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Forensic Investigation of Engineering Claims

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Objective

This report will demonstrate the rationale that exists with Forensic Investigations in the Insurance Industry. The extent of examinations, many of the methods, findings and benefits will be covered.

Introduction

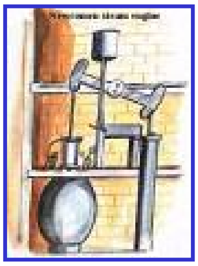
"Oh, there can be no doubt as to the sequence of events," said Holmes. "There were three of them in it: the young man, the old man, and a third, to whose identity I have no clue. The first two, I need hardly remark, are the same who masqueraded as the Russian count and his son, so we can give a very full description of them. They were admitted by a confederate inside the house. If I might offer you a word of advice, Inspector, it would be to arrest the page, who, as I understand, has only recently come into your service, Doctor."
"The young imp cannot be found," said Dr. Trevelyan; "the maid and the cook have just been searching for him."
Holmes shrugged his shoulders.
"He has played a not unimportant part in this drama," said he. "The three men having ascended the stairs, which they did on tiptoe, the elder man first, the younger man second, and the unknown man in the rear– –"
"My dear Holmes!" I ejaculated.
"Oh, there could be no question as to the superimposing of the footmarks. I had the advantage of learning which was which last night. They ascended, then, to Mr. Blessington's room, the door of which they found to be locked. With the help of a wire, however, they forced round the key. Even without the lens you will perceive, by the scratches on this ward, where the pressure was applied.
"On entering the room their first proceeding must have been to gag Mr. Blessington. He may have been asleep, or he may have been so paralyzed with terror as to have been unable to cry out. These walls are thick, and it is conceivable that his shriek, if he had time to utter one, was unheard.
"Having secured him, it is evident to me that a consultation of some sort was held. Probably it was something in the nature of a judicial proceeding. It must have lasted for some time, for it was then that these cigars were smoked. The older man sat in that wicker chair; it was he who used the cigar-holder. The younger man sat over yonder; he knocked his ash off against the chest of drawers. The third fellow paced up and down. Blessington, I think, sat upright in the bed, but of that I cannot be absolutely certain.
"Well, it ended by their taking Blessington and hanging him. The matter was so prearranged that it is my belief that they brought with them some sort of block or pulley which might serve as a gallows. That screw-driver and those screws were, as I conceive, for fixing it up. Seeing the hook, however, they naturally saved themselves the trouble. Having finished their work they made off, and the door was barred behind them by their confederate."

In the above extract from the book (The Resident Patient – Sir Arthur Conan Doyle – 1893) the Detective, Sherlock Holmes, made many assumptions and guesses in determining the events that led to the untimely death of Mr. Blessington. He deduced from the sparse evidence that there were in fact three men, who the men were and how they performed the crime. In 1893 this level of logic was considered remarkable and in all probability would have stood up to little scrutiny in a court of law. In the present however guesses would not be accepted and without hard evidence supported by Forensic science culpability would remain unanswered.

So, what is Forensics and how can this science be used in today's insurance world?

History

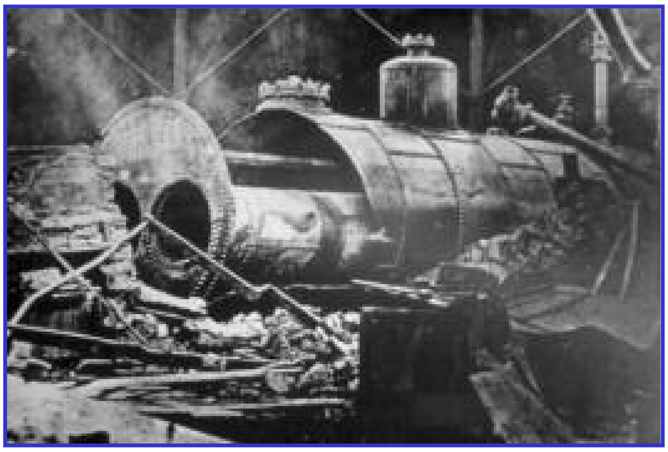
Although all industrial nations have a historical perspective on how and why Forensics developed within their countries legal climate, the history of Steam Power in the UK and ultimately the rationale behind Forensics in the Insurance industry shed a light on the needs for understanding what could go wrong.



