

ASME HANDBOOK

Metals Properties  
Engineering Tables  
Metals Engineering—Design  
Metals Engineering—Processes

ASME HANDBOOK

# Metals Engineering Design

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ASME HANDBOOK  
METALS ENGINEERING—DESIGN

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## FOREWORD

The ASME Handbook of Metals Engineering—Design is one of the many services of the Society. It came into being as a result of a survey in 1941 by the Metals Engineering Division which revealed the need of the mechanical engineer and designer for a ready reference to the properties and characteristics of metals. A preliminary study was instituted, and as a result, in August, 1945, the Executive Committee of the Council authorized the publication of a Metals Engineering Handbook and appointed a Handbook Board. This Board was set up as a continuing body, the members to be selected upon the recommendation of the Metals Engineering Division with the approval of the standing Committee on Professional Divisions and the concurrence of the Publications Committee. The personnel of the Board has changed from time to time.

The Society is grateful to the members of the Board and to the many others who have made valuable contributions to the text of the Handbook.

The Society is particularly happy to recognize the active cooperation of the American Society for Metals, which has permanent representation on the Board through a nominee of its own choice.

FREDERICK S. BLACKALL, JR., *President*, 1953  
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

This Handbook has been prepared to fill the urgent need for a reference manual related to the design engineer's point of view. A wealth of information of direct interest to him has been compiled from many authentic sources and is presented in a form which, it is hoped, will prove most useful to the experienced engineer and the embryo designer alike.

This volume comprises 48 sections, dealing primarily with the *design* function in metals engineering. Three other volumes are in preparation. One deals with the *processes* by which metals are converted to finished product. Another tabulates the *properties of metals* about which a design engineer needs information. A fourth volume collects in one place many *engineering tables* to supplement the designers knowledge of standards for shape, dimension, gears, and the like.

Contributions have been made by members of The American Society of Mechanical Engineers and other societies. Industrial organizations have been most generous in furnishing data and in permitting the use of material already in print. In each case, proper recognition is given to these sources.

LEWIS K. SILLCOX, *Chairman*  
ASME METALS ENGINEERING HANDBOOK BOARD

## 2 FRETTING CORROSION AND FATIGUE

by GEORGE SACHS

Fretting fatigue, also called "rubbing fatigue" and "chafing fatigue," is a particular type of fatigue failure, probably related to both notch fatigue and corrosion fatigue (refs. 41, 57). The main characteristic of these types of fatigue is a combination of two factors: (1) the repeated loads or vibrations which define the load applications as fatigue or endurance, and (2) a factor which reduces the fatigue strength and endurance limit obtained in the absence of this damaging factor.

In fretting fatigue, the damaging factor consists of close contact between the part subject to vibration and another part, either fitted to the vibrating part or in gliding contact with it. The most important example of premature failure from fretting fatigue is that of railway axles onto which the wheel has been press-fitted or shrunk (refs. 9, 26, 29, 35-37, 39, 40, 43-45, 51, 58, 59). Fundamentally the same failure has been also observed on shafts (refs. 15, 26) and on crankpins (refs. 55, 59). Various types of joints differ from these fitted members in that none or only a slight pressure is present during rest conditions; however, the pressures resulting from the vibrations also cause fretting-fatigue failures. The most important instance of such a joint is that between an aircraft

propeller and its hub (refs. 17, 25, 31, 41, 50). Other cases of this type are screws or bolts and nuts (refs. 10, 46, 60), keyed joints (ref. 13), couplings (ref. 14), joints between wire or wire rope and clamps (refs. 6, 21), and attachments of springs (refs. 8, 16). Failures between gliding members are those of parts running in bearings and of gear teeth (ref. 33). Possibly the fatigue failures of the bearings themselves are also a result of fretting fatigue. However, these will not be considered here. A large variety of fretting-fatigue failures have been described by Thum and Wunderlich (ref. 12).

