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Study the Effect of Nickel Coating on Fatigue Life of Low Carbon Steel Exposed to Corrosive Environments

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Abstract
Nickel electroplating on low carbon steel are widely used in many industrial application due to its benefit in improving corrosion fatigue life, increasing coating thickness provide good protection against corrosion but in other hand reduce fatigue life in addition to its high cost so applying a relatively thin layer of the electroplated nickel may give an acceptable corrosion protection in low cost. In this paper the effect of relatively thin layer (6 μ m) electroplated nickel deposited by Watts type bath on the corrosion fatigue life of low carbon steel specimens exposed to lab air and 3% NaCl solution as a corrosive environments was studied. Five groups of standard low carbon steel specimens were prepared for fatigue tests, Mechanical grinding was done for the all45 test specimens and after that Nickel electroplating coating was carried out to 18 specimens and mechanical polishing performed on the remaining 27specimens. Fatigue tests were carried out in air for nine specimens immediately after polishing and the remaining specimens were tested after exposing to lab air and 3% NaCl solution as corrosive environments for a period of 30 day using a reverse bending fatigue machine. Results indicate that fatigue life of relatively thin layer Nickel electroplated specimens was shorter by 4% than that of the uncoated mechanical polished specimens immediately tested in air and not exposed to corrosive environments, but it's corrosion fatigue life was higher by 11.46%than that of polished specimens when both exposed to lab air for 30 day and by 21.68% higher when both exposed to 3% NaCl solution for 30 day , this study indicate that relatively thin layer (6 μ m) Nickel electroplating decrease fatigue live of low carbon steel specimens exposed to un corrosive environment, but it improved corrosion fatigue life of low carbon steel specimens exposed to cyclic load and corrosive environment.
Keywords: Nickel Plating; surface treatment; fatigue life; corrosion fatigue.

1. Introduction

In many industrial applications there are a large number of equipments, like pumps, fans, blowers, compressors, mixers, steam and gas turbines work in dry or wet corrosive environments, some components of these equipments such as blades subjected to repeated load failed faster than when it work in a non corrosive environments. Combination of corrosion and fatigue may cause the rapid failure of these components. When corrosion protection break down the pitting corrosion occurs, pitting corrosion reduce fatigue life. Corrosion fatigue due to corrosive environment is very important and more severe and cause an increase in maintenance costs in addition to equipments failure, so good resistance to fatigue with good corrosion protection is required [1,2,3, 4,12].

Many methods are used to protect steel parts from corrosion fatigue such as changing stress of metal surface by shot penning, surface rolling, or adding inhibitors to the wet environment or coating by organic or inorganic materials [5]. Electroplating is used as a coating method to protect steel parts from corrosion. Electroplating generally reduce fatigue life of steel parts due to the initiation of micro cracks in the coating which then penetrate through the substrate[6,7].

Nickel electroplated on low carbon steel are widely used in many industrial application due to its benefit in improving corrosion fatigue life, increasing coating thickness provide good protection against corrosion but in other hand reduce fatigue life in addition to its high cost[8], so applying a relatively thin layer of the electroplated nickel may give an acceptable corrosion protection in low cost[6], influence of fatigue lives of low carbon steel by the coating have been explained by many research studies ,however studies on corrosion fatigue behavior of electroplated Nickel and its alloys on carbon steel are limited [1,13].

Some authors like Sunada H., (1966)[9], studied the effect of thin(100 μ m) Nickel plating deposited by Watts type bath on fatigue strength of carbon steel in air environment he found that the increase in plating thickness lower the fatigue limit.

S. J. Lennon, et al (1988)[8], studied the effect of thick (300 μ m) nickel coating deposited by sulphamate bath on the mechanical and fatigue properties of a turbine-disc steel, they concluded that thick coating decrease fatigue life of carbon steel .

T. A. Khalifa (1989)[6], studied the effect relatively thin electroplated Nickel (5.9 µm) coating with relatively thin layer (3.1) of copper undercoat on the fatigue behavior of carbon steel in dry air environment, he reported that the electroplating did not cause any change in the fatigue limit.

