# Standard Practice for Interpreting Glass Fracture Surface Features[1]

This standard is issued under the fixed designation C1256; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 Fracture features on the surface of a crack reflect the nature and course of the fracture event associated with the breakage of a glass object. This practice is a guide to the identification and interpretation of these fracture surface features.

1.2 The practice describes the various fracture surface features as to their appearance, the process of formation and their significance.

1.3 The practice does not provide the procedural information necessary for a complete fractographic analysis. Such information is available in the general literature. (See Glossary for suggested literature).

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]
C162 Terminology of Glass and Glass Products

## 3. Terminology

3.1 *Definitions:*

3.1.1 *bending stress*—a continuously and linearly changing stress across the thickness of a glass body, varying from compression on one surface to tension on the opposite surface.

3.1.2 *forking*—a mechanism whereby a propagating fracture branches into two fractures, separated from each other by an acute angle.

3.1.3 *forking angle*—the angle subtended by two immediately adjacent fractures which have just branched or forked.

3.1.4 *fracture mirror constant*—a constant, characteristic of a given glass composition, which, when divided by the square root of the fracture mirror radius, will yield the fracture stress.

3.1.5 *fracture mirror radius*—a dimension of the fracture mirror as measured along the original specimen surface. It is defined as the distance from the origin to the first detectable mist.

3.1.6 *fracture surface markings*—features of the fracture surface produced during the fracture event which are useful in determining the origin and the nature of the local stresses that produced the fracture.

3.1.7 *fracture system*—the fracture surfaces that have a common cause or origin.

3.1.8 *terminal velocity*—the uppermost limiting velocity at which a crack can propagate in a material, the approach to which is marked on the fracture generated surface by the presence of mist. The terminal velocity is approximately one half the velocity of sound in the material.

3.1.9 *uniform stress*—a state of stress that does not change within the region of concern.

## 4. Summary

4.1 This practice is intended to aid in the identification of fracture surface markings as well as to assist in the understanding of their formation and significance.

## 5. Significance and Use

5.1 Fractography is often used to help identify the events that have resulted in the fracture of a glass object. This practice defines the appearance of various fracture surface features, as well as their method of formation. Thus, there can be a common understanding of their relationship to the fracture process as well as a common terminology.

## 6. Fracture Surface Markings

6.1 *Origin:*

6.1.1 *Identification*—The origin is almost always found at the junction where the fracture-generated surface meets a free surface or a dissimilar material. Commonly, the origin is symmetrically located near the apex of the mirror and it is usually small compared to the mirror. Fig. 1 shows typical origins and mirrors bounded by mist.

6.1.2 *Formation*—The origin represents the single, unique location at which every fracture system begins to form.

[1] This practice is under the jurisdiction of ASTM Committee C14Glass and Glass Products and is the direct responsibility of Subcommittee C14.04 on Physical and Mechanical Properties

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

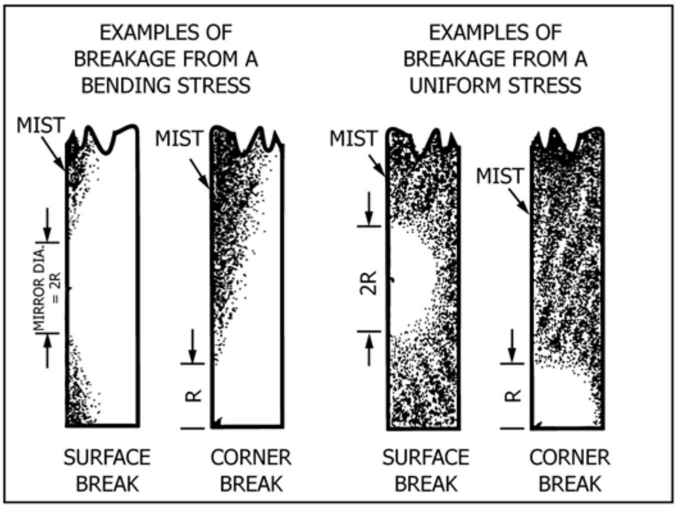


**FIG. 1 Origin Areas Produced Under Various Stress Functions and Their Typical Fracture Features**

6.1.3 *Significance*—The origin defines the location where the fracture began. It may contain the stress concentrator or it may be the stress concentrator.

