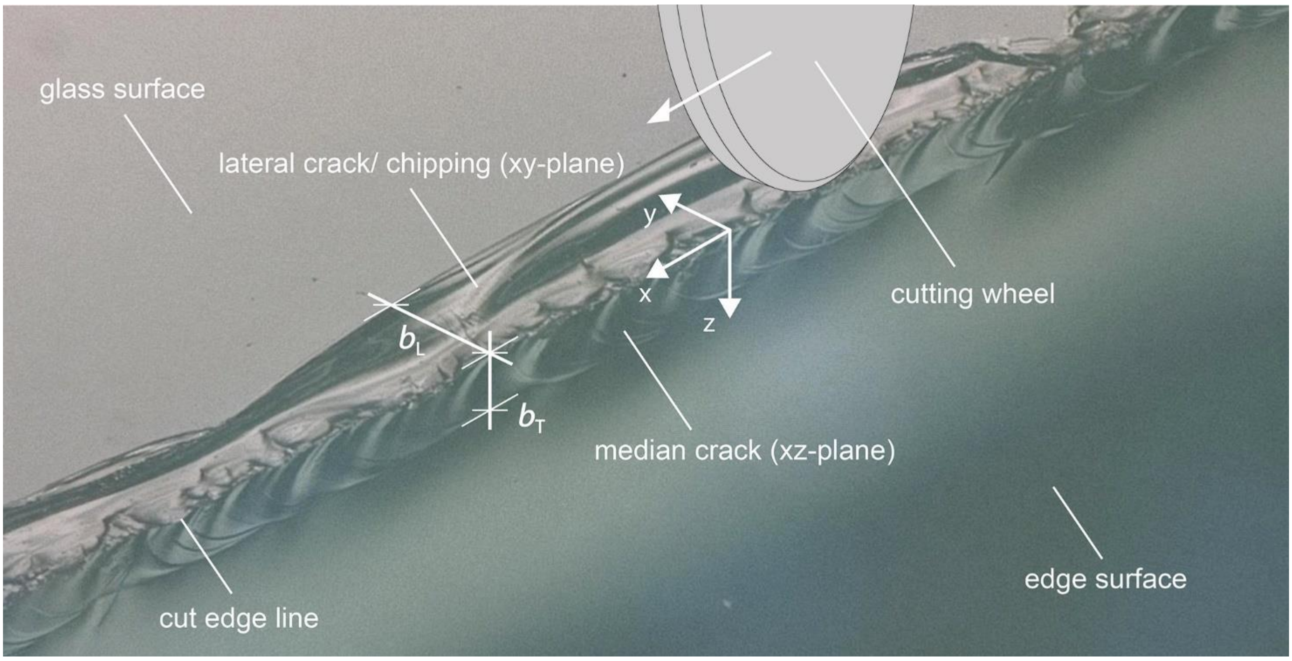


Figure 3 3D representation of the crack system of the cut glass edge [2]

2.1 Median Cracks

A glass surface “damaged” by a glass cutter displays the typical three-dimensional crack system shown in Figure 3 [2]. The median cracks - should ideally propagate in a perpendicular direction into the glass surface (xz plane in Figure 3). The subsequent breaking process depends mainly on the configuration of the median crack. The external tensile stress which occurs during the breaking process causes the median cracks to propagate in the xz plane. As soon as the crack front has arrived at the opposite glass surface, the crack has opened fully and the glass breaks. Longer median cracks promote the breaking process and often lead to a more visually appealing fracture surface.

2.2 Lateral Cracks (Chipping)

What are known as lateral cracks run on both sides of the incipient crack path. Their crack fronts at first run mainly in the xy plane parallel to the glass surface (Figure 3). Crack propagation may also be oriented towards the edge surface depending on time, so that individual glass chips may detach from the path of the crack. Directly below the indenter (cutting wheel) is a condensed area comprising a fragmented glass matrix which builds up horizontal compressive stress. This may cause the glass chips to break away from the scratch path due to the spring action. This process is also called chipping.

2.3 Radial Cracks

According to fracture mechanics, there must also be cracks with their crack tips running perpendicularly to the fracture surface in the yz plane (Figure 3). These radial cracks govern the edge strength due to their flaw effect as the tensile stress is parallel to the edge. If the fracture toughness of the material is exceeded at such a crack tip, the glass will break, with crack initiation starting at the glass edge, as can frequently be seen in, e.g. thermal breakage of glass. Unlike the lateral and median cracks described above, the cracks responsible for such edge fracture cannot so far be detected visually. The FKG working group therefore studied whether the edge strength is a function of the length of the lateral and median cracks, so that the edge strength can be qualitatively assessed by non-destructive testing.