The use of steam power in British industry began in 1712 with the introduction of the Newcomen pumping engine which was used to pump water out of the Cornish tin mines.
These were also known as "atmospheric engines" since they operated at very low steam pressure. Because of the low pressures, failures were uncommon and, when they did occur, were relatively harmless.

During the 1800's the use of steam power became much more common and by the 1840's the high pressure "Lancashire Boiler" was in widespread use as the industrial revolution took a grip on the country. This boiler was designed by the eminent engineer Sir William Fairbairn.

As a consequence of the introduction of the higher pressure equipment and the rapid growth brought on by the industrial revolution, a large number of disastrous boiler explosions occurred, causing not only damage to property but killing and injuring employees and other members of the public. The 1850's saw a vast number of deaths from boiler explosions seen as a national epidemic. Explosions were occurring at a rate of between one and two every day.



In 1846 an act of Parliament was passed, the purpose of which was to compensate the families of persons killed or injured in industrial accidents. However, the employees were generally unaware of its existence and the cost of pursuing a claim was often beyond the resources of those affected. Thus, very few claims were brought.

In the 1860's the industrial belt comprising South Lancashire, Northeast Cheshire, North Derbyshire and the West Riding of Yorkshire contained the largest concentration of boilers in the world and Manchester became the focus of boiler engineering. The leading personality in the movement was the engineer and boiler designer Sir William Fairbairn.

The Association that was formed by Fairbairn, Henry Houldsworth and Sir Joseph Whitworth became known as the Manchester Steam Users Association. This was a scientific society whose primary aim was to investigate explosions, conduct experiments and recommend inspection regimes. The success was dramatic - by 1860, only 8 out of 11,000 boilers examined had exploded.

These investigations and subsequent remedial actions became the first recorded use of Forensic examinations on Machinery

In 1854 Edward Taylor and William McNaught, both mill owners from Rochdale suggested to the Manchester Steam Users that:

"An insurance society would be better; let the inspection be the same but let the parties who inspect, back their inspection by paying if they make any shortcomings."

Fairbairn responded:

"Indemnifying the loss from explosion would be completely foreign to the association - it would mean it would be likely to become one for compensating for the loss from explosions rather than one for preventing them."

By 1855 the link between inspection and insurance could no longer be resisted and Robert Longridge, a member of the Manchester Steam Users Association, broke away to form the Steam Boiler Assurance Company which not only investigated failures and recommended inspection regimes, but also underwrote the equipment. And so, the deal was done and the engineering insurance business was born.

The pioneers of Forensics had unwittingly produced an industry which, in the years to come, would expand well beyond the boilers they initially struggled to control!

The Bomb 

The National Board (of Boiler and Pressure Vessel Inspectors) bulletin a few years ago published an account of the explosion of a six-section cast iron hot water heating boiler. This occurred when the safety valve, which had never been tested or operated, was corroded shut while the spindle was frozen to the guide. It failed to open from the over pressure caused when the main gas shut off valve failed. The violence of the explosion was said to have been the equivalent of a large bomb!

In comparison of liberated energies we know that a 30 gallon hot water tank at 90 PSI (6.2 bar) flashes into steam at approximately 331 Fahrenheit (116 Celsius) and that the energy if liberated by a rupture has 3,138,400 foot pounds of energy

Compare this with the following common explosives:

1 LB. (.45 Kg) of Gunpowder gives 960 FT. LBS.
1 LB. (.45 Kg) of Smokeless powder gives 1,260 FT. LBS.
1 LB. (.45 Kg) of Nitro-glycerine gives 2,000,000 FT. LBS.

The "Bomb" referred to above was the equivalent of several pounds of Nitro-glycerine and was just as destructive

This anecdote demonstrates the power of these explosions but also the difficulty of the tasks that Forensic investigators are confronted with.

Machinery Today

Since the industrial revolution in the late 1700's up until modern times the growing demand for efficiency has created a problem for the manufacturers of machinery. The competitive marketplace has generated a need for lighter, faster, fuel efficient, maintenance free machinery, which in turn makes the owners of those machines more competitive in their respective marketplaces.

