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DEFINITION OF REGULARITY CONTACT FATIGUE OF MATERIALS

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Abstract

This work is devoted to studying the influence of various factors on the contact fatigue resistance of materials.

Keywords: gears, wear, alloyed steel, material wear, roughness

Introduction

During the operation of gear and worm gears, it is not uncommon for cases when, after some time after the start of work, cracks appear on the working surfaces of the teeth and chipping pits (pitting) form. The chipping that has begun can then stop, and the resulting recesses in the process of further work of the transmission can gradually smooth out. In this case, “limited” (local) or “initial” chipping occurs, which does not cause much damage. It is much worse when the spalling that has begun progresses to the final damage to the surfaces of the teeth and their wear in a relatively short time.

The gear, in which the progressive surface destruction of the teeth has begun, is still suitable for transferring the load, but due to the distortion of the tooth profiles in the mesh, there are, especially in a spur gear, large additional dynamic (impact) forces that increase the rate of destruction and amplifying transmission noise. At the same time, the oil is contaminated with particles of crumbled metal, which are wedged between the teeth, damaging their surfaces and intensifying the wear process. If, in addition, the bearings are lubricated with the same oil as the gears, the bearings will also be damaged.

Continuous chipping of tooth surfaces, enhanced by abrasion by metal particles and uneven tooth surfaces, leads to tooth fracture after a more or less long period of time.

The main factor determining the occurrence and development of these processes is contact fatigue - the process of accumulation of damage and destruction of the surface layer of the metal under the action of repetitively alternating contact stresses during rolling friction, accompanied by the appearance of cracks, the development of which leads to wear by flaking and the formation pits of chipping (pitting).

The contact fatigue process is in many respects similar to the fatigue process in general (the formation and gradual development of cracks, the dependence of durability and endurance limit on a number of factors, etc.), but it also has its own specific features. They are due to the fact that a volumetric stress state is realized in the contact zone, sharp gradients of stress components take place, and maximum stresses are localized in small volumes of metal. This lead, for example, to a sharp change in the degree and nature of the deformation of the metal as it moves away from the surface. If in the surface layer, especially at the tops of micro protrusions, a significant plastic deformation of the metal is observed, then already at a depth that is only several times greater than the size of the contact pad, the stresses are only tenths or hundredths of the elastic limit. In addition, contact fatigue is characterized by the presence of two dangerous volumes: one is a thin surface layer at the contact area, the other is a subsurface zone of maximum shear stresses at a depth often less than the dimensions of the contact area. In the presence of large tangential forces on the contact area, these two zones can merge into one.

When implementing the contact fatigue mechanism, two characteristic types of surface destruction are observed: pitting and peeling wear. Peeling wear manifests itself in the form of separation of thin flakes or plates of embrittled metal. Pitting is a chipping of individual places on the surface, sometimes accompanied by a chipping (split) of rather large metal fragments. The dimensions of the spalling pits (and their number) increase with the growth of the number of loading cycles.

The contact fatigue life depends on many factors, for example, the shape and dimensions, the test specimens or parts, the nature of the application of the load and its magnitude, the presence or absence of lubrication, the mechanical properties of the material, the ambient temperature, etc. The nature of the influence of many of them, especially in interaction, has not been studied enough. Let us consider four problems here: the dependence of contact fatigue resistance on the level of mechanical properties of the material, the dimensions of the test objects, shear force and lubrication.

It has been established that the resistance to contact fatigue correlates well with the hardness of the material: usually, with its increase, the limit of contact endurance increases. This is illustrated in Figure 1, which combines the experimental data taken from our work. Different structures, even if they are homogeneous, show different resistance to contact fatigue. It should be especially noted that heat treatment of carbon steel can provide a contact endurance limit comparable to its value for alloyed steels (nitrided and carburized). This is of fundamental importance: it is not always necessary to strive for the use of expensive steels and labor-intensive technologies for their hardening in order to obtain a relatively high level of contact fatigue resistance.