3. Definition of Edge Types

The definition of edge working is based on DIN 1249, Part 11 and EN 1863-1. The present description relies mainly on geometrical and visual/optical principles. This definition alone is insufficient for determining the edge strength. Other technical production parameters need to be taken into account. An edge of higher optical quality does not permit any conclusions to be drawn on the existing edge strength.

The definition of the main glass edges in accordance with DIN 1249, Part 11 and EN 1863-1 is given below. The applicable dimensional tolerances are specified in the relevant product standards.

3.1 Cut Edge

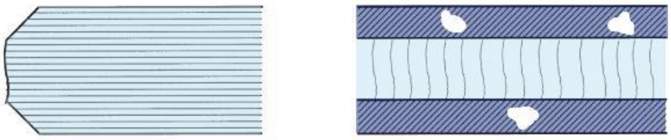
The cut edge is the unworked glass edge which results from the process of cutting sheet glass, as described in Section 2. The edges of the cut surface are sharp. Slight wave lines (Wallner lines) may occur in the edge zone, perpendicular to the cut edges. The cut edge is generally broken flat. Irregular breaks (e.g. break-offs under and over the prescribed dimensions) may occur particularly in thicker panes and non-rectangular-shaped panes.

The strength of the cut edge (KG) was fully tested during the FKG tests. The cut edge is generally the first step in glass machining. Alternative ways to cut glass are explained in Section 3.2. After cutting to size the glass edge can be worked further. The subsequent types of edge working are described in Sections 3.3 to 3.7.

3.2 Sawn Edge

The sawn edge is an edge created at a right angle or mitre angle to the pane using a radial arm saw or band saw, with inflow and outflow tracks at its beginning and end.

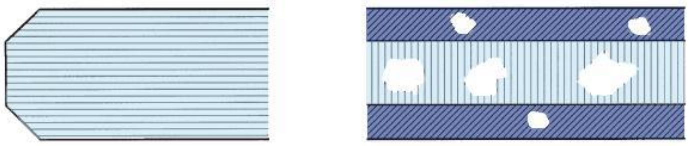
3.3 Arrissed Edge



The arrissed edge is a cut edge whose edges have been broken using a grinding tool. Arrised edge is typically applied to glass units which are subsequently thermally toughened.

Figure 4 Arrissed edge

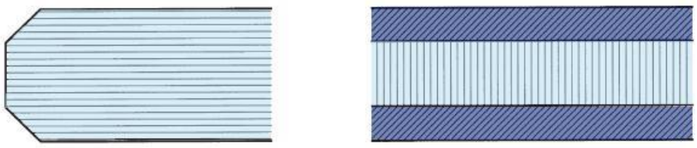
3.4 Ground Edge



The glass pane is dimensioned to the specified size by grinding the edge surface. The ground edge may feature chamfered edges (corresponding to the arrissed edge). Blank areas and flakes are permissible.

Figure 5 Ground edge

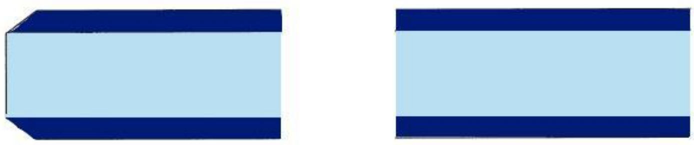
3.5 Smooth Ground Edge



The overall edge surface is worked by grinding. The smooth ground edge also features chamfered edges (corresponding to the arrissed edge). Smooth ground edge surfaces have a frosted mat finish due to grinding. Blank areas and flakes are not permitted.

Figure 6 Smooth ground edge

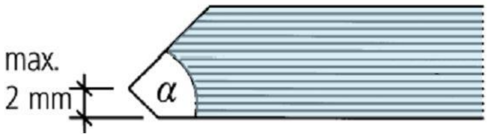
3.6 Polished Edge



The polished edge is a smooth-ground edge which is further refined by polishing. A certain amount of polishing traces is permissible. The polished edge has a glossy appearance.

