International Journal of Convergent Research 2(1) January - June (2025)

IJCR
International Journal of Convergent Research

International Journal of Convergent Research

Journal homepage: International Journal of Convergent Research

A Review: Case Studies Involving Glass Evidence

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Citation: Yadav, K., Arsh, A., Maitra, B., Sinha, A., Agarwal, S., & Vanshika. (2025). Review: Case studies Involving Glass Evidence. *International Journal of Convergent Research, 2*(1). 24-33.

ARTICLE INFO

Received: 24th April 2025
Accepted: 14th July 2025

ABSTRACT

This paper reviews forensic case studies highlighting the pivotal role of glass evidence in criminal investigations. Focusing on five diverse cases, it explores how meticulous forensic analysis of glass can uncover crucial details, such as the direction of impact, the sequence of events, and potential sources of contact. The paper outlines the primary methods used in forensic glass analysis, including refractive index measurement, elemental analysis and density gradient techniques. Each method's role in establishing connections or exclusions is evaluated in the context of the cases presented. This study highlights the forensic value of glass evidence in linking suspects to crime scenes and reinforces the need for precision to avoid misinterpretation and investigative delays.

Keywords: Glass, glass evidence, glass fracture, case study, vehicular crime.

INTRODUCTION

Glass evidence has emerged as an indispensable tool in the domain of forensic science, particularly in the investigation of crimes involving burglary, vehicular incidents, armed robbery, and violent physical confrontations. As a material that is omnipresent in modern settings—ranging from architectural structures and automotive components to household items and electronic devices—glass is not only susceptible to breakage but also prone to transfer. When shattered, microscopic glass fragments can adhere to clothing, skin, and objects, facilitating an inadvertent exchange between individuals and the environments they interact with. This transference makes glass an excellent form of trace evidence, providing a tangible connection between suspects, victims, and crime scenes. Given the dynamic and often violent nature of criminal acts, glass fragments frequently become embedded in the physical narrative of the crime, offering forensic experts an avenue for reconstructing events and establishing associative links.

Forensic glass analysis hinges on the inherent variability of glass compositions. Though glass may appear homogeneous to the naked eye, it is in fact a heterogeneous material, with properties influenced by its source materials, manufacturing techniques, and intended use. Differences in elements such as sodium, calcium, silicon, and trace metals contribute to distinct chemical fingerprints for each piece of glass. These fingerprints, once identified, can be compared across samples to determine whether two fragments share a common origin. This scientific capability empowers forensic professionals to move beyond circumstantial evidence, allowing for precise, evidentiary connections that can hold weight in judicial proceedings.

In forensic practice, multiple methodologies are employed to analyze glass. These include—but are not limited to—fracture pattern analysis, refractive index (RI) measurement, scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDX), density testing, and trajectory or impact analysis. Each technique offers a unique perspective, contributing to a multi-dimensional understanding of the sample in question. For instance, fracture pattern analysis enables experts to determine the direction, angle, and sequence of impact that led to glass breakage. This can help ascertain whether a glass pane was broken from the inside or outside, or whether multiple impacts occurred. Meanwhile, refractive index analysis, a well-established method, involves immersing glass fragments in a calibrated liquid and observing the match or mismatch of

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light refraction, thereby facilitating sample comparison.

Additionally, SEM-EDX allows for microscopic and elemental analysis, helping to uncover minute structural features and compositional nuances that are invisible to traditional microscopes. This level of scrutiny is crucial when attempting to differentiate between glasses of similar appearance but different manufacturing sources. Density assessments further contribute to classification efforts, as variations in constituent materials affect the mass-to-volume ratio of glass samples. When combined, these techniques create a robust framework for forensic interpretation.

To contextualize the relevance and practical application of these analytical techniques, this paper explores five real-world case studies in which forensic glass analysis was instrumental in solving complex criminal cases. These case studies, drawn from varied crime types and geographical contexts, demonstrate how detailed scientific investigation of glass fragments enabled law enforcement to identify suspects, understand crime scene dynamics, and, ultimately, secure convictions.

