EFFECT OF SHOT PEENING ON STRESS CORROSION CRACKING AND CORROSION FATIGUE

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ABSTRACT

The influence of shot peening on stress corrosion cracking and on corrosion fatigue is reviewed. Stress corrosion cracking is defined as environment-sensitive cracking under constant or increasing stress or strain. Corrosion fatigue is environment-sensitive cracking under cyclic stress or strain. Both, stress corrosion cracking resistance and corrosion fatigue resistance of metallic materials can be substantially improved by shot peening. Localized corrosion, however, such as pitting or intergranular corrosion may severely limit the beneficial effect of shot peening. In such cases a combination of shot peening and a corrosion-resistant surface protection system (anodizing, painting) may provide a better protection than shot peening alone but then, care must be taken to prevent mechanical damage of the surface protection systen.

KEYWORDS

Shot peening; stress corrosion cracking; corrosion fatigue; metallic materials; localized corrosion; surface protection.

INTRODUCTION

Stress corrosion cracking and corrosion fatigue can be considered as environment-sensitive nucleation and growth of subcritical cracks (Speidel and Hyatt, 1972). Since shot peening has primarily an influence on the surface of specimens and components, the present paper is concerned only with the nucleation of stress corrosion and corrosion fatigue cracks, rather than with their propagation. Moreover, the present overview is limited to the shot peening of metallic materials.

It is intended to show that shot peening is neither a panacea for all stress corrosion cracking (SCC) and corrosion fatigue (CF) problems, nor is it without use in most cases. However, it is important to know its limitations.

STRESS CORROSION CRACKING

The resistance of a given material to stress corrosion cracking is often measured by the time to failure of specimens exposed to constant stress (or strain) in a specific environment. Typical test results are shown in figures 1, 2 and 3 for stainless steels, for an aluminum alloy in chloride solutions and for a low alloy high strength steel. Obviously, shot peening improves both, the time to failure and the threshold of the applied stress below which no failures are observed in the indicated testing times. Fig. 3 indicates also the well known reason for the improvement of the stress corrosion resistance: it is the build-up of residual compressive stresses, and these in turn depend, among other things, on peening time and on the type of shot used.

Considering only the results of the type shown in figures 1, 2, and 3 may, however lead to overoptimistic interpretations of the beneficial effects shot peening has on stress corrosion resistance. Testing times in figures 1, 2, and 3 are only several hundred or thousand hours, while components of machines and structures in actual service are most often required to last many times longer. If during that time corrosion penetrates the residual compressive stress layer on the surface of the alloy, then stress corrosion cracking may be observed again. This is clearly shown in figure 4 where it is evident that aluminum alloy specimens, shot peened and exposed to alternate immersion in 3.5% NaCl solution or to the seacoast atmosphere may suffer stress corrosion cracking. In both these environments, localized corrosion is known to occur with the aluminum alloys indicated in figures 4 (Speidel and Hyatt, 1972; Speidel, 1980). Obviously, where localized corrosion may occur, a combination of shot peening plus a surface protection system against corrosion will yield far better results than shot peening alone. This is further illustrated in figure 5.

Shot peening together with a surface protection system against corrosion go a long way towards preventing stress corrosion cracking, as illustrated in figures 4 and 5. Such protection may be necessary where no inherently stress corrosion resistant materials are available. Naturally, an inherently SCC-resistant alloy, if available, should be preferred over a SCC-susceptible and protected alloy, since stress corrosion cracking may result in the susceptible alloy where the surface protection breaks down locally, as shown in figure 6. It may be possible that the painted and anodized surface protection layers suffer mechanical damage, e.g. by scratches, and then, the metal surface layer which contains residual compressive stresses from shot peening may be penetrated by pitting corrosion. From the bottom of the pits, stress corrosion cracks could result.

