8 FACTORS INFLUENCING S-N BEHAVIOR

The reference fatigue condition for *S-N* behavior is usually fully reversed R = -1 bending or axial loading using small, unnotched specimens. Section 6.3 showed how mean stresses affect this reference fatigue condition at long life. Many other factors also affect the reference fatigue condition. Some of these are complex, and we have included specific chapters or sections to discuss them adequately.

8.1 Microstructure

In solid mechanics we often model metals as homogeneous, isotropic, and linearly elastic. At the microscopic level, none of these assumptions may exist and metal fatigue is significantly influenced by microstructure. This includes chemistry, heat treatment, cold working, grain size, anisotropy, inclusions, voids/porosity, delaminations, and other discontinuities or imperfections. If the actual *S-N* data are available, microstructural effects are inherently accounted for and therefore do not have to be accounted for again. Chemistry, heat treatment, and cold working have a broadly significant influence on ultimate tensile strength, and the effects of ultimate tensile strength on fatigue limits for many metals were shown in Fig. 8. These three items have an enormous number of synergistic variations, and generalities concerning their effects on fatigue behavior are not practical here. However, some generalities can be formulated for the other microstructural aspects. Fine grains generally provide better *S-N* fatigue resistance than coarse grains except at elevated temperatures, where creep/fatigue interaction exists. Fine grains reduce localized strains along slip bands, decreasing the amount of irreversible slip, and provide more grain boundaries to aid in transcrystalline crack arrest and deflection, thus reducing fatigue crack growth rates. Anisotropy caused by cold working gives increased *S-N* fatigue resistance when loaded in the direction of the working than when loaded in the transverse direction. This is due to the elongated grain structure in the direction of the original cold working.

Inclusions, voids/porosity, and laminations act as stress concentrations and thus are common locations for microcracks to nucleate under cyclic loading, or to form during heat treatment or cold working prior to cyclic loading. Under either condition, fatigue resistance is reduced by these discontinuities. Minimizing inclusions, voids/porosity, laminations, and other discontinuities through carefully controlled production and manufacturing procedures is a key to good fatigue resistance.

8.2 Size Effects

Under unnotched bending conditions, if the diameter or thickness of the specimen is <10 mm, then the *S-N* fatigue behavior is reasonably independent of the diameter or thickness. For larger size, *S-N* fatigue resistance is decreased. The decreases may differ slightly for rotating bending compared to nonrotating bending specimens or components. As the diameter or thickness increases to 50 mm, the fatigue limit decreases to a limiting factor of about 0.7 to 0.8 of the fatigue limit for specimens less than 10 mm in diameter or thickness. Additional decreases can occur for larger specimens or components. Under unnotched axial conditions, *S-N* fatigue resistance is lower than for most bending conditions. The fatigue limit for axial loading can range from 0.75 to 0.9 of the bending fatigue limits for small specimens. Several factors are involved in the above size and axial loading effects. In bending, for a given nominal stress, the stress gradient depends upon the specimen's diameter or thickness. The larger the diameter or thickness, the smaller the bending stress gradient and hence the larger the average stress in a local region on the surface. The average stress in the local region, rather than the maximum stress, may be the governing stress for fatigue. For axial loaded unnotched specimens, a nominal stress gradient does not exist, and the average and maximum nominal stresses have the same magnitude, resulting in less size effect than in bending. In bending and axial loading, larger specimens have a higher probability of microstructural discontinuities in the highly stressed surface regions that contribute to the decrease in fatigue resistance. Another reason axial fatigue resistance is lower than bending fatigue resistance is possible eccentricity or alignment difficulties that superimpose bending stresses on the axial stresses. Also, with axial unnotched specimens, since the whole specimen is subjected to a uniform stress, hysteresis energy may not dissipate adequately and the specimen’s temperature can rise, which may decrease fatigue resistance.

8.3 Surface Finish

Since most fatigue failures originate at the surface, the surface will have a substantial influence on fatigue behavior. Surface effects are caused by differences in surface roughness, microstructure, chemical composition, and residual stress. This influence will be more pronounced at long lives where a greater percentage of the cycles is usually involved with crack nucleation, as shown in Fig. 7. The reference fatigue strengths shown in Fig. 8 were for highly polished, smooth specimens. Most engineering parts, however, are not highly polished, and grinding or machining, even if done carefully, will cause degradation in fatigue strength relative to that shown in Fig. 8.

8.4 Frequency

The influence of the frequency on S-N behavior of metals is complicated because of the synergistic effects of test temperature, corrosive environment, stress-strain sensitivity to strain rate, and frequency. Independently, both elevated temperature and corrosive environments are usually detrimental to fatigue resistance. Specimen heating at higher test frequency due to internal hysteresis damping can increase the specimen’s temperature and thus disguise the true fatigue behavior at ambient temperature. This is particularly important for lower-strength metals. Generation of heat due to cyclic loading depends on the volume of highly stressed material. Thus, axial loading and large specimens will produce more heat than small bending specimens or notched specimens, and therefore frequency effects could be different in these situations. If heating effects are negligible due to various cooling techniques and / or low stress amplitude during testing, along with negligible corrosion effects, then frequency effects can be evaluated. Under these conditions, using axial or bending specimens, frequencies ranging from less than 1 Hz to 200 Hz have had only a small effect on *S-N* behavior for most structural metals. At higher frequencies (still <200 Hz), fatigue strengths at 10^6 to

10^8 cycles have shown increases from zero to 10 percent. At higher stress amplitudes, small increases in fatigue life have also occurred; however, many of these life changes are similar to typical scatter at a given frequency. In a few exceptional cases, fatigue resistance has decreased at higher frequencies. Based on the above, with known absence of corrosion and temperature effects and other aggressive environments, frequency effects of up to about 200 Hz have often been neglected in fatigue design and testing. Other effects may be more important. The key, however, is the absence of corrosion and an increase in temperature.