# Fatigue Resistance of BISPLATE®

Bisalloy Steels

## WHAT IS FATIGUE

A metal component subjected to repeated or cyclic stresses may eventually fail even when the maximum applied stress is less than the yield stress of the parent steel. This phenomenon is known as **fatigue.**

It is known that in machines and other kinds of structures that are subjected to fatigue loads, that 80-90% of all fractures that occur are fatigue fractures.

However, it is relatively easy to appreciate why this occurs, since structures are usually designed against plastic deformation (i.e. yielding) and not against fatigue!

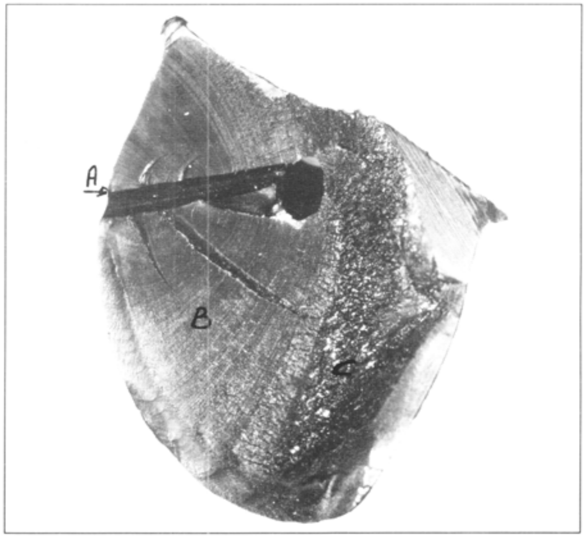
## FATIGUE FAILURES

### CHARACTERISTICS OF FATIGUE FAILURES

The surface of a fatigue fracture is distinctive and from a knowledge of various characteristics of the fracture surface considerable information can be obtained about the cause(s) of crack nucleation and the nature of the fatigue loading.

The material adjacent to a fatigue fracture displays no evidence of plastic deformation. The fracture surface is relatively smooth and generally contains concoidal markings which appear to radiate from a particular point on the outer surface, see figure 6.5.

**Figure 6.5** Fatigue fracture surface of a failed gear showing the concoidal "beach markings" radiating from the oil hole, marked (A). Also shown are the "beach markings" associated with fatigue crack growth (B), and the area where ductile overload occurred (C).



Fatigue cracks generally nucleate at the surface, and because crack growth requires a tensile stress, the direction of the fatigue crack is always perpendicular to maximum tensile stress.

Because the load is applied in a pulsating manner, the crack grows in small steps. Pulsating loads are invariably not uniform (as say a sine wave would be), so that crack growth rate variations occur and these reflected in the form of ridges on the fracture surface as can be seen in figure 6.5. These are given the name "beach markings", and are the single most distinctive feature of fatigue crack failure.

As the crack grows, the section supporting the load is progressively reduced. As such the stress of each cycle is progressively increased and the crack growth rate become faster, and the beach markings become larger and more distinct.

Ultimately, the cross sectional area supporting the load is reduced to such an extent that it is too small to support the applied load, and final failure occurs by ductile overload; the area marked C in figure 6.5.

## WHY IS KNOWLEDGE OF FATIGUE IMPORTANT WHEN DESIGNING WITH HIGH STRENGTH STEELS?

There are two main reasons:

- Firstly, fatigue cracks propogate at approximately the same rate in all steels, and since the life of welded joints is dependent upon crack propogation, welded sections of high strength steels exhibit the same strength at around 2 x $10^6$ load cycles as welded plain carbon steels.
- Secondly, a principal reason for using high strength steels is to reduce plate thickness (i.e. weight reduction). When this is done, the stresses in the steel – both static and fatigue stresses – will naturally increase for a given load case.
  As a result, design against fatigue is more important when high strength steel is used in welded structures, since fatigue strength does not increase at the same rate as static strength.

