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Forensic materials and test methods

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Abstract

In recent years, forensic engineering, a growing field of engineering, has developed. If the product malfunctions prematurely, the user will not be able to use that product, and sometimes it may lead to personal injuries. Sophisticated techniques such as SEM and DSC are used to study these problems. Forensic engineers evaluate documentary evidence so that the court can make the right decision. In this study, forensic materials and test methods are discussed. For this purpose, first, the concept of Forensic Engineering was introduced and the defects occurring in the products were examined. Then, in case of a dispute between the parties, it is explained how forensic engineers examine the products and prepare an expert report to resolve the dispute. Finally, how and with which devices macroscopic and microscopic tests, mechanical and thermal tests were performed were examined.

Keywords: Forensic materials & engineering, Design & manufacture, Defects, Testing, Litigation

1. Introduction

In recent years, forensic engineering has developed, a field of engineering that has grown significantly as artifact employers demand rising degrees of excellence. Early artefact breakdown will not only deny the employer of that artefact but may also cause individual injuries and additional harmful outcomes. For example, if a ladder fails, the user may fall and be injured. Or, if the radiator of a novel auto does not cool quickly and the mechanism fails, the car holder will seek compensation.

Those are all instances of troubles where the forensic engineer can make an impartial and empirical aid by supporting to study and reveal the reason of the crash. Techniques such as SEM (scanning electron microscope) and DCS (differential scanning calorimeter) are used to study these problems. For the court to make the right decision, the evaluation of documentary evidence is done by forensic engineers.

Forensic materials and test methods are discussed in this study. For this purpose, firstly, Forensic engineering was introduced and primary and secondary defects occurring in the products were examined. Then, after mentioning why the products are tested, it is explained how Forensic engineers examine the products and prepare the expert report to resolve the dispute in case of disagreement between the parties. Finally, how and with which devices the macroscopic, microscopic, mechanical, and thermal tests were performed were examined.

Looking at the definition of forensic engineering, forensic engineering can mean "concerning to engineers linked with lawful inquiries." The forensic engineer deals with the following legal investigations:

- Product failure (for example, a critical part of a product breaks)
- Process error (for example, failure of a production process to achieve the desired goal)
- Design error (for example, premature failure of the product)

However not wholly similar crashes initiate lawsuit. For example, a sudden flaw for instance a radiator leak may appear on a new car. If under warrant, the dealer will restore the destruction at no charge to the user. Parts with restricted lifespans are replaced usually as a precaution, and others (such as car tires) are substituted when wear becomes evident and hazardous. However, some faults are more critical than others because of what they may involve. For most failures, it is forensic engineering techniques that can detach the reason of the disappointment. Act can then be taken to relieve the trouble (1–3).

So, what are the fundamental techniques of identifying crash types? For example, when an auto won't initiate a freezing, wet dawn, there are several potential descriptions that suggest itself. The battery may not be entirely attacked, so the machine may not start over, and the spark plugs may not ignite the fuel vapor in the engine. On the other hand, fuel may not be affecting the engine since the container is blank. In the second example, a fire broke out in the engine compartment of a car; examination shows a leakage in the polymer oil tube. This leakage could be due to various possibilities such as use of incorrect materials, getting older, or corrosion. Such a fault is evidently security crucial, and merits allocated study to decide its reason.

If micro-cook stoves and individual PCs, among the machines used in the home environment, malfunction, their user manuals should be read first. Computers often come with their own "help" instructions within the package; It's useless if the computer itself collapses! If there is an electro- mechanical influence inside the mechanism, even the written manuals provided with the machine are of no use.

Troubleshooting guides for vehicles (Table 1) indicate numerous probable sources for a particular sign. For example, the figure lists five common symptoms for the cooling system and gives possible causes for each. Here, the defective section must be rapidly identified, and corrective proceedings undertaken. Another example is spilling coffee on the computer keyboard; failure is almost inevitable as water is conductive and is liable to crack the underlying printed circuit.

Table 1. Worksheet for engine heating and cooling failure [1]

<table>
<tr><th colspan="2">Cooling Systems Faults</th></tr>
<tr><td>Overheating
-Insufficient cooling in system or thermostat faulty
-Radiator core blocked or grill restricted
-Electric cooling fan or thermos switch faulty
-Valve clearances incorrect
-Pressure cap faulty
-Ignition timing incorrect/ignition system fault
-Inaccurate temperature gauge sender unit
-Airlock in cooling system</td><td>External Coolant Leakage
-Deteriorated or damaged hoses or hose clips
-Radiator core or heater matrix leaking
-Pressure cap faulty
-Water pump seal leaking
-Boiling due to overheating
-Core plug leaking</td></tr>
<tr><td rowspan="2">Overcooling
-Thermostat faulty
-Inaccurate temperature gauge sender unit</td><td>Internal Coolant Leakage
-Leaking cylinder-head gasket, cracked cylinder head or cylinder bore</td></tr>
<tr><td>Corrosion
-Infrequent draining and flushing
-Incorrect coolant mixture or inappropriate coolant</td></tr>
</table>

Fabrication is about making artefacts to an identifiable requirement. For example, the inability to obtain an artifact that can continue in the conditions must be addressed at a premature phase of artifact design. This is the artifact need recognition phase, afterwards the projection and modelling phase. Assessing and estimation initiates a pattern suitable for fabrication. Once an effective pattern appears, fabrication can be proposed. Any failure in product quality requires instant consideration from the design group. Fault analysis utilizing forensic approaches is set to detecting and correcting any design faults or manufacturing deficiencies.