Cheng-Hsun Hsu et al, (2004)[2], studied the effect of thickness of electroless Ni-Plated deposit on corrosion fatigue of 7075-T6 Al-alloy, after salt spray corrosion 100,500, and 1000 hr, they reported that the optimum coating thickness was greater than 5 µm and less than 25µm.

Cabrera et al (2006)[10], studied the effect of electroless nickel plated on 7075-T6 aluminum alloy on the corrosion fatigue of these components in 3% NaCl solution as corrosive environment, they reported that electroless nickel increased corrosion fatigue life by 60-70% in low cycle fatigue region of 104-105 cycle.

Sotomi Ishihara, et al[11], performed fatigue tests in laboratory air and3% NaCl solution on Mg alloy AZ31 plated with electroplated Ni, they concluded that The corrosion fatigue life of Ni-plated alloy in 3%NaCl solution was the same as those in laboratory air, which is mean the effectiveness of Ni-plating to protect Mg alloy from corrosion fatigue.

In this study fatigue tests were carried out on low carbon steel specimens polished and electro-plated by a thin layer (6µm)of Nickel using watts type bath. A group of polished specimens were tested in air directly after polishing to be the base point, the tests for both type were done in air after 700 hr (30 day) exposure to laboratory air and 3% NaCl solution as a corrosion environment. All the results were compared with the mechanical polished specimens which tested in air directly after polishing. Test results are reproduced in the figures and tables.

2. Materials

The low carbon steels used in this study has a chemical compositions as supplied by the manufacturer are shown in Table 1.

Table 1 chemical composition (wt%)

wt%	C %	Si %	Mn %	P %	S %	Cr %	Ni %	Mo %
Alloy steel	< 0.2	0.26	<0.9	0.01	0.03	<1.3	0.11	0.01

3. Specimens preparation

Forty five specimenswere prepared from these materials to perform bending fatigue tests, cutting and grinding machine were used to do this job,specimens dimensionsare shown in Figure(1). These samples tempered at 400oC for one hour.

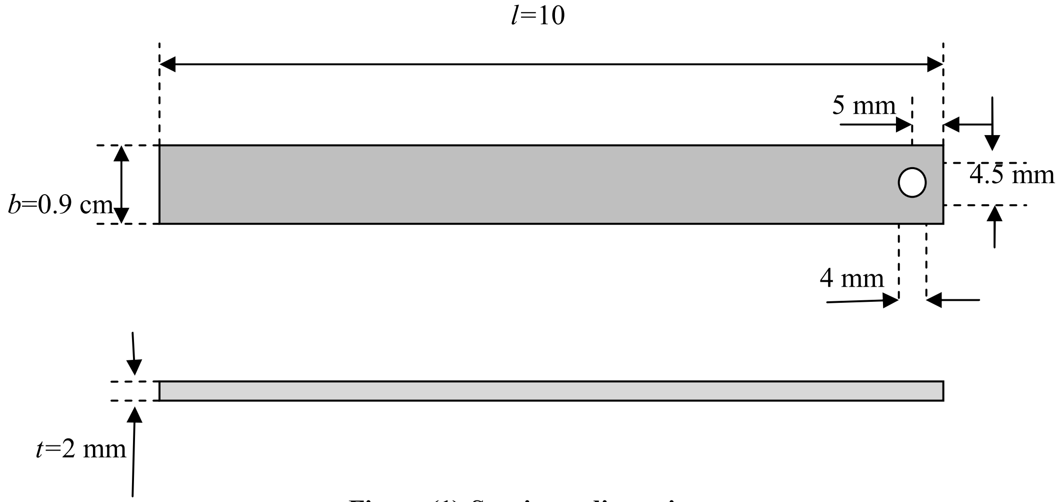


Figure (1):Specimen dimensions

All specimens were mechanical grinded by grinding machine , smoothed using silicon carbide papers (60, 80 , 180 , 400 , 800) and then cleaned by distilled water followed by alcohol

Eighteen from the above specimens were nickel electroplated by Watts type bath containing : 200 g/LNiso4, 50 g/L Mgso4, 70 g/L Na2so4, 30 g/L H3BO3, and 5 g/L NaCl at temperature 25 ^{0}C , current density 1.5 A /dm2, PH = 5 , and 20 minute electroplating time to get 6 µm of nickel coating .