6.2 *Mist Region:*

6.2.1 *Identification*—Under low power (5 – 50 × ) magnification, it has a misty appearance. Proceeding away from the origin, it becomes more fibrous in appearance and elongated in the direction of crack spread. (See Fig. 2.)

6.2.2 *Formation*—It is produced as the crack front breaks into numerous segments, which then round into one another. Their propagation aborts as the crack front approaches terminal velocity.

6.2.3 *Significance*—It defines the limit of the mirror region and indicates that the crack has nearly reached terminal velocity, or both.

6.3 *Mirror:*

6.3.1 *Identification*—The mirror is a smooth portion of the fracture surface surrounding the origin (see Fig. 2). It is commonly bounded by mist, but mist may not form when the local stress at the fracture front diminishes as the crack extends.

6.3.2 *Formation*—It represents the initial portion of the propagating crack where the velocity is accelerating from the origin to a value sufficient to induce turbulence at the crack front, that is, approaching terminal velocity, where mist and forking may appear.

6.3.3 *Significance*—It is often helpful in locating the origin. The shape defined by the mist boundary is indicative of the uniformity of the stress field at the time of failure, for example; an open mirror, defined by mist only along the original surface, implies bending; a semicircular mirror implies uniform tension: (See Fig. 1) The mirror dimensions may be used to calculate the stress at breakage, because the mirror radius is inversely proportional to the square of the stress at the time the mirror was formed. If the mirror is symmetrical, then use the radius to the mist boundary. To calculate the stress at breakage when the mirror is not symmetrical, the mirror radius is best determined by dividing the mirror diameter by two. A more detailed description of the relationship between the mirror and the breaking strength for various glasses is found on p. 364 of (**1**) and in (**2**) and (**3**). Further discussion on quantitative fracture analysis techniques is well summarized in (**4**).

6.4 *Wallner Lines:*

6.4.1 *Identification*—Wallner lines, also called ripple marks, are rib-shaped marks, frequently appearing as a series of curved lines resembling ripples created when an object is dropped into still water. (See Figs. 3-8.)

6.4.2 *Formation*—They are produced when the plane of the propagating crack front is temporarily altered by an elastic pulse.

6.4.3 *Significance*—The direction of local propagation is perpendicular to the Wallner lines; it proceeds from the concave to the convex side of the line. The shape of the line indicates the direction of stresses at various points on the crack front. The more advanced portions of the line generally correspond to regions of higher tension.