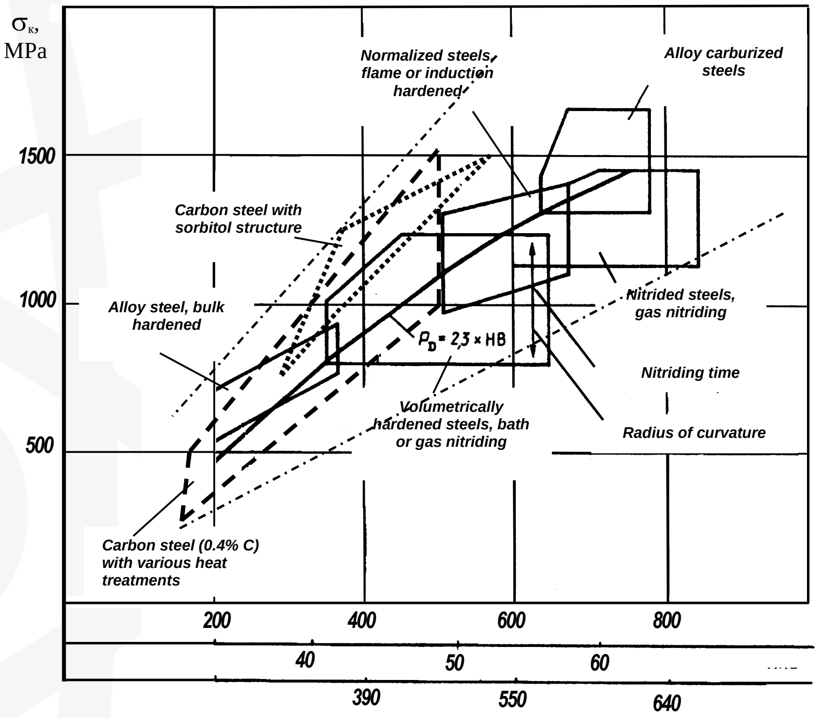

Figure 1 - Generalized dependence of fatigue resistance under contact loading (σ_{Hlim}) on hardness for different materials and hardening methods

As follows from Figure 1, the dependence of the fatigue limit under contact loading on hardness is almost linear on average (σ_{Hlim} = 2.3HB), but the dispersion of values relative to the average value reaches ± 30% or more. An important feature of the dispersion of endurance limits is that it increases significantly with increasing material hardness (see dashed-dotted lines in Figure 1)

Surface roughness has a great influence on contact fatigue resistance. Experiments have established that it is not just the surface roughness that is of decisive importance, but the ratio of the sum of the roughness of both surfaces $\sum R_z$ to the thickness of the oil film Δh, that is $\Delta k = \sum R_z / \Delta h$. Experiments show that the parameter Δk can change N by an order of magnitude, and $\sigma_к$ - up to 6 times.

The effect of roughness for metals of medium surface hardness is significant when the running-in period is equal to or greater than the fatigue test period. Unlike specimens made of steels of low and medium hardness, hardened specimens run in quickly, but the final height of the irregularities depends on the initial one.

Experimental studies have shown that the external tangential force significantly reduces the resistance of metals to contact fatigue.