Figure 7 Polished edge

3.7 Bevelled Edge



The bevelled edge forms a 45° ≤ α < 90° angle with the glass surface. The edges can be either smooth-ground or polished. The bevelled edge ends in a residual edge standing perpendicular to the glass surface. This residual edge should be 1/3, or not more than 2 mm, of the original glass thickness and should be either smooth-ground or polished and arrissed.

Figure 8 Bevelled edge

3.8 Pencil Edge

The edge surface of the pencil edge is ground to a more or less round shape. The different types of round edge are also referred to as C-shapes.

Figure 9 Pencil edge , LHS half-round, RHS flat round

4. “Cut Edge” Research Results

The following summarises the research results obtained so far for “normally cooled” (annealed) glass, the edge type “cut edge” (KG) and 8 mm glass thickness.

The extent to which the results obtained can be applied to different glass types and glass thicknesses as well as to different edge types still requires to be examined. Other factors such as glass batches, age of glass, inherent glass stress and low iron float glass (clear glass) may give different results.

4.1 General

1. The (macroscopic) optical quality of the cut edge does not allow any general conclusions to be drawn for the edge strength of float glass.

2. Current research results give indication that it is safe to apply the frequently used “rule of thumb” edge strength ≈ 80 % of float glass strength.

   As the shape and length of the edge exposed to tensile stress differ in the two tests conducted (see Section 1), the extent to which the edge strength values obtained in the FKG tests can be compared to the values set out in DIN EN 1288-3 remains to be statistically determined. The application of the edge strength values of the four-point bending test about the strong axis to the edge strength values of the four-point bending test about the weak axis is therefore currently being verified in a research project.

3. Edge strength is mainly determined by the processor and its technical equipment as well as the chosen cutting parameters.

4.2 Influence of the Cutting Parameters

4. The resulting tensile strength of the edges is dependent on many parameters which were systematically examined by the “Edge strength” working group. According to [3] the following are some of the parameters of importance for the edge strength of glass:

– Cutting technology (manual, semi- or fully automatic)

– Cutting wheels (diameter, geometry, angle, material, age/performance)

– Cutting pressure and speed

– Cutting fluid (type and composition)

– Age of cut edge

5. The edge strength can be significantly improved using the “right” cutting parameters.

6. The “suitable” cutting parameters will give reproducible results for edge strength and (microscopic) crack geometry. These cutting parameters can be applied to other cutting equipment of the same design.

7. The “suitable” cutting parameters must be determined for each type of cutting equipment.

8. The “suitable” cutting parameters must be determined for each glass thickness, glass type (e.g. clear glass) and glass manufacturer.

9. As a rule, low cutting pressure leads to higher edge strength but will also require greater effort for breaking and a higher risk of the fracture deviating from the nominal direction. The (macroscopic) optical edge quality can also be impaired as a result.

10. The right choice of cutting fluid has a beneficial effect on the edge strength of float glass.

11. The type, extend and depth of pre-damage caused by scribing with the cutting wheel governs the edge strength. The subsequent breaking process has no significant effect on the edge strength, to the best of current knowledge.

4.3 Lateral and Median Cracks

12. There is a significant correlation between the edge strength measured in the breakage test, the lateral and median cracks on the side of the cut edge where the cutting wheel scratched the glass surface during scribing, and the cutting pressure when scratching the glass surface.

13. The lateral cracks can be optically (microscopically) detected from a crack length of approx. $b_L > 150$ µm.

14. Lateral cracks indicate a major reduction in edge strength, with a characteristic decline in strength. The lateral cracks increase with increasing cutting pressure (Figure 10).

15. The length of the median crack is also dependent on the cutting pressure applied. An increase in the length of the median crack also indicates a decrease in edge strength (Figure 10).

4.4 Interpretation

16. The qualitative correlation between cutting pressure, crack length and edge strength is systematically presented in the diagram (Figure 10) for 8 mm float glass.

    Low cutting pressure produces a plateau of increased strength which decreases considerably – at first locally – with increasing cutting pressure and continues to decrease with the cutting pressure. The strength curve clearly shows the impact of lateral crack length. The lateral crack curve is almost inversely proportional to the strength curve and shows a characteristic sharp increase at the same point as the decrease in strength. The length of the lateral cracks is therefore a good indicator of the anticipated edge strength.

17. The length of the median crack also increases with cutting pressure. However, the curve is constant and without any significant increase in the area of strength decrease. If the median crack is too short, the crack can only be opened with great effort and the optical quality of the edge decreases. This often results in break-offs under and over the prescribed dimensions. A cutting pressure therefore needs to be defined with a sufficient "safe distance" α from the zone of strength decrease, but which also allows the crack to be opened in a manageable way.

