

# **A Review on Fatigue Failure in Marine and Naval Applications**

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**ABSTRACT:** Fatigue failure is a progressive damage that occurs in mechanical components due to continuous usage over a period of time. Failures occurring in the members due to the situations of dynamic or alternating loading are called fatigue failures. The damage that can occur due to fatigue can be massive especially in marine and aeronautical applications. The current work, reviews about fatigue failure in marine and naval structures and different factors influencing fatigue life of the same with special focus on corrosion fatigue. The scope of the review also includes the impact of corrosion on fatigue life of marine and naval structures. The scope further includes different types of fatigue failures, fatigue life improvement methods and preventive measures to fatigue failures.

**KEYWORDS:** Fatigue, Corrosion, Low Cycle Fatigue, High Cycle Fatigue, Coating.

## **I. INTRODUCTION**

Material fatigue is a phenomenon where structures fail when exposed to a repeated load. This type of structural damage might even occur when the applied stress range is lower than the static material strength. Fatigue is one of the most basic sources of the reason for failures of mechanical structures.

The process is divided into 3 Phases according to where the component finally fails under continuous loading are as follows:

- The crack formed when the load applied might be transformed from microscopic to the macroscopic level. During many cyclic loads.
- The macroscopic crack grows for each cycle of the load until it reaches a critical length.
- The cracked segment breaks since it can no longer sustain the peak load.

The second stage cannot be seen in certain applications. As the Microscopic crack grows quickly, causing sudden breakage of the component[1].

Fatigue life is a mechanical and scientific term that identifies until what extent the object or material will last before total failing because of concentrated stresses. There are various factors that can impact the fatigue life including the type of materials being utilized, its structure, and its shape and temperature changes.

In general, fatigue is considered as a high cycle when the peak stresses in the material are held within the elastic range while low cycle fatigue occurs when stresses are above the elastic limit. This arbitrary division can be different for material-to-material depending upon tensile properties[2].

When fatigue occurs higher than  $10^3$  cycles, which is in the range of  $10^3$  to  $10^6$  cycles is called a high-cycle fatigue model while the low-cycle fatigue model is in a range of  $10^2$  to  $10^3$  cycles. The stress levels in high-cycle fatigue are in elastic range and vary from very low to a tune of  $2/3$  of yield stress whereas, in low-cycle fatigue model, the stresses applied often fall in the plastic range. [3]

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Fatigue analysis isn't continually dependent on a stress response. This branch, in any case, has historically gotten much consideration since the dominant parts of research has been performed in administrations where stress-based models are suitable. The difference between low-cycle fatigue (LCF) and high cycle fatigue (HCF) can be made depending upon the number of load cycles needed to yield a crack. The limit between the two cycles is not discrete. However, it is typically of the order of 10,000 cycles. The physical method of reasoning in the case of HCF, the stresses are low enough that the stress-strain relation can be considered elastic. When working with HCF, the stress range is typically utilized for describing the local state. In the meantime, for LCF the strain range or dissipated energy are the common choices.

## II. FATIGUE LIFE IMPROVEMENT METHODS

2.1. All the way from beginning to end surface Nano structuring of stainless steel is offered by the surface mechanical attrition treatment (SMAT)

Considerable enhancement of the yield stress and the fatigue limit was achieved through the surface mechanical attrition treatment (SMAT). This also explains that mechanical characteristics after SMAT can be appreciably improved by the use of a short post-annealing treatment. Such annealing treatment is recommended to cause a revival at the grain boundaries leading to a reduction of the internal stress[4].

2.2 Surface enrichment technologies such as shot peening, laser shock peening (LSP), and low plasticity burnishing (LPB) can provide extensive fatigue life improvement.

LPB is a new method of surface enrichment that provides the profound stable surface compressive residual stresses with little cold work for enhanced fatigue, fretting fatigue, and stress corrosion presentation even at prominent temperatures where compression from shot peening relaxes. LPB surface treatment is applied using conventional multi-axis CNC machine tools for extraordinary control of the residual stress division developed through modification of the pressure, feed, and tool characteristics. The resulting deep layer of compressive residual stress has shown to improve high cycle fatigue (HCF) and low cycle fatigue (LCF) performance as well as foreign object damage (FOD) tolerance[5].