Most observations on fretting fatigue relate to mild steel. However, most metals and alloys appear to be susceptible to damage by fretting. It has been found to be present in aluminum alloys (refs. 17, 41, 50), magnesium alloys (refs. 17, 25, 31, 50), copper alloys (refs. 17, 41, 50), and stainless steels (ref. 41).

The type of fatigue failure observed at contact surfaces is obviously the same for contact either in relative rest or in relative movement. This is proved by the fact that the laws of fretting-fatigue failures have been established by extensive laboratory tests (refs. 1, 4, 5, 6, 11, 12, 14, 17, 20, 28, 32, 41, 42, 48), which are predominantly of the type in which failure occurs at the contact between the rotating specimen and the bearing.

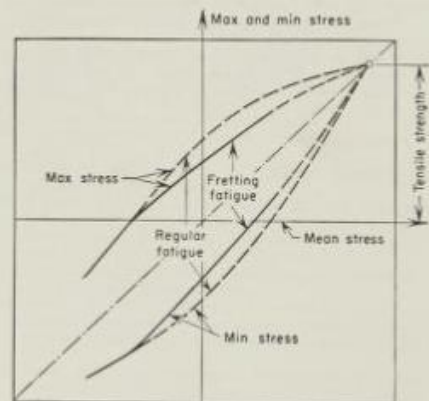


FIG. 1. Diagrammatic representation of the relation between fretting-fatigue strength and regular-fatigue strength for various conditions of axial loading.

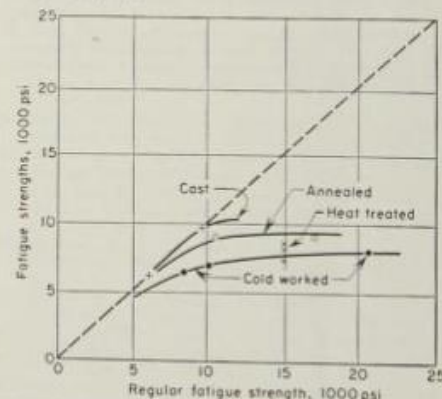


FIG. 2. Relation between fretting-fatigue strength and regular-fatigue strength for various aluminum alloys.<sup>41</sup>

Sec. 2

FRETTING CORROSION AND FATIGUE

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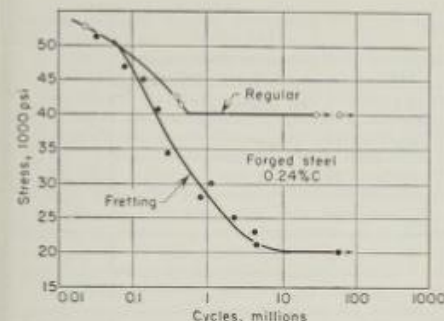


FIG. 3. Stress-cycle curves for tests on fretting fatigue and regular fatigue of a forged steel.<sup>41</sup>

The literature on fretting fatigue has been repeatedly abstracted and critically discussed (refs. 30, 34, 38, 52, 57).

The fatigue failure, under conditions where fretting is present, occurs in all instances either at the edge of the contact area between the two contacting members or close to it but within the contact surface.

The failure may occur in either one or in both contacting members.

In many instances of fretting fatigue, the production of abrasive products has been observed (refs. 2, 7, 18, 19, 23, 32). This process is usually called "bleeding," the term being illustrative for the red color of the abrasion products of steel. The absence of such abrasion products, however, is no proof that fretting does not occur and that the fatigue strength is unaffected.

The laws of fretting fatigue, as far as they have been recognized, are generally the same as those for notch fatigue and corrosion fatigue (ref. 41). Most important among these laws are:

1. A damaging effect probably occurs only in the presence of applied tensions. On the contrary, it appears that fretting in the absence of tensions, *i.e.*, in the presence of compressions only, would not adversely affect the fatigue strength. This is illustrated schematically in Fig. 1. However, definite information in this respect does not seem to exist at present. Figure 1 illustrates that the fatigue strength is reduced less the more the load condition changes from tensions only (upper right quadrant) to tension-compression, and that the damaging effect is nil in the range of compressions only (lower left quadrant).

