Fatigue of Bulk Materials Handling Machines

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Abstract

Materials handling machines are complex structures which often rely on load limiting devices to prevent damage. Fatigue damage is a consideration for machines of this type.

An investigation by the author [1] of the failures of over sixty materials handling machines found that about ten percent of failures can be attributed to fatigue failure. In most cases these failures were unexpected and lead to catastrophic consequences. Figure 1 shows the number of machine failures versus the age of the machine at failure. The failures can be divided into two groups: the first group of failures occurs within the first five years after commissioning and the second group of failures occur when the machines are greater than ten years old. About ten percent of all failures or about one quarter of the failures that occurred when the machine was greater than ten years old can be attributed primarily to fatigue damage.

In this article, the author discusses the process of fatigue damage relating to cranes and materials handling machines.

Figure 1: Number of failures versus machine life

1. Process of Fatigue Damage

The process of fatigue means that steel strength deteriorates under the action of cyclic loads and this may ultimately lead to cracking and the unexpected failure of structures. The American Society for Testing and Materials [2] defines fatigue as;

The process of progressive localised permanent structural change occurring in a material subjected to conditions which produce fluctuating stresses and strains at some point or points and which may culminate in cracks or complete failure after a sufficient number of fluctuations.

Two key points to note in this definition are:

- Progressive implies that the fatigue process occurs over a period of time. Fatigue failure may be sudden with no warning, however the mechanisms involved have been operating since the beginning of the structures usage.
- Localised implies the fatigue process operated at local areas rather than throughout the entire structure. The ultimate cause of all fatigue failures is that a crack has grown to a point at which the remaining material can no longer tolerate the stresses or strains and sudden fracture occurs.

The fatigue process involves two stages: crack initiation and crack propagation. Crack initiation involves changes to the material microstructure such that distinct crack initiation sites occur. As cycling continues, crack propagation occurs and the fatigue cracks tend to coalesce and grow along planes of maximum stress. The majority of cranes and rail mounted materials handling machines have significant welding and hence small defects (cracks) are already present. To account for this, current design standards assume that small cracks will always be present and that crack propagation is the only part of the fatigue process.

2. Statistical Nature of Fatigue

The concept of “remaining fatigue life” can be simplistic and misleading especially for older, deteriorated structures. “Fatigue life” is a statistical quantity - design curves are based on results from test specimens and considerable deviation from the average curve determined from a few specimens occurs.

Figure 2 shows typical results for fatigue tests on a fillet welded T-joint. The tests were performed with different stress ranges and the number of cycles to failure were found. The geometry and weld procedure were the same for all the test pieces. As can be seen, the test data has considerable scatter even though the test pieces and field conditions were very similar.

The usually specified reliability factor for a detail is 0.9773, that is, two standard deviations from the mean. If the structure were subjected to the design cumulative damage, and the details were working to the allowable limit, without intervention one detail in 45 on average would fail. If you consider that a typical bucket wheel reclaimer can have between 5,000 and 10,000 details, this would not be acceptable.

Design standards such as AS4100 recognise the reduced reliability for fatigue versus strength design and stipulate that dynamically loaded structures affected by fatigue must be regularly inspected for code rules to apply. Regular inspection of these structures should increase the reliability of the structure to an acceptable level.

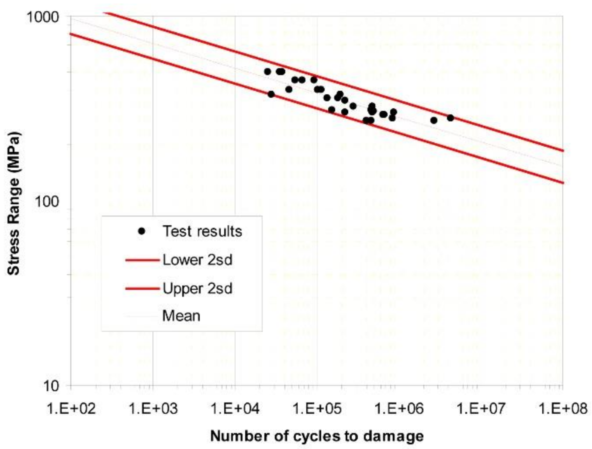

Figure 2: Test results for welded T-joint

Codes also recognise that where parts of the machine susceptible to fatigue are not accessible for inspection, then further conservatism needs to be incorporated in the design.

