Factors Influencing Fatigue

i) Loading

Nature and type of loading: -Axial tension, bending, torsion and combined loading-Mean and Variable components in case of Repeated, Fluctuating and Alternating loading and Frequency of loading and rest periods

ii) Geometry

Size effects and stress concentration

iii) Material

Composition, structure, directional properties and notch sensitivity

iv) Manufacturing

Surface finish, heat treatment, residual stresses

V) Environment

Corrosion, high temperature, radiation

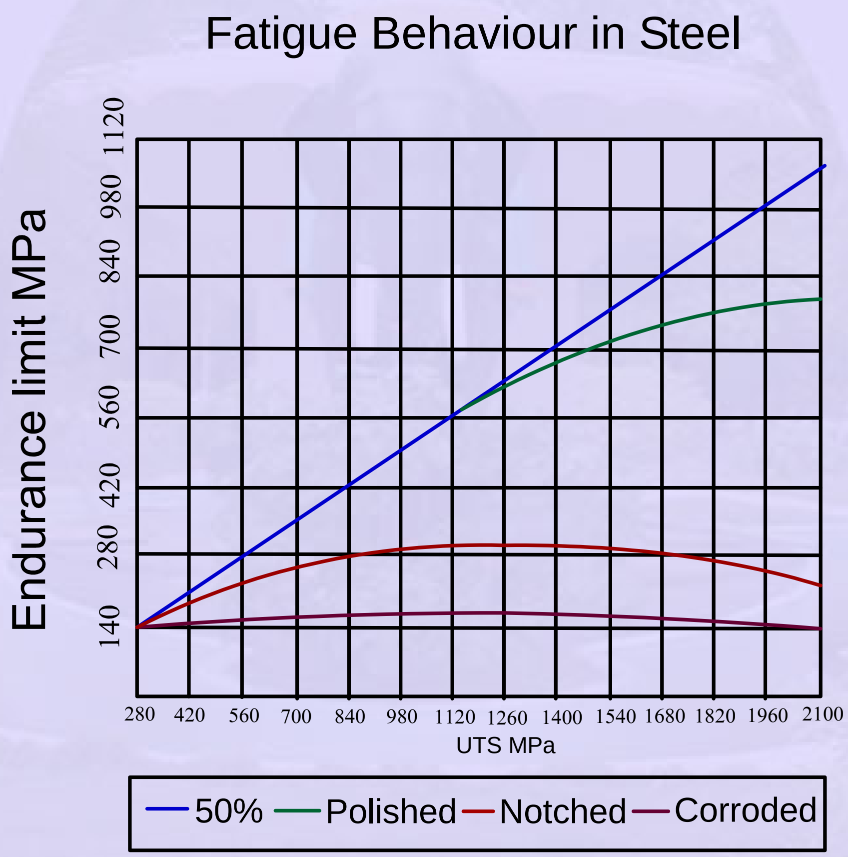
Material

As noted earlier there are two class of materials as for as the fatigue behavior is concerned, those material which exhibit well defined endurance limit and those without do not show endurance limit. Most ferrous materials and basic steels fall under the first category and some heat treated alloys of steel, aluminum etc. fall under the second category.

Composition and strength of the material are interrelated and detail discussion on strength follows later. Strength is also related to micro structure and in this respect it is interesting to note that soft structure like ferrite resist fatigue better than hard structure like cementite. However because of the higher strength that can be achieved from the same material by altering the micro structure, such structures are preferred in spite of their poor resistance

IS THERE ANY RELATIONSHIP BETWEEN UTS AND FATIGUE STRENGTH?

The endurance limit of steel displays some interesting properties. These are shown, in a general way,



in this graph, and briefly discussed below. It is a simplistic rule of thumb that, for steels having a UTS less than 1400 MPa, the endurance limit for the material will be *approximately* 45 to 50% of the UTS *if the surface of the test specimen is smooth and polished*.

That relationship is shown by the line titled "50%". A very small number of special case materials can maintain that approximate 50% relationship above the 1400 MPa level.

However, the EL of most steels begins to fall away from the 50% line above a UTS of about 1400 MPa, as shown by the line titled "Polished".

For example, a specimen of SAE-4340 alloy steel, hardened to 32 Rockwell-C (HRc), will exhibit a UTS around 1400 MPa and an EL of about 700 MPa, or 50% of the UTS. If you change the heat treatment process to achieve a hardness of about 50 HRc, the UTS will be about 1820 MPa, and the EL will be about 590 MPa, which is only about 32% of the UTS.

Several other alloys known as "ultra-high-strength steels" and some maraging steels have been demonstrated to have an EL as high as 45% of UTS at strengths as high as 2100 MPa. Also note that these values are EL numbers for fully-reversing bending fatigue.

In above figure illustrated, the line titled "Notched" shows the dramatic reduction in fatigue strength as a result of the concentration of stress which occurs at sudden changes in cross-sectional area (sharp corners in grooves, fillets, etc.). The highest EL on that curve is about 25% of the UTS (at around 350 MPa).