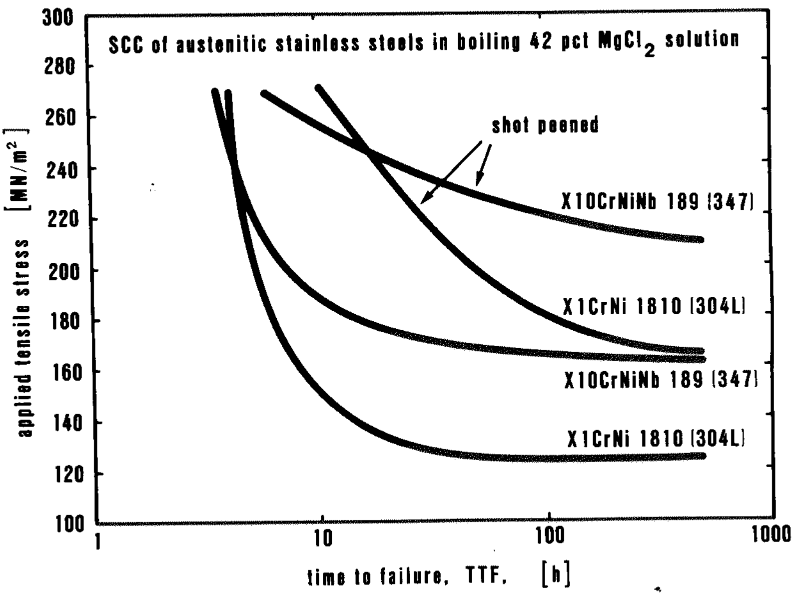

Fig. 1 Stress corrosion cracking of two austenitic stainless steels. Note that shot peening lengthens the time to failure and raises the threshold stress for SCC failure. Based on data in the work of Wiegand et al. (1968)

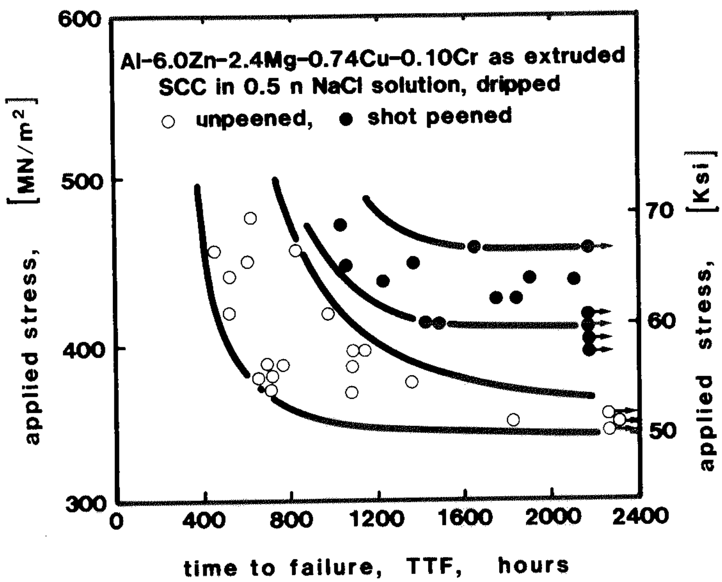

Fig. 2 Stress corrosion cracking of a high strength aluminum alloy. Note that shot peening lengthens the time to failure and raises the threshold stress for SCC failure. Based on data in the work of Hawkes, (1968).