## III. FATIGUE FRACTURE OF SHIP STRUCTURES

From recent service experience and history, it is clearly understood that Fatigue and fracture are significant failure modes of ships. To avoid costly repairs and devastating effects, we have to avoid associated failures.

3.1. Fatigue loading

Fatigue generally occurs in coexistence with changing (cyclic) loads and therefore, stresses. Cyclic loads can be further subdivided into three groups depending on their frequency and/or period.

- Loads due to varying loading conditions the fluctuations in cargo-loading conditions and integrated drafts generally cause load variations with rather low frequencies, and also long periods, the latter ranging between hours for ferries and weeks for ships sailing over long distances, and hence resulting in hundreds to thousands of load cycles in the operational lifetime.
- Loads in a seaway: Wave-induced pressures and motion of the ship in the seaway creates cyclic stresses with a relatively low frequency that is usually in the order of 0.1 Hz or periods around 10 s. For an operational lifetime of 25 years, the total number can be between 10<sup>7</sup> and 10<sup>8</sup> load cycles
- Propulsion-induced loads and vibrations: Bigger frequency loads induced by engines and propellers lead to forced vibrations with a large number of load cycles, typically 10<sup>10</sup> or even more. Additionally, wave impacts (slamming) and also small regular waves may excite hull girder vibrations (whipping and springing) in the order of 1 Hz being superimposed to the wave loads mentioned above.[6]

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## IV. CORROSION INHIBITORS IN NAVAL APPLICATIONS

According to Norman E. Hamner, The interpretation of the inhibitor suggested by the National Association of Corrosion Engineers (NACE) is, it is the substance which decreases corrosion rate when added to an environment in small concentrations. It is clearly known that the inhibitors function in one or more ways to control corrosion. Controlling corrosion may be by inducing the formation of a thick corrosion product or by adsorption of a thin film onto the surface of a corroding material or by changing the characteristics of the environment leading to reduced aggressiveness. These operational most of the observed effects and form the standard for experimental work resulting, development and engineering applications of inhibitors.

### Organic Corrosion Inhibitors

H. R. Baker and W. A. Zisman of the Naval Research Laboratory (NRL) published a report on liquid and vapour corrosion inhibitors in 1951. Their work and experiments on polar-type rust inhibitors for steel in non-aqueous fluids showed that both soaps and amine-acid complexes behaved as rust inhibitors in oils by releasing organic acids which had been held by the association. They revealed that the most effective rust-inhibiting additives are those which remain in the oil in the most highly dispersed colloidal condition and which releases those organic acids which are having the greatest ability to stop rusting of steel. According to Balezin every corrosion inhibitor, along with volatile ones, must a) be capable of establishing a stable bond with the metal surface in a given environment till a specific range of acidity and pressure and b) also create an impenetrable layer for corroding ions. Preferential adsorption occurs when an aqueous solution of one of the substituted ammonium nitrites is in contact with a clean iron surface and the resulting film inhibits the water from attacking the ferrous metal at 100°F. The optimum inhibitor concentration at 100o F is found to be 0.01% by weight. As the temperature goes higher, higher inhibitor concentrations would be required. Nevertheless, if uninhibited water comes in contact with the surface of the inhibited steel, it dissolves the adsorbed film allowing corrosion to occur.

### Microencapsulated Inhibitors

The major material problem here is the sudden and catastrophic environmentally related failures of high strength steel and aluminium alloy naval aircraftparts.As the strength of the steel is increased, so as their susceptibility to environmental cracking or fatigue failures. To bring down the corrosion processes associated with fatigue cracking, several experimental studies were carried out at the Naval Air Development Center, Warminster, PA on the feasibility of developing new inhibitors such as quaternary ammonium salts and crown ether complexes, to be applied in the original place for halting the crack propagation. Organic amine chromate salts were also investigated previously as potential inhibitors, and were found out to be generally more effective than the common inorganic primer chromates; but, instability to heat and/or light has prevented their continued development[7].

