1 Band 1: An Eye for an Eye

This band is associated with Blocks 1 and 2.

An Eye for an Eye is based on a fictional court action taken from a real case, which involved failure of materials. Frequently in real products, failure often involves several different kinds of material because failure in one component leads to failure in another, perhaps through mechanical overload.

The failure in the court case involved environmental stress cracking (ESC) of the plastic (polystyrene) eyes of teddy bears. Polystyrene is a brittle polymer that does however possess good optical properties. Like many polymers it is also susceptible to crazing followed by cracking when exposed to low levels of many organic fluids. The plastic eyes were injection moulded and attached to the textile lining in each bear's head by means of a metal spring.

As in many product failures, the problem was endemic and had severe effects on the manufacturer. In such circumstances there may be several deleterious effects.

1 Replacement of affected products becomes necessary.

2 Damage to the reputation of the manufacturer.

3 Consequential damage.

With the first, replacement costs can be substantial depending on how many products were made. Unsold stock must be removed but could probably be remade if the cause of failure is determined. The second kind of damage is more difficult to quantify, but is real if customers associate the brand name with failure, and the goodwill lost can be difficult to replace. The third kind of damage could occur if a young child picked up one of the broken eyes and swallowed it, choked and was injured. The child would then have a claim against the manufacturer.

The immediate problem when such failures occur in large numbers is to investigate the cause or causes, an added but inevitable cost. The real case never came to court although a rigorous investigation was carried out by Dr Peter Reed of Queen Mary College, London University. The case folded because one of the companies liable for the failures went into receivership and so the costs of failure could not be recouped.

However the fictional drama makes the case interesting because the way the story unfolds shows how cases may proceed if no agreement has been made before trial. It also shows how the arguments are sharpened under the pressure of cross-examination and expert witnesses must be able to respond to such pressures. This is a real problem for experts in cases that do come to trial.

The following commentary has been drawn up by Dr Reed to show what really happened in the investigation, adding a realistic background to the fictional case shown on the video.

1.1 Problem with eyes

The problem reared its head in the summer of 1978. A northern UK company was exclusively manufacturing one type of toy bear for which it had the patent rights. The main business of the toy trade is conducted in the Christmas season. Hence all supplies have to be in the shops by September ready for the Christmas rush. This company had received its Christmas stocks into warehouses all round the world by July of 1978. Then reports were received that some of the bears' eyes were 'misting over' and even falling out. The condition was described as 'bears with glaucoma or myopia'.

The situation was serious for the manufacturer. It had to embark on a 100 per cent recall of all stock from around the world to check and replace the faulty eyes and return them before Christmas sales started. It nearly caused the company to go bankrupt. Hence the interest in finding the cause of the fault and establishing who could be sued for damages.

The basic legal question in such cases is who can be shown to be responsible and made to pay – it's all about money not science. If financial success is not likely, the case is dropped – especially when it is supported by legal aid.

The eyes involved had been supplied from the same London supplier for many years without problems. The design at that time was a simple injection moulded transparent polystyrene mushroom shape with a domed head and an integral cylindrical stem. The base of the stem was simply painted black to reflect as a black pupil when assembled.

Assembly involved pushing the stem of the polystyrene (PS) eye through the bear fabric and locating a six-pronged star washer behind. The star-washer approach is widely used for clipping car body trim and other plastic bits together. It is cheap and easily fitted and does not come apart easily because the internal teeth of the star washer nip onto the stem of the plastic part. The technique was widely used in 1978 for fitting the eyes on toy animals although regulations now forbid this method.

The evolution of the eye problem came as a complete surprise to the bear company because they had been ordering the same eyes for years from the same supplier. There was no obvious difference in the eyes supplied from batch to batch. They were the same light brown PS eyes with the same steel star washers. The bear manufacturer continued to assemble the eyes using the same manual method, which involves pushing the star washer along the stem of the eye with a flat-ended tubular hand tool.

To the bear manufacturer nothing had changed to cause them to inspect the eyes supplied – until the reports arrived of glaucoma eyes in the warehouses. They then looked at the steel star washers and found if you dropped them onto a hard surface some washers gave a higher pitched ringing tone than others. No visual difference in the steel washers could be seen.

It was then the investigator was brought in and supplied with a bag of the steel washers and eyes from the bin in the stores. This turned out to be a mixture of eyes that came to be termed 'old' and 'new' eyes with washers. Naturally the eye supplier was unable to assist. As far as they were concerned the eyes supplied had always been to the same specification – light brown PS eyes of a given size with steel star washers.

1.2 Investigative methods

Several independent tests assessed the quality of the component parts. They comprised of:

- detailed measurement of the eyes and washers supplied;
- hardness tests on the eyes to check for any differences;
- sectioning, polishing and etching of the steel washers plus micro-hardness testing.

These tests showed:

1 the new eye stem diameter was 0.05 mm larger than the old at 8.636 mm – about 0.6 per cent larger;

2 the old steel washers were 0.305 mm thick compared with the new thickness of 0.203 mm – hence the higher ringing tone of the new washers when dropped;

3 the separation of the star washer teeth, the internal diameter, was 0.152 mm less in the case of the new thinner washers than the old thicker washers;

4 metallurgical examination of the steel washers showed them to be of similar steel with the same structure, having a hardness of 435 VHN;

5 the hardness of the eye showed the new eyes were slightly harder than the old, suggesting a slight difference in PS grade used but the difference was small;

6 both eyes were subjected to the simple burning test and proved to be polystyrene from the characteristic smell and black smoke produced when this plastic burns fiercely.