With these needs in mind the demands made on machinery manufacturers have taxed their engineering ability to the limits. Machines are designed and tested on computers and all specifications are theoretical. Lengthy build, test and implementation of changes to a new machine have been reduced to the bare bones, and in many cases ultimate faith has been placed in a computerised model of the machine being created.
The components that make up all machinery range from complex calculations of stress, materials, size, shape, process flows, lubrication, fuels, end result and ease of access. Also the creators of these machines have to take into account cost, life expectancy, spare parts and when needed the ability to sell to that same client the next generation of machinery. Many new designs are only built and tested when the computer indicates they are ready.

Conceptually if we are given an infinite budget and no constraints on time we could build and maintain anything we wanted to and make it last for many generations. This however is not the case and businesses run on tight budgets. With these tight budgets come major issues as machines are stretched to their limits and performance measured by output from the machine rather than input into the machine.

Event

The following tracks the findings of the Royal Commission that investigated the Longford Gas Explosion in Australia.

Gas Blast Esso's Fault
by Rachel Hawes — Headlines, The Australian Tuesday June 29th, 1999

Esso's failure to train its workers to cope with emergencies left the multi-national responsible for the Longford gas plant explosion that killed two of its workers and cut gas supplies to Victoria for a fortnight.
Esso's decision to blame its staff - including control room operator Jim Ward - back-fired, with Longford royal commissioner and former High Court judge Daryl Dawson finding that the company's failure to equip workers with the "appropriate knowledge" was the ultimate cause of the explosion in September last year.
Sir Daryl said the tragedy could have been averted "had appropriate steps been taken" to deal with process upsets on the day.
In a 287-page report, Sir Daryl also criticised Esso's handling of safety issues at the plant, including incident reporting procedures and a decision to slash the number of supervisors ahead of the explosion.
The report said the causes of the blast - which killed maintenance supervisors Peter Wilson and John Lowery, and injured eight other staff - amounted to a breach of the Occupational Health and Safety Act by Esso, a subsidiary of US energy conglomerate Exxon.

> ***"The ultimate cause of the accident on September 25 was the failure of Esso to equip its employees with appropriate knowledge to deal with the events which occurred,"***

The report said.

> ***"Not only did Esso fail to impart that knowledge to its employees, but it failed to make the necessary information available in the form of appropriate operating procedures."***

The report found the explosion occurred when a heat exchange unit in gas plant one ruptured after workers attempted to pump hot oil through freezing equipment.

Wilson, 51, and Lowery, 49, died instantly. Gas supplies to Victorian homes and businesses were cut for almost two weeks at an estimated loss to industry of Aus$1.3 billion.
Key recommendations by the royal commission include calls for stricter training obligations on Esso and the establishment of a State government body to specially administer safety procedures at "all major hazard facilities" within the State.

Aftermath

Sadly this event was not a one-off and many others parallel the Esso incident. In looking closely at the incident some things become obvious.

- Esso had taken the stance that the employees were to blame
- The Commission decided the training was inadequate
- Cost cutting had taken place
- The cause of the event was avoidable
- Lives were lost at the plant
- Gas supply and therefore possibly lives were placed in jeopardy in the nearby towns and city
- Blame had been afforded to Esso however the Government, up till the incident, had no formal controls on the safe operation of a "Major Hazard Facility" but in all probability had issued operating licences in the past

So, there are fatalities, financial cost and some ill feelings and bad memories centred on a loss. Plants can be rebuilt; new employees trained and gas produced. The horse has already run away and as it's too late to close the barn door lets move on! Shall we?

There are three key reasons why we cannot just "move on" and ignore the incident. By determining the cause we can:

Assess event or sequence of events
Assess blame
Prevent re-occurrence

But how is cause determined? An explosion is a devastating event as evidenced by these pictures of different stages of an event.

The facility is ruined beyond repair either by the initial blast tearing the steel apart or melted by the ensuing fire. The staff closest to the event might have been killed and the monitoring equipment, gages and indicators that would tell the story destroyed.

Interested parties

Upon reviewing the aftermath of an event the investigation has a number of interested parties that would be, or might be interested:

Local government
Insurance companies
Safety bodies such as Occupational Safety and Health Administration (OSHA), Health and Safety Executive (HSE), Independent Trade Groups
Manufacturers of the equipment
Owners
Etc…

For various reasons all of the above will have an interest however there can also be legal implications and the Law enforcement agencies will be interested too. The police & coroner might be involved if there is a fatality and hence possibility of a criminal acts. Until the exact cause can be identified then these parties will remain interested and act on the information once it is available.

