Effect of Prior Corrosion on Fatigue Life of Steel Alloy CK35 Under Constant Loading

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ABSTRACT:

Corrosion is a term defined as oxidation of a metal, which is observed in many parts. A structure is subjected to fatigue loading when a certain load is applied repeatedly. If this structure which was subjected to prior corrosion, under fatigue load, it reaches destruction far faster than that subjected in an inert environment. The aim of this work is to study the effect of the prior corrosion on fatigue behavior of steel alloy CK35 under constant amplitude stress. The NaCl solution used in this investigation is a 3.5wt% mass mixture of sodium chloride (NaCl) salt and distilled water corresponding approximately to the composition of sea water. The samples are immersed in the solutions for 80 days on the solution that replaces every eight days to maintain the concentration of the solution. The results observe that the fatigue life decreases in different percentage at different constant stress amplitude loading. The highest decreasing life factor is in range (9-29.3%) at amplitude stress in range (77- 62% ofσ_y) while the decreasing life factor is in range (68.7-40.2%) at amplitude stress in range (46-31% ofσ_y). Also the experimental results show that prior corrosion for 80 days reduce the fatigue limit of steel alloy CK35 for 13.229%.

Keywords: prior corrosion, fatigue life factor, S-N curve, steel alloy CK35

تأثير التأكل المسبق على عمر الكلال لسبيكة الصلب CK35 تحت حمل ثابت

الخلاصة:

التآكل هو مصطلح يعرف بأنه أكسدة المعدن والذي لوحظ في عدة أجزاء. يخضع الهيكل الى حمل الكلال فيما اذا أستخدم حمل معين بشكل متكرر. إذا كان الهيكل المتعرض الى تأكل مسبق تحت تأثير حمل الكلال فأنه يصل للفشل أسرع بكثير عن ذلك المتعرض في بيئة جافة. ان الهدف من البحث هو دراسة تأثير التآكل المسبق على سلوك الكلال لعينات من سبيكة الصلب CK35 تحت سعة اجهاد ثابت. استخدم في البحث محلول كلوريد الصوديوم بنسبة خلط

وزنية 3.5٪ من كلوريد الصوديوم والماء المقطر المكافئ تقريبا للمياه المالحة حيث غمرت العينات في المحلول المستخدم لمدة 80 يوما على ان يستبدل المحلول كل ثمانية ايام للمحافظة على تركيز المحلول. أظهرت النتائج أن عمر الكلال انخفض بنسب مختلفة بحسب سعة التحميل الثابتة المسلطة على العينات. حيث كان اعلى انخفاض لمعامل عمر الكلال تساوي ما بين (9-29.3٪) من عمر الكلال في بيئة جافة عند نسبة سعة تحميل (77 - 62٪) من اجهاد الخضوع لمادة العينات المستخدمة، في حين كان انخفاض معامل عمر الكلال بنسبة تساوي ما بين (40.2-68.7٪) عند نسبة سعة تحميل (46 - 31٪) من اجهاد الخضوع. كما أظهرت النتائج العملية أن التآكل المسبق لمدة 80 يوم لديه فعالية لتقليل حد الكلال لسبيكة الصلب CK35 بنسبة 13.229 %.

INTRODUCTION:

Many kinds of structures used in marine environments, such as ships, off shore platforms, drilling rigs, harbor works, and underwater pipelines, are made from carbon and alloy steels. Even though such steels are susceptible to corrosion, they are widely used because of their relatively low cost, ease of fabrication, availability, and range of strength levels. Since steels are subjected to corrosive degradation in marine environments, the loss in fatigue resistance due to corrosion must be taken into account in engineering design, or protection from environmental attack must be employed [1]

Chih-Kuang Lin and I-Lon Lan (2004) [2] investigated the influence of environmental factors, including pH, chloride ion, and pitting inhibitor, on the fatigue properties of AISI 347 stainless steel. Systematic fatigue tests, including both high-cycle fatigue (HCF, S-N curves) and fatigue crack growth (FCG, d*a*/d*N*-*K* curves), have been conducted in air and several aqueous environments. Results showed the HCF strength is markedly reduced in an acid solution and in a chloride-containing solution, as compared to the air value.