3. Issues with Fatigue Damage

Some of the issues associated with fatigue damage that are specific to materials handling machines are discussed in this section.

4. Environment

Fatigue crack growth rates are strongly influenced by the environment. Corrosion can have a significant effect on “fatigue life” which can be reduced by half in corroded areas. Higher stresses can be caused by pitting or reduced plate thickness. Also corroded structural steel has no fatigue limit, that is, a corroded component will fail regardless of the magnitude of the stress range [3]. In general, good fatigue design and detailing is closely linked to high corrosion resistance.

5. Weld Quality and Details

Poor weld quality significantly increases the probability of fatigue damage development. For example, the fatigue life of a component can be shortened by 2½ times if a fillet is too near an edge of a member. Welding procedure affects fatigue life considerably. Occurrences such as weld spatter, accidental arc strikes, weld flaws, poor fit-up, misalignment can lead to lower performance than its classification would indicate [3].

6. Secondary Members

The fatigue analysis usually only considers the global effects on the machine and accounts for primary structural steel alone. International research [4] shows that up to 70% of fatigue damage occurs in secondary members, which are not usually checked in the design stage (eg. brackets carrying electrical cables, welded cover plates). Damage due to effects from secondary members is not necessarily detrimental to the performance of the structure provided it is found early, via regular inspections, and repaired before the damage propagates to the main structural sections leading to failure of the structure.

7. Inspection

Dynamically loaded structures affected by fatigue must be regularly inspected for fatigue damage for design code rules regularly inspected for fatigue damage for design code rules such as Australian Standard AS4100 to apply. The limit of detectable crack size in the field is 6mm long by 2mm depth [5]. However the detection of cracks above this "detectable size" is not a certainty.

Reliable crack detection is affected by many factors [6]:

- The skill of the inspector. Experienced inspectors should have a higher likelihood of detecting cracks compared to an inexperienced person.
- The specific area to be inspected. It is easier to detect cracks in a specific location such as a particular component compared to the total machine
- The accessibility of the detail including details that may be hidden behind other structural components. Some details may be difficult to access or may be completely hidden from view by other structural members. Corrosion products or paint that may be inside the crack.

8. What to Do If Cracks are Found

Where cracks are found on a structure in service, owners need informed advice on how long they can continue to operate before undertaking repairs, replacements or further inspection and monitoring. A fracture mechanics assessment allows crack growth curves to be developed for particular details.

Figure 3 shows a typical crack growth curve on a welded structure with the crack size given on the vertical axis and the number of cycles on the horizontal axis. It can be seen that the crack growth is exponential. Once a detectable crack is found on a critical details, there may be "limited time" available to undertake remedial works.

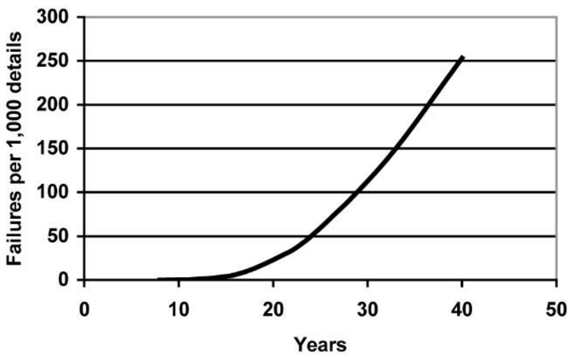

Figure 3: Crack growth rate for single edge crack in tension

9. Conclusions

It is important to note that the following points:

- Cracks are to be expected. Current fatigue design codes have details with a reliability of 0.9773 or a 1 in 45 probability of cracking at the end of their design life. This compares to structural strength design which has a reliability of 0.999. Also the reliability decreases with age of the structure.
- Satisfactory control of fatigue damage relies on adequate methods of fatigue crack detection and the ability to repair or replace the damaged component.

An effective methodology for the structural appraisal of large structures should consider:

- Structural analysis. Locate areas of high stress and investigate possible failure mechanisms.
- Fatigue analysis. Locate areas where there is a high likelihood of fatigue cracking occurring.
- Inspection. NDT of critical areas and visual inspection of non-critical and secondary members.
- Fracture mechanics assessment to predict crack growth rates and inspection regimes in critical areas.

10. References

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