Effects of various service load

This chapter describes residual fatigue life concept and effect of various service load related parameters on fatigue performance of the weld joints. Further, relationship between crack growth and number of load cycle has also been elaborated.

Keywords: Crack growth, residual fatigue life, fatigue loading, maximum stress, type of stress, maximum stress, stress ratio, mean stress, loading frequency

27.1 Crack growth and residual fatigue life

Once the fatigue crack nucleated (after the first stage), it grows with the increase in number of fatigue load cycles. Slope of curve showing the relationship between crack size and number of fatigue load cycles indicates the fatigue crack growth rate doesn't remain constant (Fig. 27.1). The fatigue crack growth rate (slope of curve) continuously increases with increase in number of fatigue load cycles. Initially in second stage of the fatigue fracture, fatigue crack growth rate (FCGR) increase gradually in stable manner. Thereafter, in third stage of fatigue fracture, FCGR increases at very high rate with increase in number of fatigue load cycles as evident from the increasing slope of the curve.

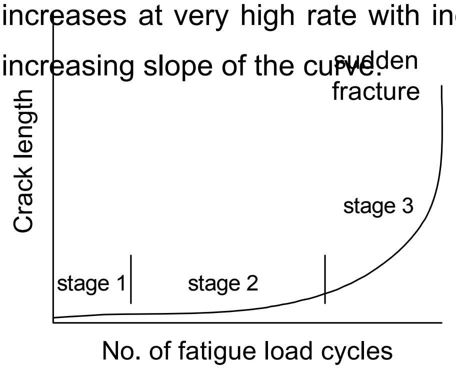


Fig. 27.1 Schematic of crack length vs. number of fatigue load cycles relationship

This trend of crack size vs. number of fatigue load cycle remains same even under varying service conditions of weld joints made of different materials. Moreover, the number of load cycles required for developing a particular crack size (during the second and third stage of fatigue facture) varies with factors related with service conditions, material and environment. For example, increase in stress range during fatigue loading of high strength and low ductility welds decreases the number of load cycles required to complete the second as well as third stage of fatigue fracture, conversely unstable fatigue crack prorogation (increasing FCGR) occurring in third stage of fatigue fracture is attained earlier. Increase in fatigue crack size in fact decreases the load resisting cross section (residual cross sectional area) of weld which in turn increases stress accordingly for given load fluctuations. Therefore, above trend of crack size vs. number of fatigue load cycles is mainly attributed to increasing true stress range for given load fluctuation which will actually be acting on actual load resisting cross section area at the any moment.

Residual fatigue life is directly determined by load resisting cross section area left due to fatigue crack growth (FCG) at any stage of fatigue life. Increase in crack length and so reduction in load resisting cross sectional area in general lowers the number of cycle required for complete fatigue fracture. Thus, left over fatigue life i.e. residual fatigue life of a component subjected to fluctuating load gradually decreases with increase in fatigue crack growth.