A tool that finds and eliminates product defects is distinguished as Pareto research [2]. The basis of the analysis is collecting fault data from the production line and dividing this data into general groups. Analogous statistical approaches now form part of consistency engineering, alternative instrument of total quality management or TQM [2]. The group can then focus on the most critical flaws operating defect tree evaluation. A reported process when affected in the mass production industry is CEDAC (cause-effect-effect with cards inserted), which uses diagrams like the one shown in Figure 1. and flowcharts like the one revealed in Figure 2. to discover "root causes" [2].

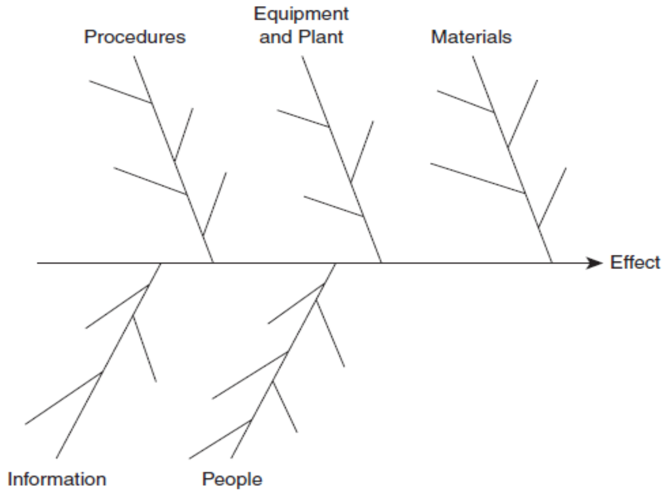

Figure 1. Cause-and-effect (CEDAC) or Ishekawa diagram [1]

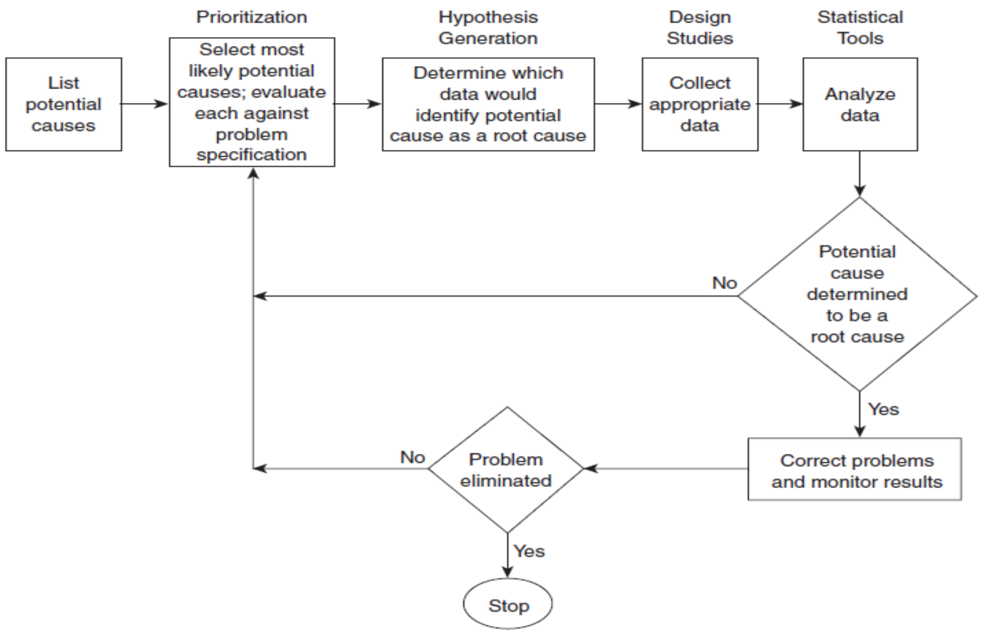

Figure 2. Troubleshooting with flowchart [1]

For product defects, it can be stated as "a defect is a characteristic of an artefact or constituent that prevents that product or component from functioning or processing properly."

There are at least two types of defects that can affect the function of the product:

1. Defects that exist in the artefact prior to selling or usage and lead to rapid refusal or working breakdown,
2. Defects in the product that develop over time and may rise the breakdown ratio when ordinary utilize of the artefact.

The set of flaws are safety-critical flaws and are of primary concern for many cases, but do not include flaws that execute an artefact impossible.

Defects found in parts can be divided into primary and secondary defects. Primary defects in most parts usually include the following:

1. Jagged corners in stressed zones
2. Interior spaces increase voltage to improper quantities when the manufactured goods are loaded
3. Variations from standard sizes during assembly (e.g. sinking of casting or mold surfaces) so that the component does not fit with others
4. Low quality construction material (e.g. dirty substance)
5. Fractures in parts

Any of similar characteristics can happen in pattern with each other and intermingle for example, a gap near a jagged corner. A more comprehensive record of flaws is performed in Table 2. Nevertheless, whether a feature is considered a flaw hangs on the condition of the product and the function of that characteristics in the artefact breakdown. For instance, if the crashes in an artefact are well below cruciality, it may be satisfactory to allow a specific degree of fractures.

Characteristics of secondary flaws, which usually emerge on a cycle, usually contain:

1. Wear of components moving versus each other
2. Fractures that happen throughout duration
3. Corrosion due to interaction with the surroundings
4. Dimensions alteration over duration
5. Objects variations over duration

as well as several another possible characteristic found on the surfaces of stuff (Table 2). As with principal characteristics, it will develop a defect if it has the potential to lead to breakage or breakdown. The difference relating artefact characteristics and flaws is intimately correlated to the work, surroundings, and use of the product.

