Effect of Alloying Additions on the Erosion Corrosion of Austempered Ductile Iron In Saline Water

Wafaa A. Ghanem*, Z. M. Hafez**

* Central Metallurgical Research and Development Institute (CMRDI).
** El Nasr Company for Coke and Chemicals Industries.

Abstract

Ductile iron has its importance due to its economic value. Both the mechanical and corrosion properties are a matter of concern. Some attempts were made to improve mechanical properties by either heat treatment or alloying additions. In this research ductile iron, austempered heat treated at 250°C, with different Ni (0-3%) and Mo (0-0.3) contents, was investigated for corrosion in rotating 3.5% NaCl at 500 rpm at room temperature. The rates of mass loss and electrochemical polarization measurements were used to measure the rate of corrosion. The surface morphology of the tested alloy samples was also examined using SEM. The results reveal that the alloying addition such as Ni or Mo has increased the corrosion resistance of the austempered ductile iron (ADI) alloys. This is attributed to the presence of protective oxide films on the surfaces of the alloys.

Keywords: Ductile iron – austempering – alloying –Corrosion – polarization.

Introduction

With the ever-growing demand for improved materials performance under severe service conditions, the need for proper material selection and utilization is a critical task. Ductile iron has been substituted as a construction material in many industries. However, it is still considered as an important material in a variety of applications (1-3). Examples of such fields are seawater, soils, sulphuric acid etc. as tanks or pipelines, automatic crank shaft, chain sprockets, refrigeration compressor crank shaft, universal joints, chain links, dolly wheels and as balls or rods for mills(4,5). In most cases ductile iron is used due to its economic advantage (6). However one of the problems which limits the use for the ductile iron is its lack of strength and its brittleness. For this reason several attempts were made to improve its strength (1,3,6). This is done by altering the structure by controlled heat treatment (7-10). It is very important to control the corrosion behavior of ductile iron as well as its strength (5,10). Austempered ductile cast irons (ADI) can easily obtain strength levels of twice as high as those of standard ductile iron grades. The matrix of ADI generally consists of fine bainitic ferrite and retained austenite, it is known that retained austenite is enriched with carbon during austempering treatment and that volume fraction of carbon-enriched austenite affects the mechanical properties of ADI. Alloying is necessary to improve hardenability and ensure heat treatment consistency. The ease with which a bainitic structure may be obtained is seen to increase with increasing additions of Ni and Mo.

The present research investigates the influence of alloying additions of Ni and Mo in austempered ductile iron on its corrosion behavior in saline water

Experimental

Materials

The material used in this investigation is austempered ductile iron with different alloying additions. The material was casted and heat-treated in metalworking and foundry division, CMRDI. Table 1 shows the chemical composition of the samples as determined by atomic absorption technique.

Table 1 Chemical Composition of the Investigated Alloys

Alloys	Element (%)							
	C	Si	Mn	Mg	S	Mo	Ni	Fe
A	3.760	2.530	0.383	0.046	0.0173	-	-	Bal
B	3.749	2.522	0.382	0.046	0.0172	0.3	0	Bal
C	3.712	2.497	0.379	0.0455	0.0171	0	1	Bal
D	3.636	2.4541	0.372	0.0446	0.0171	0	3	Bal
E	3.625	2.447	0.370	0.0444	0.0171	0.3	3	Bal
F	3.460	2.440	2.03	0.046	0.0272	-	17.86	Bal

The details of the heat treatment is mentioned in previous publication [11]. The austempering temperature is 250^{0}C. A sample with high Nickel content is used for comparison.

Measurements

Specimens Preparation

All specimens were prepared by grinding on various grades of emery papers up to 1000 mesh. After polishing, the specimens were rinsed in distilled water, degreased in acetone and dried in desiccator.

Corrosion tests

The samples were tested for corrosion in 3.5 % NaCl which was prepared from analar grade reagents in double distilled water with pH = 7.03 .

