Research Paper

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GLASS FRACTURE DETECTION: NEW WAY TO UNFOLD THE NET OF CRIME

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ABSTRACT:

Glass is a non-crystalline, often transparent, amorphous solid that has widespread practical, technological, and decorative use in, for example, window panes, tableware, and optics. Glass is most often formed by rapid cooling (quenching) of the molten form; some glasses such as volcanic glass are naturally occurring. The most familiar, and historically the oldest, types of manufactured glass are "silicate glasses" based on the chemical compound silica (silicon dioxide, or quartz), the primary constituent of sand. Soda–lime glass, containing around 70% silica, accounts for around 90% of manufactured glass. The term glass, in popular usage, is often used to refer only to this type of material, although silica-free glasses often have desirable properties for applications in modern communications technology. Some objects, such as drinking glasses and eyeglasses, are so commonly made of silicate-based glass that they are simply called by the name of the material. Despite being brittle, buried silicate glass will survive for very long periods if not disturbed, and many examples of glass fragments exist from early glassmaking cultures. Archaeological evidence suggests glassmaking dates back to at least 3,600 BC in Mesopotamia, Egypt, or Syria. The earliest known glass objects were beads, perhaps created accidentally during metalworking or the production of faience. Due to its ease of formability into any shape, glass has been traditionally used for vessels, such as bowls, vases, bottles, jars and drinking glasses. In its most solid forms, it has also been used for paperweights and marbles. Glass can be coloured by adding metal salts or painted and printed with vitreous enamels, leading to its use in stained glass windows and other glass art objects. The refractive, reflective and transmission properties of glass make glass suitable for manufacturing optical lenses, prisms, and optoelectronics materials. Extruded glass fibres have application as optical fibres in communications networks, thermal insulating material when matted as glass wool so as to trap air, or in glass-fibre reinforced plastic (fibre glass).

KEYWORDS:

SILICATE GLASS, BROKEN GLASS, OBSIDIAN GLASS, DESERT GLASS, QUARTZ GLASS, BOROSIICATE GLASS, PYREX GLASS.

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MICROSCOPIC STRUCTURE:

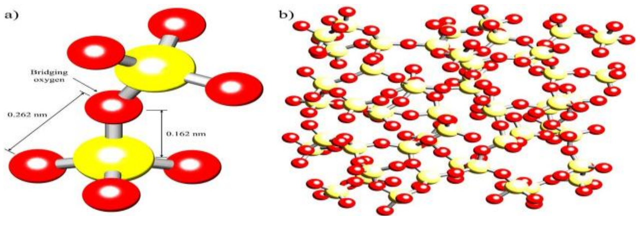


FIGURE-1: THE AMORPHOUS STRUCTURE OF GLASSY SILICA (SIO$_2$) IN TWO DIMENSIONS. NO LONG-RANGE ORDER IS PRESENT, ALTHOUGH THERE IS LOCAL ORDERING WITH RESPECT TO THE TETRAHEDRAL ARRANGEMENT OF OXYGEN (O) ATOMS AROUND THE SILICON (SI) ATOMS.

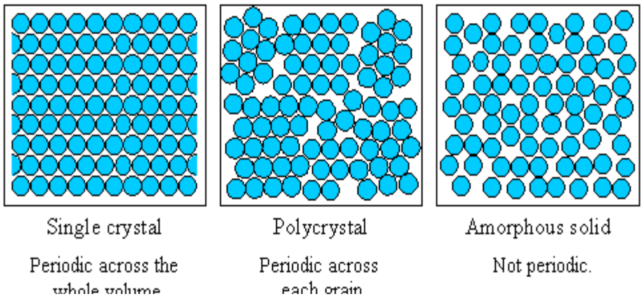


FIGURE-2: MICROSCOPICALLY, A SINGLE CRYSTAL HAS ATOMS IN A NEAR-PERFECT PERIODIC ARRANGEMENT; A POLYCRYSTAL IS COMPOSED OF MANY MICROSCOPIC CRYSTALS; AND AN AMORPHOUS SOLID SUCH AS GLASS HAS NO PERIODIC ARRANGEMENT EVEN MICROSCOPICALLY.

