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THE ELECTROCHEMICAL BEHAVIOR OF STEEL FIBERS AND ITS EFFECT ON THE PERMEABILITY OF CONCRETE

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ABSTRACT

The effect of steel fibers obtained from tyres on the permeability of concrete which governs the flow rate of the fluid into a porous solid was studied. It is found that it deceases with the addition of steel fibers. The fire steel fibers, withdraw steel fibers, phosphatized, galvanized and the effect of diameter of the fire steel fibers after treatment with HCl were tested in NaCl solution by using potentiodynamic polarization and potentiodynamic cyclic anodic polarization techniques. SEM and EDAX analysis are used to detect the morphology and identification of the elements on samples surface. The results indicated that the treated fibers posses more corrosion resistance than untreated steel fibers. The corrosion resistance increases with increasing the diameter of the steel fibers. The corrosion resistance using withdraw steel fibers is better than using fire steel fibers.

KEYWORDS: Permeability**,** Corrosion; Steel Fibers; Chemical Treatment**,** Zinc Phosphate Corrosion and Galvanized Process.

INTRODUCTION

Permeability is defined as the property that governs the rate of flow of a fluid into a porous solid. It is also can be defined as ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. The permeability occurs in hardened concrete in two scenarios; firstly**,** from the trapped air pockets from incomplete compaction and secondly from the empty space due to loss of mixing water by evaporation. Corrosion is the deterioration of steel fibers as a result of chemical reactions between it and the surrounding environment.

Both types of metal and the environmental conditions, particularly gases that are in contact with the metal, determine the form and rate of deterioration. Methods of corrosion control of steel fiber include galvanizing [1, 2] and ZnPh(phosphatizing) conversion is considered as an important addition to steel fiber in terms of corrosion resistance. It promotes passivity, widens the passive range in which pitting is less probable, improves corrosion resistance in 3.5%NaCl solution, and enhances the resistance to general and pitting corrosion**.** Galvanized steel attains corrosion protection by its zinc coating, which acts as a sacrificial anode [3]. Galvanizing has been increasingly applied because of zinc protective characteristic that associated to the steel mechanical strength, results in a versatile and economic product [4] Steel surface treatments that improve both corrosion resistance and bond strength are attractive.

The aim of the present work is to evaluate the effect of chemical treatment steel fibers of tyres under (phosphatized and galvanized) control to reduce the corrosion in NaCl solution.

EXPERIMENTAL

Material and Solutions

The material used in this investigation was four steel fibers samples 3cm in length Table (1) shows the identification of theses samples fire steel fibers (1 and 2ml diameter and withdraw steel fibers 1ml diameter. The chemical compositions of steel fibers are shown in Table (2). The withdraw steel fibers is the less in corrosion rate because there are rubber layer on the steel fiber which make as isolator in the corrosive media. Steel fibers washed with HCl 1:1, then with water, with Na_2CO_3 solution and finally with distilled water to remove any impurities**.** F**orPhosphatizing process:** The received fibers were treated with a ZnPh conversion with formulation of zinc orthophosphate dihydrate, H_3PO_4 acid and water, and prepared as proposed by Sugama and Carciello [5], the fibers were immersed for 5 mins in the ZnPh conversion at 90^0C and then were rinsed with distilled water. One of the choices for an electrical contact material is zinc, but it suffers from poor durability and corrosion resistance, the tendency to oxidize, a high thermal expansion coefficient, and high material and processing costs. The electrolytic solution 3.5%NaCl was prepared using analar grade reagent.

Scanning electron microscope (SEM) and energy dispersive X-ray analysis (EDAX) were used to detect the morphology and identification of elements on the samples surface respectively.

Table 1: Shows the Identification of the Samples

Sample No	Name
1	As received
2	After treatment with HCl
3	After phosphatizing
4	After glvanized

Table 2: The Chemical Composition of Steel Fibers

C	Mn	Si	S	P	Fe
0.8%	0.58%	0.2%	0.012%	0.008%	ball.

ELECTROCHEMICAL MEASUREMENTS

Potentiodynamic Polarization Measurements:

A three compartment cell, with working electrode, platinum sheet (counter electrode) and Ag/AgCl calomel electrode,(reference electrode) were used for measurements

Electrochemical polarization experiments were conducted using Voltalab40(PGZ301)-Radiometer, connected to a potential and current X-Y recorded. The results were finally processed in a personal computer using a data acquisition program.

Potentiodynamic Cyclic Anodic Polarization Measurements

Potentiodynamic cyclic anodic polarization was measured also by using voltalab40 (PGZ301)-Radiometer, connect to a potential and current X-Y recorded. The measurements were conducted at scanning rate 5 mv/sec. The cyclic anodic polarization were swept from (-1000 mv to1000 mv). All experiments were performed in aerated solution at room temperature at 25°C.