6.5 *Wallner Lines, Primary:*

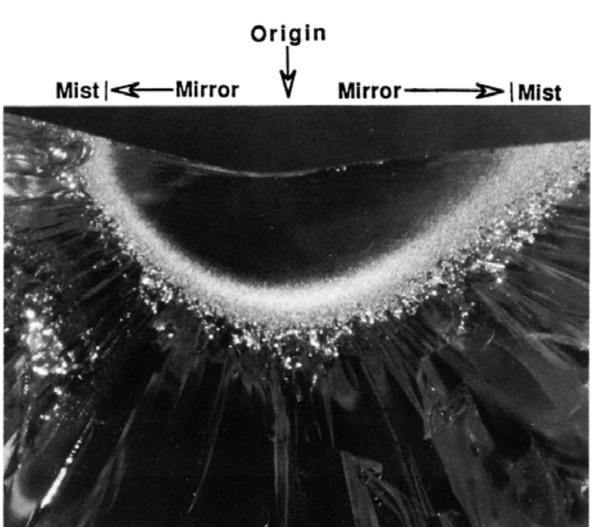


**FIG. 2 An Origin Area, with Mirror and Mist**

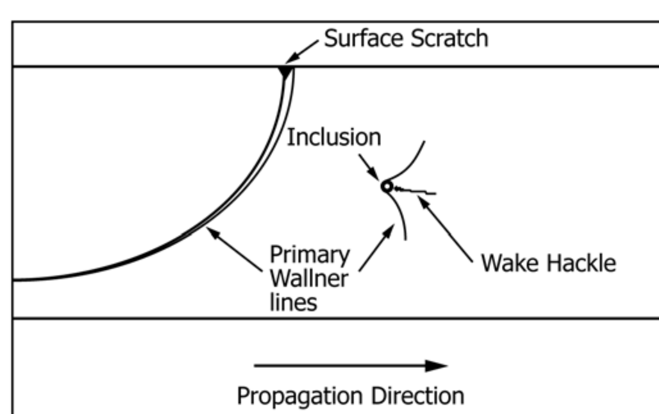


**FIG. 3 Primary Wallner Lines Generated From a Surface Nonconformity and an Inclusion**

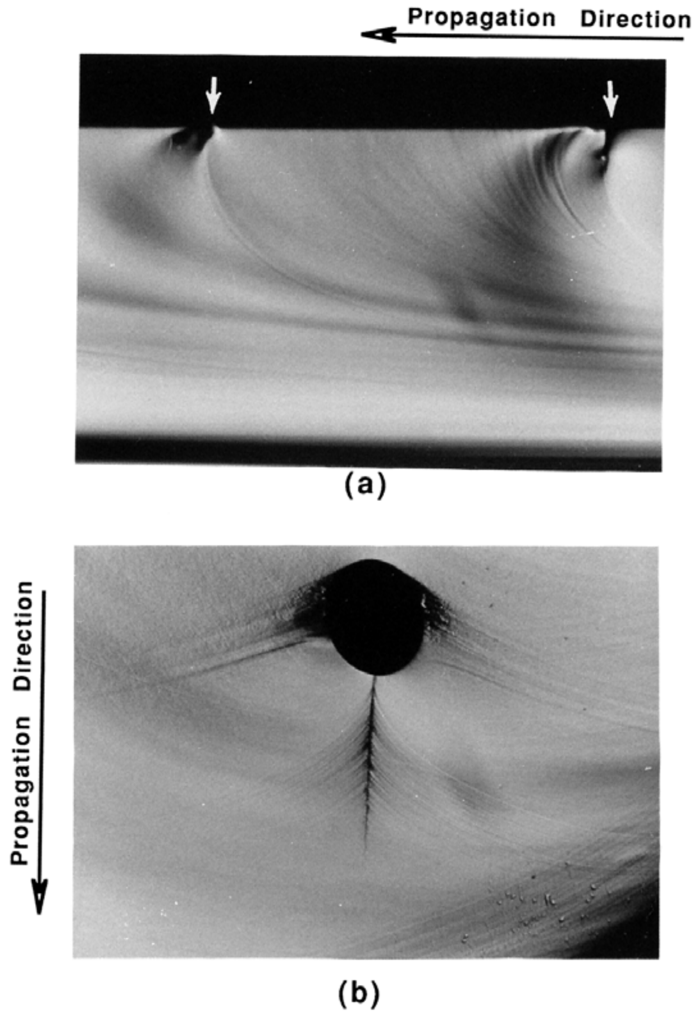


FIG. 4 Primary Wallner Lines Generated; (a) From Surface Scratches, (b) A Bubble Generating Gull Wings

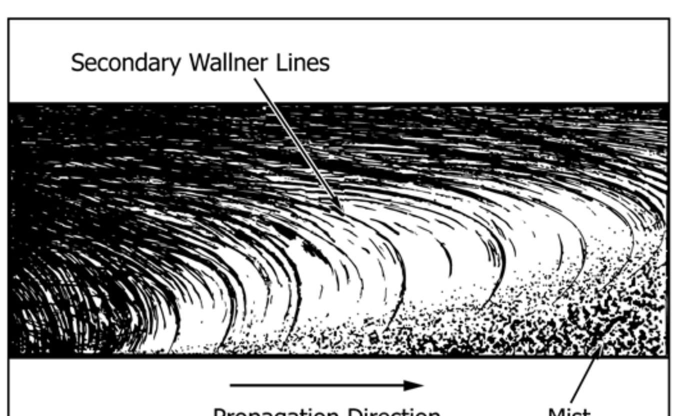


FIG. 5 Secondary Wallner Lines Generated From Mist Formation

6.5.1 *Identification*—Primary Wallner lines are usually quite distinct and always have their source associated with some discontinuity which was present before fracture. Examples would include bubbles or other inclusions, surface damage or an abrupt change in surface contour. (See Fig. 3 and Fig. 4.)

6.5.2 *Formation*—They result from the interaction of a propagating crack with an elastic pulse coming from the encounter of the crack front with a preexisting discontinuity.