The first case involves a nighttime burglary at a commercial retail store. Investigators discovered that a large display window had been smashed, and several items were stolen. Although there were no eyewitnesses, a suspect was later apprehended whose clothing bore small glass particles. Forensic analysis using refractive index measurement and SEM-EDX confirmed that the glass on the suspect's jacket was compositionally identical to the shattered window at the crime scene. This direct evidence substantiated the suspect's presence at the location during the time of the break-in, contributing significantly to the prosecution's case.

In the second case, a high-speed vehicular accident resulted in the deaths of two passengers, while the driver fled the scene. The front windshield had shattered on impact. When a person was later taken into custody under suspicion, glass fragments embedded in his scalp and clothing were analyzed. Trajectory analysis of the glass pattern and density testing revealed that the fragments likely came from a windshield, and matched the broken windshield found at the crash site. This finding linked the suspect to the driver's seat position and helped reconstruct the accident sequence.

The third case involved a domestic assault, wherein the victim was injured by a thrown glass object. Police found glass shards on the floor and on the assailant's hand. Using fracture pattern analysis and SEM-EDX, forensic scientists demonstrated that the glass on the suspect's hand aligned perfectly with the fractured rim of the broken object. This evidence corroborated the victim's testimony and was instrumental in establishing intent and culpability in the courtroom.

The fourth case study pertains to a shooting incident where the victim was inside a vehicle and the bullet had passed through the passenger window. Investigators sought to determine the trajectory of the bullet and whether the shooting occurred from outside the vehicle or was staged. Forensic experts analyzed the radial and concentric fracture lines on the glass and used impact cone geometry to determine the bullet's direction. Combined with SEM analysis of the gunshot residue and glass particles on the suspect's clothing, the investigation concluded that the shot originated from outside, dispelling the defense's claim that it was self-inflicted or accidental.

The final case concerns an attempted arson at a residential property. Entry had been gained by breaking a small kitchen window. Investigators retrieved glass fragments from the inside of the house and from the gloves found in a suspect's possession. Refractive index comparisons and elemental analysis revealed that the fragments on the gloves had a unique composition matching the kitchen window glass, including traces of specific stabilizers used in heat-resistant glass found only in that building's renovation materials. This forensic link directly implicated the suspect in the unlawful entry and subsequent arson attempt.

These case studies highlight not only the versatility of forensic glass analysis but also its power to provide definitive, science-backed conclusions. They also underline the critical importance of meticulous collection and preservation of trace evidence at crime scenes. In each of the cases reviewed, it was the combination of advanced analytical techniques and methodical investigative procedures that enabled authorities to reconstruct events with clarity and confidence.

As forensic science continues to evolve, there is a growing emphasis on refining analytical tools to increase accuracy, reduce error margins, and address challenges such as sample contamination or environmental degradation. Techniques like laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) are being explored to provide even more precise elemental profiling. Such advancements promise to expand the evidentiary potential of glass and other trace materials, reinforcing their value in modern forensic investigations.

Glass evidence, when analyzed through rigorous scientific methods, holds immense potential for revealing hidden narratives within criminal acts. As illustrated by the case studies in this paper, forensic glass analysis is a vital pillar in the pursuit of justice—one that bridges the gap between crime scene and courtroom by transforming tiny, seemingly insignificant fragments into powerful tools of truth. Continued investment in training, instrumentation, and interdisciplinary collaboration is essential to keep this forensic frontier robust and responsive to the ever-changing landscape of crime and technology.

LITERATURE REVIEW

The forensic analysis of glass evidence has attracted significant scholarly attention due to its vital role in modern criminal investigations. Historically, the foundational principles of forensic glass examination were grounded in trace evidence theory as proposed by Locard, which emphasized the exchange principle—any contact between individuals and objects results in a transfer of material. This principle has guided the collection and interpretation of glass evidence for decades. Over time, researchers began to explore more refined techniques for analyzing glass, including physical, chemical, and optical methodologies. One of the most widely studied and implemented techniques is refractive index (RI) measurement. According to Koons and Buscaglia (2002), the use of hot-stage microscopy to determine RI values allows forensic scientists to distinguish between glass samples from different sources with high precision. The GRIM system, in particular, has been validated through multiple inter-laboratory studies for its reliability and repeatability in forensic casework.