The standard definition of a *glass* (or vitreous solid) is a solid formed by rapid melt quenching. However, the term "glass" is often defined in a broader sense, to describe any non-crystalline (amorphous) solid that exhibits a glass transition when heated towards the liquid state.[1]

The United Nations has been dreaming of "Education for All" since the 1990s.The Millennium Development Goals (MDGs) have been replaced by the Sustainable Development Goals (SDGs). Up to the previous year, schools had only introduced printing presses and textbooks, but the epidemic has changed everything about education. COVID-19 has forced us to rethink our teaching and learning approaches. E-content development and rural students' access to it are currently the only issues.

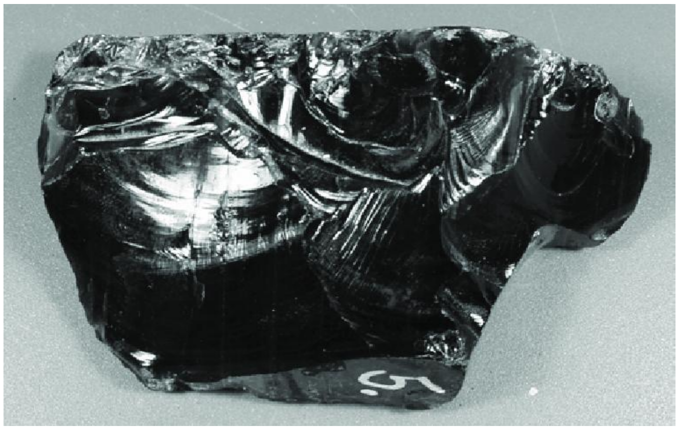
FIGURE-3: BROKEN GLASS

Glass is an amorphous solid. Although the atomic-scale structure of glass shares characteristics of the structure of a super cooled liquid, glass exhibits all the mechanical properties of a solid. As in other amorphous solids, the atomic structure of a glass lacks the long-range periodicity observed in crystalline solids. Due to chemical bonding constraints, glasses do possess a high degree of short-range order with respect to local atomic polyhedra. The notion that glass flows to an appreciable extent over extended periods of time is not supported by empirical research or theoretical analysis (see viscosity in solids). Though a material viscosity on the order of 10^{17}–10^{18} Pa s can be measured in glass, such a high value reinforces the fact that glass would not change shape appreciably over even large periods of time.[2]

Formation from a super cooled liquid: For melt quenching, if the cooling is sufficiently rapid (relative to the characteristic crystallization time) then crystallization is prevented and instead the disordered atomic configuration of the supercooled liquid is frozen into the solid state at T_g. The tendency for a material to form a glass while quenched is called glass-forming ability. This ability can be predicted by the rigidity theory. Generally, a glass exists in a structurally metastable state with respect to its crystalline form, although in certain circumstances, for example in atactic polymers, there is no crystalline analogue of the amorphous phase.[3]

Glass is sometimes considered to be a liquid due to its lack of a first-order phase transition where certain thermodynamic variables such as volume, entropy and enthalpy are discontinuous through the glass transition range. The glass transition may be described as analogous to a second-order phase transition where the intensive thermodynamic variables such as the thermal expansivity and heat capacity are discontinuous. However, the equilibrium theory of phase transformations does not hold for glass, and hence the glass transition cannot be classed as one of the classical equilibrium phase transformations in solids.[4]

Occurrence in nature: Glass can form naturally from volcanic magma. Obsidian is a common volcanic glass with high silica (SiO_2) content formed when felsic lava extruded from a volcano cools rapidly. Impactite is a form of glass formed by the impact of a meteorite, where Moldavite (found in central and eastern Europe), and Libyan desert glass (found in areas in the eastern Sahara, the deserts of eastern Libya and western Egypt) are notable examples. Vitrification of quartz can also occur when lightning strikes sand, forming hollow, branching rootlike structures called fulgurites. Trinitite is a glassy residue formed from the desert floor sand at the Trinity nuclear bomb test site. Edeowie glass, found in South Australia, is proposed to originate from Pleistocene grassland fires, lightning strikes, or hypervelocity impact by one or several asteroids or comets.[5]