6.5.3 *Significance*—The convex side is toward the direction of crack propagation. Primary Wallner lines can be used to

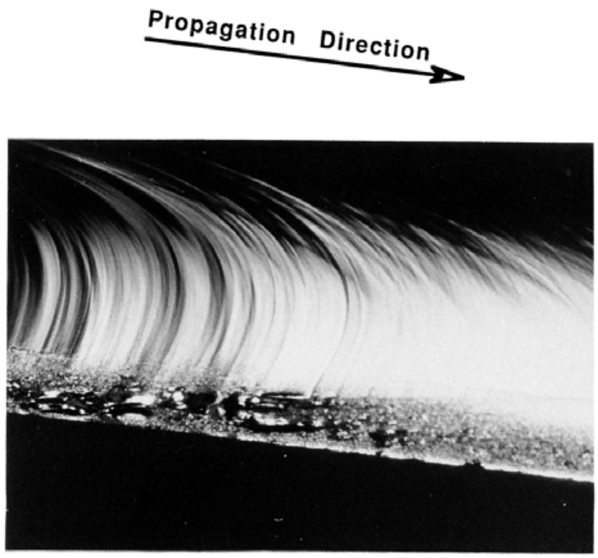


FIG. 6 Secondary Wallner Lines Generated From Mist Formation

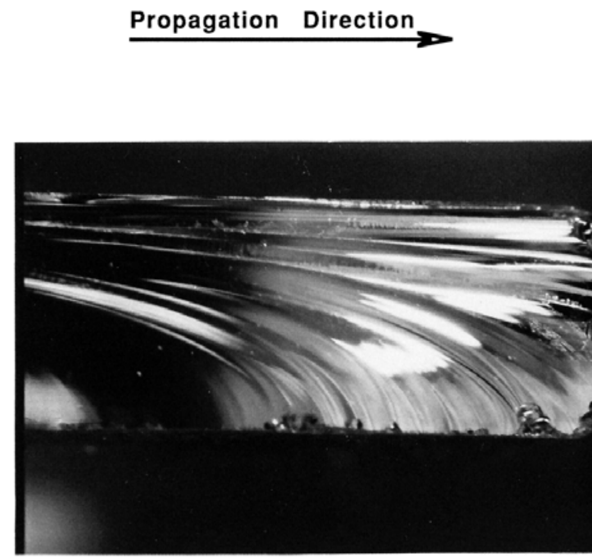


FIG. 8 Tertiary Wallner Lines

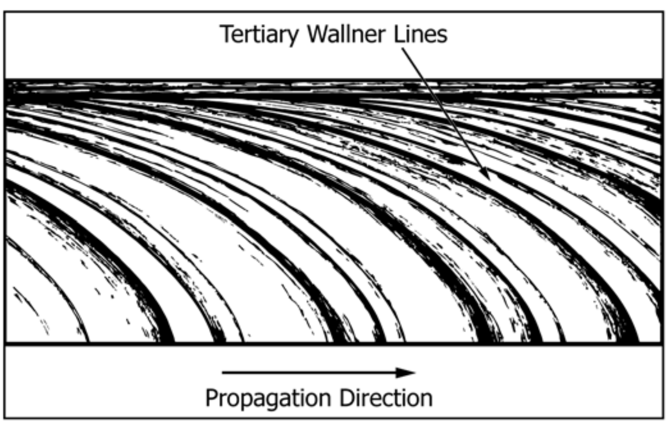


FIG. 7 Tertiary Wallner Lines Created by Sonic Pulses Produced from Mechanical Shock Which Broke the Material

determine whether a discontinuity was present before or after the breakage occured. In thin glassware, the crack breaking through to the opposite surface will generate a primary Wallner line which indicates the stress distribution at the time of failure.

6.6 *Wallner Lines, Secondary:*

6.6.1 *Identification*—Secondary Wallner lines are fish-hook shaped, numerous and closely spaced. (See Fig. 5 and Fig. 6.)

6.6.2 *Formation*—They result from perturbations of the crack front as it passes through the mist hackle that is produced when the crack approaches terminal velocity.

6.6.3 *Significance*—The convex side points toward the direction of crack propagation. They are indicative of the stress profile at the crack front. In instances where the mist hackle band is quite narrow, they verify its presence.

