How to tackle fatigue failures

The number of cycles that a metal can endure before it breaks is a complex function of the static and cyclic stress values, the alloy, heat-treatment and surface condition of the material, the hardness profile of the material, impurities in the material, the type of load applied, the operating temperature, and several other factors.

Stress Life Relations

To understand the phenomena of fatigue failure a systematic study has been conducted by a German railway engineer A.Wohler by testing axles to failure in the laboratory under fully reversed loading. His work lead to the existence of a relation between applied stress and the number of cycles to failure. This relation or the S-N diagram became the standard way to characterize the behavior of materials under cyclic stressing, and evaluate the fatigue strength of materials.

How is the fatigue strength of a metal determined?

The fatigue behavior of a specific material, heat-treated to a specific strength level, is determined by a series of laboratory tests on a large number of apparently identical samples of that specific material.

This picture shows a laboratory fatigue specimen. These laboratory samples are optimized for fatigue life. These laboratory samples are now standardized in geometry and configuration such that no extraneous factors other than the applied stress influence the fatigue life. They are

Figure 1.2

machined with shape characteristics which maximize the fatigue life of a metal, and are highly polished to provide the surface characteristics which enable the best fatigue life.

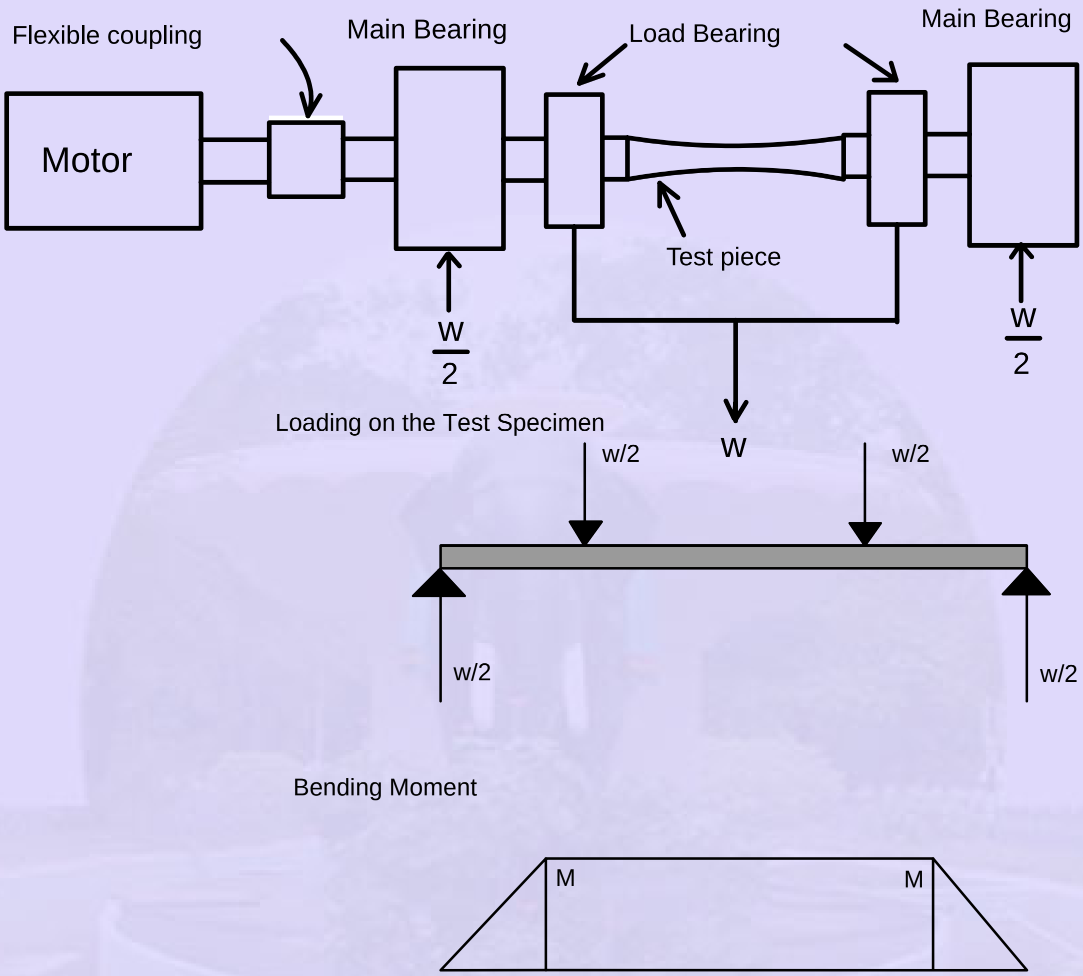
A single test consists of applying a known, constant bending stress to a round sample of the material, and rotating the sample around the bending stress axis until it fails. As the sample rotates, the stress applied to any fiber on the outside surface of the sample varies from maximum-tensile to zero to maximum-compressive and back. The test mechanism counts the number of rotations (cycles) until the specimen fails. A large number of tests is run at each stress level of interest, and the results are statistically massaged to determine the expected number of cycles to failure at that stress level.

