Note that $S_{f,k}$ is sometimes given at N_2 and sometimes at N_3. Based on data in FKM [96] it appears that between N_2 and N_3 the S-N curve can be estimated with:

$$\tilde{S}_a^{3k} \cdot N = c \qquad (5.8)$$

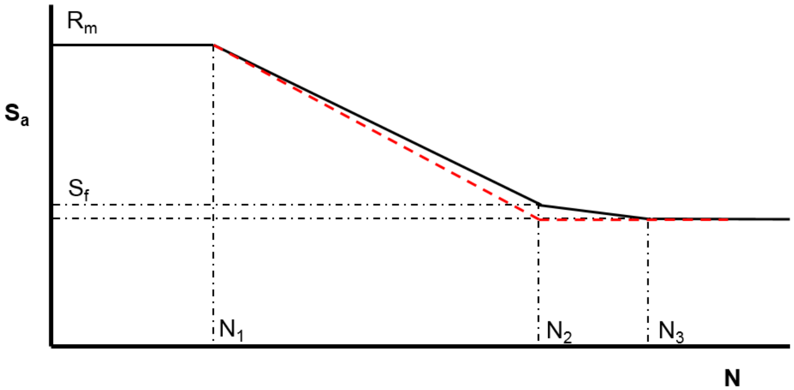

Figure 5.8: S-N curve for aluminium, copper, nickel, magnesium, austenitic steels, etc. with approximation (red dashed curve).

5.5 Mean Stress Correction

An increased S_m at constant S_a gives shorter fatigue lives and lower fatigue limits (see figure 5.9).

Several methods have been proposed to estimate the fatigue limit for mean stresses larger than zero (figure 5.10):

- Gerber [21]
- Goodman [23]
- Soderberg [70]
- Schütz [64]
- FKM [96]

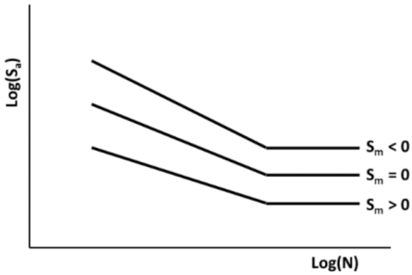

Figure 5.9: Effect of mean stress on S-N curves.

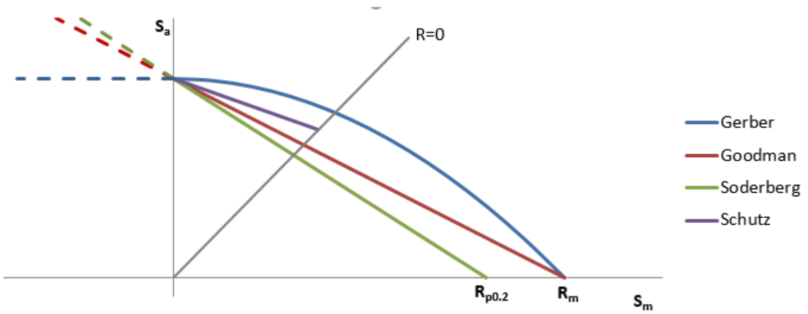

Figure 5.10: Mean stress correction methods.

Gerber proposed a parabolic correction:

$$\frac{S_f}{(S_f)_{S_m=0}} = 1 - \left(\frac{S_m}{R_m}\right)^2 \qquad (5.9)$$

This correction can be unconservative, especially for high strength materials.

Goodman proposed a linear correction:

$$\frac{S_f}{(S_f)_{S_m=0}} = 1 - \left(\frac{S_m}{R_m}\right) \qquad (5.10)$$

This correction is often conservative.

The Soderberg correction is like the Goodman correction but with the yield strength instead of the ultimate strength. This correction is very conservative.

Schütz assumes that S_f is known for both R=-1 and R=0 and proposed a linear interpolation between both. That leads to the mean stress sensitivity factor M (see figure 5.11):

$$M = tan\varphi = \frac{S_{f,R=-1} - S_{f,R=0}}{S_{f,R=0}} \qquad (5.11)$$

FKM [96] extended this correction to R<-1 and R>0, see figure 5.12. Values of M are material dependent and are shown in figure 5.13 and can be found in more detail in FKM [96] and in appendix E.

FKM/Schütz seems to give the best results, partly because this correction includes material behaviour.

Note – The mean stress correction (MSC) should be applied on the fatigue limit, not on the stress cycle. Applying the MSC on the stress cycle leads to different analysis results (see section 6.3.4 for an example).

There is one exception: using MSC according to FKM/Schütz in combination with a constant S-N curve exponent k for different mean stresses gives the same analysis result.

Unfortunately, a lot of fatigue analysis software and fatigue add-ons in FE software applies the MSC on the stress cycles irrespective of the MSC method.