  In addition, high strength steels are often used is applications that are naturally subjected to high fatigue loads, e.g. mining and transport equipment.

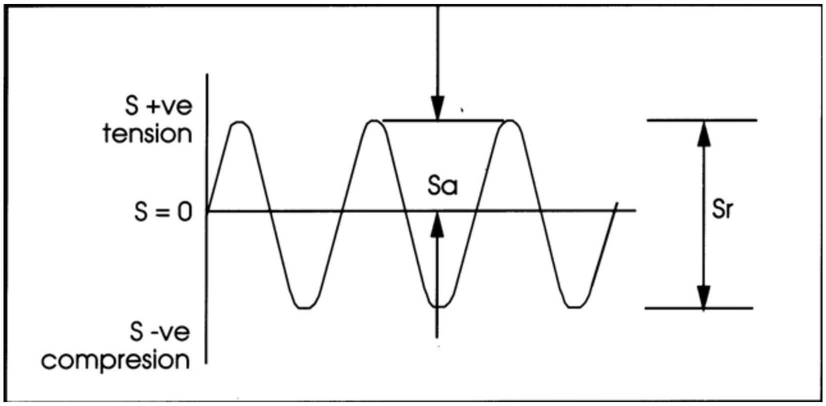
## FATIGUE STRENGTH OF STEELS

### FATIGUE DATA

Fatigue data generated under laboratory conditions is generally in the form of "the number of cycles to cause failure at a particular stress amplitude".

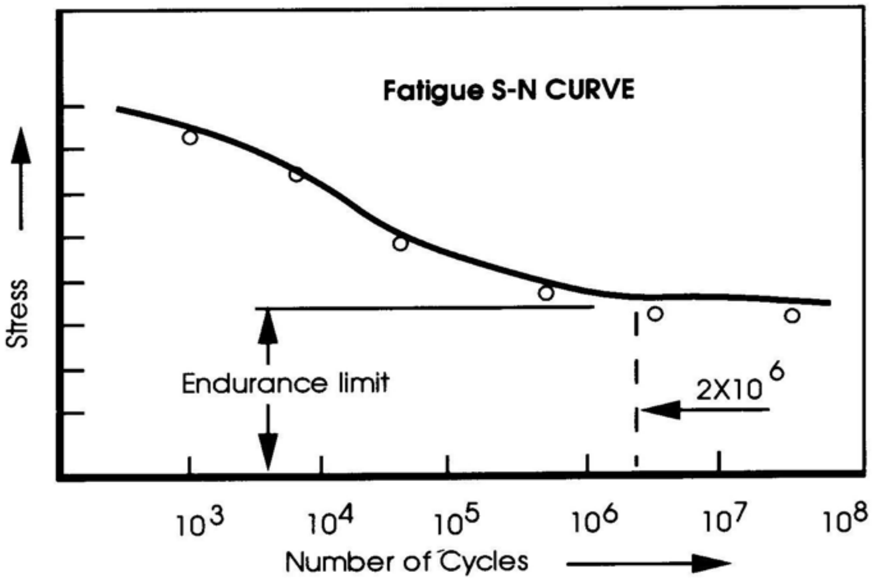
This may be in the form of simple bending, so that a point on the surface of the specimen may be in tension when bending occurs in one direction, followed by compression when bending occurs in the opposite direction. Alternatively, the specimen may be subjected to a pulsating axial load causing alternate tension and compression. This simple situation can be presented as a sine wave as shown in figure 6.6.

Figure 6.6 Diagram showing the sinusoidal type of pulsating load generally applied in laboratory type work (carried out to determine fatigue data).



The fatigue diagrams produced from “cycles to failure” tests can be presented as either stress amplitude (Sa) or stress range (Sr) and for most steels takes a form similar to that shown in figure 6.7, the cycles to failure generally being represented on a logarithmic scale.

Fig. 6.7 Diagram showing the form in which data is presented, relating number of cycles to failure for a particular stress.



