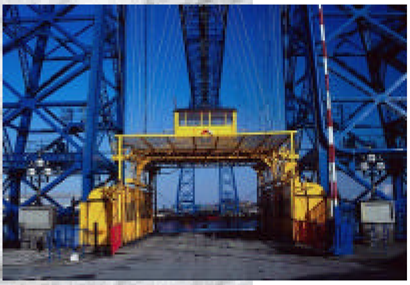

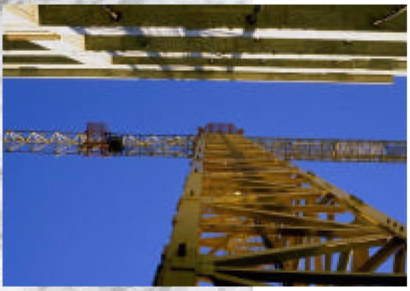

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Technical Brief Number 14

METAL FATIGUE: A SUMMARY OF CAUSES AND CURES

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TABLE OF CONTENTS

……………………………………………………………………………Definitions

……………………………………………………………………………Engineering

…………………………………………Practical Considerations for Avoiding Fatigue

A. For the Designer
B. For the User

………………………………………………………………………………Figures

……………………………………………………………………………References

METAL FATIGUE: A SUMMARY

Definitions

Fatigue fractures are due to repeated stresses at levels much below the metal's ultimate tensile strength. They are caused by the simultaneous action of cyclic stresses, tensile stresses, and plastic strain. If any of these three is not present, fatigue cracking will not begin and propagate (4).

A metal's fatigue strength will be less than its yield strength, as determined in a tensile test. In fatigue tests, failure is always a brittle fracture. Because stresses applied are usually less than yield strength, the material, even though it is ductile, has not stretched or yielded significantly when failure occurs (5). Fatigue strength may be defined as the stress, in pounds per square inch, at which failure occurs in a definite number of cycles.

The endurance limit is the limiting value of stress below which a material can presumably endure an infinite number of stress cycles. This is seen as the horizontal position of the S-N curve, figure 1. Some materials and environments preclude the attainment of a fatigue limit (2).

Fatigue fracture depends on the number of repetitions in a given range of stress rather than upon total time under load. Speed has almost no observable effect (2).

The Process of fatigue consists of three stages:

1) Initial fatigue damage leading to crack initiation
2) Crack propagation until the remaining cross section becomes overloaded
3) Finally, sudden fracture of remaining cross section (4)

A fatigue crack always originates at the point where the ratio of local stress to endurance limit is lowest (3). This will usually be at a fillet, sharp corner, or other surface discontinuity. Once started, a fatigue crack follows a path of least resistance through the metal. It often crosses grain boundaries (2).

Engineering Factors in Fatigue

The following factors influence resistance to fatigue failure:

1) Surface stress
2) Material strength
3) Material microstructure
4) Stress concentration factors
5) Type, mode, and history of loading
6) Size effect
7) Surface effect
8) Service environment

Several of these factors merit specific comment. Whatever the type of load, it is the resulting tensile stresses at or near the surface that will initiate a crack. When a part is subject to a combination of static and alternating loads in service, the significant strength of the material may be estimated by using a modified Goodman diagram. (This is shown in Reference 3 and other sources.)

Of very great significance to both the designer and manufacturing engineer are stress concentration factors. Such geometric irregularities (stress raisers) as notches, scratches, tool works, or excessively small fillets can magnify local surface stress by a factor of several times. These factors are a function of geometry and may be estimated by using a handbook, such as *Stress Concentration Factors* by R. E. Peterson, John Wiley Publishers, 1974. Fine-grained metals (such as heat hardened steels) are most sensitive to stress concentration factors, while coarse-grained steels and cast metals are much less so (3). This gradient is known as notch sensitivity.

Surface finish has a great effect on endurance strength, as shown in figure 2. The imperfections of rougher (and less costly) surfaces act as stress raisers.

Parts operating in corrosive environments may suffer a substantial loss of endurance strength, presumably due to both continuing degradation of surface condition and to other chemical phenomena. When faced with such a problem, the engineer should design with stress corrosion in mind.

Practical Considerations in Avoiding Fatigue

A. For the Designer

Theoretical surface stresses should be estimated by standard engineering formulas, and the factors then carefully chosen and applied to allow for geometric stress raisers, surface roughness, hostile environment, and characteristics of material. Following this procedure may lead to small but important changes in design and surface specifications.

Materials should then be selected and processed to withstand the calculated tensile stresses as deemed appropriate for projected service life and conditions.

The manufacturing processes must be engineered with two factors in mind:

1) maintaining adequate fatigue strength in the metal, and
2) controlling residual tensile stress on surfaces.