## V. CORROSION FATIGUE

Corrosion-fatigue is the consequence of the consolidated action of alternating or cycling stresses and a corrosive environment. The fatigue process is believed to cause the fracture to the protective passive film, on which corrosion is accelerated. At the same time, if the metal is exposed to a corrosive environment, the failure can take place at even lower loads and in a shorter time.

The stress level at which a material is believed to have infinite life is reduced or removed completely in a corrosive environment. In contrast to a pure mechanical fatigue, there is no fatigue limit load in corrosion-assisted fatigue. Corrosion fatigue and fretting are both in this class. The alternating stresses, when compared with a non-corrosive environment have much lower failure stresses and much shorter failure times can occur in a corrosive environment.

The fatigue fracture is brittle and the cracks are highly transgranular, as in stress-corrosion cracking, but they are not branched. The picture shown here shows a primary corrosion-fatigue crack that in part has been widened by a secondary corrosion reaction. The corrosive environment can result in a faster crack growth and/or crack growth at a lower tension level than in dry air. Even relatively mild corrosive atmospheres can reduce the fatigue strength of

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aluminium structures considerably, down to 75 to 25% of the fatigue strength in the dry air. No metal is immune to some reduction of its resistance to cyclic stressing if the metal is in a corrosive environment. Limiting of corrosion fatigue can be achieved by either bringing cyclic stresses or by other corrosion control measures[8].

## Corrosion Fatigue Prevention Methods

- Reducing the fatigue by curtailing vibration and pressure fluctuation.
- Reducing the corrosion by deploying high-performance alloys which are resistant to corrosion fatigue.
- Decreasing the corrosion by employing coatings and inhibitors to retard the initiation of corrosion fatigue cracks.
- It can also be averted by zinc coatings.

“An ounce of prevention is worth a pound of cure” so far as corrosion is concerned. A lecture entitled “Fighting Corrosion,” in which the author gave to the Sheffield Metallurgical Association in 1928, concluded with the following words:

“There have never been so many ways of fighting corrosion; there has never been a greater need to employ them to the maximum of our ability.”

The unavoidable increase in the cost of steel and other common alloys of commerce will, in the future, make the retrieval of metal scrap a worldwide routine. In addition, the best rescue campaign for metals is the fighting of the corrosion, which turns steel to rust and changes components to scrap for salvage. Most corrosion products, such as rust and verdigris, are lost to mankind for they are too scattered to be readily recoverable. In reviewing for the purpose of this paper the ways in which corrosion may be fought, he has divided them into three groups, thus:-

### Methods of Fighting Corrosion

1. Surface treatments and coatings.
2. Corrosion resistant metals and alloys.
3. Water treatments and cathodic protection.

An endeavour has been made to produce a useful survey of this complex and important subject in so far as that is possible within the limits of a paper. Those requiring further details are referred to the selected bibliography. We have seen that corrosion is a natural phenomenon under moist conditions, and comparable to the failure of wood by dry rot. In the case where steel is in contact with liquids, as in boilers, pipes, radiators and hydraulic systems, the use of alkali and inhibitors may greatly increase the life of components which would otherwise rapidly corrode. In the other cases where steel is in contact with the normal atmospheres, industrial atmospheres, or even chemical fumes, much can be done by the use of protective coatings.

## VI.SURFACE TREATMENTS AND COATING METHODS OF SURFACE PROTECTION

### 6.1. PLASTIC COATINGS.

### 6.2. GREASES, OILS AND MINERAL JELLIES. (Temporary Preservatives)

### 6.3. VITREOUS ENAMELLED COATINGS.

### 6.4. CEMENT AND CONCRETE COATING

### 6.5. METALLIC COATINGS OF

Aluminium cadmium, chromium, cobalt, copper, gold, lead, nickel, platinum, rhodium, silver, tin, zinc, stainless steel, etc.