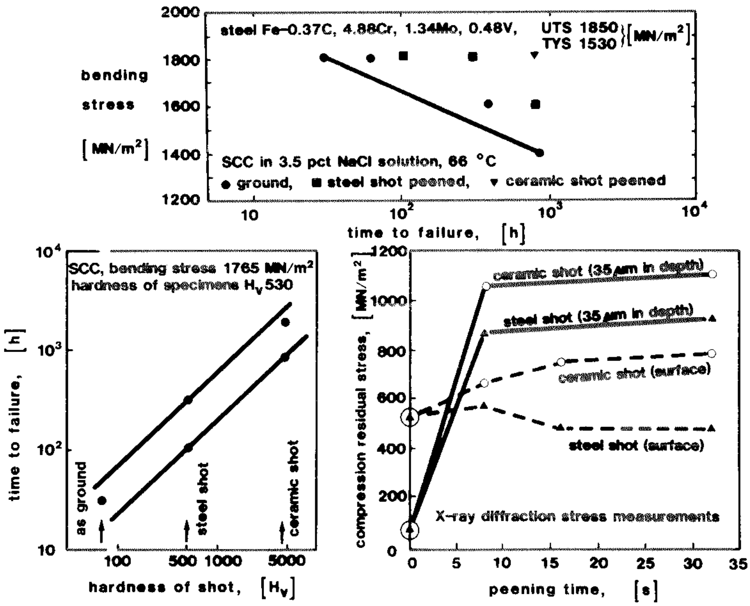

Fig. 3 Effect of shot peening on the stress corrosion resistance of a high-strength low alloy steel. Note that the time to failure depends on the type of shot used and that the residual compressive stress 35 µm below the surface depends on both, the type of shot and on the peening time. Based on data in the work of Sasaki, Shiga and Tan, (1979).

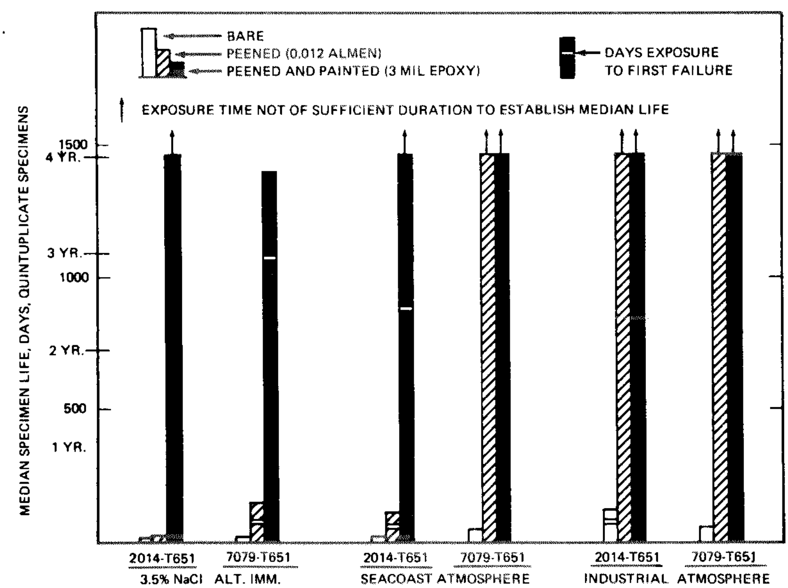

Fig. 4 Protection against SCC afforded by peening and peening plus painting on specimens of two high-strength aluminum alloys (2014 and 7079) stressed in the short transverse direction to 75% of their yield strength. After Lifka and Sprowls (1970).

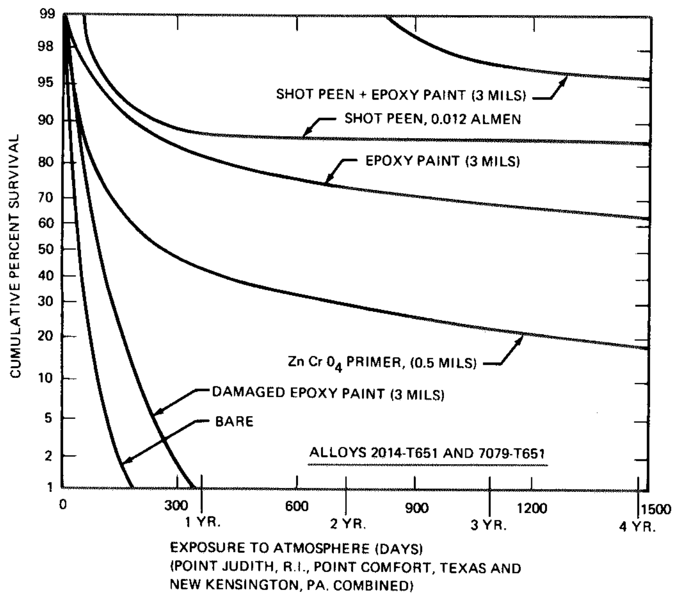

Fig. 5 Stress corrosion cracking of aluminum alloys 2014 and 7079, short transverse specimens stressed to 75% of their yield strength. Note that shot peening plus painting provide better protection than shot peening alone. Based on the work of Lifka and Sprowls (1970)

