

ARAŞTIRMA MAKALESİ

THE EFFECT OF NITRIDING ON EROSION CORROSION CREATED BY PARTICLE DEPOSITION IN TURBULENT FLOWS

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ABSTRACT

In Turbulent Flows which contain very small particles ($< 0,1\mu\text{m}$) erosion corrosion occurs as a result of particle deposition on surfaces. Fluid velocity, turbulence and deposition are main parameters on the erosion corrosion. This type of erosion can be seen in every equipment exposed to moving fluids. The particle deposition and corrosion rates depend on the particle concentration, particle diameter, fluid temperature and the nature of particles and environment.

In this study a diffusion controlled deposition model has been used to evaluate the effect of nitriding on particle deposition and erosion corrosion on metal surfaces. The comparisons between the deposition rates of nitrided and unnitrided low-alloyed steels are made and the effects of important parameters on erosion corrosion are investigated.

TÜRBÜLANSLI AKIŞLARDA PARTİKÜL BİRİKMESİ SONUCUNDA MEYDANA GELEN EROZYON KOROZYONUNA NİTRASYONUN ETKİLERİ

ÖZET

Çok küçük partiküller ($< 0,1\ \mu\text{m}$) içeren bir akışkanın türbülanslı akışında yüzeyler üzerinde partikül birikmesi sonucunda erozyon korozyonu meydana gelmektedir. Akışkan akış hızı, türbülans ve depozitler (birikmiş parça) erozyon korozyonunda temel parametrelerdir. Bu tip korozyon akışkan akışına maruz her çeşit ekipmanda görülmektedir. Partikül birikmesi ve korozyon hızı, partikül konsantrasyonu, partikül çapı, akışkan sıcaklığı, partikül ve ortamın özelliklerine bağlıdır.

Bu çalışmada, metal yüzeyler üzerindeki erozyon korozyonu ve partikül birikmesine nitrasyonun etkileri, difüzyon kontrollü birikme modeli kullanılarak araştırılmıştır. Nitrasyon işlemi uygulanan ve uygulanmayan düşük alaşımlı çeliklerde partikül birikmesi ve erozyon korozyonundaki önemli parametrelerin etkileri mükayeseli olarak incelenmiştir.

1. INTRODUCTION

Erosion corrosion is the acceleration or increase in rate of deterioration or attach on a metal because of relative movement between a corrosive film and the metal surface. Generally this movement is quite rapid and mechanical wear effects or abrasion are

involved. Metal is removed from the surface as dissolved ions or it forms solid corrosion products that are mechanically swept from the surface.

Many types of corrosive mediums could cause erosion corrosion. These include gases, aqueous solutions, organic systems, and liquid metals. Lochman and Howell [1] discuss erosion corrosion on valves and gas turbine blades created by dirty gases.

In two phase turbulent flows, small solids in suspension in liquids deposit on metal surface. Electro - chemical erosion starts as a result of different electrode potential of deposit particles and metal surface. The erosion corrosion is characterized in appearance by grooves, gullies, waves, rounded holes, and valleys and usually exhibits in a directional pattern [2].

Several studies on various superficial thermo-chemical treatments in particular nitriding and nitrocarburizing, have been carried out., but the mechanical properties of these alloys to corrosion has received considerably less attention. Some of observed benefits of nitriding have been increased fatigue and wear resistance. Limited testing by industry has indicated some improvement in the corrosion resistance of certain types of steels. Much of the research on corrosion resistance of nitrided steels were run under static conditions and erosion effects were not considered.

Varhoshkov and Sedloev [3] reports that corrosion resistance of nitrided low-alloy steels in aerated solutions of NaCl and H₂SO₄ is better than untreated steels. Buharev and Lakhtin [4] showed that high- temperature nitriding and preliminary surface treatment increase the corrosion resistance of ferrite based steels. Scalera [5] reports that the corrosion resistance of nitrided low-alloy steels treated by liquid nitriding process followed by oxidizing quench baths showed greater uniform corrosion but reduced pitting compared with non-treated steels.

2. THE EFFECTIVE PARAMETERS ON EROSION CORROSION

In two phases turbulent flow, there are mainly three effects of deposits on erosion corrosion. These are turbulence, fluid velocity and deposits on the surface. In literature the effect of deposits on erosion corrosion has received less attention than the other effects.

Many erosion corrosion failures occur because of turbulence flow condition exist. Turbulence causes greater agitation of the liquid at the metal surface than laminar flow. Turbulence results in more intimate contact between the environment and the metal [6]. Impellers and propellers are typical components operating under turbulent conditions.