27.2 Factors affecting the fatigue performance of weld joints

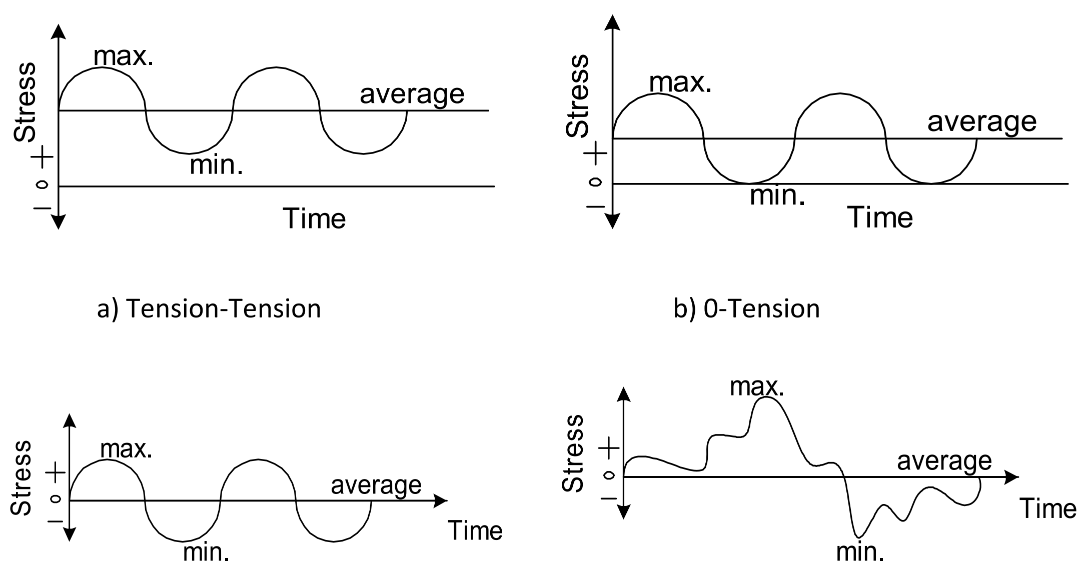
There are many factors related with service load condition, material and service environment affecting one or other stage (singly or in combination) of the fatigue fracture. The fatigue behavior of welded joints is no different from that of un-welded base metal except that weld joints need fewer number of load cycles due to many unfavorable features such as stress raisers, residual stresses, surface and sub-surface discontinuities, hardening/softening of HAZ, irregular and rough surface of the weld in as welded conditions (if not ground and flushed) besides in-homogeneity in respect of composition, metallurgical, corrosion and mechanical properties. Therefore, in general, fatigue performance of the weld joints is usually found offer lower than the base metal. However, this trend is not common in friction stir welded joint of precipitation hardenable aluminium alloys s these develop stronger and more ductile weld nugget than heat affected zone which is generally softened due to reversion in as welded conditions. The extent of decrease in fatigue performance (strength/life) is determined by severity of above mentioned factors present in a given weld besides the weld joint configuration and whether joint is load carrying or non-load carrying type. Reduction in fatigue performance of a weld joint can be as low as 0.15 times of fatigue performance of corresponding base metal depending up on the joint configuration and other welding related factors. Following section describe the influences of various service, material, environment and welding procedure related parameters on the fatigue performance of weld joints.

27.2.1 Service Load Conditions

Service conditions influencing the fatigue performance of a weld joints mainly includes fatigue load and trend of its variation. Fluctuation of the load during the service can be in different ways. The fatigue load fluctuations are characterized with the help of different parameters namely type of stress, maximum stress, minimum stress, mean stress, stress range, stress ratio, stress amplitude, loading frequency etc. Following section presents the influence of these parameters in systematic manner on fatigue. These parameters help to distinguish the type of stresses and extent of their variation.

a) Type of stress

For nucleation and propagation of the fatigue cracks, existence of tensile or shear stress is considered to be mandatory. Presence of only compressive stress does not help in easy nucleation and propagation of the crack. Therefore, fatigue failure tendency is either reduced or almost eliminated when fatigue load is only of compressive type. As a customary, tensile and shear stress are taken as positive while compressive stress is taken as negative. These sign conventions play a major role when fatigue fluctuation is characterized in terms of stress ratio and stress range (Fig. 27.2).



a) Tension-Tension

b) 0-Tension

c) Compression-Tension

d) Fluctuating stress

Fig. 27.2 Common fatigue load cycles

b) **Maximum stress**

It is maximum level of stress generated by fluctuating load and significantly influences the fatigue performance of the engineering component. Any discontinuity present in weld joints remains non-propagating type until maximum tensile/shear stress (due to fatigue loading) does not become more than certain limit. Thereafter, further increase in maximum stress in general lowers the fatigue life i.e. number of cycles required for fracture because of increased rate of crack growth in different stages of fatigue fracture occurring at high level of maximum stress leads to the reduction in number of load cycles required to completed each of the three stages of the fatigue fracture (Fig. 27.3).