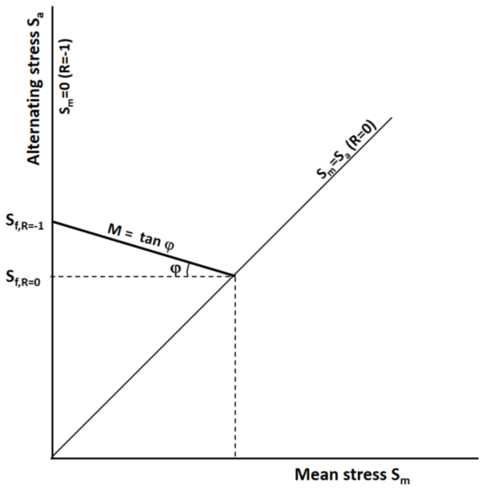

Figure 5.11: Mean stress correction according to Schütz [64].

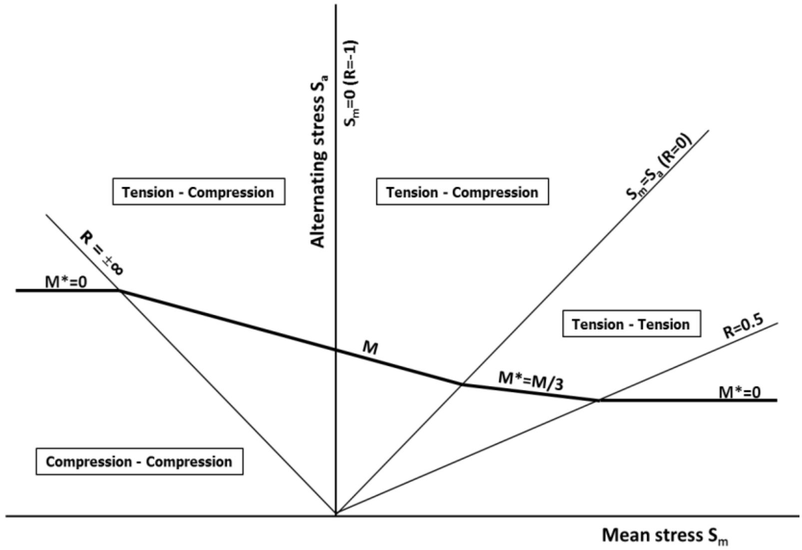

Figure 5.12: Mean stress correction according to FKM [96].

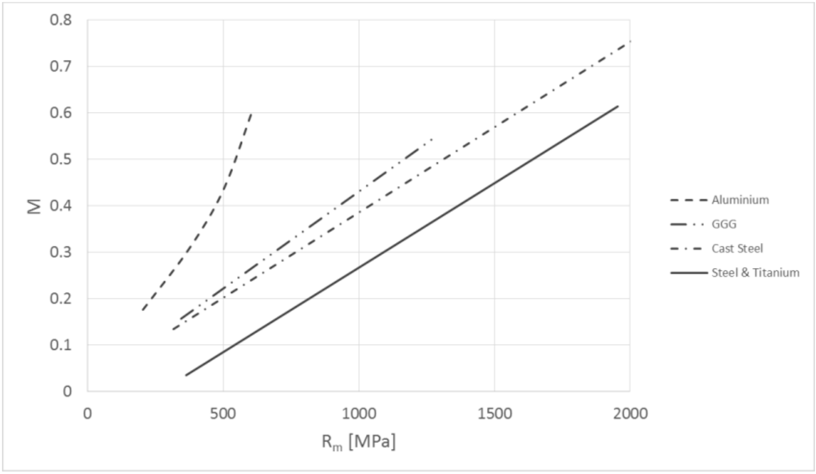

Figure 5.13: Mean stress sensitivity factors M according to Schütz [64] & DAF Trucks [40].

The above methods are methods to estimate the fatigue limit for mean stresses not equal to zero ($R \neq -1$). Note however that the complete S-N curve needs to be adjusted.

The upper asymptote is determined by the tensile strength of the material such that $S_{max} = R_m$. With increasing mean stress of a cycle the alternating stress of that cycle will reduce and thus the upper asymptote will go down, see figure 5.14. This figure also shows that the gradient of the S-N curve will be less steep with increasing mean stress or increasing stress ratio.

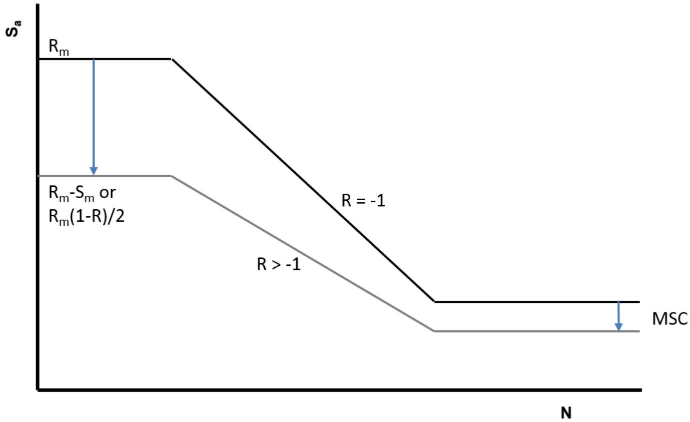

Figure 5.14: Mean stress correction on S-N curve.