Velocity of environment plays an important role in erosion-corrosion. Velocity often strongly influence the mechanism of the corrosion reactions. It exhibits mechanical wear effect at the high values and particularly when the solution contains solids in suspension. Table(1) shows the effect of velocity on a variety of metals and alloys exposed to seawater. These data show that the effect of velocity may be nil or extremely great. The effect may be nil or increase slowly until a critical velocity is reached,

and then the attach may increase at a rabbit rate. Table(1) lists several examples exhibiting little effect when the velocity is increased from 0,3 to 1,2 m/sec.

Table.1. Corrosion of Metals by Sea Water (International Nickel Company[2])

Material	Typical Corrosion Rate		
	0,3m/sec	1,2m/sec	8,1m/sec
Carbon Steel	34	72	254
Cast Iron	45	-	270
Stainless Steel (type316)	1	-	1
Admiral Bronze	4	20	170
Hydroluic Bronze	4	1	339
90-10 CuNi (0,8%Fe)	5	-	99

3. DIFFUSION CONTROLLED DEPOSITION MODEL

In general particles in a fluid are transported by diffusion except when they are very close to the wall where the diffusivity vanishes. Early attempts to predict the rate of deposition on to plane surfaces assumed that particles traversed the viscous sub-layer by molecular diffusion [7]. Provided the particles were small (<0,1 μm) this approach appeared to be satisfactory [8]. When the particle sizes were increased various investigators [9] found that deposits were larger than predicted and presumed that this was because particle inertia became important in regions where turbulence was small.

In literature there is no study on the effect of deposition to erosion corrosion. It is necessary to find the percentage of surface area covered by deposit particles for corrosion studies. Here, a statistical model has been proposed to calculate the rate of arrival of particles at the surface for deposition of very small particles in turbulent flows which is controlled by diffusion. In this model the reentrainment of particles is also taken into account. Güven and Alnıpak [10] showed that for shear velocity (U^*) which is smaller than critical value, U_c^* which is given as

$$U_c^* = \left[\frac{1}{4,95} \right] \left[\frac{\nu A}{\rho h^2} \right]^{1/3} \left[\frac{1}{d_m} \right]^{2/3} \quad (1)$$

Deposition rate

$$N = \left[\frac{\mathbf{v} \boldsymbol{\varepsilon} T_0 C}{\sigma_s^{2/3}} \right] U^* \quad (2)$$

And for U^* is greater than U_c^* deposition rate,

$$N = \left[\frac{100MC\boldsymbol{\varepsilon}}{\sigma_s^{2/3} (U^*)^2} \right] (1 - e^{-K}) \quad (3)$$

Where K is as taken, $K = \frac{T(U^*)^2}{100\mathbf{v}M}$ and

\mathbf{v} is fluid viscosity, C is the concentration of particles σ_s is Shmitz number $\boldsymbol{\varepsilon}$ is the probability of particles being greater than d_m (mean particle diameter) which is given as,

$$\boldsymbol{\varepsilon} = \int_{\frac{d_m - d_c}{\sigma}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt \quad (4)$$

d_c is critical partial diameter σ is standart deviation t is time and M (in eq, (2) is given with the following correlation.

$$M = 6,136 \times 10^9 \left[\frac{1}{(U^*)^2} \right] + 7,16 \times 10^4 \quad (5)$$

According to these formulations C , T_0 and A cause an increase on deposition and erosion corrosion. On the other hand d_m and h decreases deposition and erosion corrosion. Above critical values of shear velocity which removal starts deposition increasas, otherwise decreases [10].

4. EXPERIMENTAL STUDIES

The results shown in Table.2 are taken from the references (5,10,12).In these experiments, salt bath nitriding was performed in an electrically heated furnace under optimal conditions. After nitriding the specimens were cooled in air and different thickness of diffusion layers were obtained.

Erosion-corrosion resistance were determined in an atmosphere with constant humidity, 90-95% (20-40 °C, 20 days) and under the effect of sea-spray (25 °C, 10 days) by using weatherometer, saltspray cabinet and humidity cabinet [12]. Erosion corrosion measurements were made by using double cabinet connected with static corrosion test

apparatus and rotating-disc method. The corrosion studies were carried out by using several different techniques varying from simple weight loss measurements to some electrochemical observations[12].

These results showed that nitriding caused considerable increases to corrosion resistance in low-alloy steels and these results were in accordance with Sclear' s [5] results.