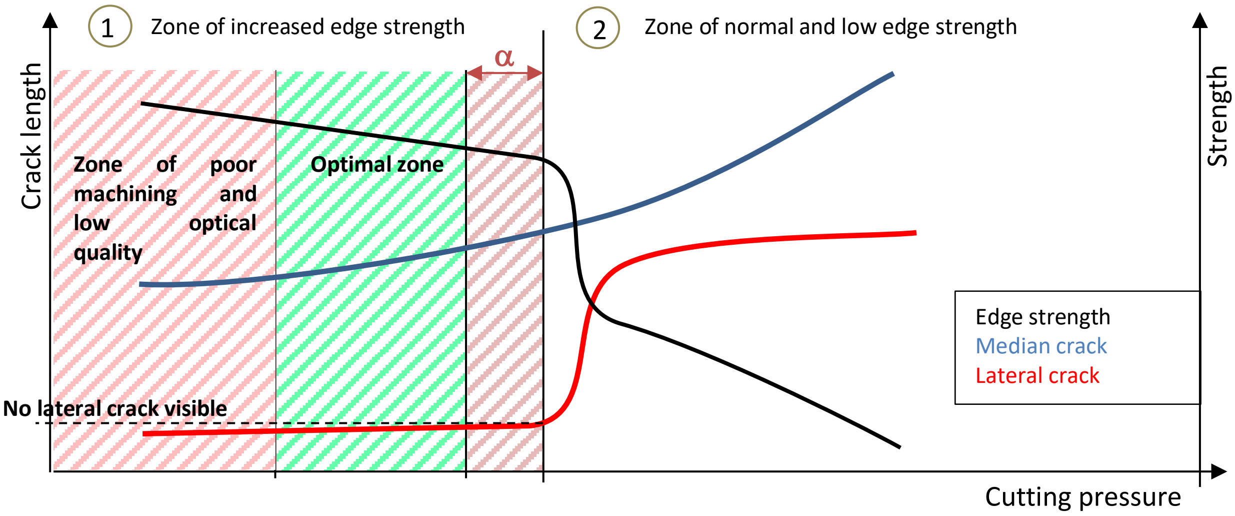


Figure 10 Qualitative correlation between cutting pressure, edge strength and crack length of median cracks b_T and lateral cracks b_L (cf. Figure 3)

5. Summary and Outlook

Cutting parameters are usually only optimised to achieve an optically appealing cut edge quality. However, this does not necessarily mean that the edge strength of an optically less appealing edge is lower in quality than that of an optically more appealing one. This requires the correct adaptation of the above-mentioned parameters influencing the cutting process. If the correlation between crack length and edge strength shown in the diagram (Figure 10) is confirmed by future research using different glass thicknesses, cutting wheel geometries, etc. a design model could be deduced from this. To ensure increased edge strength, the parameters would then need to lie in the zone 1 of increased edge strength, for example. An indicator could be, e.g. the length of the lateral cracks. The lateral crack can be optically (microscopically) measured, analysed and evaluated in terms of edge strength [1, 2, 4]. The introduction of an optical inspection of the length of the lateral cracks (non-destructive test) during production to verify the increased edge strength is currently under discussion. The goal of future research is to develop such a design concept accompanied by quality assurance measures.

In addition, many practical production processes or construction activities demand the execution of glass edges in an optically higher quality type of edge working process (acc. to Sections 3.3 to 3.8). This will reduce both the risk of damage (during transport and installation) and the danger of injury. Additional machining stages generally also produce a more appealing appearance. However, this alone does not permit a statement on the edge strength. The decisive factor here is whether the existing cracks caused by cutting can be ground out or whether they will propagate. Additional mechanical working may of course also produce new critical cracks. As regards the subsequent processing steps, it should therefore be pointed out that an increase in strength depends on various process parameters which need to be adapted on a case-by-case basis. This requires further research.

6. Literature

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This Technical Note was prepared by AK Kantenfestigkeit (working group edge strength) of the Fachverband Konstruktiver Glasbau e.V. (Structural Glass Design Trade Association)

Participants and/or test specimens from:
INTERPANE Entwicklungs- und Beratungsgesellschaft, Okalux GmbH, Saint-Gobain Eckelt Glas GmbH, Technische Universität Darmstadt (ISMD + MPA/IfW)