The corrosion tests were conducted using apparatus described in previous publication[11]. The test specimens were rectangular in shape, measuring 1 cm in length, 1.5 cm in width, and 0.6 cm in the thickness. An average area of 1.5 cm^2 of each specimen was exposed to the test solution. The specimen were mounted on Teflon discs that were driven by an electric motor.

The corrosion tests were carried out at rotational speed 500 rpm. The flow velocities were calculated from the rotational speed of the setup and were found to be 3.01 m/sec. Most of the tests were performed for duration of 30 days at room temperature (20 ^{O}C). The mass loss during the course of the corrosion tests was determined by calculating the difference in mass before and after immersion for duplicate specimens taken out of the test solution after the same interval of time.

The corroded surface is characterized using SEM and EDAX

Results and Discussions

Effect of Alloying Elements

Effect of Ni

The calculated rates of mass loss of specimens with different addition of Ni (0%Ni, 1%Ni, 3% Ni, and Ni - resist (17.86% Ni) in rotating 3.5% NaCl solution at 500 rpm are shown in Fig 1. It is clear that the calculated rates of mass loss decreased by increasing Ni content. A very small value of mass loss is measured for Ni – resist. It is clear also that the curves possess the same general feature i.e. the rate of mass loss increases gradually with the time of exposure for the first 7days, then decreases until reaches a steady state value after 30 days.

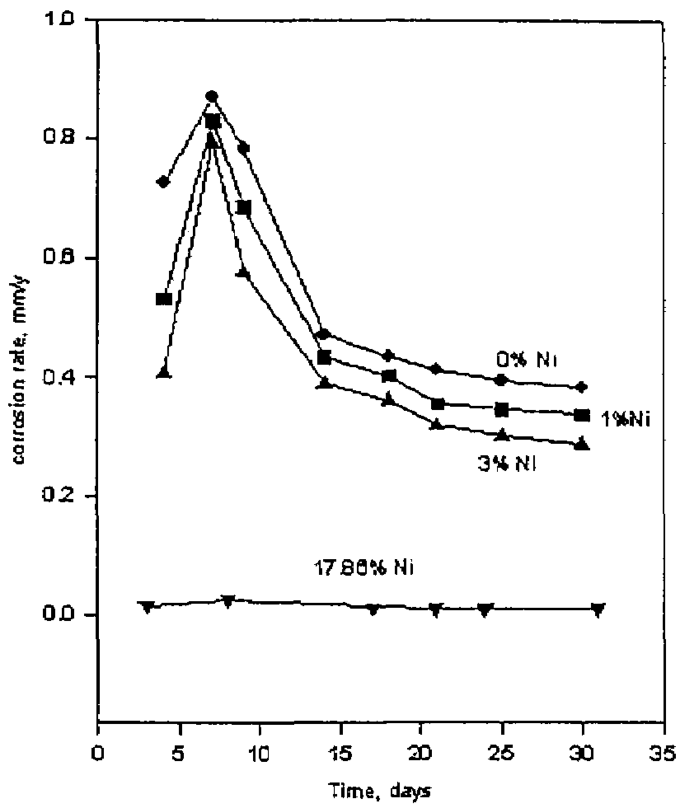


Fig. 1 Rate of mass loss of the austemperd ductile iron samples with different Ni contents tested in 3.5% NaCl with rotation speed 500 rpm at 20 C.

Fig .2 shows the potentiodynamic curves of austempered ductile iron with different addition of Ni (0% Ni, 1%Ni, 3%Ni, and Ni - resist) in rotating 3.5% NaCl solution at 500 rpm. It is clear that the corrosion current (Icorr) decreases by the addition of Ni from 4.81×10^{-5} A/cm^{2} , 4.268×10^{-5} , 3.55×10^{-5}, and 2.58×10^{-6} A/cm ^{2}, respectively. The decrease in corrosion rate as observed in Fig. 1 and Fig 2 suggests a tendency for corrosion resistance created by the addition of Ni. This may be attributed to the formation of nickel oxide which acts as a diffusion barrier for the progress of corrosion. A break in the current in the anodic part of the curve for the Ni-resist sample reveals a tendency for passivation.