Several of the characteristics that are foremost flaws in artefact pieces are problems affected by stress concentration, for instance sharp jagged corners or breaks, or foreign objects or spaces within specimens [3,4]. When stuff is loaded as fraction of their regular operation, the stress at such flaws rises over adequate constraints.

Table 2 Typical product defects [1]

	Primary Defects	Secondary Defects
Design: geometry	Dimensions (overfit, underfit)	Cracks from stress raisers
	Stress raisers.	
Design: materials	Poor materials	Degradation
	Voids	
	Inclusions	
	Contamination	
Manufacture	Poor molding, casting, etc.	Distortion over time
	Weld lines	
	Contamination	
	Cracks	
Assembly	Poor fit	
	Poor welding, etc.	Degradation on surface
Finishing	Surface blemishes	
	Packing flaws	

About product assessment, because of extraordinary price, 100% examination is hardly employed on extremely mass-produced commodities. Specimens are generally selected to be characteristic of the group, as in statistical process control (SPC) [2]. Assessments are normally executed under normal circumstances described by an international or national criterion. Although they provide some scale of quality control, it should be noted that the main purpose of universal experiments is to challenge to model the circumstances of utilize of the actual artefact. If the assessments are positive, it means that a quality artefact has been produced. Nevertheless, if the assessment or the testing technique itself collapses to discover artefact flaws, defective artefacts can contest the marketplace and reason troubles. Collapses in the experiment technique itself can happen in numerous approaches:

1. Collapse to replicate the terms of utilize
2. Testing practice is not followed properly
3. Testing may not effectively discover artefact flaws

Of course, there is a failure to test under realistic conditions. An example of this type of breakdown happened where hot water stops served their proposed function throughout circumstances of intermittent usage but declined entirely through non-stop display.

An essential instrument to consider possible failure modes in artefacts is failure modes and effects analysis (FMEA). It is not an artefact testing approach per se, but significantly a method to evaluate artefact flaws and, if required, determine alterations to artefact challenging or recommend modern testing techniques [2,5].

Pareto investigation and SPC are procedures employed by design groups for newfound or ongoing inventions. The greatest plants collect statistics on artefact lines during their quality fields. Surface imperfections are easy to spot on the line. Flaws in artefact revisited from consumers may be detected through techniques for instance normal analysis and assessment. A universal design flaw in many artefacts is sharp corners on the inventions. Whilst subjected to stress, these corners increase regional stress above the fracture stress of the relevant substance. Therefore, the crack will begin from these corners and spread towards the center of the specimen.

About the litigation, though the vast common of artefact or progression fiascos are determined by on-site examination, recompence from the vendor, or assurance coverage, there are several fiascos that cannot be simply determined deprived of lawsuit. It may result from defective components ostensibly presented by an external supplier that was detected as flawed. The individual party does not accept the claims of the other party. This can occur for a variety of reasons.

- Prove of collapse is doubtful.
- Prove was accidentally damaged or altered due to subsequent incidents.
- Prove may submit inconsistent explanations of what occurred.
- Malfunctions may have been caused by tertiary companies.
- Deficiencies may exist but have no association to the reason of the fault.
- Faults can be extensive and more genuine than separated events.
- Procedure malfunctions can be common.

Advertisement disagreements cause lawsuits in which the court is inquired to analyze the truths and understand the related law. There are further methods to resolve business disagreements. Mediation is a method in which an attorney consults with the parties individually. It is held on a permanent time, with each organization sitting in independent chambers with their own experts. The quality of the proof presented by each professional is experienced in turn by the conciliator.

For dispute cases, quarrels are ultimately solved through adjudication when all additional paths have been weakened. A court case is a communal discussion in which contrasting sectors in an argue challenge each other and struggle to induce the courtyard of the merit of their circumstance. This is repeatedly the primary conflict, or as a minimum the primary period others are present to organize and sort all the facts systematically and fairly.

A lot of study will have been equipped long earlier the hearing, along with gathering the indication to be introduced to the court and preparing the influences to be utilized for an incident. Claims are organized in the “defending” document, which are records submitted by both parties to reinforce their cases, and if there are technical problems, they are arranged by solicitors with the help of authorities. Oftentimes supposed "bones cases" may also be displayed as trial approaches and extra proof falls too bright and the primary pleadings must be amended.

Specialist engineers play an important role in bringing together a wealth of proof, both genuine and a lot of film. Therefore, if an artefact crashes, there will continuously be internal documentation from the builder, for example regarding quality control. These files may include:

- Plots, charts, and sketches
- Quality data
- Assessment of recordings
- Prototypes and patterns
- Features and specifications
- Domestic memoranda and notes amid the organizations

Such manuscripts are of fantastic prominence as a tribunal approach since they provide basic notes about the artifact dubious, as well as helping to detail the background. The claimant who experienced personal injury or wound due to artefact catastrophe has no knowledge of how this occurred.

Within the testimony and prosecution process, the raw prove that a court must think appears in many numerous forms. For a typical specialized situation, it mostly involves:

1. Real evidence
2. Statements of witnesses regarding the incident
3. Statements of experts
4. Petitions of action
5. Documents found by both parties regarding the events in question

The described series of proceedings at the judgment differs from country to country. The main purpose is to show the prove logically and consistently to the justice, who will decide which side will win the claim at the end of the process. In cases involving multiple defendants, attorneys must choose whether to continue to prosecution regardless of the virtues of the circumstance. Since the cost of the hearing is completely disproportionate to the cost of the dispute, an agreement can be reached before the hearing.