A PIECE OF VOLCANIC OBSIDIAN GLASS

MOLDAVITE, A NATURAL GLASS FORMED BY METEORITE IMPACT, FROM BESEDNICE, BOHEMIA

TUBE FULGURITES

TRINITITE, A GLASS MADE BY THE TRINITY NUCLEAR-WEAPON TEST

LIBYAN DESERT GLASS

FIGURE-4: GLASS VARIETIES

PHYSICAL PROPERTIES:

Optical: Glass is in widespread use in optical systems due to its ability to refract, reflect, and transmit light following geometrical optics. The most common and oldest applications of glass in optics are as lenses, windows, mirrors, and prisms. The key optical properties refractive index, dispersion, and transmission, of glass are strongly dependent on chemical composition and, to a lesser degree, its thermal history. Optical glass typically has a refractive index of 1.4 to 2.4, and an Abbe number (which characterises dispersion) of 15 to 100. Refractive index may be modified by high-density (refractive index increases) or low-density (refractive index decreases) additives. Glass transparency results from the absence of grain boundaries which diffusely scatter light in polycrystalline materials. Semi-opacity due to crystallization may be induced in many glasses by maintaining them for a long period at a temperature just insufficient to cause fusion. In this way, the crystalline, devitrified material, known as Réaumur's glass porcelain is produced. Although generally transparent to visible light, glasses may be opaque to other wavelengths of light. While silicate glasses are generally opaque to infrared wavelengths with a transmission cut-off at 4μm, heavy-metal fluoride and chalcogenide glasses are transparent to infrared wavelengths of 7 to 18μm. The addition of metallic oxides results in different coloured glasses as the metallic ions will absorb wavelengths of light corresponding to specific colours.[6]

Other: In the manufacturing process, glasses can be poured, formed, extruded and moulded into forms ranging from flat sheets to highly intricate shapes. The finished product is brittle and will fracture, unless laminated or tempered to enhance durability. Glass is typically inert, resistant to chemical attack, and can mostly withstand the action of water, making it an ideal material for the manufacture of containers for foodstuffs and most chemicals. Nevertheless, although usually highly resistant to chemical attack, glass will corrode or dissolve under some conditions. The materials that make up a particular glass composition have an effect on how quickly the glass corrodes. Glasses containing a high proportion of alkali or alkaline earth elements are more susceptible to corrosion than other glass compositions. The density of glass varies with chemical composition with values ranging from 2.2 grams per cubic centimetre (2,200 kg/m^3) for fused silica to 7.2 grams per cubic centimetre (7,200 kg/m^3) for dense flint glass. Glass is stronger than most metals, with a theoretical tensile strength for pure, flawless glass estimated at 14 to 35 gigapascals (2,000,000 to 5,100,000 psi) due to its ability to undergo reversible compression without fracture. However, the presence of scratches, bubbles, and other microscopic flaws lead to a typical range of 14 to 175 megapascals (2,000 to 25,400 psi) in most commercial glasses. Several processes such as toughening can increase the strength of glass. Carefully drawn flawless glass fibres can be produced with strength of up to 11.5 gigapascals (1,670,000 psi).[7]

Reputed flow: The observation that old windows are sometimes found to be thicker at the bottom than at the top is often offered as supporting evidence for the view that glass flows over a timescale of centuries, the assumption being that the glass has exhibited the liquid property of flowing from one shape to another. This assumption is incorrect, as once solidified, glass stops flowing. The sags and ripples observed in old glass were already there the day it was made; manufacturing processes used in the past produced sheets with imperfect surfaces and non-uniform thickness (the near-perfect float glass used today only became widespread in the 1960s). A 2017 study computed the rate of flow of the medieval glass used in Westminster Abbey from the year 1268. The study found that the room temperature viscosity of this glass was roughly 10^{24} Pa-s which is about 10^{16} times less viscous than a previous estimate made in 1998, which focused on soda-lime silicate glass. Even with this lower viscosity, the study authors calculated that the maximum flow rate of medieval glass is 1nm per billion years, making it impossible to observe in a human timescale.[8]