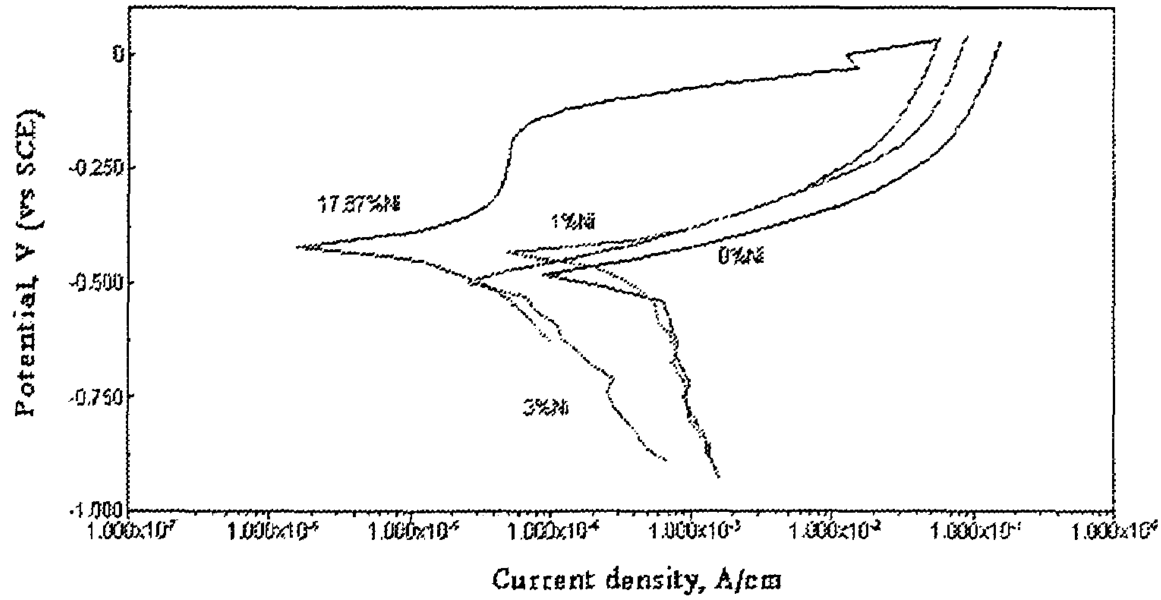


Fig. 2 Potentiodynamic polarization curves of the austempered ductile iron with different additions of nickel in rotating 3.5% NaCl with rotation speed 500 rpm at 20^{0}C.

Table 2 summarizes a comparison of the steady state corrosion rate obtained from mass loss and potentiodynamic measurements.

This result is in good agreement with Shalaby et al (12) and Molgarrd (13). The increasing in coorosion resistance with increasing the Ni addition may be attributed to the formation of protective oxide films on the surface of the samples.

Table 2 The Calculated Corrosion Rates (mm/y) with Different Additions of Ni

Alloy	Mass loss measurement	Potentiodynamic measurement
0% Ni	0.38	0.392
1% Ni	0.33	0.331
3% Ni	0.28	0.275
17.86% Ni	0.011	0.0106

Effect of Mo

The rate of mass loss of the austempered ductile irons was determined as function of time of exposure in rotating 3.5% NaCl solution at 500 rpm. The rates of mass loss of specimens with different addition of Mo (0% Mo, 0.3% Mo, (3%Ni, 0.3% Mo)) are shown in Fig .3.

Fig. 4 shows the potentiodynamic curves of the samples with different addition of Mo (0%Mo, 0.3%Mo, (0.3%Mo, 3%Ni)). The corrosion current I_{corr} decreased from 4.81×10^{-5} to 4.43×10^{-5} and 3.285×10^{-5} , A/Cm^2 , respectively. It is clear that, the corrosion current density decreases by the addition of Mo. simultaneous addition of Ni and Mo leads to additional decrease in the corrosion current density.