The above tests showed, as far as the supplier was concerned, the new and old washers had equivalent specifications and were within all reasonable limits. The thinner new washers would be easier to assemble, requiring less force to slide the washer down the eye stem. The new washers were easier to apply. So why did the new washers produce the glaucoma?

1.2.1 Cracking and crazing

Examination of samples of failed eyes returned from the warehouses showed cracking and crazing from the root of the star washer teeth. It was also reported that the failure rate from different warehouses varied. So there was a statistical problem depending on which had ‘old’ and ‘new’ eyes fitted, and the added factor of the different temperatures of different warehouses. The properties of polymers are sensitive to even small changes of temperature. As the bear manufacturer clearly put all the eye stocks in one bin it was also possible old washers had been assembled with new eyes and vice versa.

It was clear the failures were due to dry crazing in air. A quick check was made to ensure no environmental crazing agent existed in the adjacent fur fabric and proved negative. Stress data for dry crazing in PS was obtained from the literature, showing a decreasing stress level required with time. A stress level of 24 MN m^{-2} is required at 0.01 h falling to an asymptotic value of 10 MN m^{-2} after 100 h.

The origin of the stress to drive the crazing lay in the interference fit between star washer and eye stem. Then the variation in the interference fit between star washer and eye stem between old and new system became significant in the different behaviour. However crazing is a slow process. So experimental examination to reproduce the dry crazing could not be contemplated.

1.2.2 Reconstruction experiments

Various eye assemblies were made with old and new eye systems. It was further noted that the old thicker washers were stiffer and tended to scrape the sides of the eye stem during assembly. This scraping would further reduce the interference fit, lowering the force applied to the eye stem after assembly. In contrast, the thinner new washer could flex during assembly within its elastic limit and did not scrape any material from the eye stem. Therefore it was argued that the nip force after assembly of the new eyes was much greater than for the old eyes because:

1 the interference fit with the new eyes was greater on the basis of eye stem and star washer measurements;

2 the new washers did not scrape the sides of the eye stem during assembly as for the old system, maintaining the strong interference fit after assembly with the new eyes;

3 further calculations showed the new washer remained within its elastic limit (not yielded) after assembly (because it was thinner) and therefore maintained the nip force for a longer period.

These three factors jointly contributed to providing a nip force sufficient to drive dry crazes through the new eyes with time after assembly. The statistical variation in the failure rate observed lay in the variability of the manual assembly technique – some teeth would bend beyond the yield point to relieve the nip force and in some cases fur fabric was trapped under the star washer varying the nip force. And there was a variation in temperature in the various stores. Crazing is both time and temperature dependent.

1.2.3 Trial wet crazing experiments

That was the investigator's explanation of the problem based on the evidence of new and old components. Could this be corroborated in any way? Obviously attempting to reproduce the dry crazing failure was not possible – it would take too long and the statistical variables were difficult to control. Hence he resorted to some accelerated testing demonstrations using an environmental crazing agent. The ESC agents used were n-propyl alcohol and n-heptane. n-propyl alcohol is a less severe crazing agent for PS than n-heptane.

Both new and old eyes were assembled and dropped into the ESC agents. Craze growth was measured for both sets of specimens. These measurements indeed showed the rate of crazing with the new eye assemblies was much faster than for the old eye assemblies.

The cause of the problem had been diagnosed and reasonable preliminary proof of the cause had been established.

1.3 Litigation

Reports were written and submitted to the client (the bear manufacturer) and to its solicitors. The normal exchanges then took place between the solicitors for the plaintiff and those of the defendant (the eye supplier). The defendant put his company into voluntary liquidation. As actions can only be brought against the actual company supplying the product or service or its parent company (in some circumstances and only if it exists), the action fell because the company ceased to exist under the name that had supplied the original alleged faulty goods. Hence the case could not be brought to court or even settled out-of-court. The dramatic court action in *An Eye for an Eye* is well removed from what actually happened.

1.4 Afterword

The failure is typical of many actions that could have been circumvented if the two parties had tested the changes in dimensions before introduction of the new washers into the bears. It may have seemed an inconsequential change at the time but small changes can sometimes produce large effects especially where polymers are concerned.

A similar problem arose when the radiator washers were changed from traditional fibre to the new thermoplastic elastomer (Block 1, **Input 4**). The new material had been used successfully in hot water taps but the washers were only exposed intermittently to high temperatures. In a radiator however exposure is continuous when the heating is switched on and heating periods can be long,

especially in hospitals and old people's homes where warmth is essential for the well being of the patients or residents.

Each teddy bear's eye comprised a stiff metal washer bearing against a much softer polymer, so that lowering the washer inner diameter produced a larger bearing stress on the surface of the PS. This in turn encouraged dry craze growth and hence the so-called glaucoma of the eyes over a period.

Systematic testing could have discovered the problem but is expensive and time-consuming. When dissimilar materials are in contact the softer material will always experience the greater stress in a loaded system so extra care is needed at the design stage to try to forestall such problems.