influenced unfavorably by straightening. Schmidt[85] found that crankshafts for airplane engines developed distortion during processing and required a small amount of straightening when they were machine finished. When cold straightened, these crankshafts showed an endurance limit 20% lower in reversed bending than the limit for crankshafts that had not been straightened. The effect was even greater above the endurance limit, where the allowable stress was decreased by 33% for a life of 50,000 cycles and by 27% for 150,000 cycles.

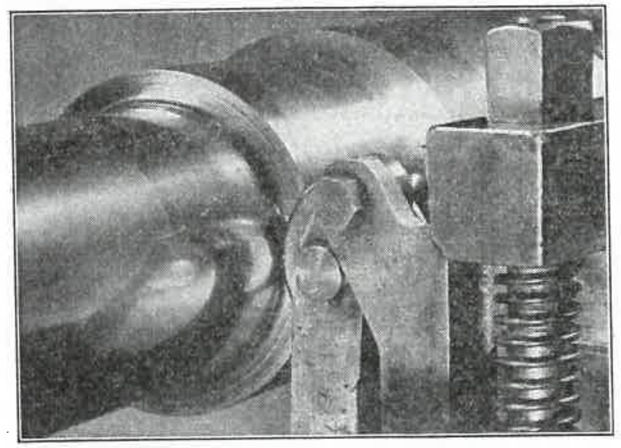

Fig. 22 Method of rolling axle fillet

Also, Horger and Lipson[86] found that the endurance limit in rotating bending of full-size automobile rear axles was 13,000 to 16,000 psi when the shafts were straightened in production. Similar unstraightened axles had an endurance limit of 20,000 psi, or at least 25% greater resistance to fatigue than the straightened shafts. The detrimental effect of straightening was overcome by shot peening after straightening.

In the above examples, the reduced resistance to fatigue found after cold straightening, was attributed to unfavorable residual tensile stresses established on one side of the crankshafts or axles.

Grinding. Residual surface stresses from grinding may be the cause of service failures (*See* Fig. 24 and 25).

Influence of Service Environment

A third general cause contributing to failure of metal parts is exposure to processes and environment, such as (1) corrosion, (2) galvanic corrosion, (3) corrosion fatigue, (4) fretting corrosion and (5) stress corrosion. Mechanical defects arising from the service environment may also cause failure. Limited space restricts the present discussion of a subject about which many volumes have been written.

Corrosion. The types of corrosive attack most commonly encountered may be limited to three: uniform thinning, pitting attack, and grain boundary attack. These are discussed in the various articles on corrosion.

Galvanic Corrosion. When two dissimilar metals are brought into electrical contact in an electrolyte, corrosion of the less noble metal (anode) occurs in excess of its normal rate in that electrolyte, while the more noble metal (cathode) is protected. This accelerated corrosion is known as galvanic corrosion. The amount of additional corrosion of the anode is proportional to the current flowing in the electrolytic cell, and the amount of current flowing is determined in turn by the emf of the cell, by the relative areas of the anode and cathode surfaces, by the conductivity of the solution, and by the rate of polarization of the electrodes. Galvanic corrosion is usually characterized by severe local corrosion at the point of contact of the dissimilar metals, if that contact takes place in the electrolyte. Galvanic corrosion is also frequently found at points, other than the contact point, where proximity of the dissimilar metal parts, relative anode and cathode areas, cell emf, and solution conductivity are properly adjusted.

Such solutions as rain water, sea water, battery acid, and some organic liquids may cause galvanic corrosion. In some instances, large quantities of salts such as hydroxides and sulfates are formed, which weaken the part through detrition and the building up of stresses, especially in faying surfaces. Corrosion of this type can be detected by visual examination.

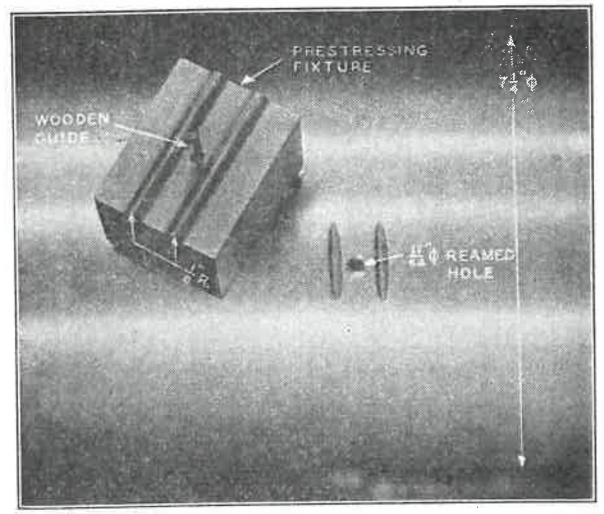

Fig. 23 Method of prestressing notches around transverse oil hole. Crankpin having transverse oil holes in bearing seat with 7.280-in. diam. Stamp used in prestressing oil holes and impression produced. Wooden plug protruding from stamp is used to locate stamp over hole. Pin No. A7-3; Type 5 oil-hole design