6.7 *Wallner Lines, Tertiary:*

6.7.1 *Identification*—These are a complex set of lines, exhibiting a periodicity and an intensity which may diminish within the pattern. They are neither hook-shaped nor trace to a discontinuity as the source of an elastic pulse. (See Fig. 7 and Fig. 8.)

6.7.2 *Formation*—They result from an interaction at the crack front with sonic waves from an external shock or from stress release at the onset of cracking.

6.7.3 *Significance*—They indicate that the failure resulted from a mechanical shock, where an elastic pulse was generated outside the plane of crack propagation.

6.8 *Dwell Mark:*

6.8.1 *Identification*—Dwell marks, also called arrest lines, have a similar rib-shaped contour to that of Wallner lines but are distinctly sharper, often exhibiting a noticeable change in fracture plane after the mark and may have twist hackle associated. (See Fig. 9 and Fig. 10.)

6.8.2 *Formation*—They are formed when there is an abrupt change in the direction of the stress field such as when the crack stops and then is restarted by a different stress field.

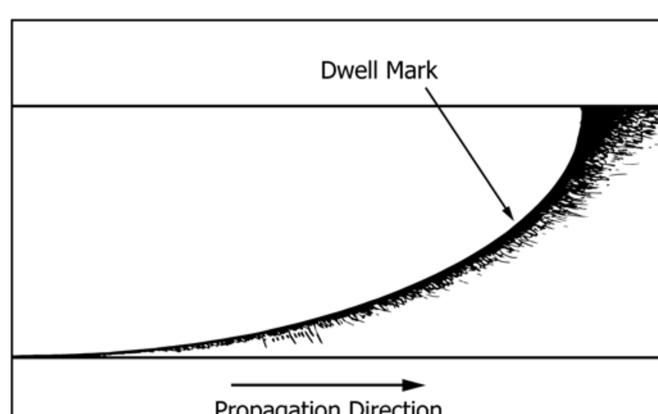


FIG. 9 A Dwell Mark is Created When the Crack Stops Propagating and/or Suddenly Changes Plane

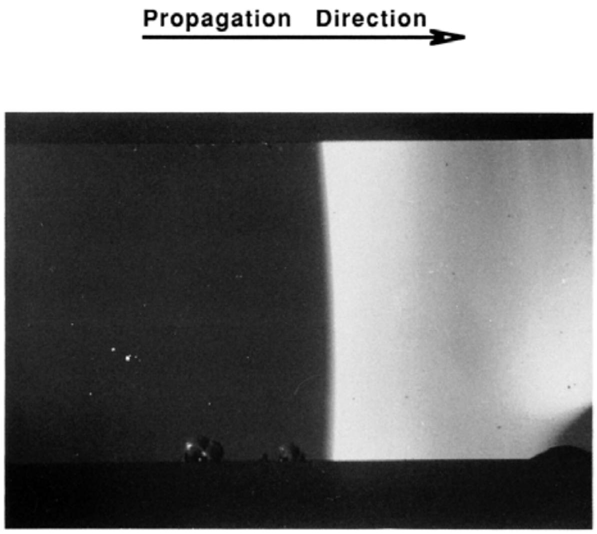


FIG. 10 Dwell Mark, the Crack Was Propagating from Left to Right

6.8.3 *Significance*—They indicate that the crack stopped propagation along a given plane and was restarted by a different stress field, along a new plane. In conjunction with other information, they may indicate a position of the crack front which separates two events in time.

6.9 *Hackle:*

6.9.1 *Identification*—Lines parallel to the direction of crack propagation separating portions of the crack surface which are parallel but not coplanar.

6.9.2 *Formation*—They are created when a propagating fracture front becomes discontinuous so that it proceeds on different planes which subsequently propagate laterally to intersect one another.

6.9.3 *Significance*—Hackle indicates the direction of crack propagation. Hackle can be useful in defining the mirror radius.

6.10 *Hackle, Twist:*

6.10.1 *Identification*—Resembles a staircase as seen from above, the stair risers representing the lines; overall it may resemble the pattern of a river, running from multiple tributaries to streams into larger rivers (also known as striations). (See Fig. 11(a).)

6.10.2 *Formation*—A lateral twist of the stress field becomes accommodated by breakup of the crack front into many segments which are parallel but not coplanar. This is followed by a lateral fracture allowing the separate crack segments to connect, thus forming the“ line” or “step” between them.