About the responsibility of forensic engineers, specialist spectators, for instance forensic engineers and experts, have an individual place at any hearing as they provide an opinion on the facts [6,7]. The expert will be given backdrop knowledge about the disaster as well as the defective product and will be trained to set up an information which must contain the following:

1. Character and consequences of breakdown
2. Testing of the defective artefact itself
3. Explanation of proof regarding the defective product
4. Potential reasons of the malfunction
5. Possible cause of the accident
6. Reconstruction of the sequence of events

Although the case or collapse no way influences a court decision, the statement should permanently be entirely empirical. Information should be and be viewed as an adequate endeavor to describe a collapse in a completely impartial manner. There are numerous directions to achieve this basic goal, but one of the most valuable is to allow the actual to prove to talk for itself.

Photographic evidence of such details, analysis of the construction material, a description of mechanical tests on the material are presented in the report, along with evidence from new, intact structures. As evidence of the defective product accumulates in the report, an image of the order of occurrences in the disaster will develop. Finally, reenactment of incidents permits the examiner to reconsider the established facts and therefore draw inferences about the trigger of the disaster.

In relation to expert reports, the procedure for giving evidence has been changed in previous years due to certain abuses of the scheme for providing professional evidence to judges in the United Kingdom. Related troubles have appeared in US courts, consistent with one American reporter [8]. Essentially, professionals should address the issues in an action in a completely impartial manner and show no bias to their teaching clients.

Experts should be careful when expressing opinions on matters in which they have no proficiency, giving particulars of their experiences, referencing nonfiction utilized in their reports, and stating who performed the assessments. Wherever there are varying views on causality, this, and the reasons for supporting a particular view should be stated. A synopsis of the results should be submitted along with an assertion that the authority recognizes his task to the court. It is equally significant to explain instructions to the expert, containing all facts that may be important to his or her opinion. Completely, the authority must prove the information by including a conventional assertion of accuracy.

Metallic materials are mostly used in engineering products. There is extensive knowledge about the main damage modes of metallic materials, as they have been used for a long time. However, it took many periods for low-cycle fatigue to be credited as a significant fracture mechanism. For example, the Tay Bridge, made of cast iron, collapsed in 1879 due to fatigue. Recent investigations have shown that low-cycle fatigue of connecting rod shoes contributes to eventual death in the Tay bridge [9]. As a moderately newfound class of substances, plastics have initiated extensive effort in many developed yields. New polymeric or composite materials are advantageous with their design freedom and light weight. However, polymers have some disadvantages due to lack of usage experience.

2. Test methods

Appropriate “test methods” must be selected to achieve testimony about the artefacts implicated and the substances from which they are prepared. Interpreting these data involves some authority information. Additionally, authority conclusions must be displayed in a way that lawyers can recognize and encompass into allowed reports and that allows courts to make decisions.

The goal of any forensic engineering exploration is to decide the reason for crashes or malfunctions. Forensic engineering is hence predominantly a problem-resolving problem. In any systematic task, one needs to be informed of the instruments available, the knowledge they supply, their constraints, and the "variations" that may be fundamental in a precise method.

Many defect issues will escort to lawsuit, maybe since the harm is subject to many numerous explanations. Therefore, the method to any substantial proof for instance a broken element is profoundly limited by the necessary to reservation and preserve it for probable investigation by others. Objects presented for investigation may be vigorous lawful testimony that cannot be shredded into test samples. The concession is if the element is extremely heavy and hence the selection of samples for testing will not damage entirety diagnostic. Forensic examinations are consequently profoundly diverse from usual quality control, where thousands of pieces are accessible for inspection. Another methodology in forensic medicine is towards non-destructive examination methods to ensure the preservation of evidence. In this section, photography, crack detection, metallography, chemical and mechanical analysis will be examined.

At the beginning of any examination, there is often an apparatus that can be taken for presented: there is an inclination to abandon the critical significance of our observes - the minimal energy of visible examination - to facilitate what we see, others can understand.

When a forensic engineer investigates remains from a crash, he must explore much more than its conventional characteristics. The objective should be to look for proof that will shed light on what may have caused the wreckage to arrive in its existing situation.

Intense examination will permit for more than just examining the pieces under study; It can also give vision into the condition that conducted to the breakdown in the initial place. Scrutiny of these characteristics admits judgement of the conditions under which tangible confirmation was collected. It could be like this.

- Visit to the crash scene
- Summons to choose testimony for workroom assessment
- Review of “crime field” photos managed by plant supervisors

It is important to safeguard that the correct items are chosen for investigation and that the precise conditions bounding an incident are known.

When performing any fault scrutiny, testimony obtained from the accident spectacle should be evaluated through visual observation. This means examining the evidence left behind after an accident over a long period of time. Observations made at the scene should be recorded with notes and photographs of the debris. This type of activity is required before laboratory analysis.

Macroscopic examination involves observing the fracture surface of a sample with a stereomicroscope at low magnification (10 to 50X). Macroscopic information about the entire workpiece is obtained [10]. With macroscopic examination, the path of fracture expansion and the source of the fracture can be established (Figure 3). In addition, the size of the residues, consistency of the structure, grain size and the existence of manufacturing flaws will be easily noticeable.

Figure 3. Fatigue failure of a machine's drive shaft (diameter = 25.4 mm) [1]

During microscopic examination, details that cannot be seen with macroscopic examination are revealed. Magnifications between 20 and 500X are typically used in an optical microscope. Microscopic scrutiny of etched portions can show grain size, phase distribution, cracks, porosity, inner flaws, surface coatings, etc. It reveals that cut and shiny specimens can be gently etched by chemical cleaning to outline the crystal structure. This is the procedure called metallography. Metallographic assessment gives a good suggestion of the class of the substance concerned and whether it has the needed structure, how it was produced, and heat treated [11,12].