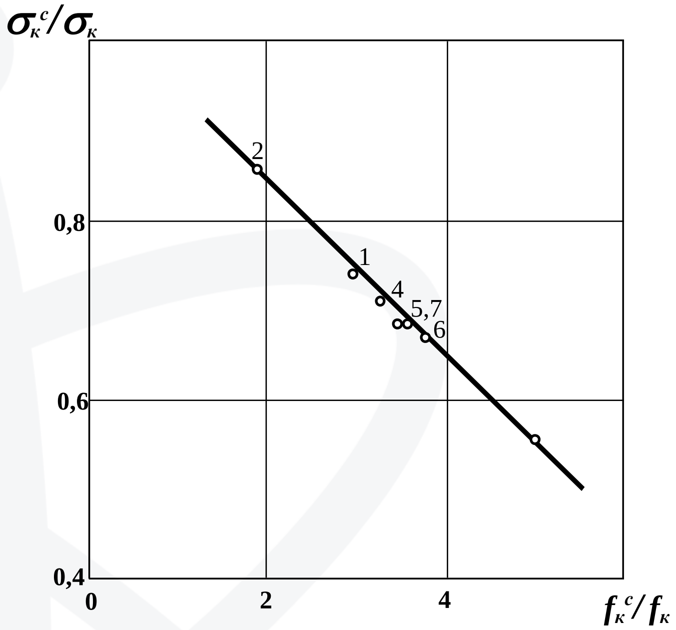

Figure 2 - Dependence of the ratio of the values of the limits of contact endurance with sliding and without sliding on the ratio of friction coefficients with sliding and without sliding for various materials

Figure 2 shows dependencies illustrating the effect of the rolling friction coefficient $f_к$ on the change in the contact endurance limit $\sigma_к$ ($\sigma_к^c$, $f_к^c$ – are the same values determined when slipping up to 20% is realized). The tests were carried out on rollers made of steel with 0.41% C (points 1 in Figure 2), nickel cast iron (2), steel 50 (3), steel 37XH3A (4), steel 45 (5), case-hardened steel (6). In a relative decrease in contact endurance, an undoubted role is played by the coefficient of sliding friction $f_{к}^{c}$ (here in all cases $f_к = 0.02 = \text{const}$) [1, 3].

The effect of reducing the endurance limit during rolling with slip for cylindrical gears, as well as rollers with parallel axes, is satisfactorily described by the empirical formula:

$$\frac{\sigma_к}{\sigma_к^c} = \frac{0{,}2 + 2{,}28 f_к - 1{,}5 f_к^2}{0{,}2 + 2{,}28 f_к^c - 1{,}5 \left(f_к^c\right)^2}, \qquad (1)$$

which is based on an expression for an approximate estimate of the reduced stress at the contact area.

In the process of contact fatigue, the surface hardness and the size of the contact area increase intensively during the first loading cycles due to plastic deformation of the surface layer. Over time, this dependence fades; after $\sim 10^5$ cycles (steel 75Kh2GNMF for rolling rolls), the hardness practically does not change, and the width of the contact area increases linearly as a result of wear up to $3 \cdot 10^6$ cycles. The surface roughness is reduced from the original 0.5 μm to 0.1 μm.

The scale effect under contact fatigue undergoes an inversion. The main regularities are as follows:

a) With an increase in the diameter d from 4 to 10 mm of contact rollers and balls made of ShKh15 steel (HRC = 62–64), their durability at $p_o = \sigma_{zmax} = 5000$ MPa increases by 2–5 times.

b) When testing samples of steel 75Kh2GNMF with a diameter of 22, 110 and 1000 mm, the following picture is observed: large samples with a diameter of 1000 mm show greater durability compared to samples with a diameter of 22 and 110 mm. Thus, at a pressure in the center of the contact area peq = 1500 MPa, the life of a sample with a diameter of 22 mm is $5 \cdot 10^5$ cycles, and that of a sample with a diameter of 1000 mm is $9 \cdot 10^6$ cycles.

c) Relative wear I - the ratio of the change in the radius of the sample to the half-width of the contact area b (excluding plastic deformation) - for a sample with a diameter of 1000 mm was I = 0 ... 29 μm / mm, and for a sample with a diameter of 110 mm I = 27 ... 163 μm/mm, that is wear is greater, the smaller the sample (usual scale effect).

d) The larger the diameter of the sample, the greater the absolute value of the depth h and the area of the centers of chipping (at the same σ_{zmax} and N). So, for steel 45 in samples d = 6.5 mm, the average depth of the spalling pits did not exceed 30–60 μm, and at d = 40 mm it reached 270 μm.

e) The greater d, the greater the number of loading cycles required to achieve the same degree of contact damage (Figure 3: steel 45 - 1, 2, 3 chipping, respectively, continuous, moderate, single).