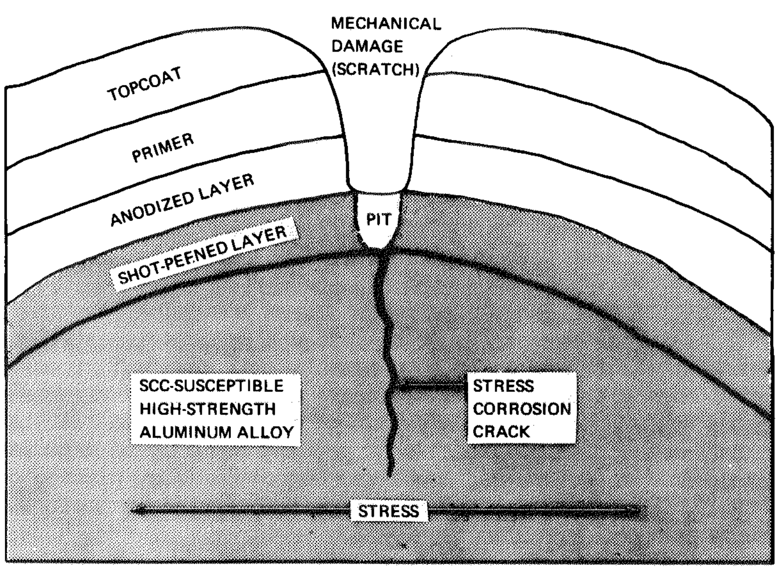

Fig. 6 Schematic representation of a stress corrosion failure resulting from the local breakdown of several protective systems. Obviously, the best defense against SCC is an entirely SCC-resistant alloy, if available.

CORROSION FATIGUE

Corrosion may significantly reduce the fatigue strength of most metallic materials, as indicated in figures 7 through 12. Note in figure 7 the strong reduction of the fatigue strength of a low alloy steel at all mean loads when the environment is changed from air to a concentrated NaCl solution. Each data point in figure 7 represents the end of an S-N curve (Wöhler curve) at 10^8 load cycles. Figure 9 shows the most often (but by no means always!) observed mechanism for the initiation of corrosion fatigue failures in service: the development of corrosion pits and their eventual transformation in corrosion fatigue cracks.

Shot peening may improve the corrosion fatigue resistance, but the degree of improvement depends on the material-environment combination. If localized corrosion is not significant, shot peening may be helpful; if, however, localized corrosion, such as pitting is pronounced, then shot peening is of little or no help in preventing corrosion fatigue. It is for this dominant role of pitting corrosion that the effects of shot peening on corrosion fatigue appear so diverse in figures 9 through 13. Compare for example figures 10, 12, and 13. Figures 10 and 12 relate to 12% chromium steels widely used in steam turbine blades and also as compressor blades in gas turbines. These steels, if tested in oxygenated hot chloride solutions, will develop corrosion pits and therefore, shot peening is of little or no use in improving their corrosion fatigue resistance. In contrast, figure 13 shows that the corrosion fatigue resistance of a slightly higher alloyed stainless steel in a less aggressive environment may be markedly improved by shot peening. The material-environment combination shown in figure 13 is appropriate for water turbine runners.

LIMITS TO THE USEFULNESS OF SHOT PEENING IN PREVENTING STRESS CORROSION CRACKING AND CORROSION FATIGUE

Figures 1, 2, 3, 4, and 5 illustrate the beneficial effect of shot peening on the resistance to stress corrosion cracking while figures 9, 10, 11 and 13 indicate that shot peening may also improve, to a limited degree, the resistance to corrosion fatigue of certain material-environment combinations. In this section we summarize some of the possible difficulties and limitations of shot peening as a stress corrosion cracking or corrosion fatigue preventative.