The progress in electronics and equipment has brought microanalytical methods out of inquiries and into routine fault scrutiny. One of the most well-known devices is the scanning electron microscope (SEM). Fractography is one of the most popular uses of SEM. Revealing surface features impossible to distinguish with a light microscope has altered forensic scrutiny. SEM is more complicated to work than optical devices. The advantages of SEM are large depth of field, very high resolution (up to 0.5 x 10^{-6} m), non-destructive examination of conductive substances and elemental assessment with EDAX.

The reactions of materials to external forces are measured by mechanical tests such as tensile, hardness, bending, torsion etc. A completely brittle material will break suddenly or gradually. Most engineering materials deform plastically [12].

Some of the most used mechanical assets are revealed by tensile testing. The maximum strength that the sample can withstand under tensile force is determined by the tensile test. Specimens for tensile tests can be circular or rectangular in cross-section. Figure 4 shows a typical tensile test specimen. Tensile testing is also utilized for quality control of products. Assessing this point will guarantee that quality and design requirements are met and preserved before the part or artifact arrives maintenance. Additionally, hardness testing is a modest, non-destructive method that will give a satisfactory assessment of tensile strength and can be performed on modest specimens.

Figure 4. View of tensile sample

Hardness testing implies assessing the size of an indentation made of diamond or hardened steel shot. The extent of harm assigns an evaluation of the tensile stress of the softer substance. It can also be utilized to predict the wear resistance, tensile strength, and class of heat treatment of the material through hardness testing [5]. Among the certification tests used, we can list Brinell, Vickers, Rockwell, Moh's and ultrasonic methods. The Vickers test applying a diamond pyramid can be utilized with very small loads.

Tension is also confronted during bending, and there are various types of tests for bending easy figures such as beams of constant section. Thus, a beam can be overloaded at three points and stretched to the point of catastrophe. As the beam deforms, one surface deforms to a convex shape and the material there is under tension, while the converse surface deforms to a hollow form under compression. It is often alleged that forensic studies, which are systematic in nature, should permanently be supplemented by lengthy scientific discussions. Figure 5 shows bending test specimens made from aluminum vehicle body panels [1].

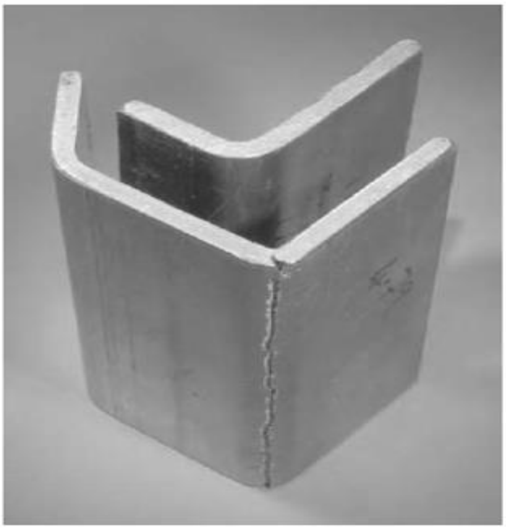

Figure 5. Performing bending tests on aluminum vehicle body panels [1]

Torsion examination delivers a procedure to determine the elastic modulus in shear, shear yield strength, and maximum shear strength. It is helpful for inspecting and testing parts, for instance axles, shafts, couplings, and twist drills, and can be employed to good benefit in testing brittle provisions. Torsion testing has the improvement of no friction. Additionally, test information is mostly legitimate for larger strain principles than tensile test records.

Differential Scanning Calorimetry (DSC) is a method utilized to study the thermal possessions of substances. Only milligram amounts of material are needed. The specimen is warmed at a persistent speed (usually 10°C/min) and the heat poured into or out of the specimen is repeatedly documented by the device. When a specimen melts down, heat is absorbed, and the melting point Tm is distinguishing of the chemical composition of the substance in investigation.

This was a eutectic Sn-Cu alloy for which a specimen from the main stock was offered for investigation. Analyzes were performed and judged to that of a recognized pure specimen. DSC discovered a liquid phase present at a temperature of almost 179 to 182ºC (Figure 6). It quickly became clear that such a liquid phase would allow surface-mount components time to "float" off the register, sooner than instantly freezing at the eutectic temperature. The trace of this sudden phase was later followed to cross-infection from a preceding melt, involving the solder manufacturer/dealer to examine their quality control processes immediately!

DSC is even more useful for polymers. Further info here contains the glass transition temperature (Tg) and the decomposition temperature when the substance decomposes. Although basic metals melt at strictly demarcated temperatures and alloys are within a certain range, plastics melt over a broader, less sharply defined range.

The changing quantity of crystallinity in plastics is an alternative distinction concerning the two classifications of materials. Many plastics are not completely crystalline and exhibit only a glass transition temperature. The measure of crystallinity in commonly used partially crystalline plastics, for example PP is changing, depends upon how the plastic is administered, and can be assessed utilizing DSC. Tg and Tm quantities are given in previous literature [13,14]. A new plastic, a thermoplastic elastomer (Hytrel), has been presented in the UK to tackle the crisis of tap leakage from fiber washers. It acted fine on both hot and cold water taps but stopped on the radiator valves. Contrast of a completely new seal with a failed seal confirmed an important improvement in crystallinity (Figure 7). DSC curves display an enhancement in heat of fusion due to exposure from approximately 30 mJ/mg to well above 40 mJ/mg.