Corrosion Fatigue. Corrosion-fatigue failure in metals results from a wide variety of service conditions, ranging from those that are predominantly corrosive in character with minor effect from stresses, through the graduated conditions, to those in which corrosion is only a minor contributing factor and the destruction of the metal results almost entirely from mechanical stresses. Fretting corrosion, discussed below, is considered by many to be a special type of corrosion fatigue. The characteristic that identifies corrosion fatigue is the accelerating effect of a corrosive condition in promoting early failure of a member subjected to alternating stresses. Characteristically, the fractures are transcrystalline, the same as fatigue fractures in the absence of a corroding medium.

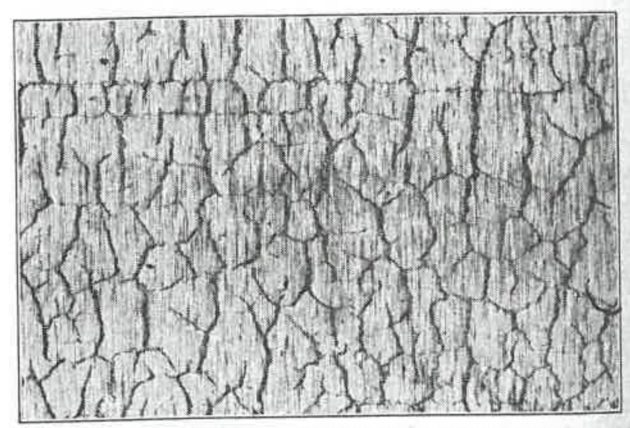

Fig. 24 Surface cracking caused by faulty grinding on a carburized and hardened 1020 steel guidepin. This type of surface on a part subjected to high stress will lead to early failure. (× 11)

Fretting Corrosion. When two parts are clamped, press fitted or shrunk together and subjected to vibratory stresses, fretting corrosion may occur. In steel, this corrosion consists of the formation of red oxide[95] between the fitted surfaces, and particularly near the ends of the fit. Fretting corrosion is also known as "friction oxidation" or "rubbing corrosion". Fretting is one of the most severe forms of weakening action on fatigue strength. A typical fatigue fracture resulting from this condition, is illustrated in Fig. 26. The endurance limit of a shaft to prevent breaking off in the fitted member is only about one-third to one-half of that for the shaft without a press fit.[96,97] Even though the shaft does not break off, because it is subjected to stresses lower than the endurance limit, fatigue cracks are often found when the assembly is pressed apart.[97]

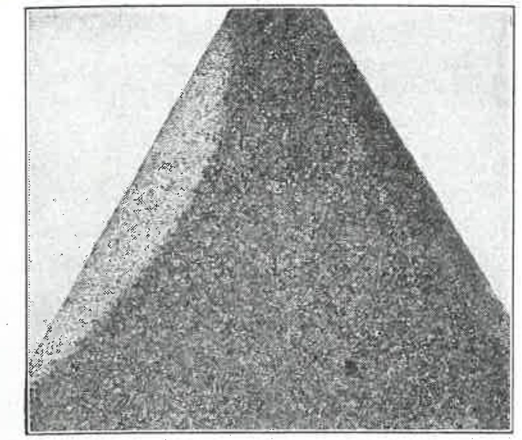

Fig. 25 Grinding of threads on bolts and screws is sometimes the cause of failure from residual stresses. The micrograph above shows hardening caused on the side of a thread by overheating in grinding. This hardening by heating in grinding leaves the thread in a highly stressed condition, which, coupled with service stresses, may cause failure. (× 100)

Fretting corrosion may occur when antifriction bearings are subjected to vibratory oscillating loads of small amplitude. Failures may be found in unused parts after shipment, and in used parts subject to the above conditions of loading. The failure is indicated by a "false brinelling" of the part and is generally accompanied by visible deposits of red oxide of iron.

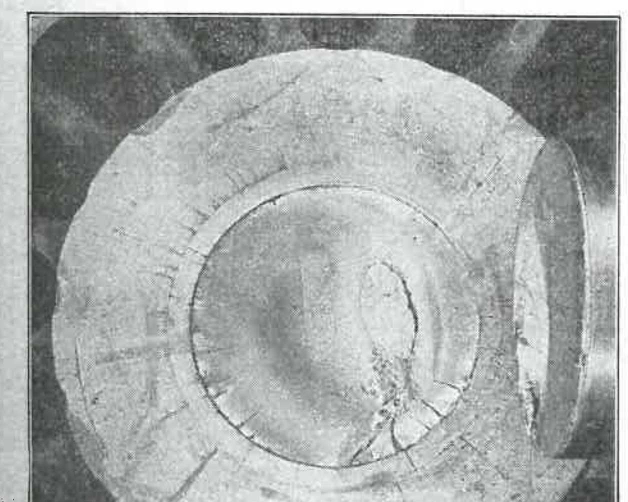

Fig. 26 Typical fatigue fracture of shaft, occurring at one end of a fitted part

Usually fatigue resistance in the presence of fretting corrosion can be greatly improved by the following methods: the shaping of the parts as shown in Fig. 27; residual compressive stresses obtained in the surface of the shaft by surface rolling;[96,97] the proper type of quench and temper;[98] induction or flame hardening;[98,99] nitriding or case carburizing; or a sprayed-metal layer of proper material.[99]