It can be seen in figure 6.7 that after about 2 x $10^6$ cycles the curve tends to flatten out, indicating an almost infinite fatigue life at stress loadings below a critical value. The critical value is generally referred to as the **fatigue limit** and for most steels is referred to at 2 x $10^6$.

Figure 6.6 and 6.7 represent a situation where the tensile stress and compressive stress are equal in magnitude so that SMAX = -SMIN. There are however, other cyclic stress situations.

For example, after the application of a tensile load the specimen may simply return to zero stress before re-application of the tensile load. Alternatively, an applied static tensile load may be present and an alternating cyclic load may be superimposed. To differentiate between such loading conditions a convenient means to define the loading conditions is achieved by the use of the **stress ratio, R** which is defined as:

$$R = \frac{\text{SMIN}}{\text{SMAX}}$$

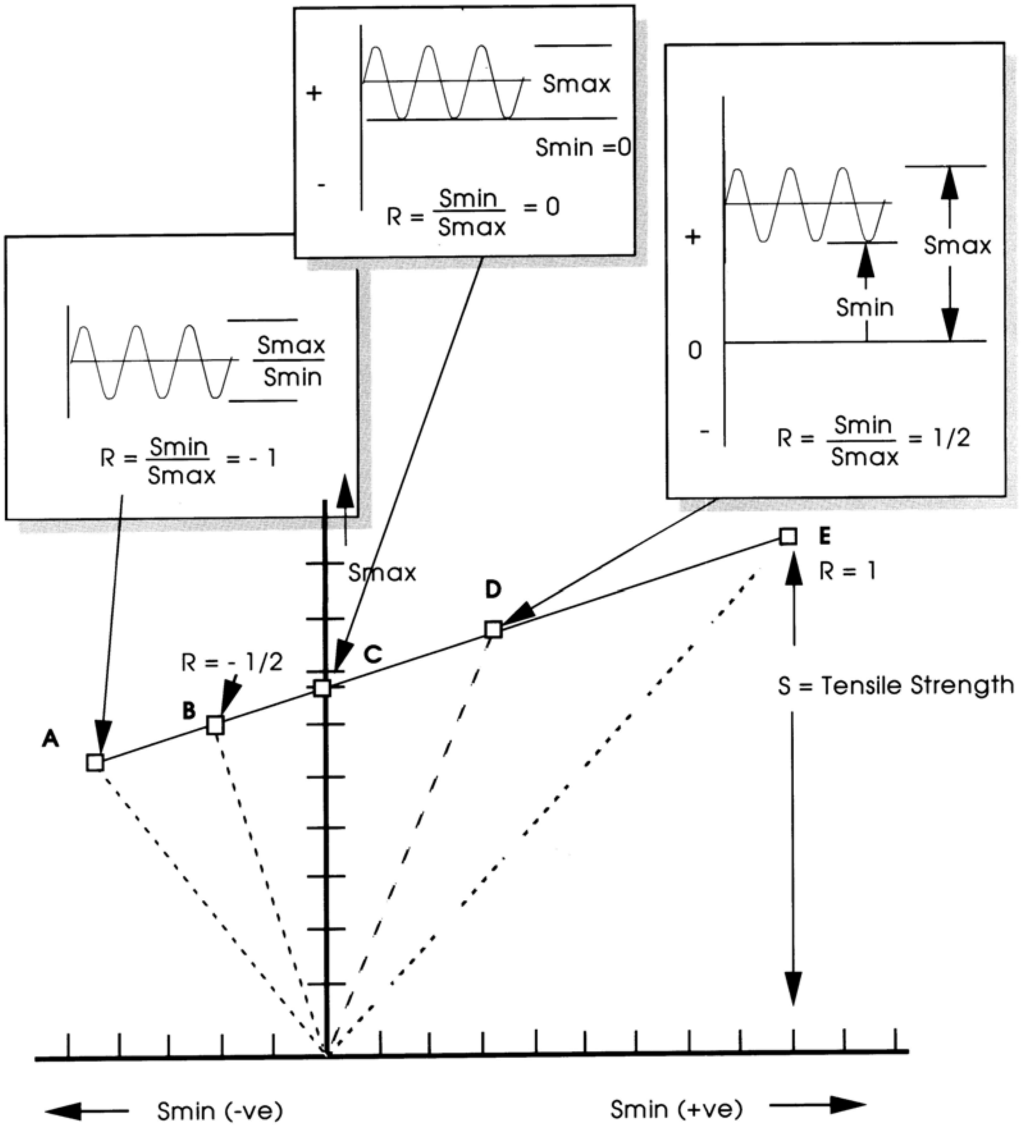
For the simple bending situation of equal tension and compression stress (shown diagrammatically in fig. 6.6) where SMAX = -SMIN, R= -1.