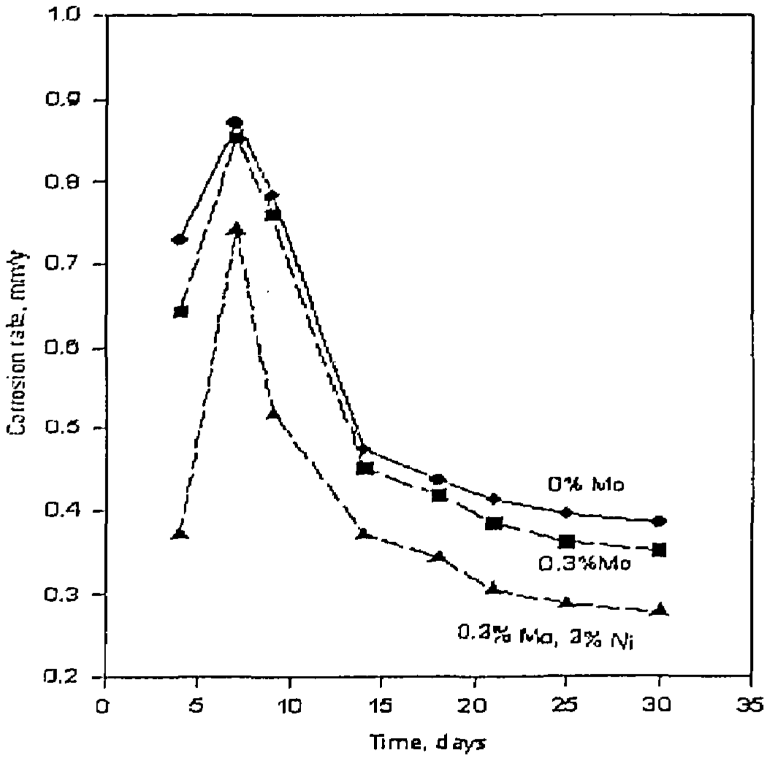


Fig. 3 Rate of mass loss of the austempered ductile iron with different additions of molybdenum in rotating 3.5% NaCl with rotation speed 500 rpm at 20^0C.

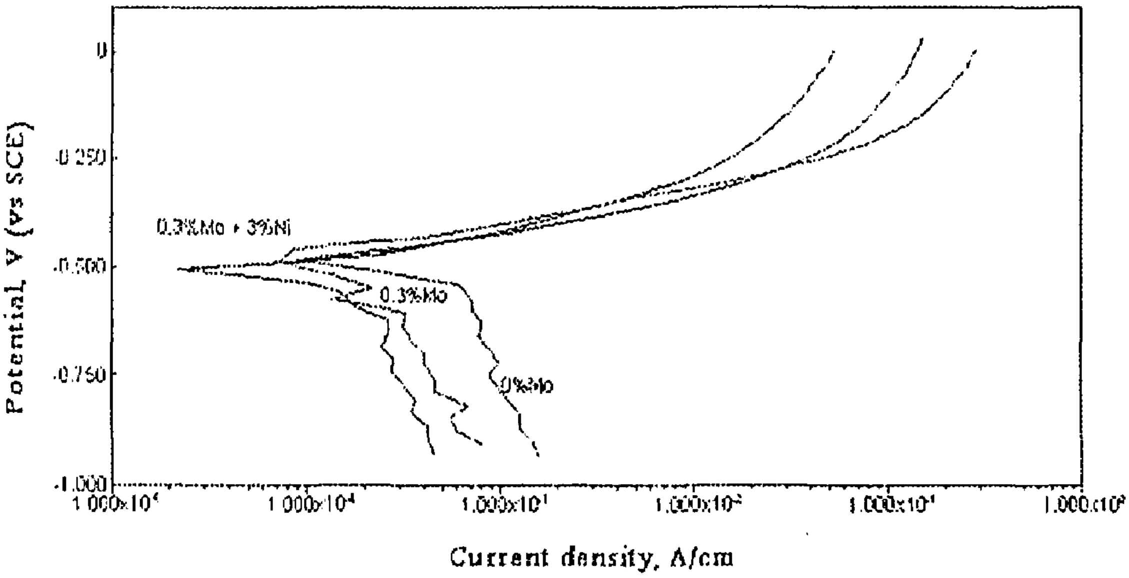


Fig. 4 Potentiodynamic polarization curves of the austempered ductile iron with different additions of molybdenum in rotating 3.5% NaCl with rotation speed 500 rpm at 20^0C.

