# Fractography of Brittle Materials

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## 1 Scope

### 1.1 Introduction

This document describes techniques used in the reconstruction of objects broken as a result of brittle fracture and the characterization of certain fracture features in brittle materials as observed through microscopic and macroscopic examination by Geologist-Forensic Examiners within the Trace Evidence Unit (TEU). Brittle materials are particularly well-suited for fractography because there is usually no distortion caused by the breakage, and objects can be reassembled to their original configuration. Refer to Frechette (1990) and Quinn (2020) for further discussion on this subject. The techniques to be used in an individual case are chosen to address the request. Not all techniques described in this procedure may be required in every case.

This Technical Procedure is implementing through incorporation by reference the ASTM International E3392, Standard Guide for Forensic Physical Fit Examination. ASTM E3392 is on the Organization of Standard Area Committees (OSAC) Registry of Approved Standards.

### 1.2 Principle

The reconstruction of objects broken as a result of brittle fracture and/or examination of points of impact and fracture features may yield the following information:

- Determining that broken pieces were once part of the same broken object
- Type of breaking force
- Direction of force
- Angle of incidence
- Type and/or description of object
- Point(s) of impact
- Sequence of impact occurrence

Additional information concerning the mechanism of breakage may also be revealed through examination of broken objects. The References can be consulted for procedures for determining additional information.

## 2 Equipment/Materials/Reagents

- Cameras
- Forceps
- Magnifying glass, loupe or equivalent
- Micrometer capable of measuring in inches to the fourth decimal place
- Measuring equipment such as rulers, tape measures or equivalent
- No. 2 pencil/Charcoal pencil
- Personal protective equipment (PPE) as needed
- Short wavelength (254 nm) ultraviolet (UV) light source

- Stereobinocular microscope with minimum 4 diameters magnification
- Transparent tape
- White paper/tracing paper

## 3 Standards and Controls

Not applicable.

## 4 Sampling

Not applicable.

## 5 Procedure

A. Objects broken as a result of brittle fracture may be reassembled to show that they were once part of the same object, or as an aid in further fractography examinations.
    1. Place sample identification markings on all pieces that may be used in reassembly.
    2. Observe surface characteristics, curvature, material type, color, thickness, and fluorescence for glass objects to ensure that all pieces could be from a single object. Sort pieces from different objects as necessary.
    3. When possible, surface features, fluorescence in glass, and curvature may be used to ensure that they are placed in the same orientation (e.g., top side facing up). Surface features, fluorescence in glass, and/or curvature may not be present in all broken objects.
    4. Assemble pieces.
        i. Surface features and defects existing before the fracture, where present, will match up across a fracture.
        ii. The meshing of pieces can be felt when two pieces will not slip past one another with gentle pressure.
        iii. The edges of meshing pieces will be examined to verify that fracture features such as Wallner lines match up across a fracture.
        iv. During reassembly, the pieces may be attached to one another with transparent tape.

B. The cause of fracture may be determined. Fractures are caused by thermal stresses, impacts, and bending. Manufacturing defects can also cause fracturing but are outside the scope of this document.
    1. Thermal fractures occur when heat is applied to an object unevenly, causing localized expansion or contraction which results in rupture. These fractures may be recognized by curved cracking which often develops a meandering path, cracks perpendicular to the surface, and a symmetrical mirror at the crack origin.
    2. High velocity impacts may be recognized by the development of a Hertzian cone. Increased velocity of the impact results in cracks radiating from the Hertzian cone, and possibly the development of concentric cracks.

3. Low velocity impacts may be recognized by the absence of a Hertzian cone, although a zone of crushing may be present; cracks radiating from the point of impact; and when enough force is applied, the development of concentric cracks.
4. Examine points of impact for residues and remove for further examinations, if necessary.
5. Bending may be recognized by a series of cracks which form sub-parallel to each other, and perpendicular to the breaking force.

C. The direction of breaking force in impacts and bending may be determined.
   1. Perforations of brittle objects by high velocity projectiles will produce a coning or cratering effect with the opening being larger on the exit side. Even when there is little or no loss of material, a ring-shaped crack forms at the point of impact, flaring outward with depth into the material.
   2. In low velocity impacts, radial cracks initiate opposite the side of the breaking force. Examine the crack face on radial cracks near the point of impact. Use the orientation of Wallner lines to determine the side of crack initiation. Wallner lines near the point of impact on radial cracks will initiate on the side opposite of the breaking force. Wallner lines on concentric cracks near the point of impact may also be used to determine the side of crack initiation, but these cracks initiate on the side of the breaking force. Other fracture features, such as cantilever curl, may be of some utility in determining direction of impact. In tempered or laminated glass, Wallner lines cannot be used to determine the side of crack initiation.
   3. In bending, cracks form perpendicular to the breaking force. As the object bends, cracks initiate on the convex side of the bend. Use the orientation of Wallner lines to determine the side of crack initiation. Other fracture features, such as cantilever curl, may be of some utility in determining direction of bending force. In tempered or laminated glass, Wallner lines cannot be used to determine the side of crack initiation.

D. A high-speed projectile striking an object at an angle produces a skewed Hertzian cone, shortened on the direction from which the projectile came, and elongated on the exit side.

E. The sequence of breakage can be determined by observing intersecting cracks.
   1. Only cracks which developed as a result of the breakage event need to be examined.
   2. New cracks terminate at preexisting cracks.
   3. If the stress that caused a crack continues after it terminates in a preexisting crack, a new crack may form on the other side of the preexisting crack, but it will jog. Wallner lines and twist hackle on the reinitiation crack are discontinuous with those on the arrested crack even when the jog is small.
   4. If crack systems from a series of impacts do not intersect, determining the sequence of the impacts in not possible.

F. If desired and feasible, overlay paper on both sides of impact areas and rub with pencil to preserve observations. At the discretion of the Geologist-Forensic Examiner, the object may be photographed.
    1. Specialized photography can assist in documentation of fracture features, especially on broken glass objects examined in situ.

G. Record all pertinent observations and measurements in case notes.

## 6 Limitations

A. Brittle fracture examinations can be severely restricted due to damage of the evidence that could occur from improper collection and preservation at the scene or during shipping.

B. It is usually impractical to reassemble tempered glass objects.

C. Glass objects held tightly in a frame may not exhibit primary Wallner lines perpendicular to the direction of breaking force.

## 7 Safety

A. Broken glass should be handled while wearing appropriate gloves and eye protection.

B. Ultraviolet (UV) light in the range of 254 nm is classified as UVC. Prolonged exposure to UVC light can cause burning of skin, cornea, and conjunctiva, and can also cause nuclear cataracts. Care must be taken to minimize exposure to UVC light. A laboratory coat and opaque gloves will be worn to protect the skin and use of the UVC light should be severely limited to reduce the potential for damage to the eyes.

## 8 References

ASTM. Standard Guide for Forensic Physical Fit Examination. E3392-24, 2024.

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FBI Laboratory Safety Manual (current version)

## 9 Revision History

| Revision | Issued | Changes |
|---|---|---|
| 04 | 09/01/2021 | Added “usually” to Section 1.1.<br>Updated Equipment list in Section 2.<br>Changed “Mineralogy” to “Geology” in Approval Section.<br>Updated TL in Approval Section. |
| 05 | 01/28/2022 | Reformatted entire document including updated references. |
| 06 | 01/02/2025 | Added ASTM E3392 reference.<br>Clarified 5F1. |