TYPES

SILICATE:

FIGURE-5: QUARTZ IS THE MAIN RAW MATERIAL IN COMMERCIAL GLASS PRODUCTION

Silicon dioxide (SiO_2) is a common fundamental constituent of glass. Fused quartz is a glass made from chemically pure silica. It has very low thermal expansion and excellent resistance to thermal shock, being able to survive immersion in water while red hot, resists high temperatures (1000–1500°C) and chemical weathering, and is very hard. It is also transparent to a wider spectral range than ordinary glass, extending from the visible further into both the UV and IR ranges, and is sometimes used where transparency to these wavelengths is necessary. Fused quartz is used for high-temperature applications such as furnace tubes, lighting tubes, melting crucibles, etc. However, its high melting temperature (1723°C) and viscosity make it difficult to work with. Therefore, normally, other substances (fluxes) are added to lower the melting temperature and simplify glass processing.[9]

Soda–lime: Sodium carbonate (Na_2CO_3, "soda") is a common additive and acts to lower the glass-transition temperature. However, sodium silicate is water-soluble, so lime (CaO, calcium oxide, generally obtained from limestone), along with magnesium oxide (MgO), and aluminium oxide (Al_2O_3), are commonly added to improve chemical durability. Soda–lime glasses (Na_2O) + lime (CaO) + magnesia (MgO) + alumina (Al_2O_3) account for over 75% of manufactured glass, containing about 70 to 74% silica by weight. Soda–lime–silicate glass is transparent, easily formed, and most suitable for window glass and tableware. However, it has a high thermal expansion and poor resistance to heat. Soda–lime glass is typically used for windows, bottles, light bulbs, and jars.

Borosilicate: Borosilicate glasses (e.g. Pyrex, Duran) typically contain 5–13% boron trioxide (B_2O_3). Borosilicate glasses have fairly low coefficients of thermal expansion (7740 Pyrex CTE is 3.25×10^{-6}/°Cl as compared to about 9×10^{-6}/°C for a typical soda–lime glass). They are, therefore, less subject to stress caused by thermal expansion and thus less vulnerable to cracking from thermal shock. They are commonly used for e.g. labware, household cookware, and sealed beam car head lamps.

FIGURE-6: A PYREX BOROSILICATE GLASS MEASURING CUP

Forensic glass analysis is the application and analysis of glass to determine details about a crime. Glass evidence comes in many forms in various types of criminal cases. Glass can be analyzed to understand its origin using comparative analysis which may include measurements relating to physical match, refractive index, density and elemental analysis. It is also possible to analyze glass fractures to better understand the angle, direction and sequence of force as well as the projectile used.[10]

In case work: Glass analysis is applicable to a wide range of forensic cases. In burglary or rape cases, window pane may be broken and analyzed. In assaults, broken glass bottles may be found and analyzed in addition to glass fragments that may remain on clothing. Glass analysis is also applicable to motor vehicle crashes, particularly hit and run cases, as glass from headlights can be analyzed.

Collection from crime scenes: Depending on the form of the evidence, glass analysis can be collected in several ways. When possible, it is preferred that the entire item of evidence, such as a glass fragment or sweater with glass shards, is collected. Glass evidence can also take on the form of trace evidence. In these cases, trace evidence lifters, forensic vacuums or tweezers can aid in the collection of the glass evidence. Small glass fragments or shards can be secured in a pharmacist's fold and in an envelope. It is also important that the location from where the glass was recovered is noted. When it is suspected that an individual has small glass fragments on their person, their hair can be combed and caught on examination paper in an attempt to recover potential glass fragments. In addition to combing the hair, the individual can remove their clothes on examination paper which can then be sealed and saved for examination at a later time.[11]

METHODS OF FORENSIC ANALYSIS:

Comparative analysis: It is possible to compare multiple glass fragments using the techniques described below in order to understand if the glass fragments can be excluded as originating from the same source.

Physical match: Two glass fragments may be physically matched with one another. This may exclude the glass fragments from having originated from a different source.