Table 3 lists the steady state corrosion rates from the foregoing results obtained from mass loss and potentiodynamic measurements. It can be seen that the addition of Mo lead to increase the corrosion resistance. It worthy to mention that the combined addition of Ni and Mo lead to increase in the corrosion resistance

Table 3 The Calculated Corrosion Rates (mm/y) with Different Additions of Mo

Alloy	Mass loss measurement	Potentiodynamic measurement
0% Mo	0.38	0.392
0.3% Mo	0.35	0.344
0.3% Mo, 3% Ni	0.26	0.255

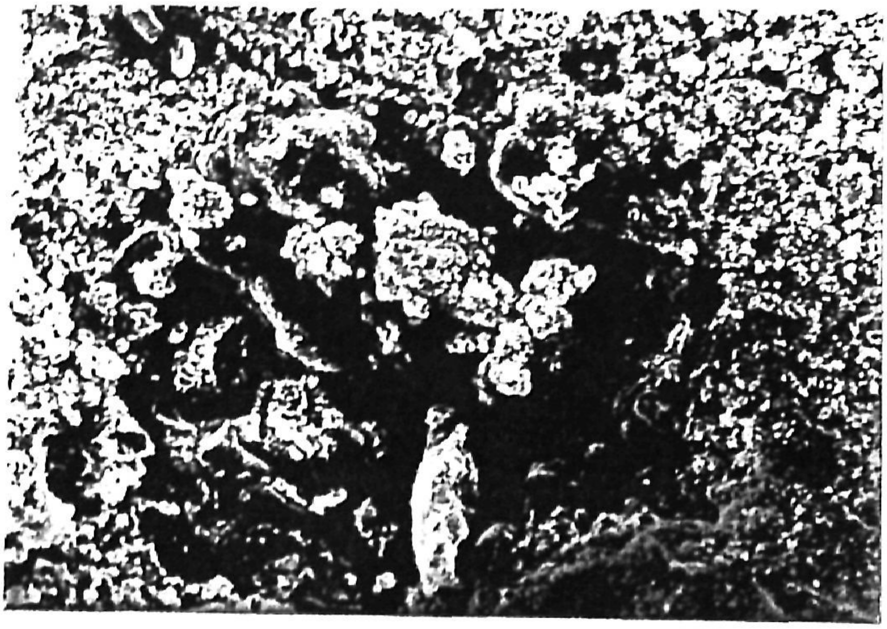
Our results fit very well with Lee et al (14) which found that the combined addition of Ni and Mo lead to increase the corrosion resistance more than the addition of Mo alone.

The increase in corrosion resistance of ADI with increasing the Mo addition may be attributed to that the addition of Mo contents above about 0.2% Mo segregates to intercellular areas to protective oxide films on the surface.

Effect of Alloying Elements on the Corrosion Morphology

Fig. 5 and 6 shows SEM micrographs of the corroded samples observed on austempered ductile iron alloys with different percentage of alloying elements [(0.3% Mo, 0% Ni), (0% Mo, 1% Ni), (0.3Mo, 1% Ni), and (0.3% Mo, 3% Ni)] in flowing saline water. The corrosion product morphology revealed that thicker oxide film was formed with some blisters on the surface, but decrease with the increasing of alloying element (Ni or Mo). The corrosion products as observed by naked eye were dark gray in color with some reddish - brown areas.