Stress-Corrosion Cracking. This type of failure in metals differs essentially from corrosion fatigue. The principles of stress corrosion are discussed in the article on page 227, and data are given there concerning the stress-corrosion cracking of common ferrous and nonferrous alloys. For information on stress relief, see the article on page 237.

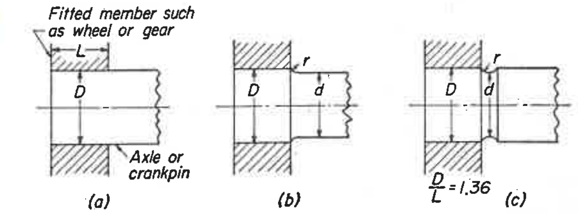

Fig. 27 Correct shaping of fitted parts. (*a*) Conventional method; bending fatigue resistance, 100%. (*b*) and (*c*) Improved methods; bending fatigue resistance, about 130%. Fillet and groove *r* to be surface rolled except when *r* in (*b*) can be large (about 0.4 *D*). If the portion of the shaft in (*a*), (*b*) and (*c*) over which outer part is fitted is surface rolled, then fatigue resistance is more than 200%. (The above data are based on breaking-off strength of full-size fatigue tests in rotating bending of shafts 7 to 9½ in. in diam and made of 0.50% C steel normalized and tempered.)

Mechanical Factors in Service Environment. Service environment may establish such conditions that the properties of the material are affected or the stresses in the material exceed the allowable design values. The loosening of a threaded connection, the hardening of gaskets and shock-absorbing devices because of aging and other factors that may affect clearances, change the rates at which loads are applied, which may mean that parts will be subjected to impact or repetition of loads that they were not designed to withstand. When the examination of a fracture indicates an impact failure or a progressive failure at a few alternations of stress, it is advisable to investigate the possibility that other parts of the machine may have become loose or distorted, thus throwing an excessively high or unusual load on the part that failed.

Temperature changes that result from unusual operating conditions, may cause failure on account of reducing the strength by an annealing action or by the melting and spheroidizing of the constituents that have low melting points. Measuring the hardness may indicate the damage, but a microscopic examination is often necessary, especially for aluminum-base and magnesium-base alloys. Low atmospheric temperatures are generally above the temperatures at which the properties of most metals are affected. However, high stresses may be induced by the unequal contraction of unlike metals with different coefficients of expansion.

Mechanical defects, such as scratches, cuts and bruises on the surface, are stress raisers and will lower the resistance to failure from alternating stresses. This subject has been ably discussed in a book entitled, "Prevention of Failure of Metals Under Repeated Stress",[70] prepared by the staff of Battelle Memorial Institute.

References

1 S. Timoshenko, "Strength of Materials", D. Van Nostrand, 1930
2 R. E. Peterson, Amount Gained in Fatigue Strength of Machine Parts by Using a Material of Higher Tensile Strength, Proc SESA, 3, 149–51 (1946)
3 R. J. Roark, "Formulas for Stress and Strain", 2nd Ed, McGraw-Hill Book Co., 1943
4 "ASME Design Data" (Special Pamphlet), American Society of Mechanical Engineers
5 R. E. Peterson and A. M. Wahl, Two- and Three-Dimensional Cases of Stress Concentration and Comparison with Fatigue Tests, Trans ASME, AMP 55-19 (1933)
6 N. C. Riggs and M. M. Frocht, "Strength of Materials", Ronald Press, 1938
7 G. H. Neugebauer, Stress Concentration Factors and Their Effect on Design, Product Eng, 14, 82 (Feb 1943)
8 R. E. Peterson, Relation Between Life Testing and Conventional Tests of Materials, ASTM Bull (March 1945)
9 H. F. Moore, A Study of Size Effect and Notch Sensitivity in Fatigue Tests of Steel, Proc ASTM, 45, 507 (1945)
10 G. A. Hankins and G. W. Ford, The Mechanical and Metallurgical Properties of Spring Steels as Revealed by Laboratory Tests, J Iron Steel Inst (London) 119, No. 1, 217–253 (1929)
11 G. Burns, The Properties of Some Silico-Manganese Steels, J Iron Steel Inst (London) 125, No. 1, 363–391 (1932)

METALS HANDBOOK 1948