The most widely used fatigue-testing device is the R.R Moore high-speed rotating beam machine. This machine subjects the specimen to pure bending (no transverse shear).

Standard Testing

A rotating bending machine (RBM) is mostly suitable to test the fatigue properties at zero mean stress. A schematic sketch of the test device is illustrated in the figure below. A standard test specimen is clamped in bearings at the ends and loaded at two points as shown. With this type of device the region of rotating beam between built-in ends is subjected to pure bending with a constant bending moment all along its length. While under the influence of this constant moment, the specimen is rotated by the drive spindles around the longitudinal axis; any point on the specimen is thus subjected to completely reversed stress pattern.

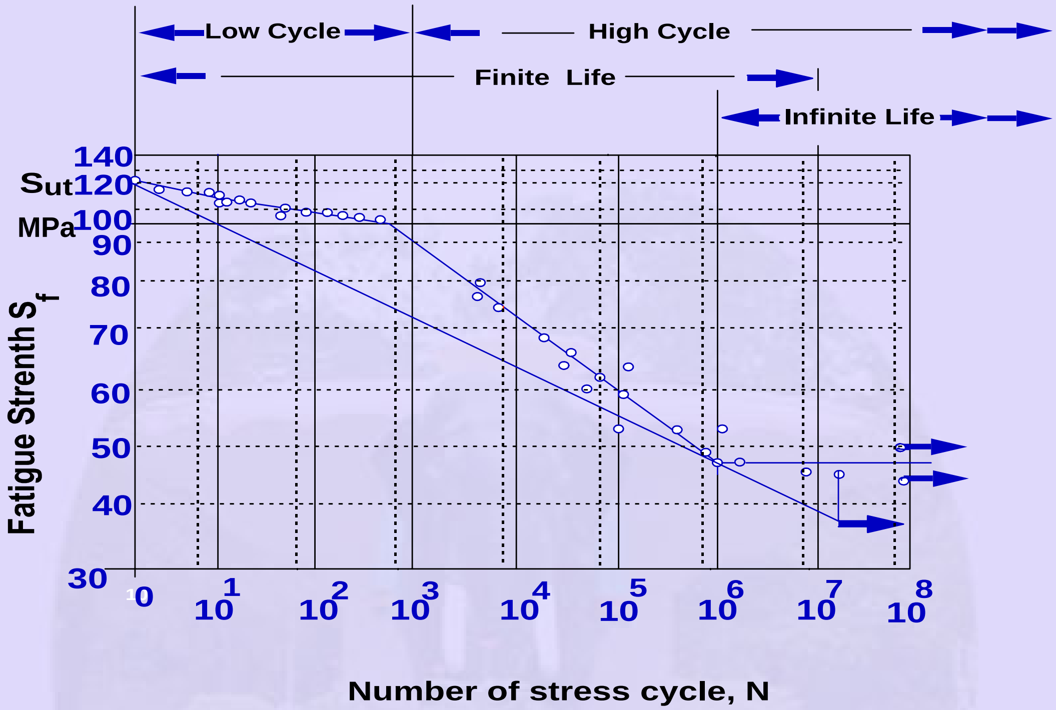
RBM-Fatigue Testing



The S-N Diagram

Tests on several specimens are conducted under identical conditions with varying levels of stress amplitude. The cyclic stress level of the first set of tests is some large percentage of the Ultimate Tensile Stress (UTS), which produces failure in a relatively small number of cycles. Subsequent tests are run at lower cyclic stress values until a level is found at which the samples will survive 10 million cycles without failure.

The results are plotted as an S-N diagram (see the figure) usually on semi-log or on log-log paper, depicting the life in number of cycles tested as a function of the stress amplitude. A typical plot is shown in the figure below for two class of materials.



Endurance or Fatigue Limit

In the case of the steels, a knee (flattening or saturation) occurs in the graph, and beyond this knee failure will not occur, no matter how large the numbers of cycles are. The strength (stress amplitude value) corresponding to the knee is called the endurance limit (S_e) or the fatigue limit. However the graph never does become horizontal for non-ferrous metals and alloys, hence these materials do not have an endurance limit.