5.6 Additional Correction Factors

In general, the fatigue data obtained from tests are generated under idealized conditions. To obtain realistic fatigue data, results from tests under realistic conditions should be taken, or, if those results are not available, the fatigue data should be modified using correction factors. Correction factors can be applied for:

- Material technology
- Surface roughness
- Surface treatments
- Size
- Temperature
- Environment
- Reliability

Factors are either applied on the complete S-N curve (figure 5.15) or on the fatigue limit (figure 5.16).

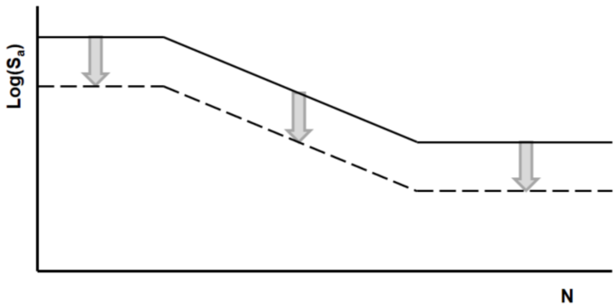

Figure 5.15: Correction factor applied on complete S-N curve.

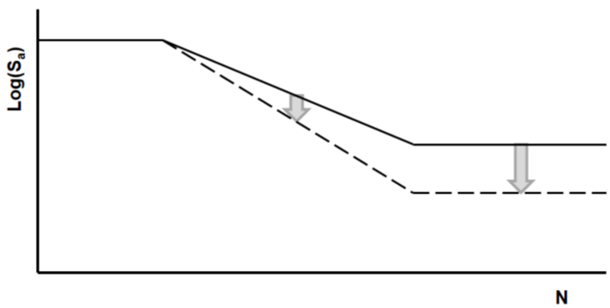

Figure 5.16: Correction factor applied on fatigue limit.

Material technology factors can be required if there is an effect of grain direction or an effect of thickness on the material properties. If the properties are affected, the complete S-N curve is affected proportionally. Note that anisotropy sometimes may have unexpected effects, especially during macro crack growth, which are not easily covered by factors.

Specimens often have a very smooth surface. Most structural components do usually not have such a finish. The higher surface roughness act as micro stress concentrations and therefore reduce the fatigue limit. Correction factors for surface roughness should be applied on the fatigue limit.

With surface treatments, the surface conditions can be modified, leading to either better or worse fatigue properties. Correction factors for surface treatments are usually be applied on the fatigue limit. Note that improved surface conditions may lead to sub-surface initiation.

The surface roughness is determined by the manufacturing process. However, manufacturing processes and surface treatments have also an effect on residual stresses, see figure 5.17. Residual stresses in compression are favourable for fatigue.

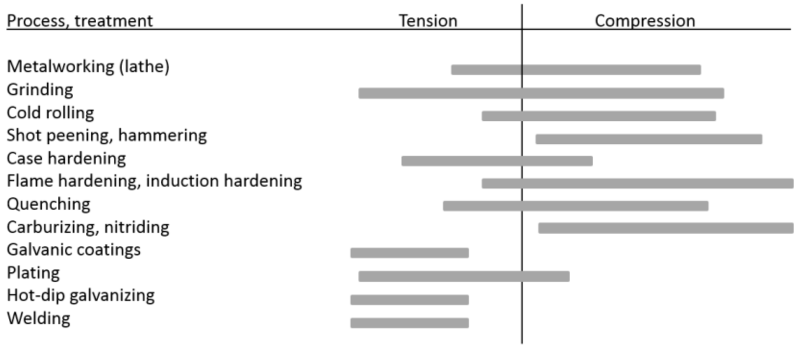

Figure 5.17: Effect of some processes and treatments on residual stresses [40,100].

The size effect is included in the fatigue notch factor (section 5.4 and appendix C).

At high temperatures, mechanical properties will be reduced. This is also the case for fatigue properties. This implies that the complete S-N curve will be reduced. At low temperatures, mechanical properties will be better but ductility decreases. The lesser ductility leads to increased notch sensitivity which is cancelling out the improved properties.

The environment may have a large impact on fatigue properties. The actual effect depends very much on combination of materials, loading, frequency, temperature, type of environment, etc.

Reliability is discussed in chapter 11.

In appendix F, some actual correction factors are given.