6.10.3 *Significance*—They verify general and even local propagation direction. The local direction of crack propagation proceeds from the smaller tributary features toward the direction of convergence and larger features.

6.11 *Hackle, Shear:*

6.11.1 *Identification*—A spray or fan of twist hackle which curves or radiates away from a central line toward opposite surfaces. (See Fig. 11(b).) Also known as striations or Woodworth’s Feathers.

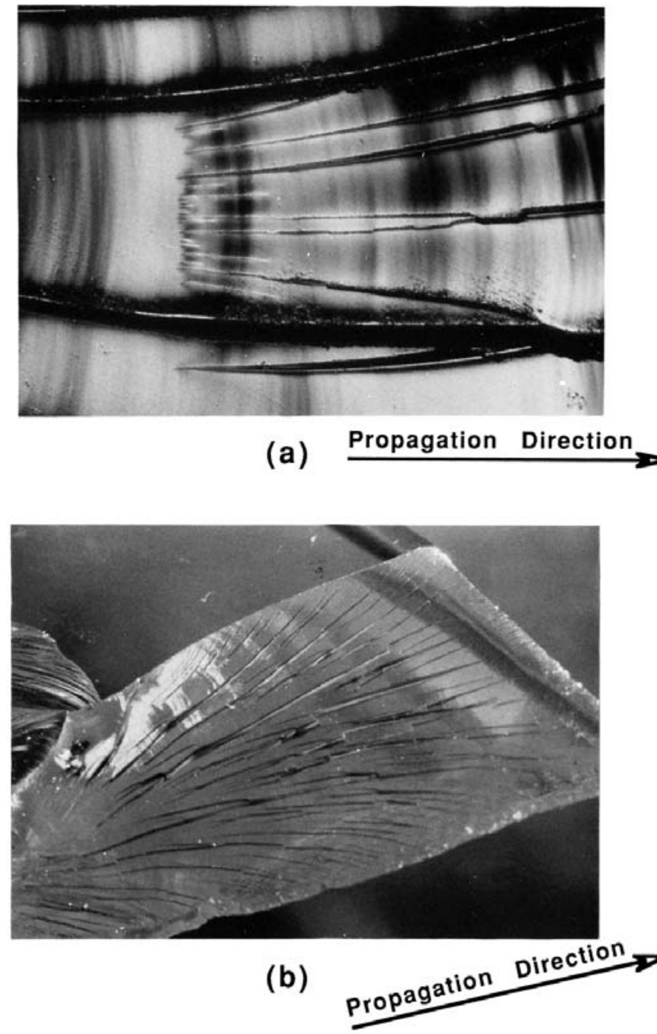


FIG. 11 Hackle, (a) Twist Hackle, (b) Shear Hackle

6.11.2 *Formation*—It results from the addition of a shear stress to the principle tensile stress.

6.11.3 *Significance*—Indicates that there was a shear stress present at the time of fracture. The shear stress may be indicative of a transition between two types of forces, such as bending force in the sidewall of a vessel which changes to uniform tension across the bottom of a vessel, producing shear hackle as the crack rounds the corner.

6.12 *Hackle, Wake:*

6.12.1 *Identification*—A single hackle step at the trailing edge of an inclusion. (See Fig. 3 and Fig. 4(b).)

6.12.2 *Formation*—As the crack front passes by an inclusion it splits, producing two parallel but non-coplanar cracks which join after the crack front has passed beyond the trailing edge of the inclusion.

6.12.3 *Significance*—It indicates the local direction of crack propagation and calls attention to the presence of the inclusion.

6.13 *Scarp:*

6.13.1 *Identification*—A single line on a fracture surface which is unlike any other fracture feature. Examples of two common types of scarps are shown in Fig. 12(a) and (b), Cavitation scarp and Sierra Scarp, respectively.

6.13.2 *Formation*—It marks the line of confluence between two portions of the crack front which travel in different planes as a result of local direction differences in crack advancement. These differences are due to unequal access of moisture to the two portions of the crack front.

6.13.3 *Significance*—It can only be present if there has been an opportunity for water to access the crack front. Its presence specifically defines the presence of water at the time of the fracture event. Its absence, however, is inconclusive. There are various types of scarps as discussed in greater detail in **(4)**, **(5)**, and **(6)**.