2. The damaging effect, for a given load application, such as rotating bending, is highly dependent upon the material (ref. 41). For certain groups of materials, such as aluminum alloys, the fretting-fatigue strength has been found according to Fig. 2 to be equal to the regular fatigue strength (determined for polished specimens) if this value was very low. With increasing regular fatigue strength (or tensile strength, or hardness), the effect of fretting becomes increasingly larger. Thus, for high-strength alloys, the fatigue

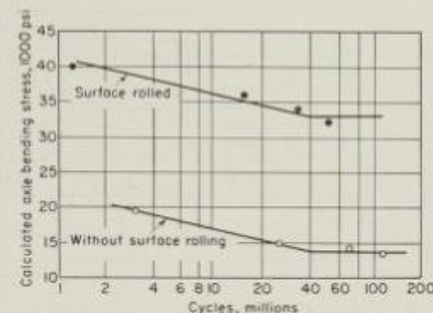


FIG. 4. Effect of surface rolling on the fretting-fatigue strength of SAE 1045 steel axles.<sup>19</sup>

strength in presence of the damaging effect (under conditions of either severe fretting, notching, or corrosion) is practically independent of either the regular fatigue strength or the tensile strength.

The fretting-fatigue strength is also dependent, according to Fig. 2, upon the structural condition of an alloy, to a slight extent. Cast alloys are apparently more resistant than annealed ones, which in turn are more resistant than either cold-worked or heat-treated alloys, on the basis of equal strength.

3. The damaging effect increases with increasing loads. As shown in Fig. 3, it becomes generally apparent only if the load range is sufficiently low to cause failure after a considerable number of cycles, anywhere above 10,000 cycles at least. Furthermore, as shown in Fig. 3, stress-cycle curves indicate that no true fretting endurance limit exists, the value of the

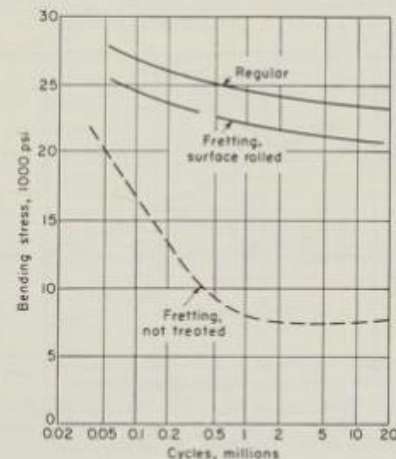


FIG. 5. Stress-cycle curves for regular fatigue and for fretting fatigue of surface-rolled and untreated specimens of magnesium alloys.<sup>14</sup>

| Key | Spec. dia, in. | Roller size and feed |                  |          | SAE 1045<br>Steel normalized and drawn |
|-----|----------------|----------------------|------------------|----------|----------------------------------------|
|     |                | Dia, in.             | Contact rad, in. | Per inch |                                        |
| ○—○ | 0.3            | 0.44                 | 0.09             | 224      | $\frac{1}{2}$ - dia cold-rolled        |
| △—△ | 1              | 1.46                 | 0.31             | 60       | $1\frac{1}{2}$ - " " "                 |
| □—□ | 2              | 2.92                 | 0.63             | 60       | $3\frac{1}{2}$ - " " "                 |