Applied by:-

- (a) Cementation.
- (b) Hot-dipping processes
- (c) Electroplating.
- (d) Metal cladding.

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- (e) Metal spraying
- 6.6. CEMICAL COATINGS (Surface Treatments)
  - (a) Aluminium-oxide coatings.
  - (b) Iron-oxide coatings.
  - (c) Phosphate coatings
  - (d) Chromate coatings and selenium.
  - (e). Coloured oxide films.
- 6.7. PAINTS & RELATED PRODUCTS
  - (a) Lacquers.
  - (b) Tars and bitumens.
  - (c) Stoved or baked enamels.
  - (d) Oil paints.
  - (e) Enamels[9].

## VII. EFFECT OF CORROSION ON FATIGUE SERVICE LIFE

- 7.1. Chloride-induced corrosion is a point of big perturb in reinforced concrete (RC) structures. To maintain actual health and to predict the remaining service-life of structures, it is important to understand the structural behaviour and the failure mechanism of structures exposed to chlorides under fatigue loading conditions. The failure mechanisms can be studied by conducting tests one of the tests is a beam test, whereby two RC beam is loaded dynamically and developed to investigate the performance of an RC structure among the first loading and structural failure. Another test is a Parallel rebar test, whereby a plain rebar is loaded dynamically, it focuses on the behaviour of a plain rebar in a chloride environment. The results of both tests showed that corrosion reduces with the maximum number of iterations until failure. Deflections of the beams and elongations of the rebars show a consequential increase which closes to fatigue failure. Another method is the finite element model to simulate the impact of corrosion on the structural performance of a plain rebar. Prefatory calculation results showed that high local stresses close to the damaged interfaces, these high stresses result in local fatigue damage, which can actuate global failure of the structure [10].
- 7.2. The effects of corrosion deterioration on metal structures produces;
- (i) Reduction in the effective cross-sectional area, the moment of inertia, torsional and warping constants. This might alter the overall stiffness of the structures and therefore resulting in the change of stress state in the remaining part of the material/member.
  - (ii) There will be a considerable reduction in the fatigue strength (i.e. degrade the S-N curve in air) can be observed when the interaction of corrosion (i.e. mostly pitting and crevice) and cyclic loading effects the mechanical properties of metal and, therefore, cracks initiate from the corrosion-induced surface (i.e. CF). Ultimately, these may cause a depletion of the fatigue life of metal structures which are subjected to loss of coating, rust or corrosion wastage. The nature of the fatigue strength of corroded metals depends on multiple parameters like types of corrosion, type and state of corrosive environment, rate of corrosion, chemical composition of the metal, etc. Broadly speaking, laboratory fatigue testing of corroded samples is highly popular for simulating the fatigue strength behaviour of corroded materials. Nevertheless, it is clear that testing corroded specimens is a time-taking process, and it is further more complicated to simulate a real corrosion situation in the environment. Based on this reason, a very limited number of experimental studies are found, especially in the field of civil engineering, related to structural steels. Henceforth, there is a definite necessity of simpler models or methodologies to find out the fatigue strength of corroded materials. To support this necessity, the major objective of this review paper is to illustrate/check the various possibilities of suggesting an interpolation formula for the fatigue strength of corroded material.

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## VIII.CONCLUSION

Fatigue failure is a complex phenomenon and there is no straight forward approach to arrive at the fatigue life of a mechanical structure. However, there are some global and local methods like Nominal stress method, Hot spot method, Local stress method, Local strain method etc. to compute the fatigue life of a structure taking all parameters into consideration. Fatigue life of a component can be improved by surface treatments like chemical coatings, metallic coatings, greases, oils and mineral jellies, paints & related products, plastic coatings, cement and concrete coating, vitreous enamelled coatings, Corrosion of a component can degrade the fatigue life of the structure. Hence by reducing the corrosion on the surface, better fatigue life can be achieved.

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