Since the beneficial effect of shot peening on stress corrosion cracking and corrosion fatigue resides in the surface layer of residual compressive stresses, it is most important not to permit corrosion to penetrate this residual stress layer. This can be attempted either by choosing a sufficiently mild service environment or by surface protection systems or by the selection of fully corrosion resistant materials. The full beneficial effect of shot peening can only be expected if during service neither general corrosion nor localized corrosion (e.g. pitting corrosion) nor crevice corrosion do occur. Some of the major influential parameters on these kinds of corrosion are summarized in figure 16.

A further problem with shot peening may be the formation of untempered martensite in austenitic stainless steels. Such martensite may be much more susceptible to stress corrosion cracking and hydrogen embrittlement than the austenite itself. Thus, before shot peening can be confidently used as a stress corrosion preventative with austenitic stainless steels, careful tests should be run to investigate the possible formation of martensite and its effect on the overall SCC resistance of

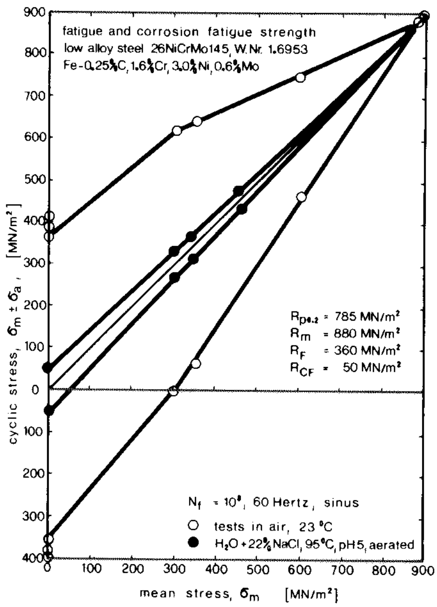

Fig. 7. Effect of the environment and mean stress on the fatigue strength of a low alloy steel.

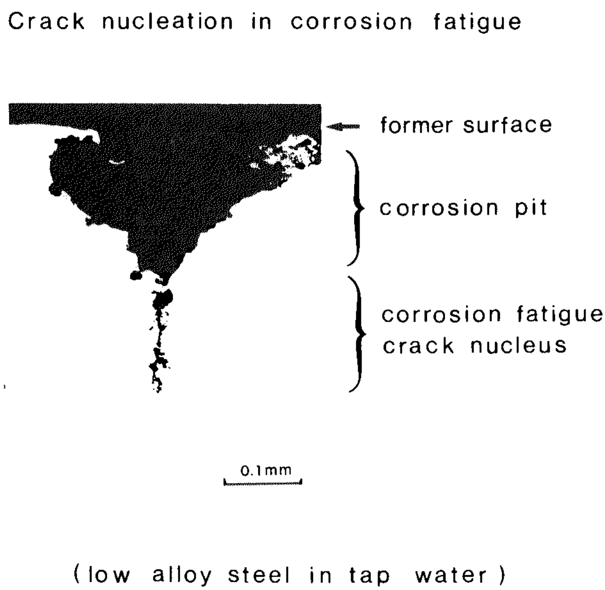

Fig. 8. More often than not, corrosion fatigue service failures are initiated by localized corrosion such as pitting.

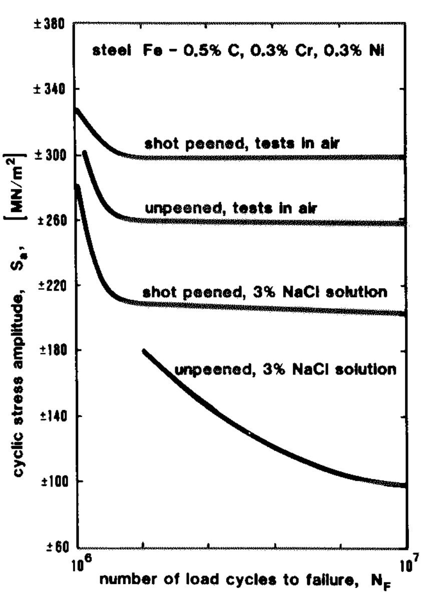

Fig. 9. The apparent beneficial effect of shot peening on the corrosion fatigue resistance of this steel may be less pronounced at higher numbers of load cycles. Data based on the work of Akimov (1956).