Before electroplating the specimens were degreased in alcohol and in alkaline solution and then pickled in HCl solution. After electroplating the samples washed with distilled water, dried at room temperature for 24 hours to avoid hydrogen embrittlement.

The remaining 27 specimens mechanical polished using two types of alumina (0.5 micron and 0.3 micron) Then cleaned by distilled water and by alcohol.

4. Fatigue test

Five groups of standard low carbon steel specimens were prepared for fatigue tests. Fatigue tests were carried out in air for nine specimens immediately after polishing and the remaining specimens were tested after exposing to lab air at 3% NaCl solution as corrosive environment for a period of 30 day using a reverse bending fatigue machine, with a maximum capacity of 800 N/mm2, a maximum speed of 6000rpm and a stress ratio of R= -1.All the tests were performed at room temperature. The specimens were subjected to an applied load from the right side perpendicular to the axis of specimen and hence a bending moment was developed. Therefore, the surface of the specimen was under succession tension and compression stress. The value of the bending stress (σb), measured in (N/mm2), for a known value of deflection (δ), measured in millimeter (mm) was calculated from the relation[4].

The applied load (P) was calculated by using eq. (4 – 3) from the deflection which set from the test machine.

$$p = \frac{\delta \times E \times b \times t^3}{4 \times l^3} ------------------------(4-3)$$

By substitute the value of P in eq. (4 – 4) then σ_b can be determined from the formula

$$\sigma_b = \frac{6 \times l \times p}{b \times t^2} ------------------------(4-4)$$

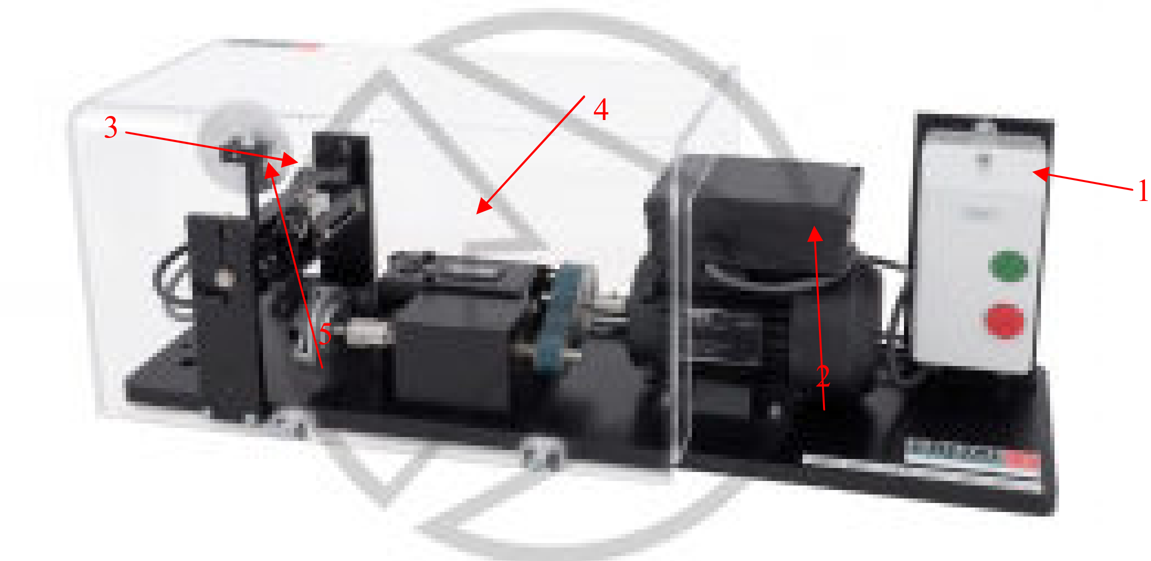
Where:

σb: applied stress (MPa) , l= length of the specimen(mm)

b= width of the specimen (mm)

t= thickness of the specimen (mm)

p= applied load (N), δ= applied deflection (mm)



5. Results and discussion

Fig.(1) shows the stress- cycle (S-N) curves of polished specimens measured directly after polishing and after exposing to laboratory air environment for 30 day (700hr) period .The black line is the curve of the specimens tested directly after polishing and blue line is the curve of the specimens tested after 30 day. As can be seen from the figure the corrosion fatigue life of that exposed to 30 day to lab air decreased compared with that measured directly after polishing due to the effect of the corrosion that occurred on the surface of the specimen and then a micro cracks initiated from the corroded area and then propagate through the specimens substrate which lead to failure. Also the figure show that the fatigues limit is 200 MPa for the directly tested specimens and 170 MPa for the specimens which tested after 30 days in air.