The Insurance Perspective

<u>Insurance Liability</u>

In most cases the event itself is obvious. An explosion after all leaves little doubt that a major mishap occurred but many of the interested parties want to know more. In order to obtain that information a thorough analysis of the scene has to take place. This is where the interested parties obtain the services of a Forensic Investigator who hopefully can uncover the mysteries that surround an event.

Historically large claims have occurred where the damage was so extensive the issues of cover were placed in doubt. An explosion of a large pressure vessel for example can leave doubts over causation and therefore where the liability lays or indeed if there is any liability at all. The confusion usually involves a Property or Engineering Insurance contract provider or can, and often does, include the manufacturer of the machine or vessel involved. In most cases the insurer covers the claim, but in some the manufacturer may also have some liability or even total liability. The only method of certainty is to determine what caused the event and ultimately who, if at all, has the liability.

Determining liability is certainly important to the insurer and getting a claim paid is equally important to the insured, but there is more to this process than the financial element. The event has still occurred and in cases where there is a fatality or injury the Liability insurer needs to be made aware.

Another benefit to the insurance angle is the ability not just to determine which contract would respond but if any other parties should share or cover the liability.

<u>Other Liability</u>

The manufacturer of the machine, a contractor or sub-contractor or operator/owner all have vested interests in the Forensic results.

The manufacturer of the machine might be carrying a warranty and needs to know if they can deny liability should the owner fail to operate the equipment properly. Also they might need to place their own Products Liability Insurer on alert. The reliability of their product is of extreme importance and many manufacturers will act quickly to dispel blame, liability or bad publicity. A Forensic Investigation is a good tool to achieve some of these goals.

Contractors and sub-contractors can also be involved as they perform work on, or around, the equipment involved. A Contractors Professional Liability Insurance should respond to situations where a Forensics Investigation proves they were negligent. The Insurer however needs to be careful the Contractor is not named on the Policy as this will negate the opportunity to pass the loss over to that Contractors Liability policy.

The operator of the plant, as an employee of the insured will not be held liable. The owner likewise may not be held liable unless they deliberately caused the damage. If a Forensics Investigation proves that the Owner was not diligent in hiring, training and maintaining the equipment, they can be fined by a local authority. Also the confidence from shareholders, employees and customers can suffer so the owner needs to be able to respond positively if the Forensics Investigation results point to the owner as a negligent party.

If an event occurred and no Investigation took place to determine cause, doubts rightly or wrongly would linger over who was at fault. These doubts are all negative in relation to confidence, amity and good faith. Reputations in the business world mean a great deal and a company that is seen to trade unfairly, not be in tune with the local economy/environment and not be in control of its operation will suffer over the long term. The Union Carbide event in India was a classic case of a company's reputation being adversely impacted by a devastating event.

Although it is always difficult to accept the responsibility that a Forensics Investigation highlights it does allow the responsible party to respond positively. When a manufacturer has been found culpable the manufacturer can begin the process of good faith. Payments to injured parties and positive risk control and safety measures are all actions that can be taken.

The real benefits from a Forensics Investigation can be obtained not in looking backwards to assign blame but in looking forwards to prevent another similar event. If the investigation uncovers the cause then the responsible engineers and safety representatives can work on a fix. Whether the fix is structural or procedural the end result should be positive. Fixes might be simple such as placing guards on machinery, opening a valve in a particular sequence or replacing gaskets more frequently. Other fixes might be more sophisticated such as re-machining parts, changing to a different material or replacing whole units. Regardless of how severe the fix is it cannot be as severe as a life threatening situation or the financial implications of not doing anything at all.

The Forensic Investigation

Obviously not all events are dramatic and involve total disruptions but the steps an investigator must take tend to be consistent no matter how large or small the event is.

The Forensic examiner essentially acts as a "Detective" and treats the event with an open mind. The investigator begins to build up a database of information through witness reports and physical evidence. If performance data is available then this also becomes a part of the equation. It is not just enough to discover the broken part or parts and why it failed but also the entire timeline of events that led up to the failure.

Forensics Vs Failure Analysis

Forensics takes into account the timeline of damage, no matter how rapid, that occurred during the event. In this fictitious example each stage of an event can be mapped.