Moller et al.(2006) [3] studied the corrosion effect of a low carbon steel (SAE 1006) in natural seawater and various synthetic seawaters. It was found that the steel corroded nearly four times faster in a 3.5% solution than in natural sea water. The corrosion rate after immersion in synthetic sea water is similar to the corrosion rate after immersion in natural seawater

Marcelino and Herman (2010) [4] investigated the corrosion behavior on the reverse bending fatigue strength of AISI 4130 steel used in components critical to the flight-safety. The tests were performed on hot-rolled steel plate specimens, with load ratio R =-1, constant amplitude, 30 Hz frequency and room temperature. It was observed that the reverse bending fatigue strength of AISI 4130 steel decreases due to the corrosion.

Kang et al. (2011) [5] analyzed the fatigue crack propagation in high performance steel, HSB800 in air and seawater environments using three-point single-edge notched bending fatigue tests. A 3.5% sodium chloride solution was used as the seawater, and several types of loading conditions, according to the stress ratio and loading frequency, were applied. The results showed that the corrosion fatigue crack in seawater was more rapidly propagated than was that in the air environment.

Jianhua Liu et al (2011) [6] studied the effect of pre-corrosion on fatigue behavior of high strength steel 38CrMoAl with a fatigue test method using the accelerated pre-corrosion specimen in the neutral salt spray environment. Moreover, the fatigue behavior of the steel for different pre-corrosion time is investigated by the axis-direction tensile fatigue test. The fatigue life distribution characteristics of the pre-corrosion specimens are studied using the statistical probability methods, and the mathematical expectations and the standard tolerances of the material fatigue lives after different pre-corrosion time are obtained. It is found that the crack initiation of the high strength steel is accelerated by the preferential corrosion at the local plastic deform areas.

Zhao et al (2012) [7] studied the corrosion fatigue experiments on X80 steel in 3.5% NaCl solution on a researcher-developed cantilever-bending corrosion fatigue testing machine. The morphology of corrosion pits and the change in the surrounding microstructure are carefully examined using SEM and TEM. The results showed that the corrosion fatigue crack initiation is due to not only the corrosion pits' stress concentration effects but also the adhering corrosion products; the action of corrosion products on fatigue crack initiation is explained using physical models.

Mohamed et al (2012) [8] investigated the effects of corrosion of a high mechanical strength martensitic stainless steel that is used in aeronautic applications. HCF tests (between 10^5 and 10^7 cycles) are carried out in two environments: (i) in air and (ii) in an aqueous solution NaCl at a loading frequency of 120 Hz. Surface crack initiation is observed in air, whereas in solution, the crack initiated at corrosion defects. The decrease in fatigue strength due to corrosion is observed to be 33% at 10^7 cycles compared to the same test conditions in air.

S .A .Al-Taher et al (2014) [9] investigated the pitting corrosion behavior of 304 and 316 stainless steel alloys in 3.5% NaCl solution Experiments were performed using potentiodynamic polarization and potentiostatic techniques at room temperature.. The fatigue strength of the pitted samples was determined using plain-bending fatigue test machine. The fracture surface was also investigated using scanning electron microscope (SEM).The results show that SS 304 is more susceptible to pitting corrosion and has lower fatigue strength than SS 316 for the unpitted alloys samples. For both alloys, the single pitted samples shows that a deterioration percentage in fatigue is of about 15% while the multi pitted samples shows a deterioration percentage in fatigue of about 33% compared to the unpitted samples.

The aim of this work is to study the effect of prior corrosion on the fatigue life of steel alloy CK35 under constant amplitude stress.