(a)



(b)

Fig (5) : SEM micrograph of the corroded surface of the ductile iron with different additions of Ni:

(a) 0.3 %Mo, 1% Ni, 200X

(b) 0.3% Mo, 3% Ni, 750X

(a)

(b)

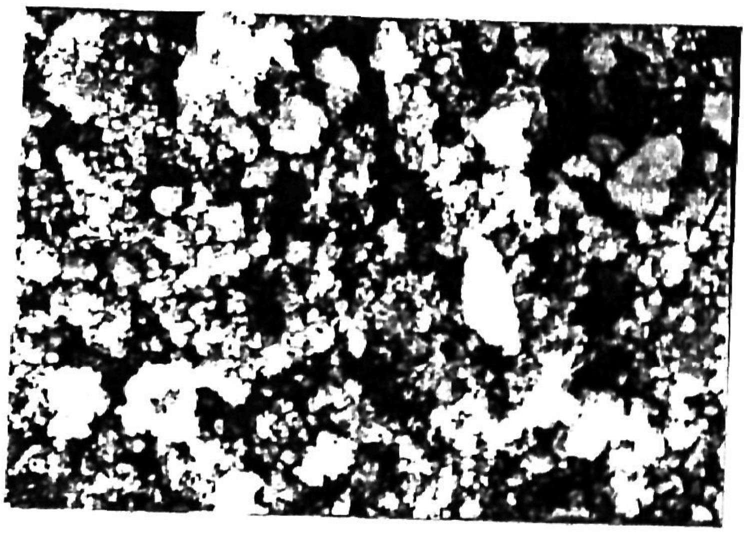


Fig (6) : SEM micrograph of the corroded surface of the ductile iron with different additions of Mo:

(a) 0 %Mo, 1% Ni, 1000X

(b) 0.3% Mo, 1% Ni, 500X

Fig. 7a shows SEM micrographs of corrosion attack on Ni - resist cast iron alloy. The figure showed that the surface with swollen blister around the graphite nodules. Slight yellowish brown corrosion products observed by naked eyes in some areas of the samples.

After descaling of nickel-resist cast iron cast alloy, the figure 7 b showed that the depth and width of localized attack was very small as compared with the as received austempered ductile iron alloys Fig. 8

The EDS and XRD analysis of the corrosion product observed on the surface of the unalloyed and alloyed austempered ductile iron (0.3% Mo, 1% Ni) were as follows.

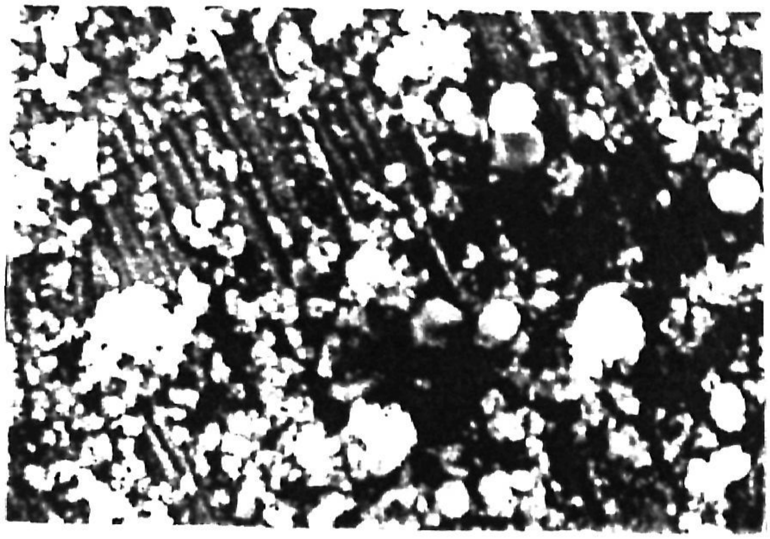
Table 4 Corrosion products Analysis of Unalloyed Austempered Ductile Iron.