Event	**Time**	**Effect**
Boiler fuel pump loses power	Initial	Initial cause – lack of power
Boiler suffers flame failure	5 Seconds	Initial effect – lack of fuel
Pump regains power and trip override fails	10 Seconds	Proximate cause of damage is failure of fuel shut out (Fire eye)
Fuel enters boiler and ignites unconsumed fuel vapour	15 Seconds	Cause of explosion is re-entry of fuel into hot boiler (Flare-back)
Boiler explosion	16 Seconds	Actual damage or event
3 Men Killed	17 Seconds	Effect
Surrounding Property Damage	18 Seconds	Continuation of event
2 More Killed	18 Seconds	Continuing Effect
Flying Object Damage (600 Meters from building)	22 Seconds	Finality of event
Total Time of event	**22 Seconds**	

In the table above the failure analysis might have focussed on the explosion, as this is where the greatest damage occurred however the actual event was the failure of the Fire Eye to detect a flame out and prevent fuel from re-entering the boiler. From this information the event can now be narrowed down further to determine the answers to the question 'Why did the boiler blow up in the first place?'

Taking the failure of the Fire Eye as the proximate cause of loss the investigator will then be able to look at the maintenance, testing and repair histories to determine why the part failed.

- Did the owner disable the safety device?
- Did an employee disable the unit or improperly maintain the unit?
- Was it frequently tested and if so by whom and how often?
- Was it beyond its useful life?
- Was it the correct component for that boiler?
- Did the manufacturer give adequate or correct instructions for installation and use?
- Was the management negligent in operating the equipment?
- Did the management take all precautions to protect the employees?
- Was the manufacturer of the Fire Eye negligent in the application and instructions issued on the unit's installation and use?
- Was the employee qualified to operate and/or maintain the unit?

In the case of Esso mentioned earlier the commission's findings addressed some of these items and placed the blame with the owner not the staff member. The commission did find that maintenance was satisfactory but the training on operating the equipment was not. A Forensic examination discovered the cause of the event was due to "***a heat exchange unit in gas***

plant one rupturing after workers attempted to pump hot oil through freezing equipment" (SIC). Essentially they did not follow an operating procedure correctly.

The ensuing thermal shock might only be determined once an investigator could sift through tons of rubble and debris, follow the clues of the explosion's path and look for the components that indicate the root of the explosion.

As the investigator tracks through the remains they are looking for clues as to the blast pattern, the impact damage from one part to another. For example if a stream drum or header show no signs of external damage other than where the tubes ripped from the tube sheet then the blast more than likely was not from the drum.

Among the debris the investigators probably found the heat exchanger somewhere in the middle of the site with a rupture where the sides are pushed outwards (Split Lip Rupture). From this point the investigator would begin the tasks of testing the metal, reviewing the patterns left from the explosion including thinness of the steel, cracking, embrittlement, impact and location. Erosion and corrosion will be addressed, shear patterns, and fatigue will all become a part of the analysis.

Tests (addressed later) will be performed to extract the causes and timeline of the events. Then, once satisfied the primary component has been discovered the investigation will switch to the events that made the primary component fail. Was it overpressure, fatigue, erosion. Maybe it was not metallurgical but, as in the example, was due to the operators or even a failure of a downstream component such as a mixing valve. The investigator will search for clues, some obvious, other not so obvious, until the proximate cause is discovered.

The Esso blast was determined to be from Thermal Shock, induced when a hot medium was introduced to freezing equipment. The initial clues could well have come from the Forensic examination of the structure of the steel of the heat exchanger. Clues left on the steel would point to certain types of failures and thermal shock would leave its own fingerprint on the metal.

The investigator would then, once thermal shock was factored, endeavour to see how it could have happened. In many cases the root cause would be obvious. It was a freezing cold day and the plant was in start up mode. Once a valve was opened the introduction of a hot medium (Steam, oil) would cause the loss. However, in other cases the investigator must track through the system to see where the possibilities exist for thermal shock.

A Steam Turbine failure occurred at one plant where water in the steam impacted the blades. All indications were the Superheater operated at the correct temperature and traps, valves, temperatures and drains were correctly functioning. So what happened? The investigator performed a trace of the entire system and discovered an old, unused De-superheater inlet valve had been momentarily opened by a subcontractor working on a low pressure system and thought the valve was the cut in/out to that system. It was not reported, as the sub-contractor knew he had made a mistake and tried to cover it up. The investigation however traced this as the root cause and could place the proximate cause squarely on the contractor's action.