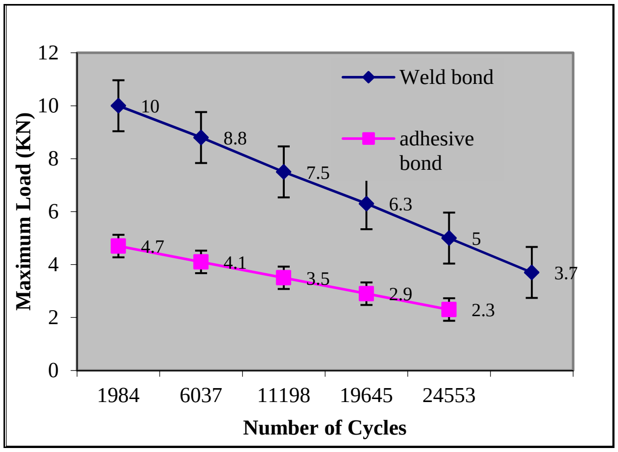


Fig. 27.3 effect of maximum load on fatigue life of weld bond and adhesive joints

c) Stress range

It is the difference between maximum and minimum stress induced by fatigue load acting on the engineering component of a given load resisting cross section area.

Difference of maximum and minimum stress gives the stress range directly if nature of stress remains same (tensile-tensile, compressive-compressive, shear-shear during loading. However, in case when load fluctuation changes nature of load from tensile and compressive, shear and compressive or vice versa then it becomes mandatory to use sign conventions with magnitude of stress according to the type of loading for calculating the stress range.

Zero stress range indicates that maximum and minimum stresses are of the same value and there is no fluctuation in magnitude of the load means load is static in nature therefore material will not be experiencing any fatigue. Conversely, for premature failure of material owing to fatigue it is necessary that material is subjected to enough fluctuations in stress during the service. The extent of fluctuation in stress (due to fatigue) is measured in terms of stress range. In general, increase in stress range lowers the fatigue life.

Most of the weld joint designs of real engineering systems for fatigue load conditions are therefore generally based on stress range or its derivative parameters such as stress amplitude (which is taken as half of the stress range) and stress ratio (ratio of minimum to maximum stress). In general, an increase in stress range decreases the fatigue life as evident from the fatigue behavior of friction stir weld joints in different temper conditions (Fig. 27.4)

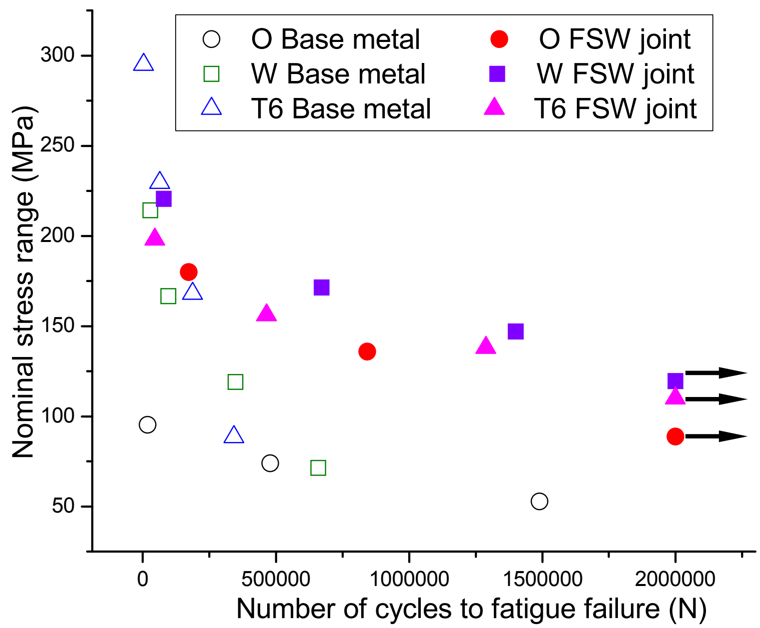


Fig. 27.4 Effect of stress range on fatigue life of friction stir weld joints

d) Stress ratio

It is obtained from ratio of minimum stress to maximum stress. Lower value of stress ratio indicates greater fluctuation in fatigue load. For example, stress ratio of 0.1, 0.2 and 0.5 are commonly used for evaluating the fatigue performance of weld joints as per requirement (Fig. 27.5). Stress ratio of 0.1 indicates that maximum stress is 10 times of minimum stress. Stress ratio of zero value suggests that minimum stress is zero while stress ratio of -1 indicates that the load fluctuates equally on tensile/shear and compressive side. The decrease in stress ratio for tensile and shear fatigue loads (say from 0.9 to 0.1) adversely affects the fatigue performance.