5.7 Accuracy

The accuracy of a fatigue life analysis is affected by several aspects:

- Large amount of scatter.
- Small changes in stress level results in significant differences in fatigue life.
- Accuracy of S-N data.
- Accuracy of correction factors.
- In case of FEA: small changes in meshing can lead to significant changes in fatigue life.

In figures 5.18 to 5.20 the effect of the accuracy of the stress level, the fatigue limit and S-N curve gradient on the estimated fatigue life are shown.

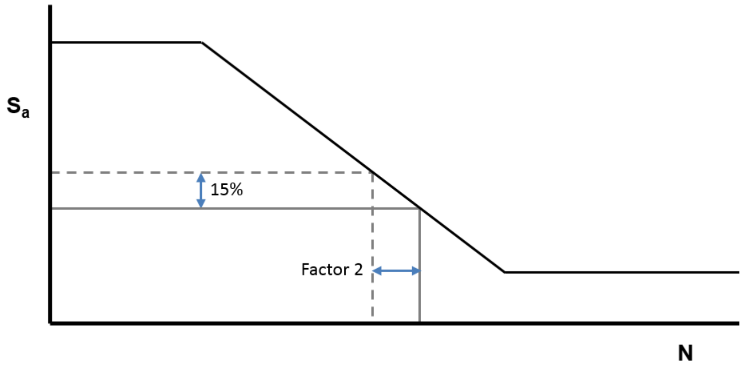

Figure 5.18: Effect of stress level on fatigue life (k=5).

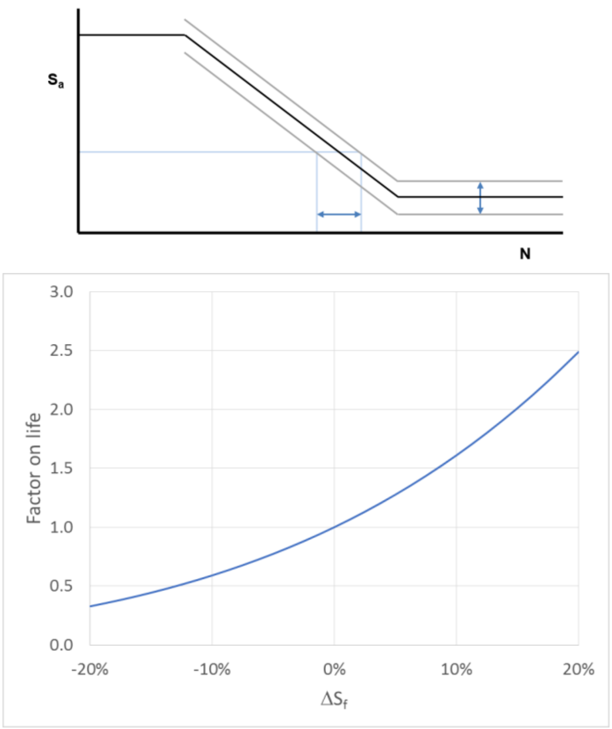

Figure 5.19: Effect of fatigue limit on fatigue life (k=5).

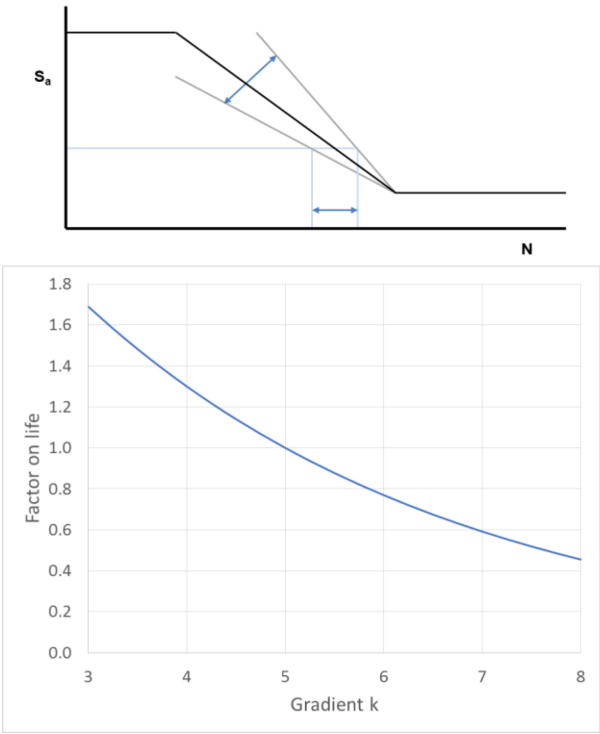

Figure 5.20: Effect of gradient on fatigue life.

The lower the accuracy of data and factors and the more these data and factors are estimated, the lower the accuracy of the prediction will be. Therefore:

Prediction of absolute fatigue life is an illusion