In addition to RI measurement, advancements in elemental analysis have significantly enhanced the discriminatory power of forensic glass examination. Studies by Almirall et al. (2005) and Trejos et al. (2013) have shown that techniques such as Energy-Dispersive X-Ray Spectroscopy (EDX) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) provide detailed elemental profiles of glass fragments, enabling differentiation even between glasses manufactured by the same company. These analytical approaches have been praised for their sensitivity and specificity, although they require careful calibration and control of surface contamination. SEM-EDX, in particular, has been used not only for compositional analysis but also for observing surface morphology and fracture characteristics, adding a structural dimension to chemical profiling. The integration of these tools has become common practice in many forensic laboratories globally, supporting their continued relevance in complex case scenarios.

Physical comparison techniques, particularly fracture pattern analysis, also play a significant role in forensic interpretations. Pioneering work by Thornton (1974) and subsequent research by Brodbeck and Karger (1990) laid the groundwork for understanding radial and concentric fractures, determining the direction and sequence of impacts, and estimating the angle and force involved in glass breakage. These studies emphasized the forensic value of fracture lines in reconstructing events at crime scenes, especially in shooting and explosive cases. Further enhancements in this domain have come through 3D imaging and digital reconstruction technologies that allow forensic experts to virtually simulate and visualize breakage events.

Density assessment, though considered a supplementary tool, has been historically used in forensic science due to its simplicity and effectiveness in classifying glass types. Studies by Stoney and Thornton (1985) suggested that density measurements, when used alongside RI and elemental analysis, improve the evidentiary strength of comparisons. Although modern techniques have overshadowed it in terms of precision, density analysis remains valuable in initial screening and bulk comparison processes.

Trajectory analysis has recently gained prominence due to its application in firearm-related investigations and vehicular crime reconstructions. Forensic scientists such as MacDonell (1997) and more recently Curran et al. (2011) have explored the use of trajectory reconstruction tools, including laser alignment kits, to deduce the path of projectiles through glass. These methodologies have shown significant utility in determining shooter positioning, angle of attack, and sequence of events, particularly when glass is a barrier between the victim and the assailant. The literature also underscores the need for multidisciplinary integration, combining ballistic knowledge with fracture mechanics for more accurate crime scene reconstruction.

In sum, the body of literature surrounding forensic glass analysis is rich and evolving, with each method offering unique contributions to the interpretation of trace evidence. From the optical assessments pioneered in the 20th century to the current integration of chemical and structural analysis techniques, the field has progressed to accommodate the demands of contemporary forensic challenges. The reviewed studies collectively highlight the importance of using multiple complementary techniques to increase the evidentiary value of glass fragments. This multi-modal approach not only enhances the accuracy and specificity of findings but also strengthens the admissibility of glass evidence in court proceedings. As forensic science continues to evolve, there is a growing call for the refinement and standardization of protocols to ensure consistency and scientific rigor across laboratories worldwide.

METHODOLOGY

The forensic analysis of glass evidence is an intricate process involving a series of scientific techniques, each of which contributes uniquely to the identification, characterization, and comparison of glass fragments. As glass is a highly variable and ubiquitous material, its forensic examination requires precision tools and multidisciplinary approaches. The methodologies used in forensic laboratories span optical, physical, and chemical domains—each offering specific insights that can link evidence to crime scenes or individuals with high degrees of certainty. Among the most widely utilized techniques are Refractive Index (RI) measurement, elemental composition analysis through energy-dispersive X-ray spectroscopy (EDX) and scanning electron microscopy (SEM), as well as physical comparison techniques such as fracture pattern analysis, density assessment, and trajectory mapping. These combined methods form a robust forensic toolkit capable of producing scientifically valid and courtroom-admissible evidence.