Fig.(2) shows the comparison of fatigue carves of polished specimens in laboratory air and in 3% NaCl solution environment after 700 hr exposure, these curves indicate that the fatigue life for specimen exposed to 3% NaCl solution for 700 hr was lower (145 MPa) than that in air (170 MPa) because in air fatigue cracks initiated at the whole surface and in3% NaCl solution fatigue cracks initiated at corrosion pits which were the cause of the large decrease in fatigue life relative to air[11].

Comparison of fatigue curves shown in Figure (3) indicated that fatigue life of nickel coated specimen (192 MPa) was lower by 4% than that of the directly tested polished specimen (200 MPa), Tensile residual stresses, micro sharp cracks in coating acts as a stress raiser for the substrate resulting the initiation and propagation of fatigue cracks leading to the decreasing in fatigue life and steel failure [8].

Comparison of fatigue curves between polished specimens and nickel electroplated specimens shown in fig.(4) indicated the effect of Ni-electroplating on corrosion fatigue life of low carbon steel exposed 30 day to laboratory air environment ,fatigue life of nickel electroplated specimens (192 MPa) were higher by 11.46% than that of polished one (170 MPa). In corrosive air environment nickel electroplated layer protect low carbon steel surface from corrosion.

Fig.(5) shows the S-N curves of Ni-electroplated carbon steel after 30 day exposure to lab air (192 MPa) and 3% NaCl solution (190 MPa), these curves indicated that there was no effect of the corrosive environment was found since the fatigue life of them approximately was the same due to the protection effect of the coating .

Fig.(6) shows the S-N curves of Ni-electroplated carbon steel samples and polished samples both exposed 30 day to 3% NaCl solution as corrosive environment, it indicated that the corrosion fatigue life of Ni-electroplated steel (190 MPa) was higher than polished one (145 MPa) by 21.68% , this clearly certify the effectiveness of Ni-electroplating to protect low carbon steel from corrosion fatigue.

Table (1) Fatigue test data of uncoated mechanical polished specimens immediately tested

Stress amplitude (MPa)	Number of cycles to failure
400	134824
300	436712
290	1742555
280	2746746
250	3246746
210	4114551
200	9534567
187	unfailed
156	unfailed

Table (2) fatigue tests of uncoated polished specimens tested after 30 day in lab. air.

Stress amplitude (MPa)	Number of cycles to failure
400	134824
300	436712
270	2485103
240	2993176
200	4791764
180	6019572
170	10534877
185	unfailed
156	unfailed

Table (3) fatigue tests of un coated mechanical polished specimens tested after 30 day in (3% NaCl solution)

Stress amplitude (MPa)	Number of cycles to failure
400	59086
300	273981
270	1836520
240	2295164
200	3758320
170	5325956
145	10000000
140	unfailed
135	unfailed

Table (4) Fatigue test data of nickel plated steel specimens tested after 30 day in lab. air

Stress amplitude (MPa)	Number of cycles to failure
400	115674
300	428987
280	2581621
250	3173682
230	3564329
210	3954325
192	9743105
165	unfailed
180	unfailed

Table (5) shows the data of fatigue tests of nickel plated steel specimens testedafter 30 day in(3% NaCl solution)

Stress amplitude (MPa)	**Number of cycles to failure**
400	**108643**
300	**411876**
280	**2480966**
250	**3007764**
230	**3534278**
210	**3912356**
190	**10000000**
185	**unfailed**
180	**unfailed**