If only a tensile pulsating load is applied and SMIN = 0, then R = 0.

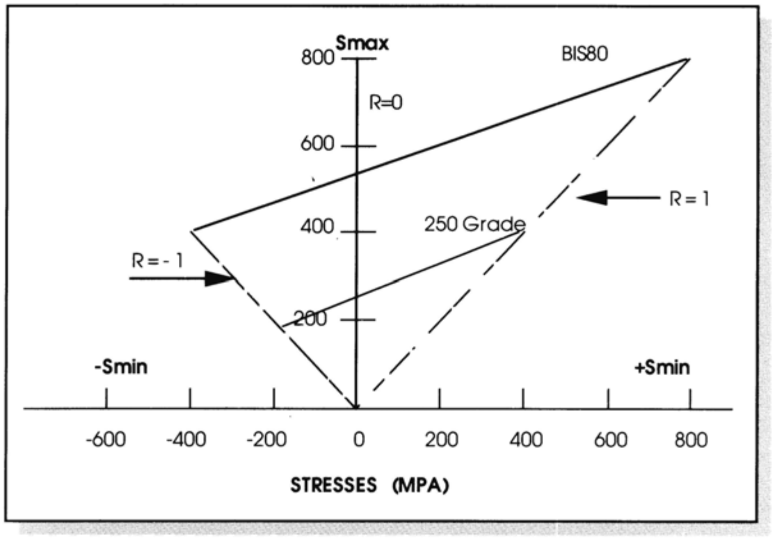
When a pre-existing tensile static load is present and pulsating loads are applied R becomes positive; the limiting case of R = 1 when the static load equals the tensile strength of the steel.

Obviously there can exist a variety of loading conditions between R=-1 and R = 1. These are represented in the form of a **Goodman Diagram** as shown in figure 6.8. It can be seen that Smin is represented on the abscissa (negative and positive) and Smax is represented on the ordinate. In such diagrams, the line ABCDE represents the stress ratio, R, at failure from -1 to +1 for a specified number of cycles to failure, i.e. 2 x $10_6$.

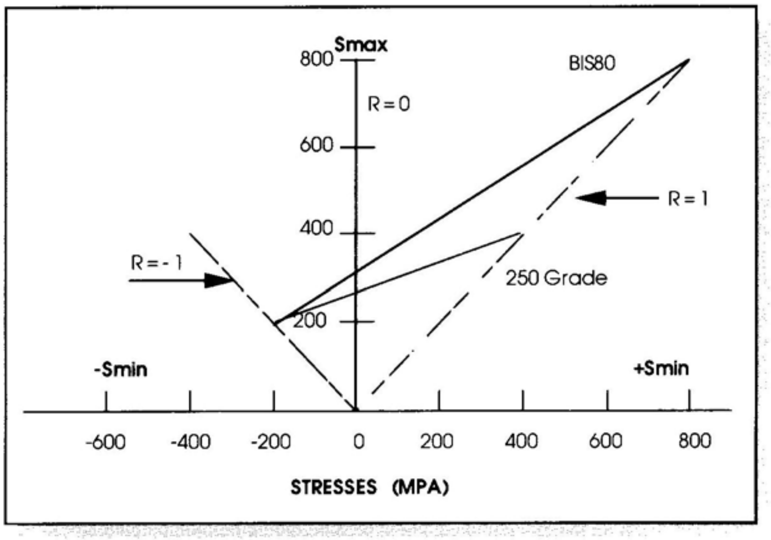
Fig. 6.8 Goodman Diagram depicting the various stress configurations required to determine the points on the diagram.