Digging Deep

With many failures being based on metallurgy this report will focus on that particular component. It must be recognised however that plastics & rubber, chemicals, oils, gases and many other materials can and do form parts of Forensic investigations.

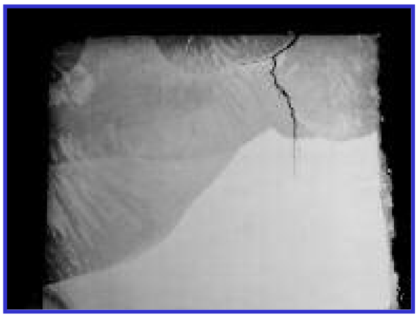
The Potato Peeler

The Forensic examiners perform many functions in determining the cause of a loss. Once the part has been identified then the science begins. In this picture the crack on the jacket of the potato peeler has been uncovered.

From the evidence the examiner will begin to pinpoint the cause. The investigator might deduce the pattern indicates a structural flaw, an immediate sudden event, a creeping event, where the crack initiated, chemical influence, overheating or some other internal or external influence.

The area would then be cut out and examined in great detail, literally under a microscope.

This side view targets the crack from a different perspective and gives an indication to the root cause of the event. By tracing the crack the investigator/laboratory can look at the granular path of the steel, areas where the steel shows different properties and even generate a history of the steel's initial production.

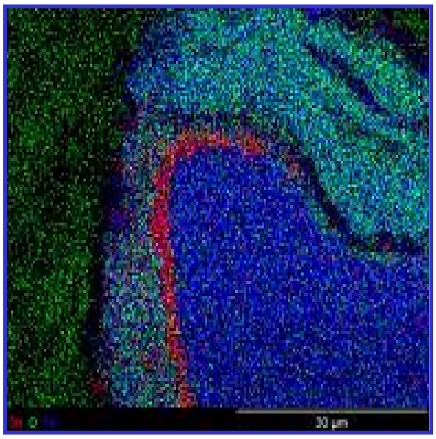


By looking closely at the picture a darker area exists at the top centre. The crack runs along its right hand side and then traces downwards following a path through the steel. Is this where two different properties come together and have provided a weak spot in the fabric of the steel? Or did the crack start at the bottom and work its way upwards? The investigator will make that determination and then decide why the crack manifested in the first place.
If, as the picture tends to show, the darker steel does in fact contain different properties than the lighter steel why? Was it a part of the design?
Some of the causes could be improper heat treatment at the manufacturing phase, improper weld (if this was a welded part), excessive or localised overheating or improper materials selection and application. Once the cause has been determined then the investigator can report to the relevant interested parties.

A Steam Control Valve

The Steam Control valve in the adjacent picture had a crack at the top lip. Early detection of the crack prevented a worse incident. But what caused the crack and where does the liability lay.

Closer inspection highlights the crack but more sophisticated methods need to be used to ensure the cause is fully understood



The Forensics investigator's toolbox contains many methods of extracting information. This image tells the trained eye more about the cause than a normal visual or even a standard x-ray exam could show.

Procedures include corrosion studies and defect/fracture analysis on the structural and behaviour properties of metal, including grain size, hydrogen embitterment, hardness, case depth, improper heat treating, stress fracture, inclusions, micro-constituents and boundary conditions.

Types of Examination

Firstly it must be stressed that Forensics are post loss and not Pre loss. Many businesses perform similar tests to Forensics examinations such as Non Destructive Examination (NDE) however these are performed in the interest of loss prevention. Some of the same examinations are performed such as Magnetic Particle, Thickness, x-ray Spectroscopy and others.

In many instances information on the material being examined might not be available so the examination could involve determining material composition through chemical, spectral or strain/stress testing. Different grades of steel possess different properties and therefore have differing applications.

