A Review on Thermal Crack Growth Based Fatigue Life Prediction

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***Abstract* - The fatigue failures results in 70-90 percent of failure in most of the machines, automobile parts etc. As most of the moving components such as railway wheel, engine components are subjected to heating, this heating causes thermal stresses on components, and this thermal stress induces thermal fatigue in components. The thermal fatigue results in increase in the rate of initiation, propagation of cracks in the materials which results in decrease in service life of components so to understand the thermal fatigue is necessary.**

***Keywords*: Fatigue, thermal stress, thermal fatigue, cracks, service life.**

1. INTRODUCTION

Components subjected to alternating heating and cooling have been found to crack and eventually fail. This phenomenon is termed as thermal fatigue.

1.1 THERMAL STRESSES

When temperature changes it induces thermal expansion in the material.

$$\varepsilon=\alpha\Delta T$$

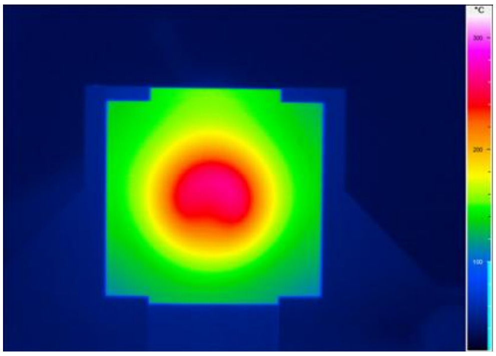
ε is thermal expansion (mm).

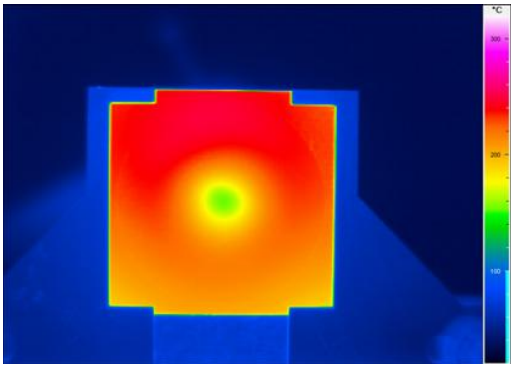
α is the linear coefficient of thermal expansion (1/K).

ΔT is the temperature change causing the expansion (K).

If this expansion is hindered, thermal stresses arise. The magnitude of the arising stresses is such that if applied as an external load they would result in strain equal to the hindered expansion. Thermal stresses can arise because of either external or internal constraints. Internal constraints can be caused by non uniform temperature distribution or non uniform material properties. If the thermal stresses arise due to internal constraints, the loading is called pure thermal loading, or just thermal loading. If the stresses are due to external constraints, term thermo mechanical loading is used.

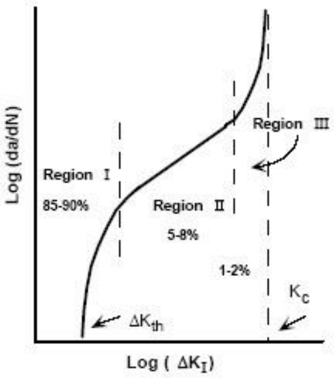
If failure occurs during one cycle of thermal stress because of a rapid temperature change, the phenomenon known as thermal shock, while failure occurring after multiple thermal stress cycle caused by a cyclic temperature change are referred to as thermal fatigue.





2. CRACK INITIATION, PROPAGATION AND FAILURE

Crack growth can be divided into three stages:

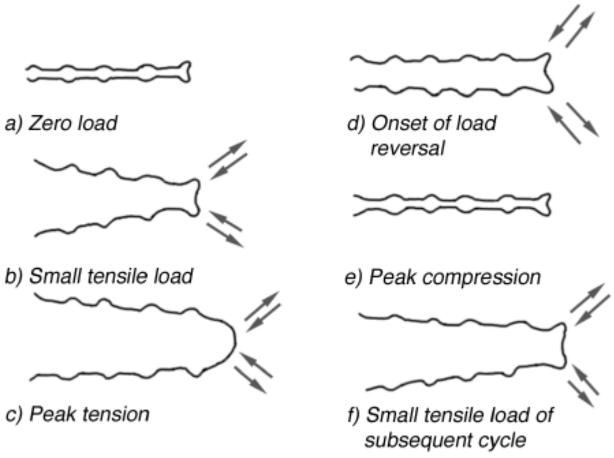


Stage 1: Crack initiation

Crack initiation usually occurs at stress concentration sites originating from component geometry, machining irregularities or surface imperfections. During the compressive part of the cycle, the increase in temperature lowers the yield strength of material, and the compressive strain may become plastic when substrate prevents deformation. During the tension part of the cycle, the concentrated thermal stress is larger than the yield strength of the material, and reversed plastic deformation may occur. After sufficient number of cycles, the localized plastic deformation will cause a fatigue crack. Once a crack is initiated, propagation occurs along a plane perpendicular to the maximum tensile stress.