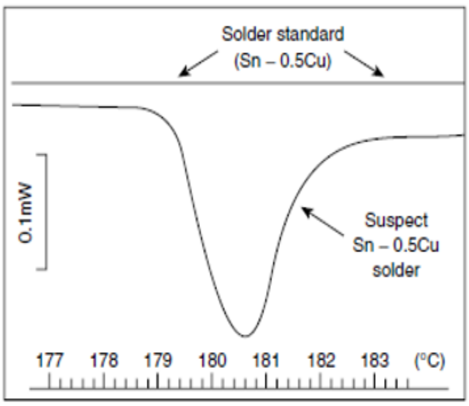

Figure 6. DSC scan of eutectic Sn-0.5Cu solder. The melting temperature of solder is 227°C. The solder exhibited a melting phase at ~186°C [1]

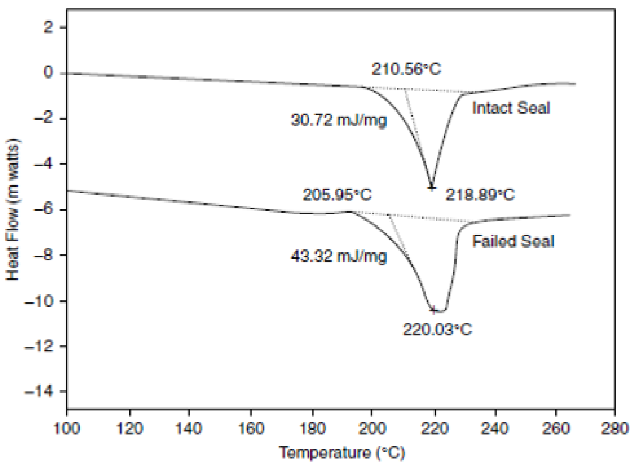

Figure 7. Melting behavior of Hytrel thermoplastic elastomer seals as shown by DSC spectra [1]

Spectroscopy absorbs exposing a thin sample to a beam of infrared radiation and documenting the absorption spectrum of the substance. The nature of the plastic chains fabricates absorption at wavelengths property of the plastic and aids in the identification of the material. There are as a minimum two ways to prepare a specimen thin enough for investigation. Films commonly need to be 20 to 60 microns thick so that infrared light can pass through the specimen. A thin film can be cast from an appropriate polymer solution, or a thin slice can be cut utilizing a microtome. FTIR (Fourier transform IR) is a complex form of spectroscopy in which the thin specimen can be scanned continually to increase resolution.

The technique is significant for plastics, it is regularly utilized for crashed substances, but caution is required as the technique is partially harmful. For instance, when a disabled woman was severely wounded due to her stick breaking, the broken polymer piece was examined as exhibited in Figure 8. Spectrum taken from a solvent-cast film displayed that the substance was a polypropylene copolymer. Though, it displayed abnormal absorption at 1736 cm^{-1} as detected when compared with the reference spectrum [15]. When the material deteriorates, the chains break and durability decreases; This describes wherefor the stick fractured once the woman put her weight on the apparatus.

The procedure guide contains locating pre-weighed PE powder into a device that is then sealed and rotated in a large oven. The polymer melts and bonds to the walls and solidifies when the oven cools. High processing temperatures are required because of the high viscosity of the molten plastic. Oxidation usually occurs on the outer surfaces of the artefact, and when exposed to sunlight the chains favorably break down at these points. Figure 9 exhibits the magnified oxidation peak in a thin solvent-cast film from a road cone attacked by UV radiation available in sunlight. The difficulty was resolved by including a UV absorber and antioxidant to the raw power polymer.

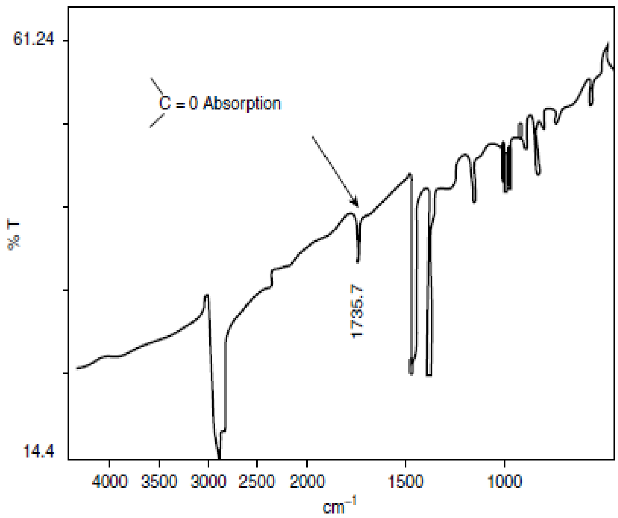

Figure 8. Infrared spectrum of polypropylene in metal crutch showing carbonyl absorption because of oxidative degradation [15]

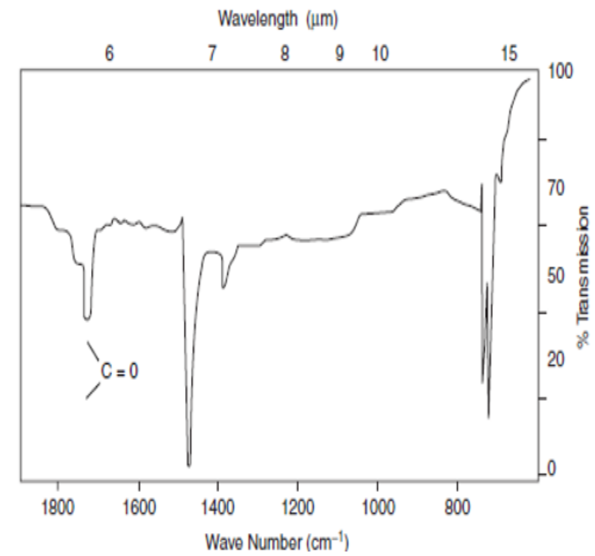

Figure 9. Infrared spectrum of a PE road cone shows intense absorption due to UV attack leading to brittle cracking [15]