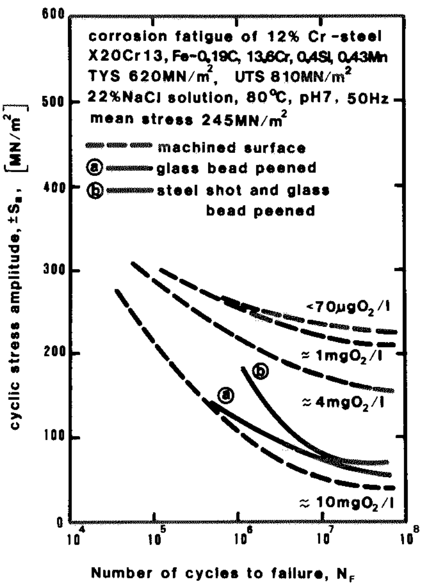

Fig. 10. Effect of shot peening on the corrosion fatigue resistance of 12%-chromium steel. Note that in the highly aggressive, oxygen saturated chloride solution shot peening has only a marginal beneficial effect. Based on data obtained in a cooperative research program by German steam turbine manuf. (1980).

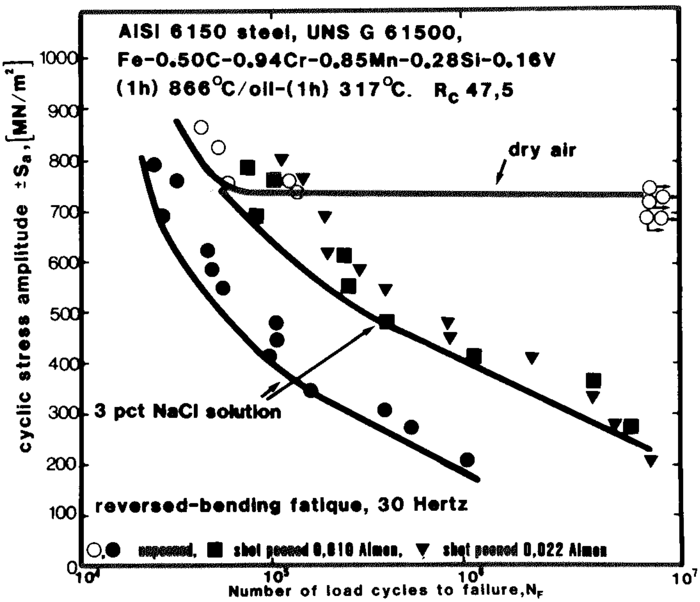

Fig. 11. Effect of shot peening on the corrosion fatigue resistance of a high-strength low-alloy steel. Note that shot peening may increase the number of load cycles to failure, but in no case is a fatigue limit reached. Based on data in the work of Baxa et al. (1978).

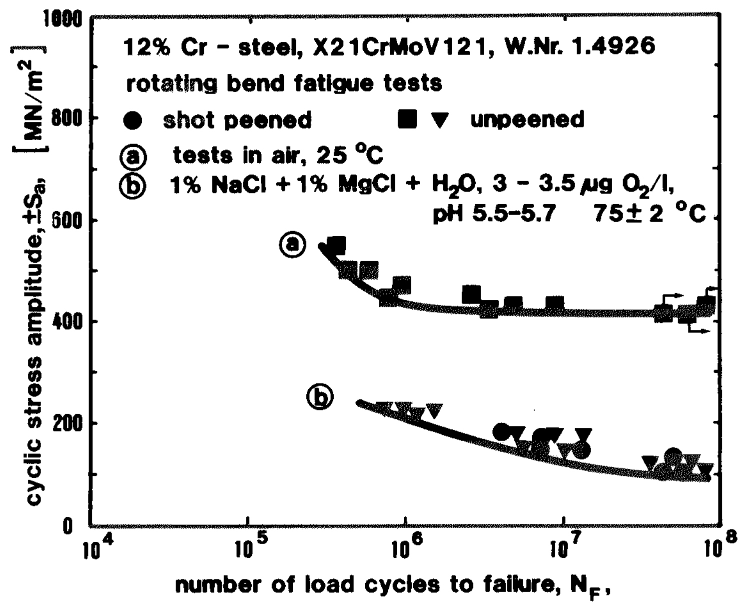

Fig. 12. Shot peening does not measurably improve the corrosion fatigue resistance of 12% chromium steels in hot oxygenated mildly acidic chloride solutions because corrosion penetrates the compressive stress layer. Based on data in the work of Maggi (1981).