One of the most fundamental and widely applied techniques in glass forensics is the measurement of the refractive index (RI) of a glass fragment. This optical property indicates how light bends as it travels through a glass medium and is highly sensitive to the glass's internal composition and structure. RI measurement provides a discriminating metric for comparing fragments from different glass sources. The most common instrumentation used for this purpose is the Glass Refractive Index Measurement (GRIM) system. This system employs a hot-stage microscope setup wherein the glass fragment is immersed in a calibrated immersion oil. The temperature is gradually increased until the refractive index of the oil matches that of the glass fragment—indicated by the disappearance of the Becke line under the microscope. This match point allows for the precise calculation of the RI.

The reliability and precision of RI measurements make it a cornerstone of forensic glass analysis. When used under controlled environmental conditions, especially with regulated temperature, the GRIM system can produce reproducible RI values with high levels of accuracy. However, external factors like contamination or improper temperature control can affect the measurement. Therefore, forensic practitioners often use RI values in conjunction with additional techniques to increase discriminatory power. A compelling case study showcasing the utility of this method involves a motor vehicle accident where glass fragments embedded in the victim's skull were analyzed using RI measurement. The analysis was pivotal in linking the fragments to a specific car windshield, ultimately contributing to the reconstruction of the crash dynamics and confirming the location of impact relative to the victim's position.

Complementing the optical analysis is the elemental analysis of glass, which uncovers the chemical "fingerprint" of the material. Elemental profiles are highly discriminating, as glass composition varies significantly depending on manufacturing processes, additives, and the intended use of the product. A primary method for conducting such analyses is Energy-Dispersive X-Ray Spectroscopy (EDX), often coupled with a Scanning Electron Microscope (SEM). In EDX, a focused electron beam bombards the sample, exciting the atoms in the material, which then emit X-rays characteristic of the elements present. This allows forensic analysts to identify and quantify the elemental composition of a glass fragment with considerable specificity.

The integration of EDX with SEM adds another layer of analytical depth. While EDX delivers elemental composition, SEM provides detailed, high-resolution imagery of the surface morphology of glass samples. The electron beam in SEM creates a range of signals—secondary electrons for topographical mapping, backscattered electrons for compositional contrast, and characteristic X-rays for EDX analysis. This dual approach facilitates not just comparison of chemical profiles but also detailed structural analysis of fracture lines, surface deposits, or manufacturing defects. However, the technique requires careful sample preparation and may be affected by surface contamination, which can mask the true elemental composition.

In addition to optical and chemical properties, physical comparison and pattern analysis play a critical role in forensic glass investigations. One of the key approaches is fracture pattern analysis, which involves the examination of radial and concentric fractures created when a glass object breaks. This analysis provides valuable information about the direction and force of impact. For instance, the side of glass that experiences the initial impact will exhibit radial fractures extending from the point of force and concentric fractures forming as secondary stress relief. By studying these patterns, forensic analysts can determine whether the glass was broken from the inside or outside, how many impacts occurred, and the likely sequence of breakage events—information that is invaluable in violent crimes, shootings, or explosions.

Closely related to fracture analysis is the assessment of glass density, which helps in the classification and comparison of fragments. Density testing is typically performed using a density gradient column, a tube filled with a liquid gradient of known densities. When glass fragments are introduced into the column, they settle at the point in the gradient that matches their own density. This provides a quick and effective method to compare unknown fragments to control samples or known glass sources. While not as discriminating as elemental analysis, density assessment remains useful, particularly when RI values overlap or when corroborating other findings.

One of the more advanced and scenario-specific physical methods is trajectory analysis, particularly relevant in cases involving projectile impacts such as bullets or thrown objects. Trajectory analysis involves reconstructing the path taken by a projectile as it passes through or impacts a glass surface. Investigators employ tools such as laser trajectory kits, which allow them to align the entry and exit points of glass breakage to determine angles of impact. From this, analysts can calculate discharge angles, the height of the shooter, and the relative positions of individuals at the crime scene. Such reconstructions are crucial in firearm-related incidents, where understanding the trajectory can either support or contradict witness testimonies and suspect narratives.