Element	Atomic %
O	79.18
Si	2.76
Fe	18.06

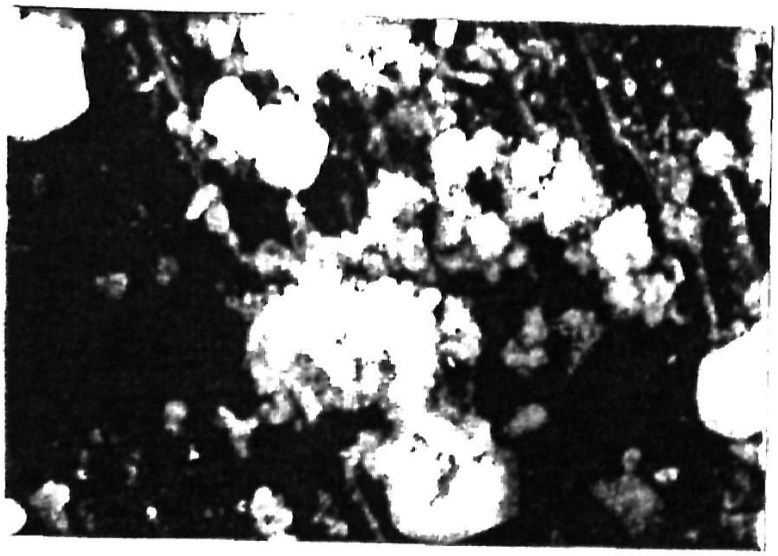
Table 5 Corrosion Products Analysis of Alloyed Austempered Ductile Iron (0.3% Mo, 1% Ni)

Element	Atomic%
O	75.39
Si	1.77
Fe	22.04
Ni	0.68
Mo	0.13

(a)



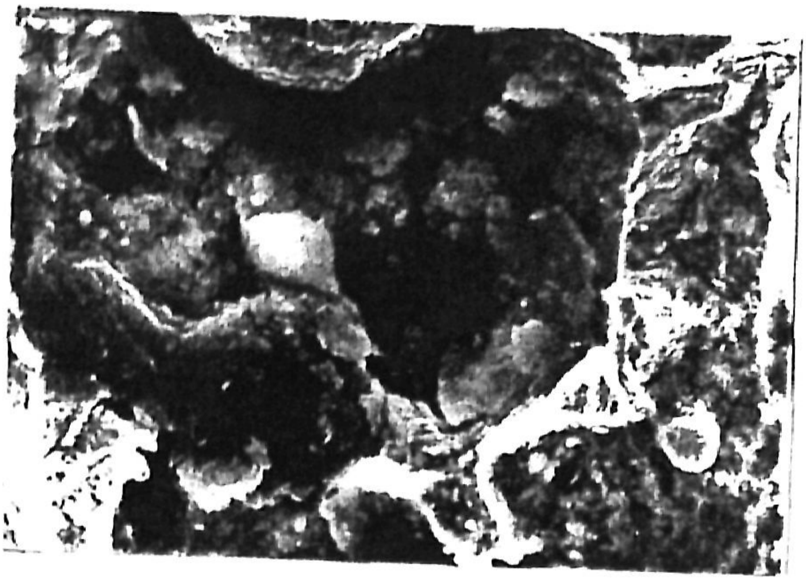
(b)



Fig(7) :SEM micrograph of the corroded surface of Ni - resist alloy

(a) before descaling, 1000X

(b) after descaling, 200X



Fig(8) :SEM micrograph of the corroded surface of astempered ductile iron after descaling, 1000X

It may be concluded that the scale observed on the unalloyed ductile iron alloy consisted of Fe_2O_3 , Fe_3O_4 , and SiO_2. On the other hand the scale observed on the allayed ductile iron (0.3% Mo, 3% Ni) consisted of Fe_2O_3, Fe_3O_4, SiO_2, NiO_2, and MoO_2.

This results was confirmed by the EDS and XRD results obtained for the scale of the unalloyed ductile iron [12] which consisted of Fe_2O_3, and SiO_2.

Conclusions

Increasing of alloying additions, such as Ni or, Mo, lead to decrease in the corrosion rates of austempered ductile iron alloys which may be attributed to the formation of protective oxide films on the surfaces of casting.

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