Fatigue - Not a Tiring Matter

Fatigue failures are the most common types of fractures in machines and probably constitute about 90% of all fractures. Such fractures develop after a large number of load applications, generally at a stress level below the yield strength of the material.

Fatigue cracking extends as a result of cyclic stress. The crack extends as each cycle of stress is applied. Sources of the cyclic stress could be vibration, thermal or pressure cycling or the component's own weight while rotating.

When a failure occurs through fatigue all efforts should be made to preserve the fractured surface as it can reveal valuable information on the cause of failure. As a fatigue crack extends, this results in a reduction of thickness in the location of the crack and a subsequent increase in the stress level in the remaining section. A stage is reached when the remaining section can no longer withstand the load and an overload occurs. Fatigue fracture surfaces are typically smooth whereas overload surfaces are dull and rough. The ratio of the overload section to the fatigued section gives an indication of whether the component was subjected to a high or low loading, for example a small area of overload would indicate a low overall stress.

Fatigue surfaces are usually characterised by the presence of beach marks. These beach marks can indicate the origin of the crack or multiple origins as may be the case. While it may be obvious in many cases that fatigue was the cause of failure, the actual reason for the initiation of fatigue is a key issue in looking at recovery after an insured has been indemnified under a Machinery Breakdown Policy.

Earlier, we indicated that fatigue propagates at a stress lower than the yield strength of the materials. This statement is made in relation to the overall stress on a component, however, in the case of fatigue, what occurs is a very localised increase in the stress. This localised concentration of stress is generally caused by 1 of 3 broad groups.

- Those caused by changes in geometry of the part such as holes, keyways, threads, steps or changes in diameters in shafts and boltheads, etc.

- Surface discontinuity such as nicks, notches, machining marks, pitting, corrosion, etc.

- Defects inherent in the material such as non-metallic inclusions, minute cracks, voids, etc.

Once the crack is actually formed the crack tip itself acts as a substantial stress raiser allowing it to extend although the overall stress is low.

Engineers overcome fatigue by, for example, removing vibration, specifying smooth surface finishes, specifying materials with improved toughness, ensuring there are radii between thickness changes, etc.

In the case of rotating shafts, it has been established that if the stress is reduced to a certain level a shaft can withstand an infinite amount of cycles without the propagation of fatigue cracks. Australian Standard AS 1431 can be used to design a shaft with an infinite fatigue life. The standard takes into account stress concentrations such as changing section, the presence of sleeves, spacing between bearing points, etc.

There are very few machinery breakdown claims that have been the subject of litigation. One old case is Sun Alliance and London Insurance Group v Northwest Iron Co Ltd (1974) NSWLR 625. In this case, during a stoppage for routine inspection and maintenance, cracks of up to 7 feet long were discovered in a hollow steel cylinder with walls 100mm thick which formed part of an ore crushing mill. The cracking was as a result of metal fatigue attributed to bad design.

"Breakdown" was defined in the policy to mean *"…… the actual breaking….. of any part of a machine whilst the machine is in use arising from either mechanical or electrical defects in the machine caused by sudden stoppage of the functions thereof and necessitating repair or replacement before it can resume working.*"

Sheppard J interpreted actual breaking not to be limited to a breaking, which itself caused immediate stoppage of the machinery, but also to include the case where it was discovered during a routine inspection. We note that current industry insurance clause and definition wording no longer refers to the need for actual breaking, presumably as it would be of little effect, in light of the case discussed.

The case also considered whether fatigue could be considered as "*a wasting away or wearing out of the relevant part of a machine caused by, or naturally resulting from, ordinary use or working*." The fatigue cracks were not considered to fall under this description.

Consideration would have to be given to the specific policy wording to see if the fatigue cracking would fall under any exclusion. Wordings in the market vary significantly and the intentions are not always clear. For example, could fatigue be considered to fall within the following exclusions?

- Repair or replacement necessitated by any direct consequences of progressive or continuous influences from working.
- You are not insured for the costs incurred in repairing wear-and-tear or gradual deterioration, including slowly developing deformation or distortion.
- For loss of damage which is specifically wear-and-tear, corrosion, erosion, cavitation, oxidation, gradual deterioration due to atmospheric conditions, or otherwise.
- The cost of replacement or restoration following gradual deterioration.
- The cost of replacement or repair of gradual deterioration.

The cost of rectifying wear-and-tear, which means wasting or wearing out of any part of insured plant caused by, or naturally resultant from, ordinary use or working or gradual deterioration, including slowly developing deformation, distortion or cracking.

While fatigue can occur within days for a component subject to a high number of cycles often it can take many years for a fatigue crack to progress through the thickness of the material before an actual failure occurs. It would appear that something that occurred over several years would be considered as gradual deterioration or as a direct consequence of progressive or continuous influences from working and hence exclusion may apply.

In the event that the exclusion does apply, a further consideration has to be given to whether it would apply to the final instantaneous failure of a component where a fatigue crack had progressed to the extent that the remaining section could not carry the load. The implications of this can often be serious for insureds that often have business interruption policies tied to their Machinery Breakdown Policy. For cover under the business interruption section, an identifiable event under the Machinery Breakdown Policy, but for the application of any deductible, is necessary.

It can be argued that while the fatigue damage may fall under the exclusion, the final instantaneous overload does not and, consequently, the Insured may not be indemnified for the majority of the material damage however, this would permit them to be indemnified for the resultant business interruption loss, which may be of a far greater quantum.

It may be that discovery of a fatigue crack, which cannot be repaired, is discovered during routine maintenance. For reasons given above it is likely that this would fall within the insuring clause of a Machinery Breakdown Policy which could lead the insurer to be exposed to business interruption losses. As fatigue is progressive, once the crack is established it would take a finite number of cycles for the crack to extend to the point where an

overload failure occurs. Determining the number of cycles, which a component can still be subjected to prior to reaching this point of instantaneous failure, is complicated, however there are some methods that may allow the component to be placed back in service and monitored, which could prevent a business interruption loss.

Acoustic emission is one of these methods and is a technique that listens for extension of a crack through the sound it emits. An increase in the frequency of crack extension noises tends to indicate that the final failure may be approaching, however a steady rate of crack growth may allow continual monitoring until a replacement is found without risk to property or persons. Ultrasonics is a method that can be used to determine the actual depth of a crack. Intermittent monitoring to obtain some appreciation of the rate of crack extension could allow a continuation of work with considerable savings.

Fracture mechanics can be used to determine the thickness of material remaining before the final fracture occurs. Usually, this approach would be used where rectification or replacement will take place over a longer period. While generally most designers would avoid welds where there is a chance of fatigue, temporary weld repairs, conducted with suitable filler materials, weld procedures and heat treatment, can limit the downtime.

Fatigue is an extremely complicated type of cracking which can also give rise to complications in policy response with respect to both the material damage and any associated business interruption cover. An understanding of fatigue and the critical issues surrounding it, as well as the factors which cause it to initiate, need to be evaluated to ensure the correct policy response and any successful recovery action.