3. Recent Studies

A previous article reviewed recent advances in the use of forensic engineering in civil engineering education [16]. This article discusses approaches to incorporating forensic science and failure case studies into the civil engineering curriculum. These approaches have been reported to include stand-alone forensic engineering courses, general design projects, and integration of case studies into the curriculum. In a previous forensic review of structures on durability [17], it was shown that the total cost of the element, including the cost of durability loss, depends on the thickness of the concrete cover, the design service life, and the discount rate. The middle part of Figure 10 shows a series of processes: "Structural Environment" and impacts (rain, de-icing salts, etc.), and "Environmental impacts" (reinforcement corrosion, material decay). Environmental effects can generally be combined with action effects (middle part of Figure 10). The resulting effects can lead to loss of strength of structures or excessive width or deformation of cracks. These limit states – ULS and SLS – are shown in the lower part of Figure 10.

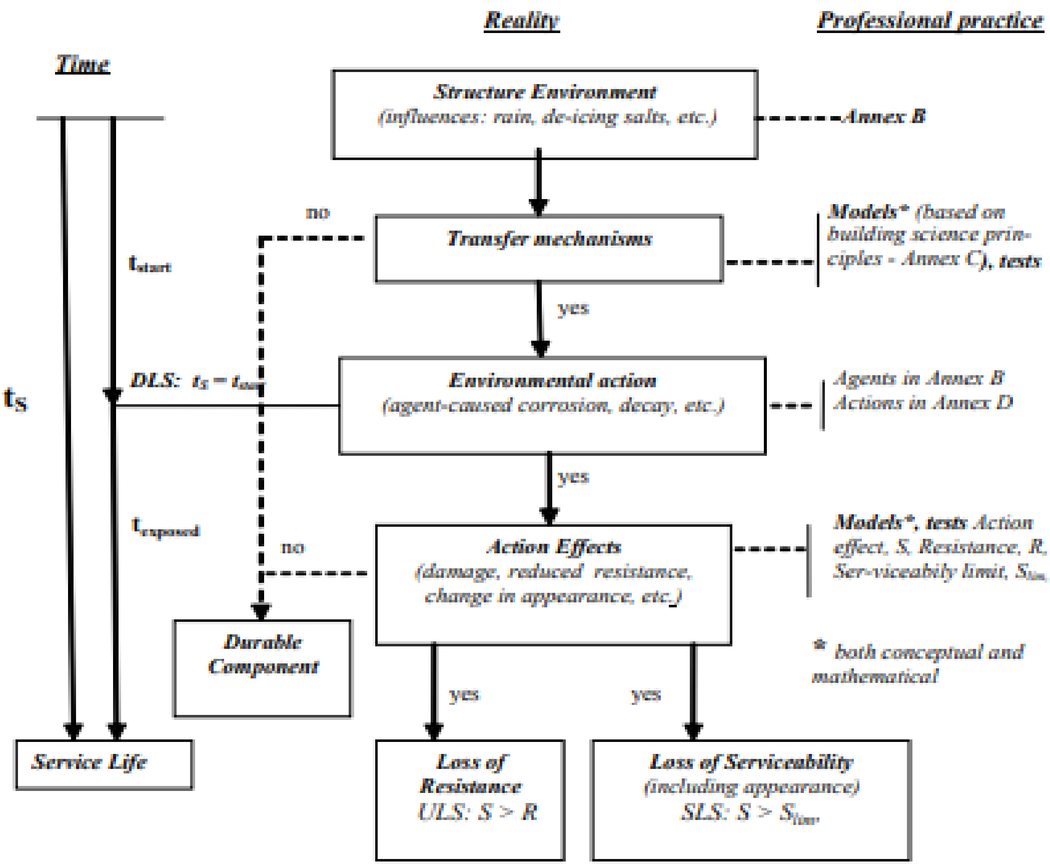

Figure 10. Durability limit state method [17]

Also, in a study on the use of 3D printing in 2020 [18], the use of 3D printing in the medical field was examined. Since people's physical characteristics vary from person to person (child, young, old, etc.), it was evaluated that the use of 3D printing would be beneficial. Since the development of 3D printing is still ongoing, it was concluded that it would be interesting to follow the developments in the use of 3D printing in the medical field. Improved prediction of the compressive strength of concrete can facilitate quality management. A study conducted last year used a state-of-the-art machine learning method to predict the compressive strength of concrete. In this study presented in 2023 [19], machine learning techniques and a newly developed meta-heuristic optimization algorithm were applied to long-term big data obtained from 75 concrete plants. A new algorithm was developed for the optimal machine learning model. The traditional method tends to overestimate the actual compressive strength value. However, in the presented study, more realistic concrete strength values were estimated by developing a suitable expert system that facilitates the use of the proposed model.