These analytical techniques are not used in isolation; rather, they form a composite methodology where multiple lines of evidence are synthesized to arrive at a comprehensive forensic conclusion. For example, in a shooting case, refractive index data might establish that a fragment came from a vehicle's side window; SEM-EDX might confirm that the fragment contains specific trace elements consistent with that manufacturer; fracture patterns might reveal the bullet's point of entry, and trajectory analysis could identify the shooter's position. Together, these methods transform a microscopic fragment of glass into a powerful piece of evidence capable of anchoring a forensic narrative.

As forensic technology advances, newer methods such as Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) are also being introduced to perform more precise elemental profiling with minimal sample destruction. These advanced methods hold promise for even greater accuracy and discrimination, but the foundational techniques outlined here continue to provide essential insights in forensic practice.

In summary, the methodology of forensic glass analysis is multi-faceted, integrating optical, elemental, and physical examinations to establish the identity, origin, and contextual relevance of glass fragments. Each method contributes uniquely to the forensic process, and when used collectively, they form a powerful evidentiary toolkit capable of reconstructing events, linking suspects to crime scenes, and upholding the integrity of criminal investigations.

RESULTS AND DISCUSSION

The application of forensic glass analysis techniques has proven essential in many case studies, illustrating the forensic significance of glass evidence. Here, we examine notable cases where glass analysis was pivotal in solving crimes:

Case Studies

Case study 1: Fire in the Hole (Lucien C. BS. Haag, March 2012)

In this recent shooting case, a man was fatally wounded in the front passenger seat of a Lincoln Navigator. The shot was fired by a police officer positioned near the vehicle's front right fender or side mirror. The officer claimed the victim was aiming at a weapon, justifying the shot, while witnesses alleged the victim's hands were raised in surrender. The primary forensic challenge was to determine the victim's arm position at the time of the incident. Forensic experts focused on forward and backward fragmentation patterns to reconstruct the victim's position when the bullet penetrated the passenger window.

Key findings included:

i. Forward and Backward Fragmentation: The bullet passed through the tempered glass of the front passenger window before hitting the victim. The angle of the impact caused a specific forward and backward dispersion pattern of glass fragments. Backward fragmentation, with shards directed into the vehicle, resulted in "pseudostippling" on the victim's left forearm, showing where glass particles impacted the skin, similar to a stippling effect from gunpowder.

ii. Trajectory and Fragment Path Analysis: The angle of the window, tilted inward by about 20 degrees, influenced the downward trajectory of glass particles into the vehicle. This trajectory meant that glass particles would primarily affect areas below the path of bullet, impacting the victim's left arm and shoulder region while leaving the right arm below the path of fragmentation.

iii. Autopsy and Forensic Analysis: Autopsy findings showed pseudostippling on the left forearm, but none on the right. This detail, combined with trajectory analysis, indicated that the victim had his right arm below the path of glass fragments, consistent with a position where he might have been holding an object rather than having his hands raised.

The distribution of glass fragments and the lack of injury to the right arm suggested that the victim's arms were not raised. The pseudostippling pattern supported the officer's account that the victim's arms were in a position consistent with handling a weapon at the time of the shot. Consequently, the forensic findings concluded that the victim was likely in a posture where he could have been perceived as posing a threat to the officer. This case underscores the importance of forward and backward glass fragmentation analysis in reconstructing events and determining positions in shooting incidents.