6.14 *Cantilever Curl:*

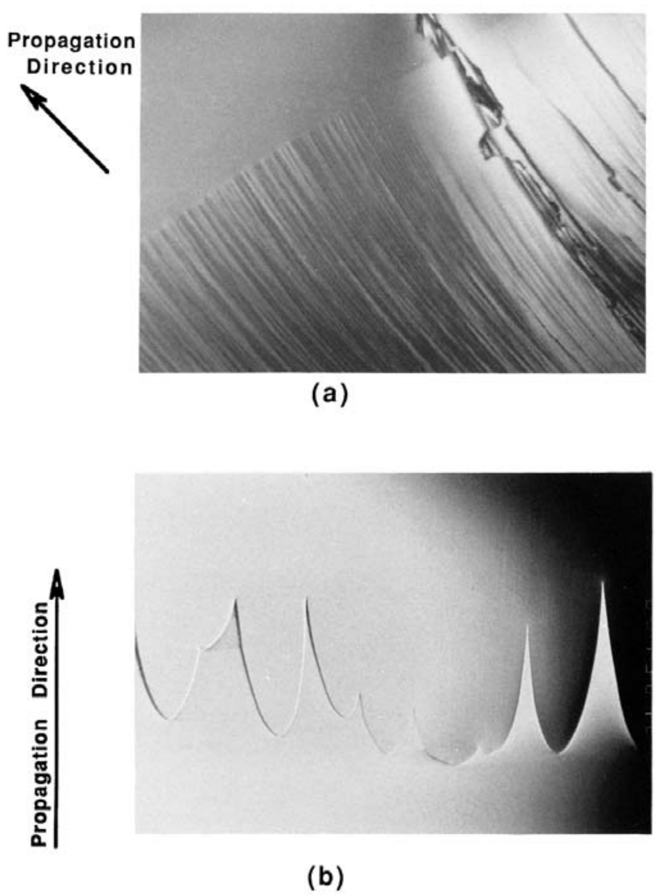


FIG. 12 Scarp, (a) Cavitation Scarp, (b) Sierra Scarp

6.14.1 *Identification*—A flat crack surface, more or less perpendicular to one free surface, which curves as it approaches the other surface so that it intersects that other surface at an oblique angle. (See Fig. 13.)

6.14.2 *Formation*—When a crack is generated by a bending stress, it initially propagates perpendicular to the free surface which is in tension and upon which the fracture originated. As the crack propagates through the thickness toward the free surface that was originally in compression, the plane of tension rotates, causing a rotation in the developing crack surface, so that, by the time it intersects the opposite free surface, a ridge, or lip, has formed. That ridge is strongly tilted with respect to the general crack plane.

6.14.3 *Significance*—Its presence opposite the origin indicates that breakage occurred from a bending force.

## 7. Precision and Bias

7.1 Since for the most part, the results cannot be expressed quantitatively, the precision and bias cannot be so expressed either. However, this practice is the result of the combined efforts of numerous investigators who concur that adherence to this practice, combined with an understanding of the principles discussed in several monographs (Refs. **(1)** through **(4)**, and **(6)**), will result in qualitatively accurate interpretations of the fracture events which create a set of glass fragments.

## 8. Keywords

8.1 breakage; cantilever curl; crack propagation; failure; fractographic; fracture; Fractography; hackle; mirror; mist; origin; scarp; Wallner line

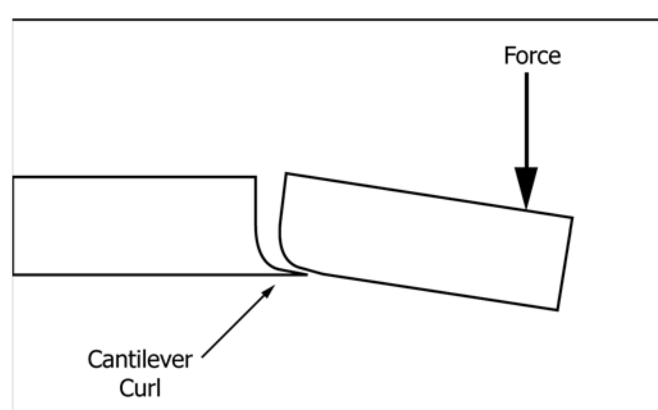


FIG. 13 Cantilever Curl, Formed on the Compression Side Under a Bending Stress

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## GLOSSARY
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