LECTURE 28 Strength under Cyclic Stresses (Part 1)

1 Cyclic Stresses and Fatigue Failure

Many machine parts are subjected to **cycles** of varying stresses during operation. For example, the railroad car axle rotating together with the wheels undergoes **cyclic stresses**. This is due to the fact that the points of the rotating axle are alternately in the tension and compression zone.

Experience shows that a part may fail under varying stresses after a certain number of cycles whereas no failure occurs under the same stress constant in time.

The phenomenon of failure under varying stresses is called **fatigue.**

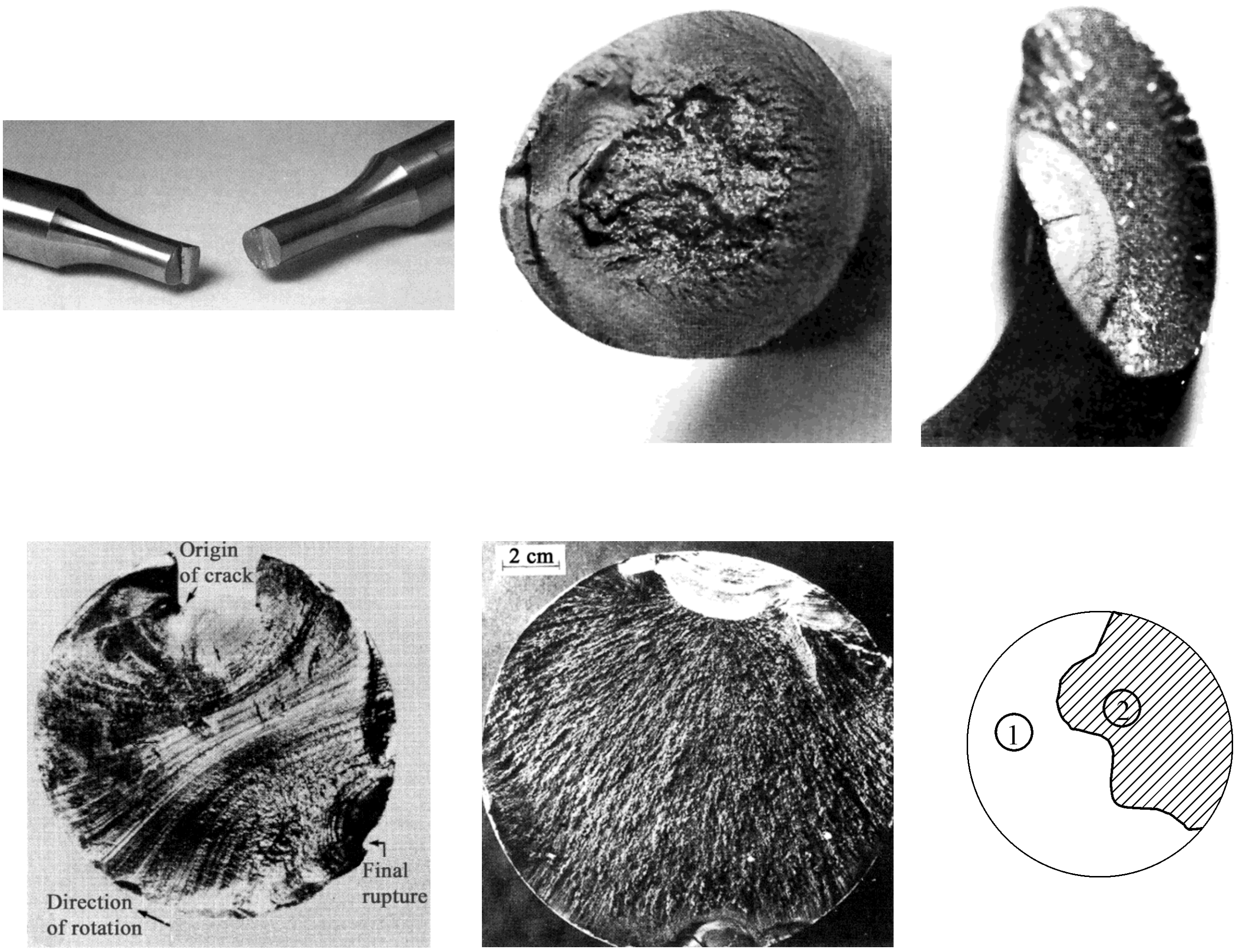


Fig. 1

After failure occurs two zones can usually be distinguished on the **fracture surface** of a part (see Fig. 1). In one zone it is very difficult to discern the crystals with the naked eye. The fracture surface has smooth contours. In the other zone the signs of recent brittle fracture are clearly observable. The crystals have sharp edges and silky surface.