In their study on forensic engineering of construction materials conducted by Ingham and Leek [20] in 2016, it was observed that failures were caused by inadequate design, inadequate workmanship, or defective materials, and often a combination of these problems. Case studies based on examples are presented with the aim of improving future design and construction practices. Also in 2009, a study on "forensic engineering of fire-damaged structures" was reported by Jeremy Ingham [21]. This article describes the role of forensic engineers in investigating fire-damaged structures constructed of concrete, steel, and masonry. Forensic engineering procedures described include on-site inspection and testing techniques, laboratory testing, and structural fire analysis. The design and implementation of repairs are also discussed. As a result, structures damaged by fire can often be repaired rather than replaced. Engineers can successfully evaluate fire-damaged structures using a variety of forensic engineering techniques. The article "Re-evaluation of the Tay Bridge collapse" written by Lewis and Reynolds [22] in 2016, reported that "the connections holding the bridge together were defective, and these defects caused fatigue cracks to form in the cast iron shoes, and these cracks reached critical levels on the night of the disaster". It has been stated that many east-west shoes were broken when a local train passed over the bridge during a storm on the evening of December 28, 1879. It has been reported that the towers on the high girders collapsed and the bridge collapsed because the train was so heavy.

Another article published in 2007 examined “using X-ray computed tomography to examine pavement materials” [23]. In this article, a detailed review of the applications of X-ray computed tomography in the characterization of asphalt concrete is presented. Asphalt and concrete materials have been examined using X-ray micro-computed tomography (Figure 11) or micro-computed tomography. It has been reported that by using these techniques, more durable and long-lasting transportation infrastructure systems can be built.

Figure 11. View of X-ray micro-CT system [23]

4. Conclusions

The ensuing inferences can be attracted from the existing research:

a. Forensic engineering is an engineering field that plays a role in clarifying issues such as product failure, process error and design error in relation to legal investigations.

b. Production is about requiring artefacts to a identifiable requirement; This is the product need identification phase, followed by the planning and modeling phase. Once a productive model occurs, manufacture can be conceived. Any failure in product quality requires instant consideration from the design group. Fault analysis utilizing forensic approaches is key to detecting and correcting any design faults or manufacturing flaws.

c. Product defects are divided into primary and secondary defects. Primary defect features include sharp corners, abnormal deviations from dimensions during assembly, cracks in components. The appearance of these features in any part is a serious defect and is unacceptable. However, if, for example, flaws in an artifact are well under cruciality, it may be agreeable to accept some degree of cracking. The second type of defect features, whose shapes emerge over a period, include wear of sections that do not proceed alongside each other, flaws formed by cycles of use, and pollution resulting from contact with the environment. As with initial characteristics, secondary defects will develop flaws if they have the potential to cause breakage, malfunction, or aesthetic refusal.

d. Because of extreme price, 100% assessment is hardly employed on most mass-produced artifacts. Specimens are often selected to be characteristic of the group, as in SPC. Examinations are performed beneath national or international normal circumstances. If the assessments are positive, it means that a quality artifact has been completed. Pareto testing and SPC are methods employed by design crews for both newfound and established artifacts.

e. Though the vast maturity of artifact or procedure disappointments are determined through on-site investigation, payment from the vendor, or assurance coverage, there are some collapses that cannot be undertaken without lawsuit. This may be caused by defective components allegedly supplied by an outside contractor. One party does not accept the demands of the other party. Advertisement arguments repeatedly cause lawsuits in which the court is questioned to analyze the facts and understand the pertinent law relevant to the argument.

f. In the investigation of the crime scene, first the accident scene is visited, then evidence is collected for laboratory examination, and finally "crime scene" photos undertaken by the patrol or shop examiners are examined. For these investigations, it is important to choose the right objects as evidence and to know the circumstances of the incident.

g. Macroscopic examination involves observing the fracture surface of a failed component at low amplification (10 to 50X), first utilizing a stereomicroscope. Macroscopic findings will discover knowledge that represents the whole part. The main principle of microscopic scrutiny is to discover details that are too small to be viewed with macroscopic investigation. Enlargements typically scale from 20 to 500X for a light microscope. With optical microscopes, the grain size of the samples, phase dissemination, flaws, porosity, inner flaws, etc. is examined. Revealing surface descriptions that are hopeless to distinguish with an optical microscope is possible with electron microscopes. One of the recognized devices is the SEM. Fractography is one of the most general benefits of SEM.

h. The behaviour of materials under various external loads is measured by mechanical tests. The performance of systems operating under tensile load is measured by tensile testing. With this method, both elastic modulus and tensile strength are determined. Hardness is the resistance of the surface against a hard object immersed in the surface of the material. The extent of the harm gives an evaluation of the tensile stress of the easier objects. Either a round hard steel such as a ball or a diamond pyramid or cone is pressed onto the material surface. Methods such as Vickers, Brinell and Rockwell are used to measure hardness. We should also note that three-point bending, and torsion tests are also used to test different loading situations of different materials.

i. DSC is a method utilized to study the thermal possessions of supplies under cautiously measured specifications. The specimen is warmed at a persistent speed (mostly 10°C/min) and the heat flow into or out of the specimen is repeatedly documented by the device. Once a specimen thaws, heat is absorbed and the melting point Tm is generally property of the chemical composition of the substance under investigation, as the subsequent specimens show.

j. Spectroscopy involves exposing a light specimen to a beam of infrared radiation and documenting the absorption spectrum of the substance. The characteristics of plastic chains fabricate absorption at wavelengths that are distinctive of the plastic and thus is an initial assistance in identifying the substance. Films generally need to be 20 to 60 microns thick with the aim of infrared light can approve through the specimen. FTIR is a complex form of spectroscopy in which the thin sample can be scanned repeatedly to increase resolution.

Declaration of competing interest

I declare that there is no conflict of interest regarding the publication of this paper. I hereby declare that the information given in this disclosure is true and complete to the best of my knowledge and belief.

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