Experimental work:

The tests for the chemical composition and mechanical properties of the steel alloy CK35 used in this work is carried out at the Specialized Institute for Engineering Industries of the Ministry of industry using spectrum analyses. The experimental chemical composition of steel alloy CK35 with the standard chemical composition is presented in Table (1) while the experimental mechanical properties with the standard values are listed in Table (2).

Table (1): Chemical composition of steel alloy CK35 in wt. %

Element	C	Si	Mn	Ni	S	p	Cr	Cu	As
Standard Values (ASM)	0.32 -0.4	0.17 - 0.37	0.5 -0.8	max 0.3	max 0.04	max 0.035	max 0.25	max 0.3	max 0.08
Experimental Values	0.307	0.26	0.65	0.023	0.018	0.028	0.13	0.015	0.0035

Table (2): Mechanical properties of steel alloy CK35.

Mechanical properties	Yield strength σ_y (MPa)	Ultimate strength (MPa)	Elastic modules (GPa)	Elongation %
Standard Values (ASM)	650	740	206	12
Experimental Values	660	690	200	10

Fatigue Test Specimens Preparation:

24 specimens were prepared according to DIN 50113, 12 specimens (without corrosion) for dry fatigue and 12 specimens for corrosion-fatigue tests. Figure (1) shows the configuration of fatigue test specimen. The surface of the specimen is smoothed by using silicon carbide papers for finishing.

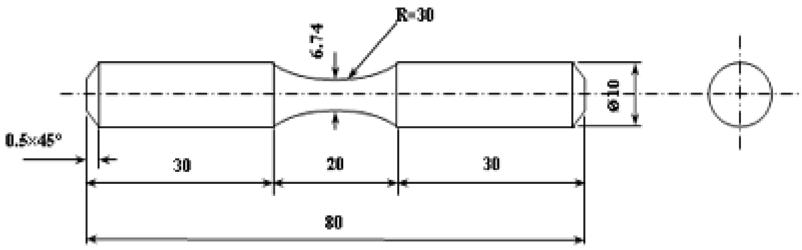


Figure (1): Specimen geometry and dimensions for fatigue test (all dimensions in mm)

Immersion:

The NaCl solution used in this investigation is a 3.5wt% sodium chloride (NaCl) salt and distilled water corresponding approximately to the composition of sea water.

The immersion are performed in continuously aerated solutions using three specimens per solution. The volume of the solution is 2000 ml. The specimens are immersed in the solutions for 80 days. The water in the test cells is refreshed every 8 days to maintain the concentration of the solution.

Fatigue Tests Procedure:

All fatigue tests were carried out in the laboratories of electromechanical engineering department, University of Technology using PUNN rotary fatigue bending machine for more information see reference [10]. The experiments are conducted at room temperature and at stress ratio R=-1. The stress ratio represents the minimum stress to the maximum stress in each cycle.

Results and Discussion:

Specimens without and with corrosion were tested at constant stress amplitude with (-1) stress ratio at room temperature to find the effect of corrosion on the experimental fatigue life and to evaluate the corrosion fatigue life factor .The experimental results are given in Tables (3 and 4) The S-N curve was obtained from these results as shown in figure (3). The equation of power law regression is given by [11]:

$$\sigma = aN^b \qquad \text{..... (1)}$$

Where

(σ) is the applied stress, and (a),(b) are the fitting parameters. The regression constants representative of the fatigue trends, from the model, and the fatigue endurance limit at 10^7 cycles are given in Table (5).