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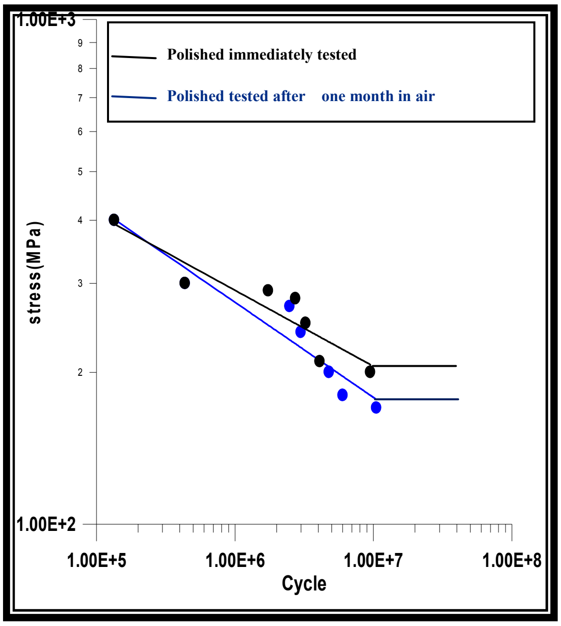
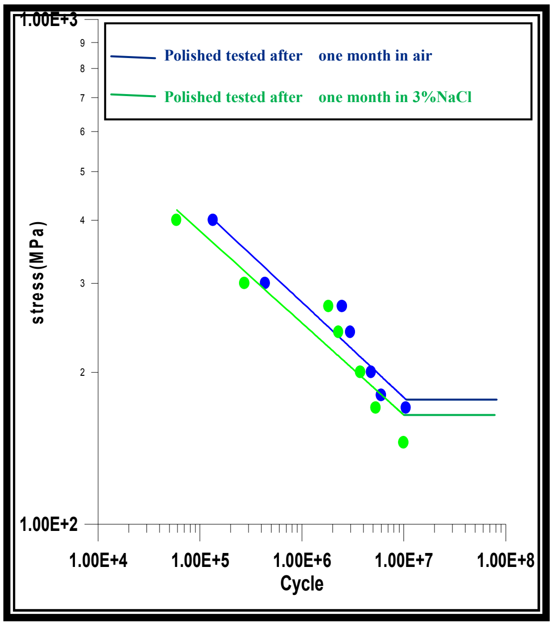


$\sigma_b = 2332.463 * Nf^{-(0.15072)}$

$\sigma_b = 3724.843 * Nf^{-(0.188565)}$

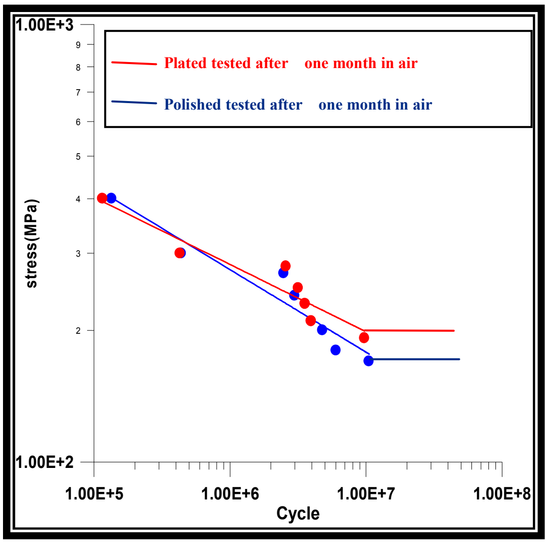
Figure: (1) S.N curve of polished specimens tested directly after polishing and of that exposed 30 day to laboratory air environment



$\sigma_b = 3724.843 * Nf^{-(0.188565)}$

$\sigma_b = 3103.76 * Nf^{-(0.182208)}$

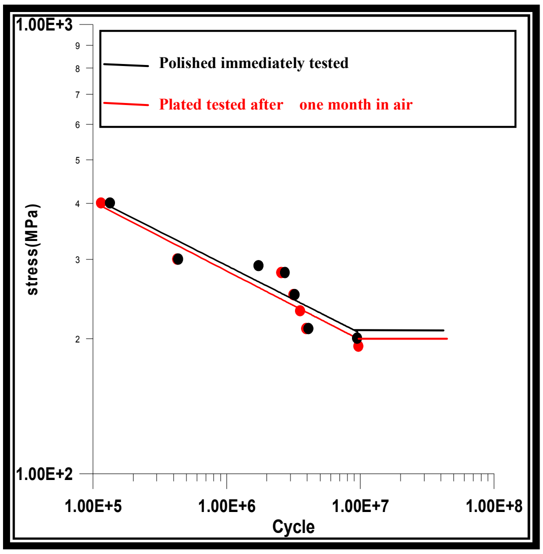
Figure: (2) S.N carves of polished specimens in laboratory air and in 3% NaCl solution environment after 30 day exposure