2 Basic Characteristics of a Cycle

Consider first the case of the uniaxial state of stress. The law of variation of the principal stress σ in time is represented by the curve shown in Fig. 2:

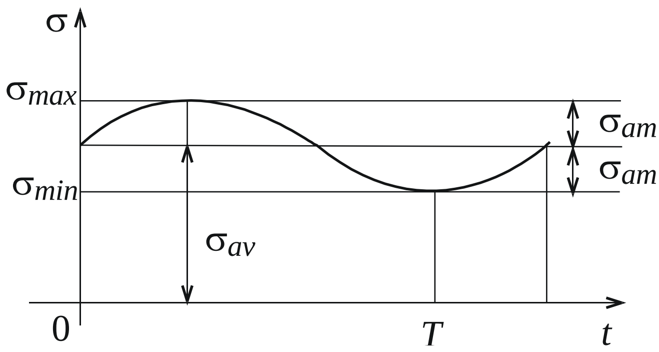


Fig. 2

The maximum and minimum stresses of the cycle are denoted by $\sigma_{\max}$ and $\sigma_{\min}$. Their ratio is called the **asymmetry factor**

$$r = \frac{\sigma_{\min}}{\sigma_{\max}}. \tag{1}$$

Cycles having identical indices r are said to be similar.

In the case $\sigma_{\max} = -\sigma_{\min}$ and $r = -1$ the cycle is referred to as **completely reversed (symmetrical) cycle** (Fig. 3):

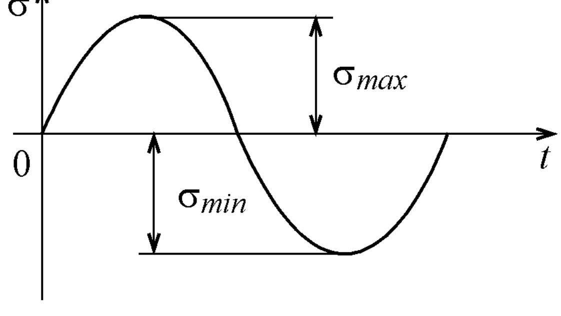


Fig. 3

By the another words r is called the **coefficient of asymmetry** of cycle. It is equal to the algebraic ratio of the minimum stress to the maximum stress.

The **average stress** can be found by the formula:

$$\sigma_{av} = \frac{\sigma_{\max} + \sigma_{\min}}{2}.$$

For the symmetrical cycle

$$\sigma_{av} = 0.$$

The **amplitude stress** is

$$\sigma_{am} = \frac{\sigma_{\max} - (-\sigma_{\min})}{2} = \sigma_{\max}.$$

If $\sigma_{\min} = 0$ or $\sigma_{\max} = 0$, the cycle is termed **pulsating**:

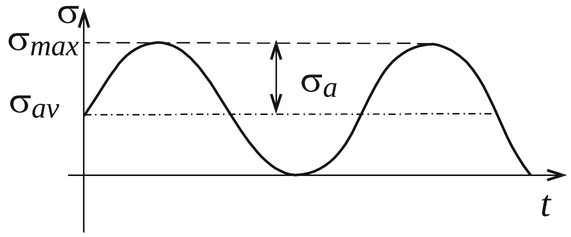


Fig. 4

In this case $r = \frac{\sigma_{\min}}{\sigma_{\max}} = \frac{0}{\sigma_{\max}} = 0$.

If $\sigma_{\min} \neq 0$, $\sigma_{\max} \neq 0$, the cycle is called **asymmetrical**.