Refractive index: The refractive index of a glass fragment may be determined and compared with that of another glass fragment in order to understand if they can be excluded from having originated from the same source. The refractive index can be determined using immersion methods as well as automated methods. Immersion methods entail the use of liquids with known refractive indices. The glass fragments are immersed in the liquids, often oils, and Becke lines are examined according to the Becke line test. Automated methods entail a camera and computer which make measurements of glass fragments in varying temperatures.[12]

Density: The density of a glass fragment can be determined using a density meter. The density of a glass fragment will depend on the batch characteristics and composition. Although, density is tested less frequently than refractive indices, it can be used to determine if two glass fragments more likely originated from a different source.

Elemental analysis: Many techniques can be used to understand the elemental composition of a glass fragment. Glass fragments from the same source have the same elemental composition and thus, elemental analysis enables an analyst to understand if multiple glass fragments likely do or do not originate from the same source. There are many techniques that can be used for elemental analysis of glass. These include scanning electron microscopy-x-ray spectroscopy, x-ray fluorescence spectroscopy, mass spectrometry, optical emission spectroscopy and inductively coupled plasma methods.

Glass fractures: Glass fractures can be analyzed in order to determine which side of the glass was force applied that ultimately resulted in its fracture. For example, determining which side of a window was smashed in order to because it to break may help crime scene investigators understand if someone broke in through the window or broke out through it. On the other hand, if there are multiple fractures on a pane of glass, they can be analyzed to determine what the order in which the fractures were made was. Analysis of glass fractures may also provide insight about the direction through which the projectile came from and may provide hints about what the projectile was that cause the fracture.

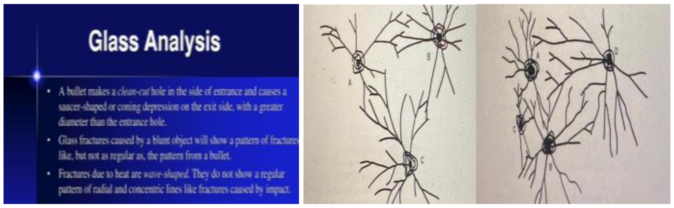
FIGURE-7: RADIAL AND CONCENTRIC FRACTURES IN GLASS FRACTURES

When a projectile, such as a rock or bullet, hits a pane of glass, radial and concentric fractures form. These are often the key components of glass fracture analysis.[13]

Projectile: When a high velocity projectile, such as a bullet, fractures a pane of glass, it can leave what is known as a cone fracture. A cone fracture is a hole in a glass pane surrounded by radial and concentric fractures. The hole is narrower at the point of entry and widens towards the exit point, giving the appearance of a cone.

Angle of force: The shape of the hole formed by a projectile may also give information about the angle through which the force was delivered. A symmetrical hole could be formed by a projectile hitting the glass at a 90 degree angle while elliptical holes can be formed by projectiles hitting a pane of glass from the left or right side.

Direction of force: The side from which a glass fracture was made can be determined by examining the radial fractures of a glass fracture. The 3R rule is used to make a determination about which direction a fracture was formed from. The 3R rule states "radial fractures make right angles to the rear." By examining the radial fractures and the direction in which they form a right angle, the rear side of the pane of glass (opposite the side the force was applied) can be determined.[14]



Glass Analysis

- A bullet makes a *clean-cut* hole in the side of entrance and causes a saucer-shaped or coning depression on the exit side, with a greater diameter than the entrance hole.
- Glass fractures caused by a blunt object will show a pattern of fractures like, but not as regular as, the pattern from a bullet.
- Fractures due to heat are *wave-shaped*. They do not show a regular pattern of radial and concentric lines like fractures caused by impact.

FIGURE-8: GLASS FRACTURE A WAS FORMED BEFORE B. THIS CAN BE DETERMINED BY EXAMINING THE AREA OUTLINED BY THE RED ARROW IN WHICH THE RADIAL FRACTURE OF B IS INTERRUPTED BY THAT OF A.