Generally, fatigue strength is improved by any heat treatment that increases hardness. Residual tensile stresses left by processing (such as welding or straightening) must be considered and dealt with. Electroplating can reduce fatigue strength; plating cycles can cause hydrogen damage to steel, particularly those of high strength, and hard plating materials are usually in tension after plating (4). Electrochemical polishing can also be detrimental by means of removing work-hardened material from the surface. Electrical discharge machining typically gives a hardened but microcracked surface, having poor fatigue resistance (1). Peening, burnishing, and other cold working which induce compressive stresses on a surface are helpful. Peening of hot welds is not advisable.

Brittle lacquer and small strain gauges are useful in determining actual stresses in critical areas.

The loss of properties from thermal processes such as welding, hard facing, and stress relieving must be considered, as well as the imperfect integrity of materials.

B. For the User

1) Any service condition that imposed stress not intended by the manufacturer can cause early failure. A common example is misalignment of rotating shafts; this can give very high tensile stresses that cycle with every rotation and induce high fatigue.
2) Any thermal repair technique, such as welding, brazing, or hard facing, can greatly reduce metal strength, lock in residual stresses, and create stress raisers. All three of these consequences contribute to fatigue failure.
3) Scratches, dents, and other damage from rough handling can shorten service life.

Figures

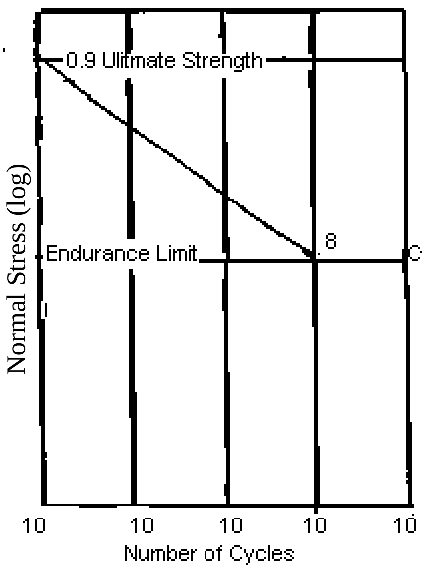

Figure 1. S-N curve for standard steel samples subjected to reverse bending loads.

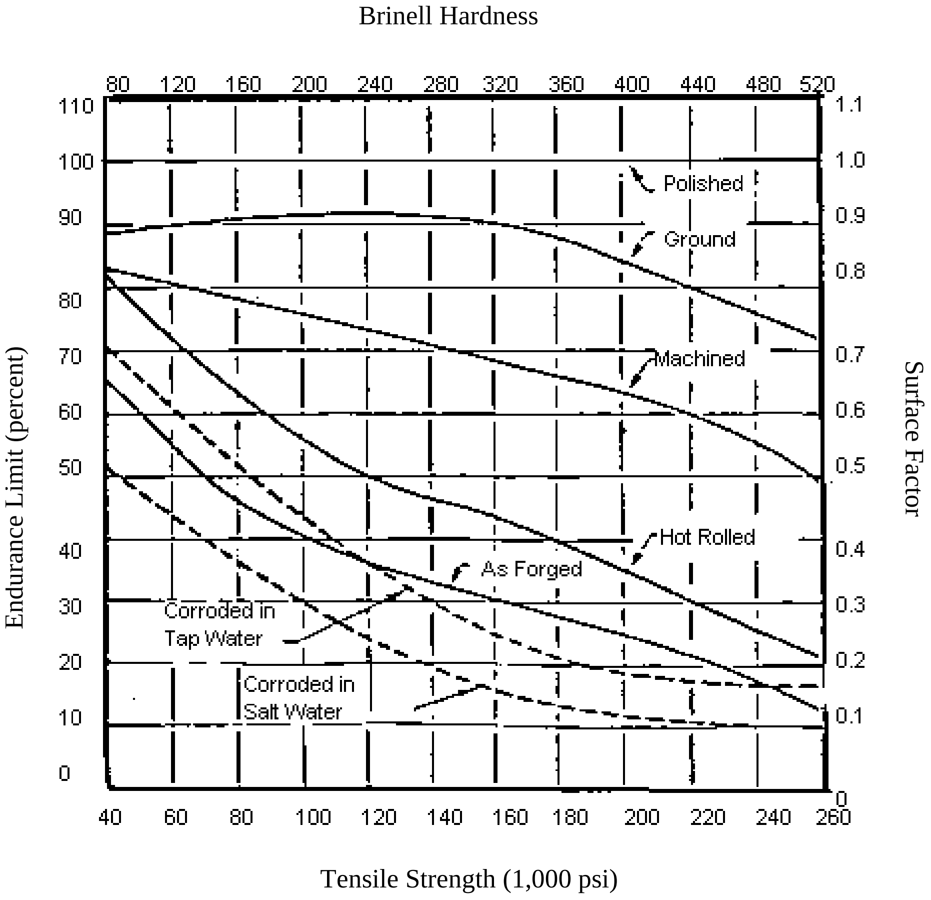

Figure 2. Effects of surface finish on endurance strength.

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