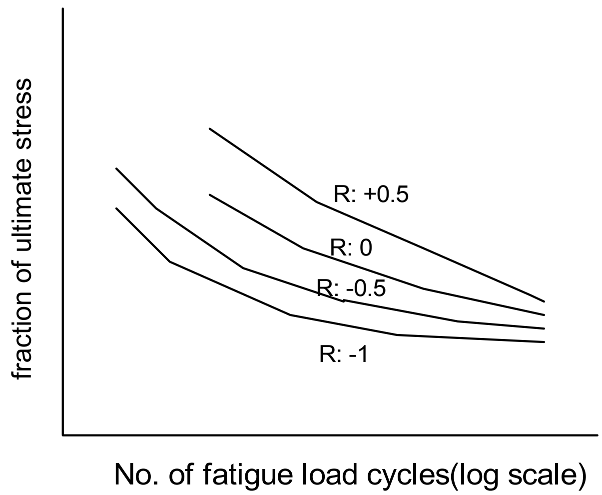


Fig. 27.5 Effect of stress ratio (R) on fatigue life (N) for given stress conditions

e) Mean stress

Mean stress is average of maximum and minimum stress. The influence of mean stress on the fatigue life mainly depends on the stress amplitude and nature of mean stress. Nature of mean stress indicates the type of stress. The effect of nature of mean stress i.e. compressive, zero, and tensile stress, on the fatigue life at low stress amplitude is more than that at high stress amplitude. It can be observed that in general mean tensile stress results in lower fatigue life than the compressive and zero mean stress (Fig. 27.6). Further, increase in tensile mean stress decreases the number of load cycle required for fatigue crack nucleation and prorogation of the cracks which in turn lowers the fatigue life.

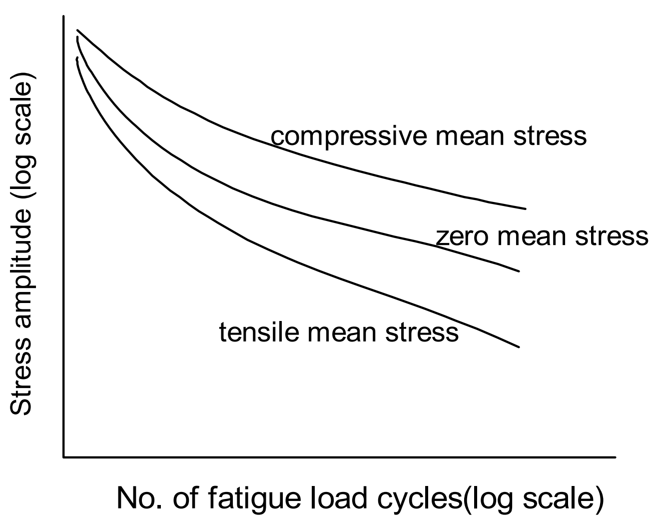


Fig. 27.6 Effect of type of stress on S-N curve

f) **Frequency of fatigue loading**

Frequency of the fatigue loading is number of times a fluctuating load cycle repeats in unit time and is usually expressed in terms of Hz which indicates the number of fatigue load cycles per second. Frequency of fatigue loading has little influence on fatigue performance.

References and books for further reading

- R. Radaj, Design and Analysis of Fatigue Resistant Welded Structures, Woodhead Publishing, (1990)
- R S Parmar, Welding engineering & technology, Khanna Publisher, 2002, 2nd edition, New Delhi.
- John Hicks, Weld Joint Design, Abington Publishing, 1999, 3rd edition, England.
- S. J. Maddox, Fatigue strength of welded structures, Woodhead Publishing, (1991)
- Welding handbook, American Welding Society, 1987, 8th edition, volume 1 & 2, USA.

Source:
http://nptel.ac.in/courses/112107090/27