The surface finish of a material has a dramatic effect on the fatigue life. That fact is clearly illustrated by the curve titled "Corroded". It mirrors the shape of the "notched" curve, but is much lower. That curve shows that, for a badly corroded surface (fretting, oxidation, galvanic, etc.) the endurance limit of the material starts at around 140 MPa for materials of 280 MPa UTS (50%), increases to about 180 MPa for materials between 280 and 1400 MPa UTS, then decreases back toward 140 MPa as the material UTS increases above 1400 MPa.

WHY IS THE SURFACE SO IMPORTANT?

Fatigue failures almost always begin at the surface of a material. The reasons are that (a) the most highly-stresses fibers are located at the surface (bending fatigue) and (b) the intergranular flaws which precipitate tension failure are more frequently found at the surface.

Suppose that a particular specimen is being fatigue tested (as described above). Now suppose the fatigue test is halted after 20 to 25% of the expected life of the specimen and a small thickness of material is machined off the outer surface of the specimen, and the surface condition is restored to its original state. Now the fatigue test is resumed at the same stress level as before. The life of the part will be considerably longer than expected. If that process is repeated several times, the life of the part may be extended by several hundred percent, limited only by the available cross section of the specimen. That proves fatigue failures originate at the surface of a component.

Frequency: υ or f in units of Hz. For rotating machinery at 3000 rpm, f = 50 Hz. In general only influences fatigue if there are environmental effects present, such as humidity or elevated temperatures

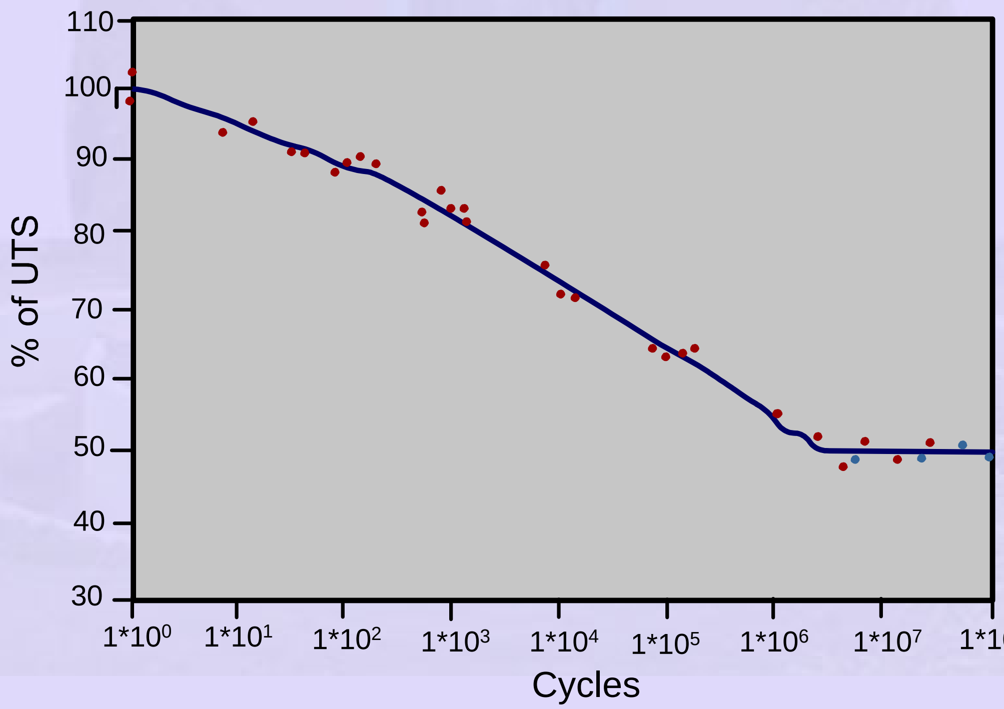
Waveform: Is the stress history a shine wave, square wave, or some other wave form? As with frequency, generally only influences fatigue if there are environmental effects.

Is the endurance limit an exact number?

It is important to remember that the Endurance Limit of a material is not an absolute nor fully repeatable number. In fact, several apparently identical samples, cut from adjacent sections in one bar of steel, will produce different EL values (as well as different UTS and YS) when tested, as illustrated by the S-N diagram below. Each of those three properties

(UTS, YS, EL) is determined statistically, calculated from the (varying) results of a large number of apparently identical tests done on a population of apparently identical samples.

The plot below shows the results of a battery of fatigue tests on a specific material. The tests at each stress level form statistical clusters, as shown. a curve is fitted through the clusters of points, as shown below. The curve which is fitted through these clusters, known as an "S-N Diagram" (Stress vs. Number), represents the statistical behavior of the fatigue properties of that specific material at that specific strength level. The red points in the chart represent the cyclic stress for each test and the number of cycles at which the specimen broke. The blue points represent the stress levels and number of cycles applied to specimens which did not fail. This diagram clearly demonstrates the statistical nature of metal fatigue failure.



DO REAL-WORLD COMPONENTS EXHIBIT THE "LABORATORY" EL?

Unfortunate experience has taught engineers that the value of the Endurance Limit found in laboratory tests of polished, optimized samples does not really apply to real-world components.

Because the EL values are statistical in nature, and determined on optimized, laboratory samples, good design practice requires that one tries to determine what the actual EL will be for each specific application. This is a time consuming process and at preliminary design levels may not be feasible or desirable. As more and more knowledge is gained on the fatigue aspects, this is now over come by applying a number of correction or modification factors as discussed in the next lesson.