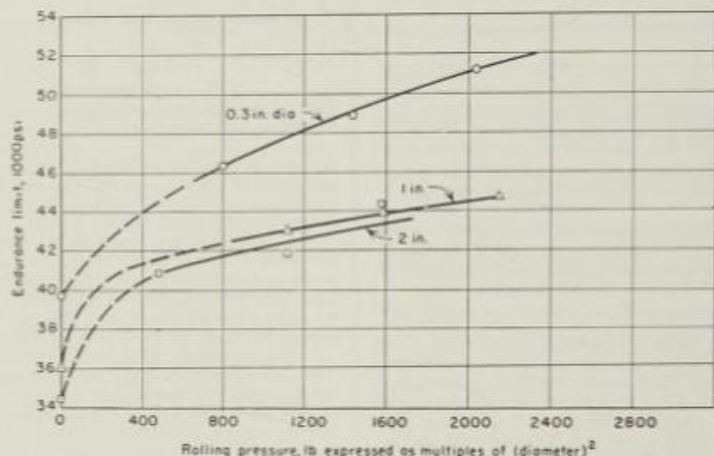


Fig. 6. Effect of roll pressure on the fretting-fatigue strength of surface-rolled SAE 1045 steel axles of various section sizes.<sup>11</sup>

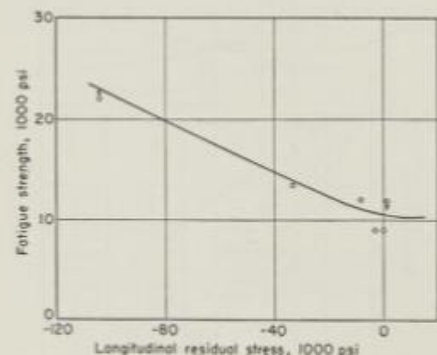


Fig. 7. Relaxation between fretting-fatigue strength and residual stresses of 0.4 to 0.5 per cent carbon steels according to tests by Horger and Neifert.<sup>12</sup>

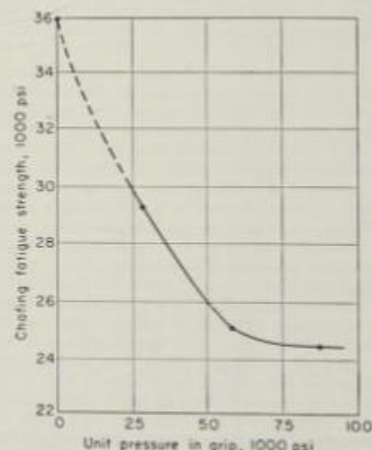


Fig. 8. The effect of clamping pressure on the fatigue strength of cantilever-type steel specimens.<sup>13</sup>

fatigue strength steadily decreasing with increasing number of cycles.

4. Certain mechanical and thermal treatments remove most of the damaging effects.

Mechanical treatments used thus to improve the life of parts, particularly of railroad axles, are surface rolling with one or several polished rolls (refs. 13, 22, 24, 35, 39, 56), and peening or shot blasting (refs. 39, 47, 53, 54). Effects of such treatment are illustrated in Figs. 4 and 5. Improvement resulting from such processes depends upon the processing conditions, such as the roll size and rolling pressure in surface rolling (refs. 31, 35), as shown in Fig. 6, or the shot size and pressure in shot blasting (ref. 47).

By flame-hardening the contact surface, an improvement similar to that obtained by mechanical treatments can be achieved (refs. 36, 39, 54).

It appears that these beneficial effects are attributable only to a minor extent to a structural improvement of the material. Most of the improvement is explained by the introduction of compressive surface stresses by either the mechanical or thermal treatments (refs. 31, 43), which prevent development of tensile stresses during vibration. The relation between the magnitude of such stresses and fretting-fatigue strength is illustrated in Fig. 7.

Thin soft inserts between, and coatings of one of, the contact surfaces also increase the fretting-fatigue strength (refs. 11, 31).

The analogy between fretting fatigue and notch fatigue has been also confirmed by photoelastic studies of contacting parts (refs. 15, 46). These show that the stress distribution in a loaded press-fitted part is nearly the same as that in a single piece of the same over-all shape. This explains why the fatigue strength of press-fitted parts can be raised by stress-relieving measures similar to those applied to notched (filleted) parts.

However, the fatigue strength of press-fitted parts is quite dependent upon the pressure initially present in the press fit (ref. 11), as illustrated in Fig. 8.

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## PART FOUR

## Metallurgical Factors in Design