Endurance Limit

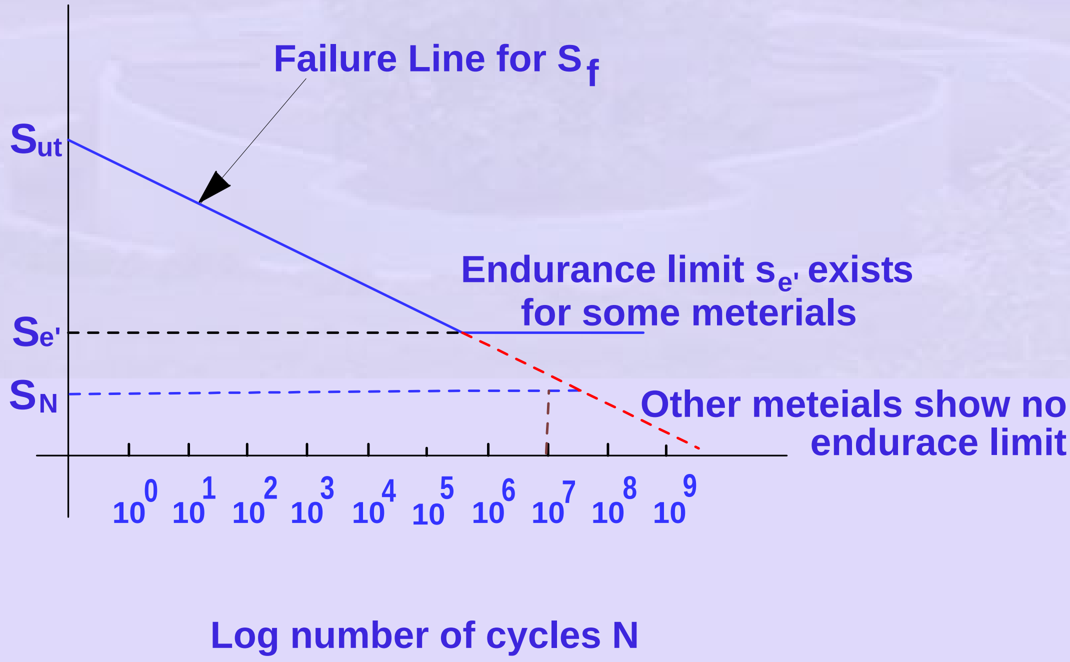
Endurance or Fatigue limit - definition

Endurance or fatigue limit can be defined as the magnitude of stress amplitude value at or below which no fatigue failure will occur, no matter how large the number of stress reversals are, in other words leading to an infinite life to the component or part being stressed. For most ferrous materials Endurance limit (S_e) is set as the cyclic stress level that the material can sustain for 10 million cycles.

In general, steel alloys which are subjected to a cyclic stress level below the EL (properly adjusted for the specifics of the application) will not fail in fatigue. That property is commonly known as "infinite life". Most steel alloys exhibit the infinite life property, but it is interesting to note that most aluminum alloys as well as steels which have been case-hardened by carburizing, do not exhibit an infinite-life cyclic stress level (Endurance Limit).

Endurance or Fatigue Strength

For such materials, which do not have an endurance limit, to use in design applications it is customary to define a fatigue or endurance strength (SN) as the value of the stress amplitude at a specified life (in terms of stress reversals) usually $5X10^6$ or 10^7 cycles. The specification of fatigue strength without specifying the corresponding life is meaningless. The specification of a fatigue limit always implies infinite life.



S-N Diagram-Operational Regions and Design Concepts

Low Cycle Fatigue

The body of knowledge available on fatigue failure from N=1 to N=1000 cycles is generally classified as low-cycle fatigue.

Low Cycle Fatigue

High Cycle Fatigue

High-cycle fatigue, then, is concerned with failure corresponding to stress cycles greater than 10^3 cycles.(Note that a stress cycle (N=1) constitutes a single application and removal of a load and then another application and removal of load in the opposite direction. Thus N= ½ means that the load is applied once and then removed, which is the case with the simple tensile test.)

High Cycle Fatigue

Finite and Infinite Life

We also distinguish a finite-life and an infinite-life region. Finite life region covers life in terms of number of stress reversals upto the knee point.(in case of steels) beyond which is the infinite-life region. The boundary between these regions cannot be clearly defined except for specific materials; but it lies somewhere between 10^6 and 10^7 cycles, for materials exhibiting fatigue limit.

Finite Life

Infinite Life