From laboratory controlled fatigue tests the Goodman Diagrams for two steels having tensile strengths of 400MPa (AS3678-Grade 250), and 800MPa (BISPLATE® 80 grade) are shown in figure 6.9. Here it can be seen that over the entire fatigue stress range there is a distinct advantage in using the higher strength BISPLATE® 80 grade steel.



However, most structures involve welded connections, so that when examining a simple butt weld joint (with the weld bead left in place) a different Goodman Diagram emerges.



It can be seen in figure 6.10 that for butt welds when R = -1 (equal tension and compression) the fatigue strength of BISPLATE® 80 is reduced by more than half its base material value (fig 6.9) and to substantially the same values of AS3678-Grade 250. This indicates that there is very little advantage in using high strength steels under such loading condition. On the other hand, for conditions where R is positive, i.e. high static loads with a superimposed pulsating load, there is a distinct advantage in the use of high strength steels.

## WHERE CAN HIGH STRENGTH STEELS BE USED TO ADVANTAGE?

There are a number of key areas in which high strength steels can be used to advantage, in structures subjected to fatigue loading, as follows:

### PARENT PLATE MATERIAL UNAFFECTED BY WELD

Welding can influence the fatigue behaviour of steels due to:

(a) the existence of geometrical stress concentrations in the vicinity of welds due to weld deposit profiles.
(b) The presence of welding deposits such as porosity, lack of fusion, slag inclusions, etc, which facilitate the initiation of fatigue cracks, and
(c) The generation of residual stresses in the welded component.

Obviously, in structures in which welds are absent are absent or where welds can be suitably located in areas of low stress, high strength steels can be used to advantage (as fatigue strength is higher than for plain carbon steels).

### HIGH STRESS LEVELS

In many structures, the load consists of a high static load with a "superimposed" smaller fatigue load. In this instance, it is relatively easy to exceed the permissible static stress or the yield of plain carbon steels.

As we have seen previously, we can permit the same stress range at high stress levels as at low low stress levels. In these cases, R is in the range R = 0 to R = +1.

### LOW LOAD CYCLE NUMBERS

The region for the permissible stress range is limited by the S-N curve and by the yield stress (or permissible static stress) of the steel.

In other words, high strength steels are advantageous when the number of load cycles is less than $10_5$, there is a full load spectrum (constant amplitude) and R = 0.

### SUITABLE LOAD SPECTRA

In many situations, there are multiple fatigue loading conditions (different amplitudes) and hence it is incorrect to design with constant amplitude data if the load is of variable amplitude.

### WHEN IT IS POSSIBLE AND DESIRABLE TO INCREASE THE FATIGUE STRENGTH OF THE WELDS.

There are a number of techniques available to improve the fatigue strength of welded joints, including: redesign of the joint itself, removal of butt weld reinforcement, reduction of the stress concentrating effects by grinding or TIG dressing the toes of fillet welds, and reduction of the residual stress pattern around welds by thermal stress relieving treatments or shot peening.

With each of these techniques, substantial improvement in the fatigue strength of the as-welded joint is possible, although the resultant fatigue strength will always be less than that of the parent plate material.

References/further reading

- Fatigue of Welded Structures, T.R. Gurney, Cambridge University Press UK 1979
- Australian Standard AS1554 Part 5- 1989. SAA Structural steel welding code "welding of steel structures subject to high levels of fatigue loading."
- American Institute of Steel Construction, Specification for the design, fabrication and erection of structural steel for buildings, 1978.