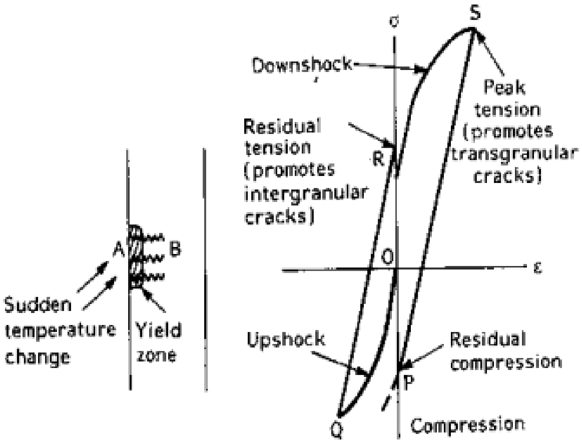
Stage 2: Crack propagation

Crack growth proceeds by a continual process of crack sharpening followed by blunting, Crack propagation during crack growth often produces a pattern of fatigue striations with each striation representing one cycle of fatigue. Although striations are indicative of fatigue, fatigue failures can occur without the formation of striations. Striations are micro structural details that are best examined with a scanning electron microscope and are not visible to the naked eye.



Stage 3: Failure

The crack will continue to grow as long as cyclical tensile stresses are present. At some point, the crack size becomes large enough to raise the stress intensity factor K at the crack tip to the level of materials fracture toughness K_c and sudden failure occurs instantaneously on the next tensile stress-cycle.



3. FATIGUE LIFE PREDICTION MODEL

Paris law:

The total fatigue life of a component can be divided into three phases:

(i) crack initiation,
(ii) stable crack growth, and
(iii) unstable crack growth.

Crack initiation accounts for approximately 40–90% of the total fatigue life, being the phase with the longest time duration .Crack initiation may stop at barriers (e.g., grain boundaries) for a long time; sometimes the cracks stop completely at this level and they never reach the critical size leading to the stable growth.

This law formulated by Paris and is commonly used to model the stable fatigue crack growth:

$$\frac{da}{dN} = C \cdot \Delta K^{m};$$

and the fatigue life N is obtained from the following integration:

$$N = \int_{a_i}^{a_f} \frac{da}{C \cdot (\Delta K)^{m}}$$

ΔK is the stress intensity factor range

C and m are material-related constants.

The integration limits a_i and a_f correspond to the initial and final fatigue crack lengths.

3. DIFFERENT TYPES OF MODELS USED

1. Damage Accumulation Model

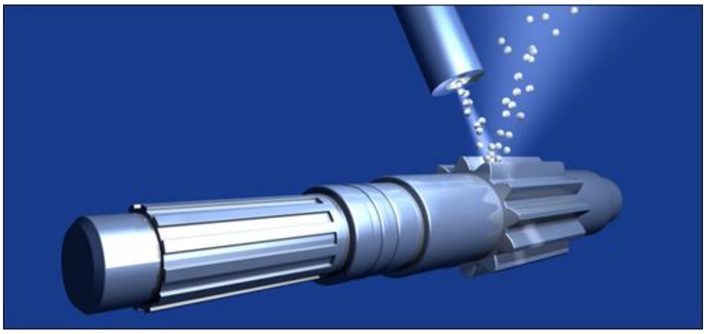
2. Strain-Rate Partitioning

3. Crack analysis codes
    - a) CANIS J
    - b) CANIS G
4. S-N curves
5. HdM-methods
6. Energy based approach
7. Palmgren-miner linear damage hypothesis
8. The Stress-Life Approach
9. The Strain-Life Approach
10. The LEFM Approach etc.

4. FATIGUE LIFE IMPROVEMENT

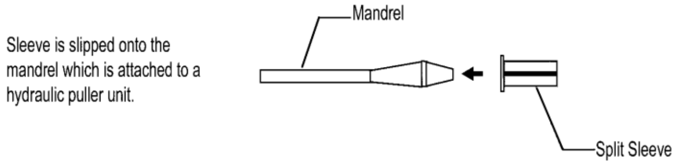
4.1 PEENING

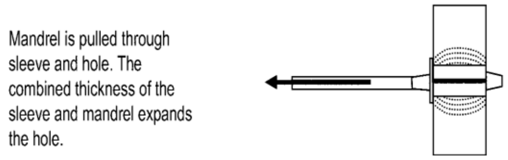
One of the best methods of improving fatigue life is to induce residual compressive stresses on the surface of the part. This can be accomplished by shot peening. Shot peening involves propelling fine steel or cast-iron shot into the surface at high velocities. The severity of the stress or the induced stress is measured by the residual deformation of shot-peened specimens called Almen strips. In addition to inducing compressive stress on the surface, the surface layers are also strengthened by the cold working that occurs during shot peening. Important variables in shot peening are hardness of the shot, the size, the shape, and the velocity. Shot peening must be carefully controlled so as not to introduce surface damage to the part. Shot peening imparts greater fatigue life during high-cycle fatigue than it does for higher-stress low-cycle fatigue. In low-cycle fatigue, large stresses in the plastic range cause “fading” of the residual stress pattern.



4.2 COLD WORKING

Cold working of holes is usually conducted using either the split-sleeve or split-mandrel Method. Both methods involve pulling a mandrel through the hole that expands the hole diameter, creating plastic deformation of material around the hole and a resulting residual compressive stress field.





5. CONCLUSION

The economical effects of unexpected failures can be very high, e.g., in power, process and paper industries. Failures may threaten property and even life. The existing design methods do not give adequate tools for design against thermal fatigue. In the case of thermal fatigue, the increase of safety by using heavier constructions is not only uneconomical but also often impossible. A huge number of fatigue life prediction models have been proposed, yet none of these can be universally accepted. Authors all over the world put efforts into modifying and extending the already existing theories, in order to account for all the variables playing key roles during cyclic applications of loadings. The fatigue problems are very complex this makes topic very interesting and new approaches arise continuously.

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