Any asymmetrical cycle may be represented as the result of superimposing a steady mean stress σ_{av} and a completely reversed stress with amplitude σ_{am}:

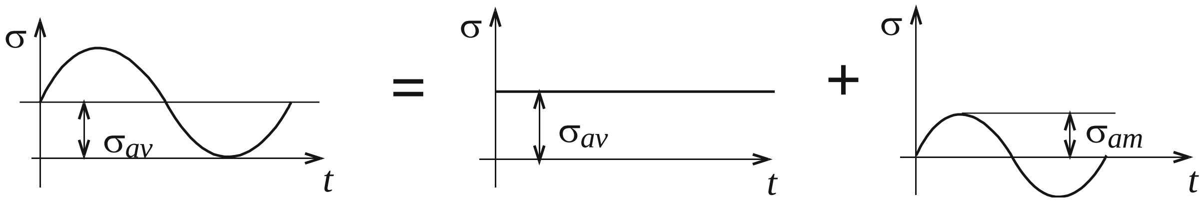


Fig. 5

The process of crack formation under varying stresses is induced by the accumulation of plastic strains. It might, therefore, be expected that fatigue strength is determined by only the maximum and minimum stresses of the cycle and is independent of the law of variation of stresses within the range $\sigma_{\max}\ldots\sigma_{\min}$. Consequently, cycles with $r = const$ are equivalent. In the same way, as experiments show, the effect of the frequency of the cycles is of no significance. Thus it is sufficient to know the values of $\sigma_{\max}$ and $\sigma_{\min}$ or σ_{av} and σ_{am} to determine the **fatigue strength** for a specified cycle.

3 The Fatigue Limit

Let us now proceed to the mechanical characteristics of a material. For cyclic stresses they are determined from special tests. In the majority of cases tests are carried out for reversed stresses. It is common practice then to use the principle of pure bending of a rotating specimen.

A test example (**specimen**) 1 is mounted in rotating **holders** 2 and 3. A force is transmitted by means of a weight suspended from rings 4 and 5. A **counter** 6 registers the number of revolutions of the specimen. When the specimen breaks, the motor 7 is automatically disconnected through a **button** 8 (see Fig. 6).

Fatigue tests are usually carried out on a series of 10-15 specimens. The number of cycles that can be repeated without fracture is designated and usually specified at the level of 10^7.

By performing a series of tests it is possible to determine the number of cycles that a specimen sustains before fracture for different values of $\sigma_{\max}$ of the cycle. The number of cycles increases with decreasing $\sigma_{\max}$.

The results of the tests are used for plotting the diagram in coordinates: maximum stress $\sigma_{\max}$ – number of cycles *N* (so called *S*-*N* diagram) (see Fig. 7).