The casting and treatments of steel is an exact science, as many of the end uses require high degrees of safety. Bridges, cranes, boilers and engines all require certain properties to be present in the steel and that includes the chemical composition, heating and cooling cycles and even welding procedures. Also the ability to mix certain steels or metals can be problematic as oxidation and other chemical reactions can occur. A US Navy vessel suffered a major steam leak when the bolts used on the main steam valve were of the wrong material. A black coating over the brass bolts led the civilian maintenance worker to mistake them for steel and when the pressure and temperature was admitted to the valve the bonnet blew off. Eight men were killed within seconds, all because of misapplication of materials.

<u>Some of the Forensic examinations include:</u>

<u>Magnetic Particle</u>
Magnetic particle inspection is a method that can be used to find surface and near surface flaws in ferromagnetic materials such as steel and iron.

The technique uses the principle that magnetic lines of force {flux) will be distorted by the presence of a flaw in a manner that will reveal its presence. The flaw (for example, a crack) is located from the "flux leakage", following the application of fine iron particles, to the area under examination. There are variations in the way the magnetic field is applied but they are all dependent on the above principle.
The iron particles can be applied dry or wet, suspended in a liquid, coloured or fluorescent. While magnetic particle inspection is primarily used to find surface breaking flaws, it can also be used to locate sub-surface flaws. But its effectiveness quickly diminishes depending on the flaw depth and type.
Surface irregularities and scratches can give misleading indications. Therefore it is necessary to ensure careful preparation of the surface before magnetic particle testing is undertaken.

Dye Penetrant
Liquid penetration inspection is a method that is used to reveal surface breaking flaws by bleedout of a coloured or fluorescent dye from the flaw.
The technique is based on the ability of a liquid to be drawn into a "clean" surface-breaking flaw by capillary action. After a period of time called the "dwell", excess surface Penetrant is removed and a developer applied. This acts as a "blotter". It draws the Penetrant from the flaw to reveal its presence. Coloured (contrast) penetrants require good white light while fluorescent penetrants need to be used in darkened conditions with an ultraviolet "black light".
Penetrant inspection can be used on any material. It is essential that the material is carefully cleaned first, otherwise the Penetrant will not be able to get into the defect. If surface Penetrant is not fully removed, misleading indications will result.

X-ray
High voltage x-ray machines produce X-rays, whereas gamma rays are produced from radioactive isotopes such as Iridium 192. The x-ray or gamma rays are placed close to the material to be inspected and they pass through the material and are then captured on film. This film is then processed and the image is obtained as a series of grey shades between black and white.
The choice of which type of radiation is used (x ray or gamma depends on the thickness of the material to be tested. Gamma sources have the advantage of portability, which makes them ideal for use in construction site working.
X-rays and gamma rays are very hazardous. Special precautions must be taken when performing radiography Therefore the operator will use these inside a protective enclosure or with appropriate barriers and warning signals to ensure there are no hazards to personnel.

Electron microscope
The Scanning Electron Microscope (SEM) creates the magnified images by using electrons instead of light waves. The SEM shows very detailed 3-dimensional images at much higher magnifications than is possible with a light microscope. The images created without light waves are rendered black and white. Samples have to be prepared carefully to withstand the vacuum inside the microscope. The sample is placed inside the microscope's vacuum column through an airtight door. After the air is pumped out of the column, an electron gun [at the top] emits a beam of high-energy electrons. This beam travels downward through a series of magnetic lenses designed to focus the electrons to a very fine spot. Near the bottom, a set of scanning coils moves the focused beam back and forth across the specimen, row by row. As the electron beam hits each spot on the sample, secondary electrons are knocked loose from its surface. A detector counts these electrons and sends the signals to an amplifier. The final image is built up from the number of electrons emitted from each spot on the sample.

Eddy Current
Eddy current testing is an electromagnetic technique and can only be used on conductive materials. Its applications range from crack detection, to the rapid sorting of small components for flaws, size variations, or material variation. Commonly it is used in the aerospace, automotive, marine and manufacturing industries.
When an energised coil is brought near to the surface of a metal component, eddy currents are induced into the specimen. These currents set-up magnetic fields that tend to oppose the original magnetic field. The impedance of coil in close proximity to the specimen is effected by the presence of the induced eddy currents in the specimen.
When the eddy currents in the specimen are distorted by the presence of the flaws or material variations, the impedance in the coil is altered. This change is measured and displayed in a manner that indicates the type of flaw or material condition

Ultrasonic
Ultrasonic inspection uses sound waves of short wavelength and high frequency to detect flaws or measure material thickness. It is used on aircraft, the power station's generating plant, or welds in pressure vessels at an oil refinery or paper mill.
Usually pulsed beams of high frequency ultrasound are used via a hand-held transducer, which is placed on the specimen. Any sound from that pulse that returns to the transducer like an echo is shown on a screen that gives the amplitude of the pulse and the time taken to return to the transducer. Defects anywhere through the specimen thickness reflect the sound, back to the transducer. Flaw size, distance and reflectivity can be interpreted.
Because of its complexity considerable technician training and skill is required.