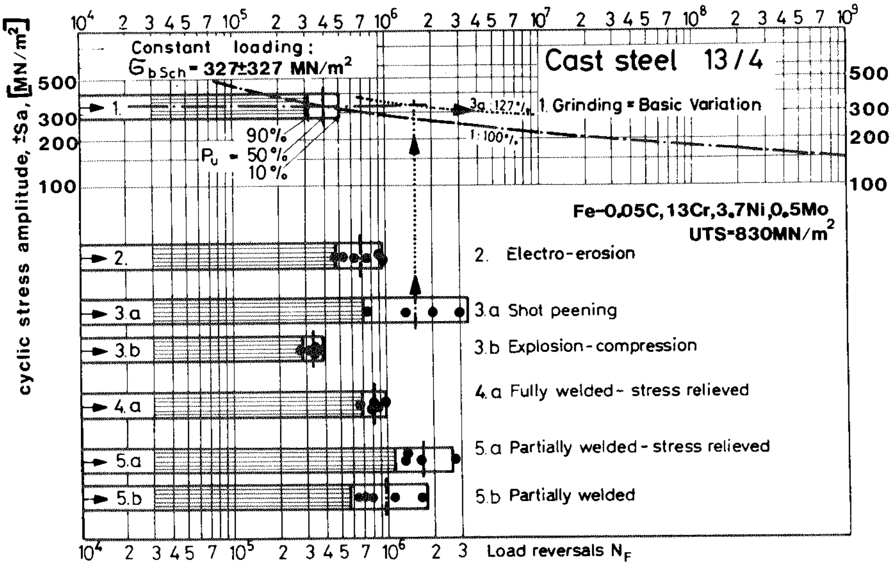

Fig. 13. The corrosion fatigue resistance of a cast stainless steel in water at 20° C is improved by shot peening. Based on the work of Mahnig et al. (1974).

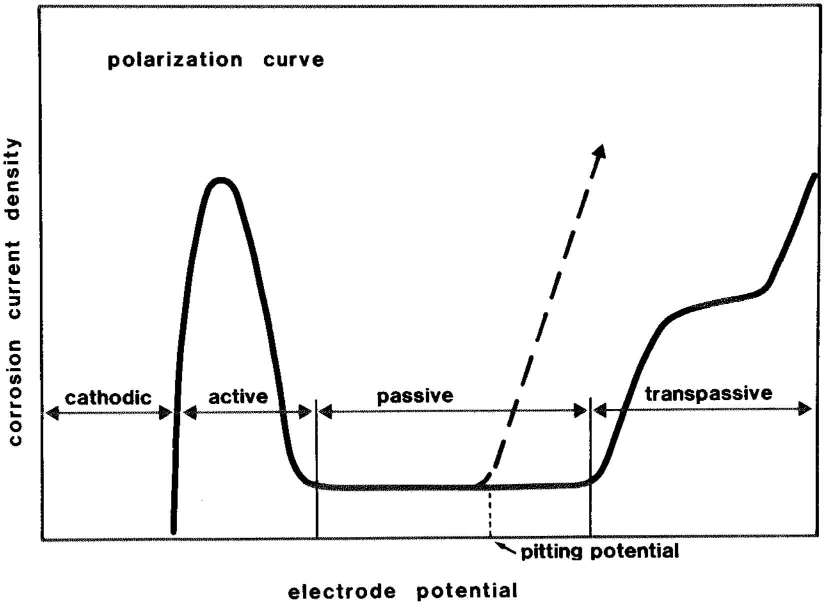

Fig. 14. Pitting corrosion is observed in passivating material-environment combinations if the electrode potential is more positive than the pitting potential.