Table (3): basic S-N fatigue results (dry fatigue) at room temperature (RT)

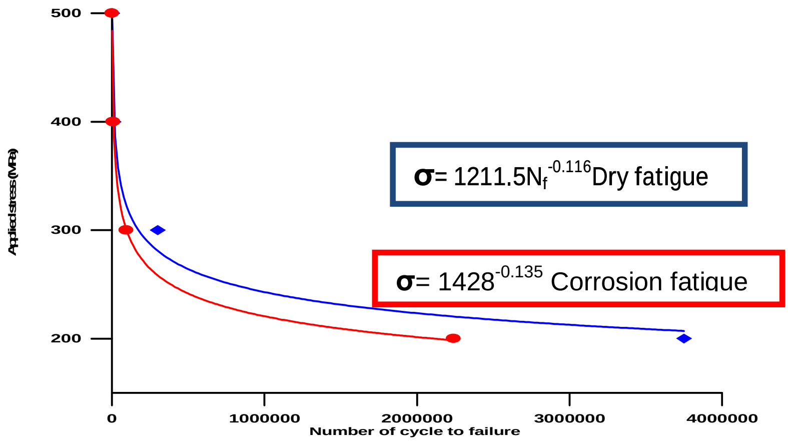
Specimen No.	Amplitude stress (MPa)	N_f(Cycles) Average
1,2,3	0.77 σ_y	2750
4,5,6	0.62 σ_y	11317
7,8,9	0.46 σ_y	300500
10,11,12	0.31 σ_y	3750000

Table (4): constant stress Fatigue-corrosion interaction results at (RT)

Specimen No.	Amplitude stress (MPa)	N_{fc}(Cycles) Average
13,14,15	0.77 σ_y	2500
16,17,18	0.62 σ_y	8000
19,20,21	0.46 σ_y	94000
22,23,24	0.31 σ_y	2240000

Table (5) Fatigue parameters and fatigue strength for low carbon steel alloy.

Description	a	b	Fatigue strength at 10^7 cycles (MPa)	Reduction in Fatigue strength%
without corrosion	1211.5	-0.116	186.7	-
with corrosion	1428	-0.135	162	13.229



Number of cycles to failure (N_f)

Figure (3): (S-N) curve of dry fatigue and corrosion fatigue for steel alloy CK35 at room temperature.

Corrosion- fatigue life factor (CFLF %):

It can be observed that the effect of pre corrosion on fatigue behavior, by estimating the decreasing corrosion- fatigue life factor (CFLF %) at different amplitude stress. Table (6) shows Corrosion- fatigue life factor (CFLF %) at different amplitude stress by using equation (2).[12]

$$CFLF \quad \% \ = \frac{N_{f_D} - N_{f_C}}{N_{f_D}} \times 100 \quad ....(2)$$

Where

(N_{fD}) and (N_{fc}) is the dry and the corrosion fatigue life respectively. The results show the effect of pre-corrosion on fatigue life of specimens under low loads tests have more reduction as under (0.46 and 0.31 ofσ_y) MPa tests than high loads tests as under (0.77 and 0.62 ofσ_y)MPa. This reduction in fatigue life because the pitting which caused by pre-corrosion on the surface of the specimens accelerate the crack initiation of fatigue cracks and it clearly shows when the test loads under low loading tests.

Table (6): The Corrosion-fatigue life factor (CFLF) at different amplitude stress.

Amplitude stress MPa	Average N_{fD} (Dry-Fatigue)	Average N_{fc} corrosion -Fatigue	Corrosion- fatigue life factor (CFLF)
0.77 σ_y	2750	2500	9%
0.62 σ_y	11317	8000	29.3%
0.46 σ_y	300500	94000	68.7%
0.31 σ_y	3750000	2240000	40.2%

Scanning Electron micrograph (SEM):

Scanning Electron micrograph (SEM) has also have been used in order to observe the damage in the steel alloy CK35. The examined for dry fatigue and pre corrosion-fatigue samples have been done at the Center of Nano technology and advanced materials at the University of Technology. The surface morphology of pre-corroded specimens differed substantially from surface morphology of dry specimens without corrosion condition. Figure (3) show a typical micrograph of what is observed ductile fatigue fracture for steel alloy CK35 under dry fatigue test, while Figure (4) show a typical micrograph of what is observed fatigue ductile fracture with incidents of brittle cleavage facets which indicates some brittleness brought by prior corrosion for examination of the specimen surfaces of the pre corrosion-fatigue test for steel alloy CK35. This finding is agreement for decreasing of fatigue life for prior corrosion specimens.