Table 2. Erosion corrosion resistance of low-alloyed steels [5,10,12]

Steel Type	Treatment	Corrosion rate (mgr/m ² hour)		
		Static Conditions		
		Moist Atm.	Steam	Salt Spray
1330	Non-nitrided	0,2714	1,3104	2,6216
	Nitrided	0,0177	0,0211	0,0924
2510	Non-nitrided	0,1817	0,9601	1,7604
	Nitrided	0,0101	0,0089	0,0211
4130	Non-nitrided	0,1666	0,8102	1,7103
	Nitrided	0,0116	0,0118	0,0221
Steel Type	Treatment	Corrosion rate (mgr/m ² hour)		
		Erosion Corrosion		
		Moist Atm.	Steam	Salt Spray
1330	Non-nitrided	0,4641	2,1672	3,7113
	Nitrided	0,1301	0,3762	0,6120
2510	Non-nitrided	0,3724	1,7922	2,7632
	Nitrided	0,1211	0,2897	0,4761
4130	Non-nitrided	0,3221	2,0029	2,9449
	Nitrided	0,0611	0,0917	0,2798

Nitriding effects the particle adhesion governed by colloidal forces which depend on chemical properties of the respective materials. After nitriding molecular movements and molecular attraction forces of the surface material also decreases [3].

The deposition rates of nitriding and unnitrided low-alloyed steels are calculated to show the effect of nitriding on deposition. Hamaker constant of $0,1 \times 10^{-20}$ J for the system of steel-water-ferric oxide was used to numerical applications for the system of nitrided steel-water-ferric oxide. Hamaker constants can be estimates by using Liftshitz theory and data given by Visser [11]. In this study this value has been predicted as $2,2 \times 10^{-20}$ J for nitrided steels. Figure 1. which is obtained by using Eq (1) and Eq (2) shows nitriding effects on deposition.

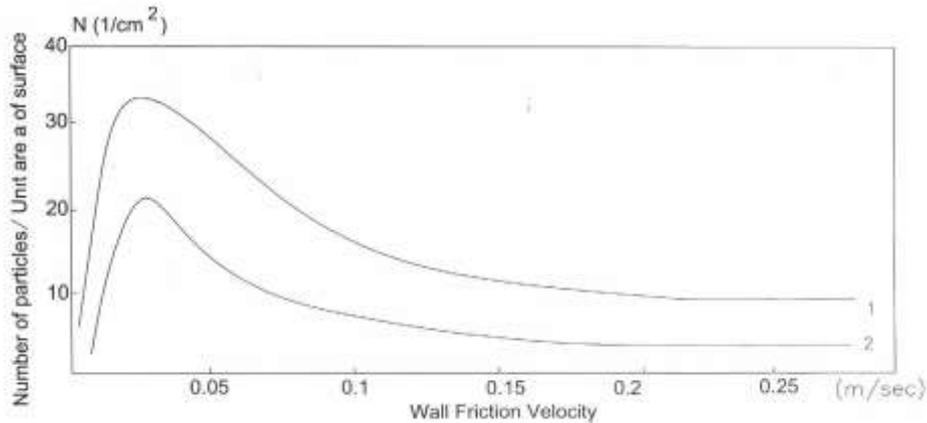


Figure 1. Deposition of ferric-oxide particles onto nitrided and unnitrided low-alloyed steel surfaces from water flow, plotted as $N = N(U^*)$.

1. Unnitrided-low alloyed steel

2. Nitrided-low alloyed steel

$T_s = 288 \text{ K}$

$\sigma = 0,3 \text{ } \mu\text{m}$

$\sqrt{\nu} = 1,144 \times 10^{-2} \text{ cm}^2/\text{s}$

$C = 400 \text{ 1/cm}^3$

$\rho = 1,018 \text{ gr/cm}^3$

$d_m = 0,5 \text{ } \mu\text{m}$

$h = 250 \text{ nm}$

$T = 25 \text{ min.}$

5. CONCLUSIONS

Nitriding and erosion corrosion experiments showed that the corrosion resistance of nitrided low-alloyed steels treated by liquid nitriding process followed by oxidizing quench baths increases. On the other hand nitriding causes considerable decreases on deposition rates.

In turbulent flows turbulence and velocity are known effects on erosion corrosion. Besides these effects, the other important parameters on erosion corrosion created by particle deposition were investigated. To (medium temperature), c (concentration of particles) and A (Hamaker constant) cause an increase on erosion corrosion, but h (the gap between particles and the surface) and d_m (mean particle diameter) cause a decrease on erosion corrosion.

NOTATION

A	Hamaker constant
C	concentration of particles
d_c	critical particles diameter
d_m	mean particle diameter
h	the gap between a particle and the surface

T_0	medium temperature
T	fixed time interval in deposition formula
k	Boltzmann constant ($k = 1,380 \times 10^{-16}$ erg / °K)
N	number of particles/unit area of surface
U^*	wall friction velocity $(\tau_w/\rho)^{1/2}$
U^*_c	critical value of U^* at which removal starts
σ	standart deviation
σ_s	Schmidt number = $3 \mu \sqrt{dm} \pi / K T_0$
τ_w	wall shear stress
ν	kinematic viscosity
ρ	fluid density
ϵ	probability of particles being greater than d_m

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