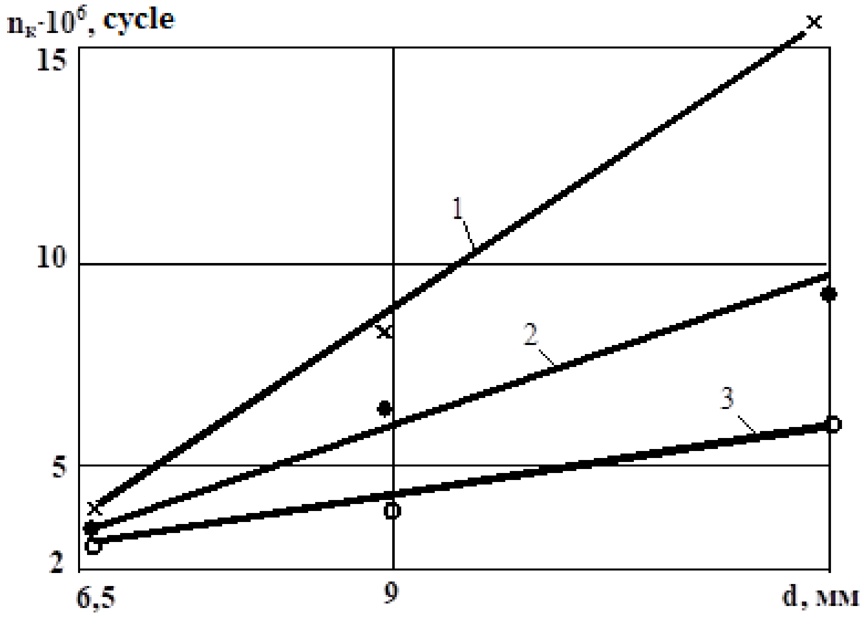

Figure 3 - Dependence of the number of loading cycles on the diameters of the samples

So, at σ_{zmax} = 1700 MPa and chipping depth h = 38...44 μm after $3 \cdot 10^6$ cycles, the chipping area S = 1.16...1.41 mm^2 was achieved, while for samples with a diameter of 12 mm, approximately the same damage required $8 \cdot 10^6$ cycles.

If the theory of the scale effect for ordinary fatigue is well developed, then for contact fatigue it, according to the available information, has only a qualitative character. Apparently, a satisfactory theory of the scale effect can be constructed on the basis of a statistical model of a deformable solid with a dangerous volume.

When rolling without lubrication, fatigue cracks practically do not occur: they are formed in the presence of lubrication, including drip. The effect of lubrication on the process of contact fatigue is twofold.

a) At high pressures in the contact zone, the oil has a negative effect. Under the action of the incoming surface, as well as due to capillarity, the oil penetrates into friability, irregularities, microcracks and expands them, causing accelerated chipping of metals (wedging effect). This phenomenon is especially pronounced if one of the surfaces in the zone of increased pressure is subjected to tension, which contributes to the opening of microcracks. The content of water impurities in the lubricant, as well as lubrication with water, leads to saturation of the surface layer of steel with hydrogen, and, consequently, to hydrogen embrittlement, which sharply accelerates the process of contact fatigue.

b) On the other hand, at moderate pressures in the contact zone, the oil film contributes to a more uniform distribution of pressure over the actual contact surface; it is an effective heat transfer agent; causes a hydrodynamic effect - entering the narrowing part of the gap, the lubricant separates the surfaces of the metals, so that fluid friction occurs in the joint. All this contributes to an increase in the resistance of metals to contact fatigue.

Conclusion

Thus, the influence of various factors on the contact fatigue resistance of materials is diverse and complex. And it is required to carry out a complex of special studies (theoretical and experimental) in order to satisfactorily describe the phenomenon of contact fatigue as a specific process of accumulation of surface damage, accompanied by wear of the material and ending with local destruction of the working surface.

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