Metallurgy
In these examinations the material is tested for Tensile Strength, Material Composition and Content. If the material is known then the tests are fairly simple as they would focus on how the material should perform. If the material is unknown then the tests will look to determine the strength and qualities and match those against the application of the steel/material.
Some of these tests are mechanical, some electrical and others chemical depending on desired result and material.

Forensics Labs also test for:

Hydrogen embrittlement
Another form of stress-corrosion cracking is *hydrogen embrittlement.* Although embrittlement of materials takes many forms, hydrogen embrittlement in high strength steels has the most devastating effect because of the catastrophic nature of the fractures when they occur. Hydrogen embrittlement is the process by which steel loses its ductility and strength due to tiny cracks that result from the internal pressure of hydrogen (H_2) or methane gas (CH_4), which forms at the grain boundaries. In zirconium alloys, hydrogen embrittlement is caused by Zirconium hydriding. At nuclear reactor facilities, the term "hydrogen embrittlement" generally refers to the embrittlement of zirconium alloys caused by zirconium hydriding

Services that form a part of the Forensics exam

Aside from the obvious, Forensics also provide these services

- Failure and Damage Analysis of Metals, Products, Structures and Equipment

- Analysis and Reconstruction of Accidents involving vehicles, equipment, aircraft, marine craft and rail equipment.
- Metal and Product Evaluations relative to product liability, conformance to design specifications, adequacy of performance, alterations or modifications by users, and hazards in operation.
- Recommendations for corrective action in metal product design, alloy selection, fabrication and quality control.
- Performance of Research and Development.
- Analysis of Items recovered from fires or explosions.
- Restoration of Obliterated Serial Numbers and Identification Markings.
- On-Site Evidence Recovery and Field Examinations, including metal detector searches.
- Co-ordination of Examinations requiring multi-technical disciplines
- Litigation Preparation Assistance, including case reviews and preparation of technical interrogatories and courtroom exhibits.
- Expert Witness Testimony and Consultation

Using the Information

Once completed the relevant interested parties can now use the results of Forensics examination. The report should indicate the sequence of events; the root causes of the event and provides all supportive documentation to support the findings.

The law enforcement and coroner will obviously determine criminal acts but in the majority of engineering related claims the cause is not a deliberate human act. Many events however do point to human error and at some point in the timeline a person or persons may have made mistakes.

The timeline of an event can extend not just to the actual event or sequence of events but all the way back to the origination of the materials used in the construction of the machinery.
If we track the construction of a boiler it actually begins at the steel mill where the raw products are fabricated. In the table below each phase of the construction offers a chance to affect the boiler and thus create a loss. Forensics will sometimes take that loss back to the early stages of development.

Activity	Activity that affects construction/operation
Steel is smelted in furnace	Improper temperature Improper mixture
Steel is poured/rolled	Improper temperature Improper curing Improper compression Improper timing/cooling
Steel is heat treated	Improper temperature Improper timing
Plate is sent to manufacturer for rolling	Improper composition Improper bending/temperature technique
Steel is welded	Improper preparation Improper technique Improper materials Improper Post Weld Heat Treatment
Boiler is assembled	Improper chemical composition/material selection Improper design

	Improper assembly
Boiler is tested	Improper firing ratio Improper chemical treatment Improper set up
Boiler is operated	Improper firing ratio Improper fuel Improper water chemistry Improper application

In many of these steps the human factor could have triggered a potential future event. These are expressive of the problems but by no means are exhaustive as to all of the steps that can negatively influence the operability of a machine.

Summary

The continued use of Forensic Investigations in Insurance Claims provides many insights into what happened, it determines where liabilities are attached and more importantly can be used to prevent future losses from recurring. The cost of such investigations is small when compared to the benefits gained from the data provided by this branch of science.