Sequence of force: When multiple fractures are made to a pane of glass, it is possible to understand the order in which those fractures were made by examining the radial fractures. Radial fractures end when they cross paths with another existing fracture line, thereby producing a method to understand the order in which multiple fractures were made.

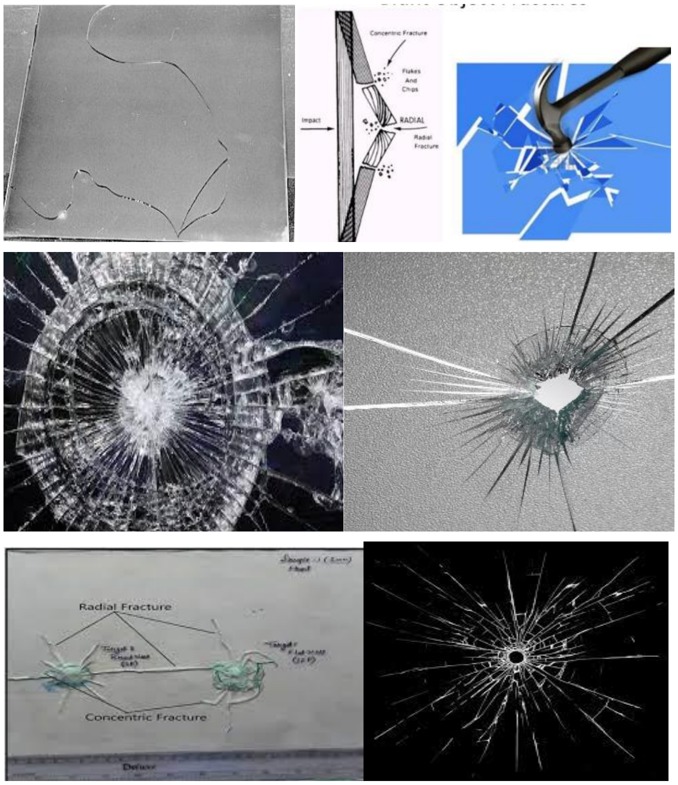


FIGURE-9: VARIOUS TYPES OF GLASS FRACTURES

CONCLUSION:

Glass or glass fragments serve as physical evidence of great value for the investigation of many offenses such as burglary, arson, hit and run cases, shooting, and assault. The glass bends when a force is applied on any one of its surfaces when its elasticity limit is reached then the glass fractures. Different characteristics are observed in the fractured glass like redial fracture, concentric fracture, cone fracture, etc. Glass fractures caused by the impact of bullets will reveal a pattern of radial, concentric, and cone fractures. Fracture in glass that is formed due to impact of blunt object will produce only radial and concentric fractures but there is no cone fracture. Glass fractures are created due to excessive exposure to heat do not show a regular pattern. So, from the pattern of the class fractures, we can identify the object which is penetrating through the glass. We can also identify the direction from where the object is coming from the fracture pattern. The density and refractive index are the most useful property of glass that helps in comparison. It has been established that the chances of two fragments of class, taken from two different crime sources are identical in density or not. Glass fractures are used to determine the force, direction, and sequence of impact on the glass fragments. Concentric fractures from rough circular shapes around the point of origin. Radial fractures are linear, extending from the center of the impact outward. The ridges (Wallner lines) on radial cracks nearest the point of impact are at right angles to the side opposite, or to the rear, of the impact. This phenomenon is referred to as the 4R rule, (Ridges on Radial cracks are at Right angle to the Rear.) The two types of fracture patterns are formed when a projectile hits glass surface – Radial and Concentric. Another type of fracture formed by penetration of high velocity of projectiles is cone fracture. This fracture is characteristics with wider on the exit side and smaller on the entry side of the bullet hole.

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Dr Viral A Prajapati (PharmD) and team are extremely excited to frame this article which is totally under forensic science *Glass fracture detection: new way to unfold the net of crime* because all are influenced with this song शीशा हो या दिल हो आख़िर टूट जाता है लब तक आते-आते हाथों से साग़र छूट जाता है. The entire project is guided by Prof Dr Dhrubo Jyoti Sen [Techno India University, School of Pharmacy, Kolkata].

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