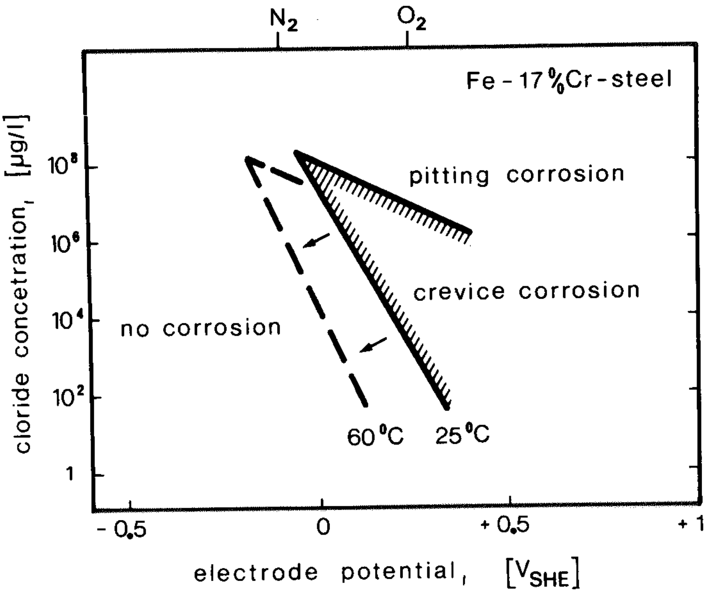

Fig. 15. In addition to the electrode potential, the chloride concentration, the temperature, and the presence of crevices all have a strong influence on the development of localized corrosion which may serve as the mechanism for initiating corrosion fatigue cracks.

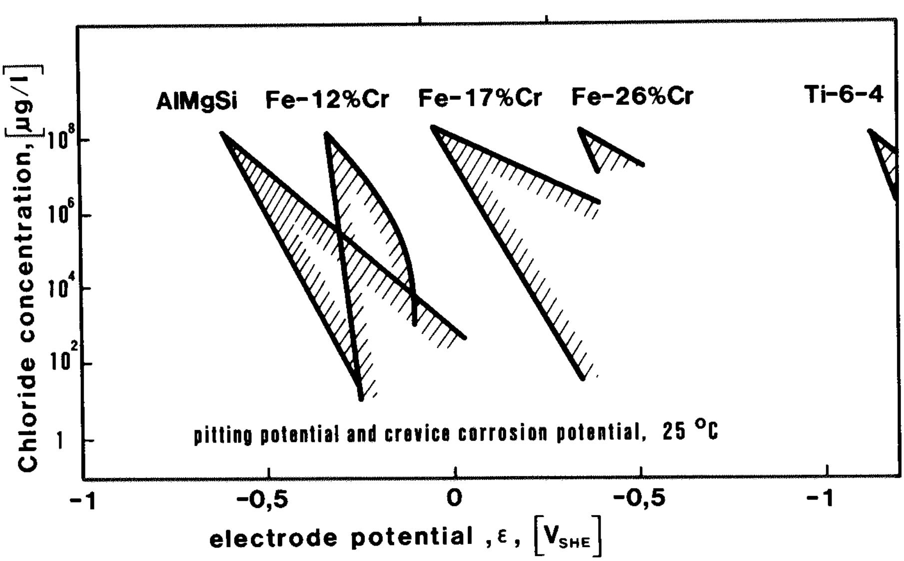

Fig. 16. Steels with extremely high chromium (and molybdenum) contents, as well as titanium alloys are far more resistant to pitting corrosion and crevice corrosion than steels with lower chromium contents or aluminum alloys. In materials fully resistant to localized corrosion, the beneficial effect of shot peening on corrosion fatigue may be greatest.

the shot peened component.

Finally it is important to keep in mind that in stress corrosion cracking and corrosion fatigue, short tests may not be conservative in predicting long service times.

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