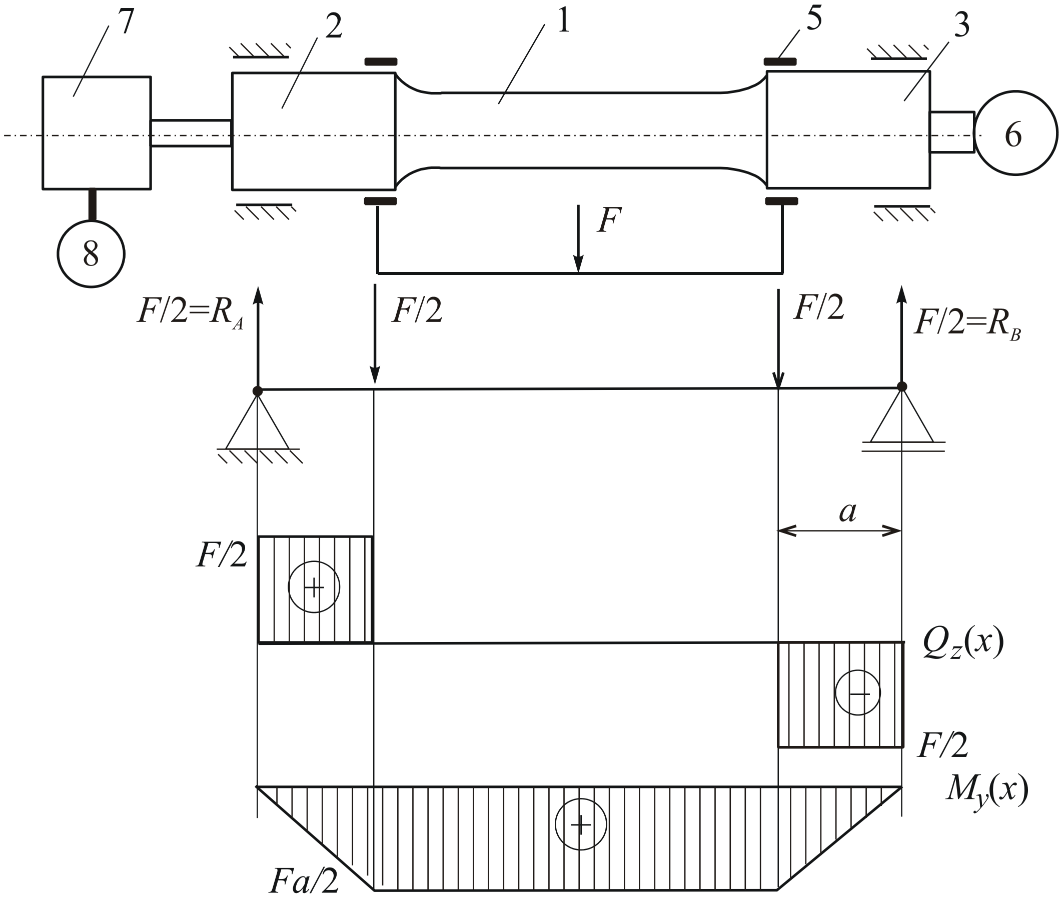
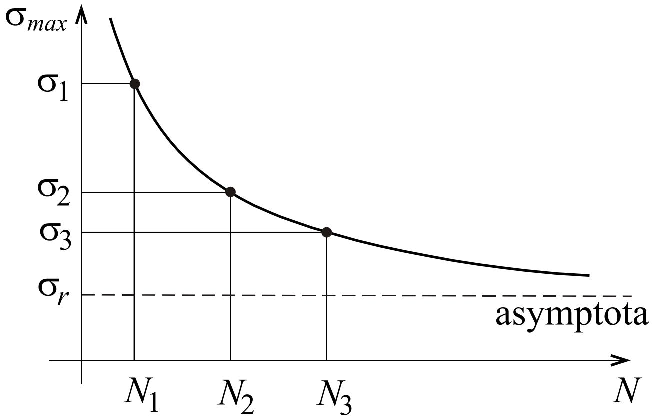


Fig. 6

The lower (right) portion of the curve approaches asymptotically a certain stress which is exactly the **fatigue limit** (**endurance limit**, **fatigue strength**) of the tested material. This type of curve is called **Wohler's curve**. Experiments show that for most ferrous metals it is possible to indicate the greatest maximum stress at which the material does not fail for any number of cycles.



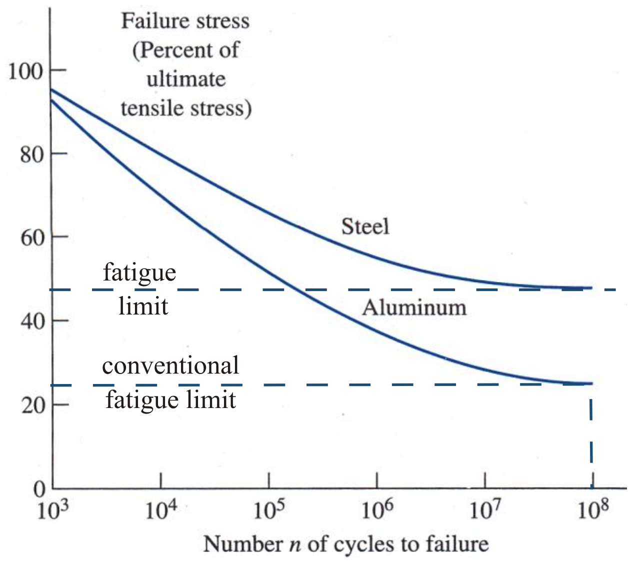


Fig. 7

The endurance limit is denoted by σ_r, where the subscript r corresponds to the **cycle ratio** (asymmetry factor). Thus, for a completely reversed cycle the symbol of the endurance limit becomes σ_{-1}, for a pulsating cycle σ_0, etc.

For non-ferrous metals and for high-hardness steels it is not possible to determine the number of cycles that a specimen can withstand without subsequent fracture. In cases like these the concept of the **conventional endurance limit** is therefore introduced. The conventional endurance limit is the stress at which a specimen is capable of sustaining 10^8 cycles.