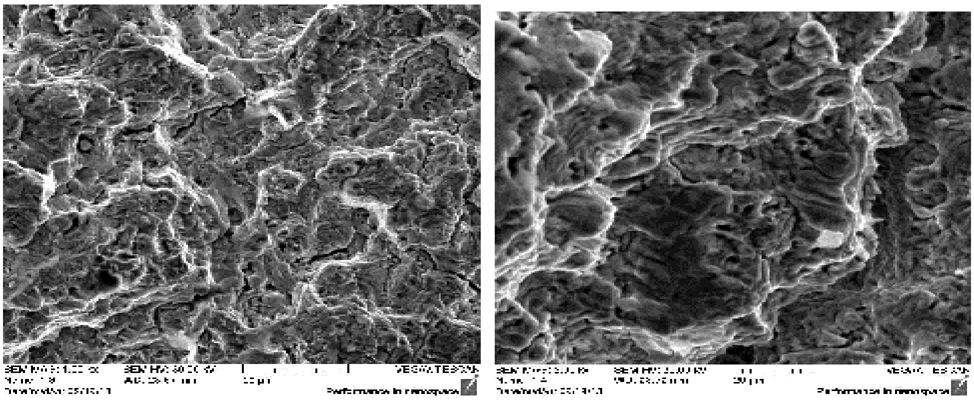


Figure (3) shows a typical ductile fatigue fracture micrograph for steel alloy CK35

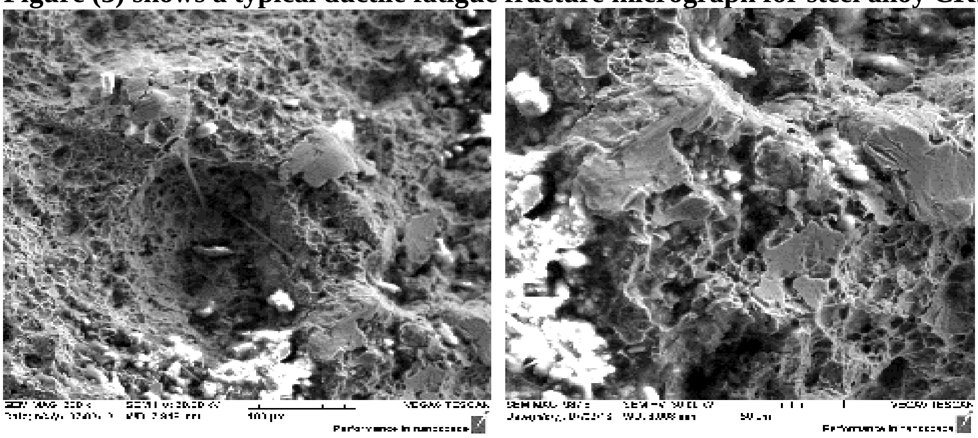


Figure (4): show micrograph of fracture surface morphology of the specimen surfaces of the pre corrosion-fatigue test for steel alloy CK35.

CONCLUSIONS

The results show effect of prior corrosion for steel alloy CK35 with NaCl solution used in this investigation on fatigue life with as;

1.Fatigue life of corroded specimens is greatly decreased especially at high stresses for 80 days submerging in 3.5% NaCl. The decreasing of Corrosion- fatigue life factor (CFLF) is in range (9-29.3%) and (68.7-40.2%) at constant stress amplitude loading in range (62-77% ofσ_y) and (31- 46% ofσ_y) respectively.
2.The reduction in fatigue strength is 13.229% by pre-corrosion for 80 days for material used in this work.
3.Scanning Electron micrograph (SEM) results shows fatigue ductile fracture with incidents of brittle cleavage facets which indicates some brittleness brought by prior corrosion.

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