$\sigma_b = 2361.069 * Nf^{-(0.153616)}$

$\sigma_b = 3724.843 * Nf^{-(0.188565)}$

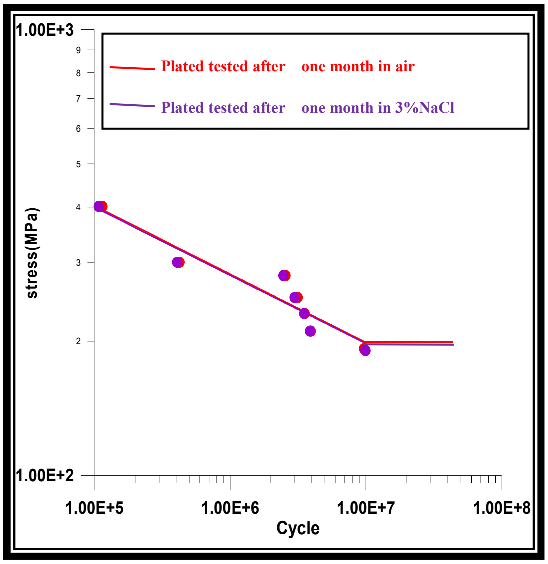
Figure: (4) S.N carves of polished specimens and Nickel plated specimens in air environment after 30 day exposure



$\sigma_b = 2332.463 * Nf^{-(0.15072)}$

$\sigma_b = 2361.069 * Nf^{-(0.153616)}$

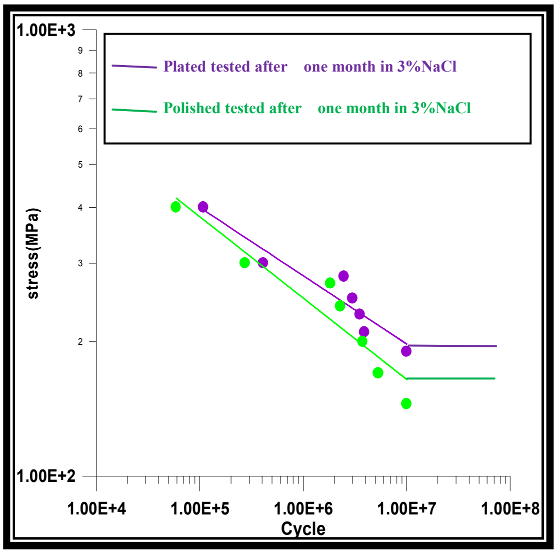
Figure: (3) S.N carves of plated specimens in laboratory air and polished specimens directly tested.



$\sigma_b = 2361.069 * Nf^{-(0.153616)}$

$\sigma_b = 2281.024 * Nf^{-(0.153002)}$

Figure: (5) S.N carves of plated specimens in laboratory air and in 3% NaCl solution environment after 30 day exposure



$\sigma_b = 2281.024 * Nf^{-(0.153002)}$

$\sigma_b = 3103.76 * Nf^{-(0.182208)}$

Figure: (6) S.N carves of polished specimens and plated specimens in 3% NaCl solution environment after 30 day exposure

6. Conclusions

Mechanical polished low carbon steel specimens gave good fatigue resistance due to the compressive stress gained by polishing process.

Mechanical polished low carbon steel behavior showed low corrosion fatigue life in laboratory air and in 3% NaCl solution.

Nickel electroplating in non corrosive environment reduced the fatigue life of low carbon steel specimens by 4% due to the tensile residual stress and micro cracks contained in the coating.

In this work 6 µ m layer of electroplated Nickel improved fatigue life of low carbon steel specimen in corrosive environment and exposed to cyclic load in laboratory air by 11.56 % and in 3% NaCl solution by 21.68%.

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