Figure 1: *Impact of Glass on Bullet*

Figure 2: *A shot passing through windshield*

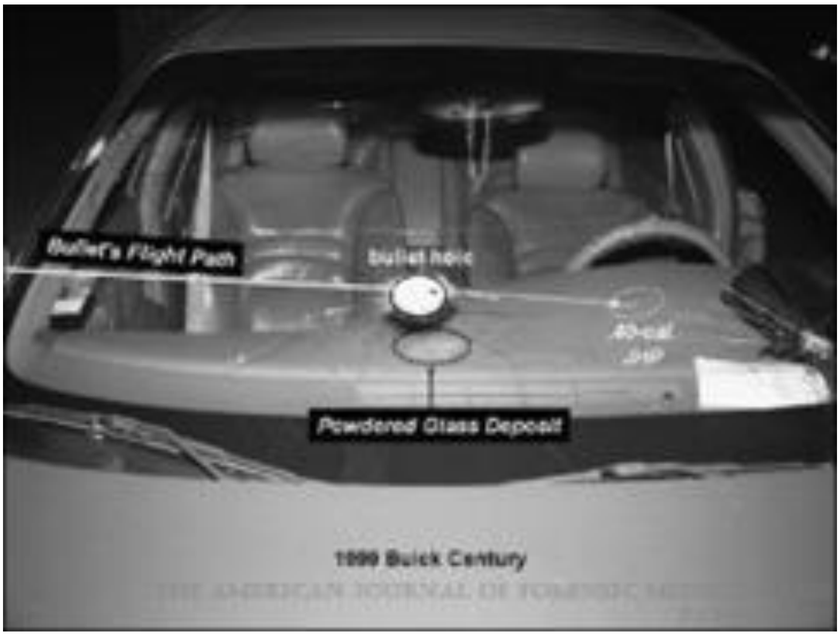

Figure 3:

A: A stand-in representing the decedent in the Lincoln Navigator, illustrating the shooter's version of the subject's position at the time of firing his .38 Special revolver.

B: A stand-in for the decedent in the Lincoln Navigator, reflecting the position of the subject at the moment of the shooting, as described by other occupants of the vehicle.

Case study 2: Glass Penetrating Skull Injury mimicking Projectile Injury (Ryan Blumenthal, 2022)

This case centres on a fatal motor vehicle accident involving a 29-year-old male driver in May 2021. The vehicle overturned and collided with a wall, causing fatal head trauma. A notable complication in the case arose due to a small glass shard that penetrated the left occipital region of the victim's skull, mimicking a projectile wound. This unusual injury raised questions about the cause, and without the glass fragment embedded in the wound, it could easily have been mistaken for a gunshot wound or similar projectile injury.

The forensic analysis of the glass fragment was essential in distinguishing the trauma as accidental rather than ballistic. Various glass analysis methods were employed to verify the glass source, study the fracture pattern, and clarify the injury's origin:

i. Microscopic Examination: This helped analyse the size, shape, and edges of the glass fragment,revealing fracture characteristics like hackle marks, striations, and break patterns. These findings indicated a blunt force impact rather than a high-velocity projectile, supporting the conclusion that the injury was accidental.
ii. Refractive Index (RI) Measurement: The Refractive Index of the glass fragment was compared to the car's windshield or window glass to confirm its source. The unique RI properties of automotive glass were crucial in identifying the shard as originating from the vehicle.
iii. Density Gradient Analysis: By determining the density of the glass shard and comparing it with other glass samples from the vehicle, analysts confirmed that it matched the type of glass used in the car’s windshield, thereby linking it directly to the accident scene.
iv. Elemental Analysis (EDS or ICP-MS): This technique helped identify the elemental composition of the glass. Windshield glass has distinct elemental properties due to specific manufacturing processes, enabling analysts to confirm it as automotive glass.
v. Fracture Pattern Analysis: Analysts examined the radial and concentric fractures on the glass. Unlike the distinct patterns of high-velocity impacts, the fractures from this incident showed irregular patterns characteristic of a blunt force accident, helping to differentiate it from a ballistic injury.

Detailed forensic glass analysis provided critical insights, allowing examiners to determine that the fatal injury was due to accidental trauma rather than a projectile. This case highlights the importance of thorough forensic analysis in accurately interpreting unusual injuries.

Figure 4: *A tiny glass fragment that entered the left occipital area of the skull.*

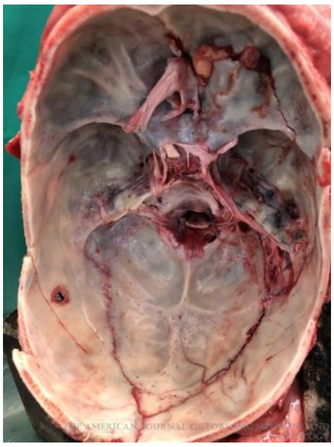

Figure 5: *This bone defect exhibits inward beveling. A small glass fragment is observed at the centre of the wound.*

Case study 3: The Hit-and-Run Case of Susan Nutt (Tatiana Trejos, Waleska Castro, Jose r. Almirall,2010-17-19; Panadda, C. Ratchapak and P. Nathinee,2018)

In February 1987, 19-year-old Craig Elliott Kalani was killed in a hit-and-run incident while walking his dog in his neighbourhood in northwest Oregon. His body was discovered later that night, and police found glass fragments near the scene & in Craig's pockets. This evidence became a crucial lead in the investigation. The police began searching for a vehicle that was involved in the hit-and-run. They located a car owned by Susan Nutt that had damage from a hit-and-run collision. To link the vehicle to the crime, investigators needed to match the fragments of glass found at the scene to Susan's car.

Forensic experts first performed a physical match of the glass fragments to the damage on Susan’s car. Later, a more detailed elemental analysis was carried out, revealing that the glass fragments from both the crime scene and Susan’s car was composed of the same 22 chemical elements. This analysis confirmed that the glass fragments came from Susan's car. Based on this evidence, Susan Nutt was convicted in connection with the hit-and-run death of Craig Kalani. She received a sentence of up to five years in prison, followed by a five-year probation period.

This case demonstrates how forensic techniques, including physical matching and chemical analysis, can be used to link evidence to a suspect in criminal investigations.

Case study 4: The Jigsaw Case (J. M. Curran, T. N. Hicks, J. S. Buckleton, 2000)

A suspected hit and run case involving a dead cyclist was found on a poorly lit local road in July, 1972. Various evidences including large glass fragments and the victims’ clothes were recovered from the crime scene. Few days later, a glass sample was recovered from a suspect’s car.

The large glass fragments showed a characteristic pattern for headlamps and in some a serial code was seen. A “jigsaw fit analysis” was done to match the glass fragments with each other. On examination with a comparison microscope, the edges of the glass fragments formed during the breaking matched with the fragments that have been fitted with the jig saw analysis. The serial codes of the glass fragments discovered earlier were found to be characteristic of a certain type of car similar to that of the suspect’s car. But since matching was not possible, a physiochemical test was done that revealed that it was from the same car.

The glass fragments from the victim’s clothes were subjected to similar analysis and the likelihood ratio justified the hypothesis that it had originated from the suspect’s car which led to the conclusion that the car was connected to the hit and run case.

Case study 5: Determination of Headlamp State (P. Baudoin, R. Lavabre, 1996; R. Goebel, 1975)

In November 1979, two cars collided to each other after dark. The driver of the car who drove into the other testified that he hadn’t seen the other car owing to its headlights being switched off which was immediately disputed. In order to check the viability of the statement, the bulbs were sent to the laboratory.

The determination of the dispute could be made by whether the glass envelope was broken during the collision or in case of no breakage, the experts determine any deformations or presence of any specific coating on the tungsten filament.7 The presence of dark blue, reddish violet coating8 due to reaction of tungsten with oxygen or a fragment of melted glass indicates that the bulb was turned on during the collision. On examination the following observations were made:

i. Stereo-Magnifying Glass: Glass envelope was found broken
ii. A single object of 1mm melted onto the filament was noticed which was detected spectroscopically via Scanning Electron Microscope.

These conclusions proved that the headlights were on during the collision. Absence of the tungsten oxides could be attributed to the fact that it could be lost during packing or transporting of the damaged bulb.

CONCLUSION

This review of forensic case studies emphasizes the critical role that thorough and accurate analysis of glass evidence plays in criminal investigations. Across the cases presented, meticulous examination of glass fragments—whether through refractive index measurements, elemental profiling, or density comparisons—proved essential in linking suspects to crime scenes and reconstructing sequences of events. These findings underscore the need for forensic practitioners to apply established glass analysis techniques consistently and with precision to avoid misinterpretations, as illustrated by the case where flawed analysis led to investigative complications.

We hope that these insights will encourage enhanced training, stricter adherence to methodological standards, and increased awareness within the forensic community, ultimately strengthening the reliability and impact of glass evidence in criminal justice.

ETHICAL DECLARATION

Conflict of interest: The authors declare that there is no conflict of interest regarding the publication of this paper.
Financing: This research received no external funding.
Peer review: Double anonymous peer review.

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