RESULTS AND DISCUSSIONS

Influence of Steel Fibers on the Permeability of Concrete

Transport Mechanisms

The degradation processes of concrete are governed by transport mechanisms which can be roughly divided into transport in the bulk material and transport in micro and macro cracks. The relevant transport mechanisms in the bulk material include ionic diffusion, gas diffusion, liquid sorption, gas permeability and liquid permeability [6]. Tables (3) represent the results of permeability

Table 3: Permeability of Concrete Samples

Sample	Sample No.	Permeabilityg/h
without steel fiber (wo)	1 (Wo)	29
with steel fiber after treatment with HCl (Af)	2 (Af)	7
with normal amount of adebond (N)	3 (N)	4
with over amount of adebond (O)	4 (O)	1.25

Permeability of concrete, which can be defined as the penetration of a fluid through its pores, is considered one of the most important transport mechanisms and can be directly related to the concrete's durability[7]. In sound concrete, the permeability is attributed to the capillary porosity of the cement paste. Aldea et al. [8] determined that fiber reinforcement provides improved resistance to water permeation.

As shown in Fig(1) and Table (3) sample No.4 possess the lowest permeability, for the rest samples the permeability increases in the order

$4 < 3 < 2 < 1$

This means that the steel fibers delay the initial corrosion process as well as decreasing permeability, and decreasing volumetric expansion and contraction. In addition, it shows the ability of fibers to arrest crack formation and to control crack propagation [9-13].

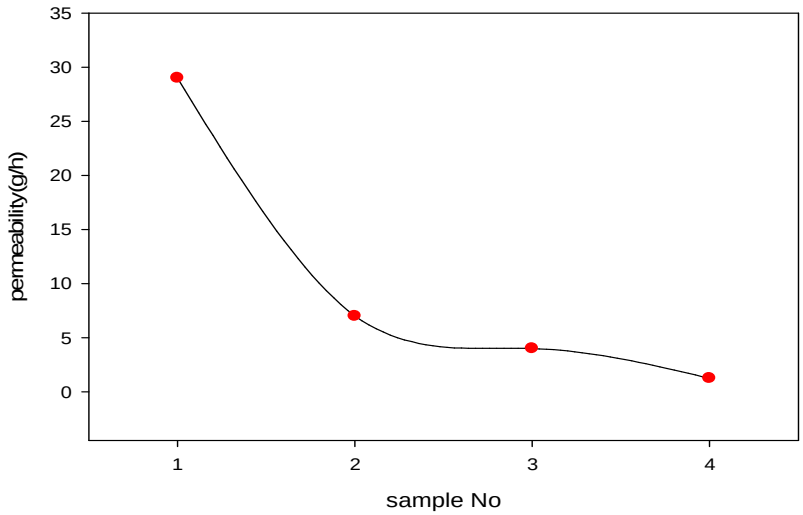

Figure 1: Permeability of Steel Fiber Reinforced Concrete

Potentiodynamic Polarization Measurements

Figure.2 represents the potentiodynamic polarization measurements of the designed four samples as showed in table (1), fire steel fibers (1 and 2 ml)and with- draw steel fibers (1 ml) in 3.5% NaCl solution. Based on the results reported in Figure 2, there are significant decrease of current density in the active dissolution region and lower maximum current density in the phosphatized steel fiber than galvanized steel fiber. So sample No.3 is the most corrosion resistance than the rest samples.

The corrosion resistance increasing as follows

3 > 4 > 2 >1

Tables (4-6) show the comparison between the corrosion rate of steel fiber samples, with the ZnPh layer and with Zn layer. It can be noticed that, the steel fiber samples after chemical treatment have the lowest corrosion rate as compared with the as received one. Sample No.3 has the value of corrosion rate =59.8 µm/y for 1ml fire steel fiber, 21.15 µm/y for 2ml fire steel fiber and 25.4 µm/y for 1ml withdraw steel fiber as compared to sample No.1 which has the value = 93.87 µm/y for 1ml fire steel fiber, 38.66 for 2 ml fire steel fiber and 27.73 for 1 ml with draw steel fiber. So the general sequence of corrosion resistance increasing in the order.

3 > 4 > 2 > 1

As shown from Figs(3,4) the fire steel fiber samples 1 ml in diameter is more corrosive than 2ml fire steel fiber and also more corrosive than 1 ml withdraw steel fiber. As shown in Tables (4-6) the value of corrosion rate of sample No. 1= 93.87 µm/y for 1ml in diameter fire steel fiber, but for the same sample the value =38.66 µm/y for 2ml in diameter fire steel fiber and = 27.73 µm/y for 1 ml in diameter withdraw steel fiber. While sample No.2 which lower in corrosion rate than sample No.1 has value = 84.39 µm/y for 1ml in diameter fire steel fiber but for the same sample =29.11µm/y for 2ml in diameter fire steel fiber and =27.34 µm/y for 1 ml in diameter withdraw steel fiber. So the general sequence of the four samples according to the increasing in corrosion resistance is

3>4>2>1

Table 4: The Corrosion Parameters of Four Fire Steel Fiber Samples1m in Diameter In 3.5%Naclsolution

Sample No.	I_{corr} µA/cm^2	Tafel Slopes β_a mV	β_c	Corrosion rate µm/y
1	8.02	281.6	-112.5	93.87
2	7.21	105.9	-140.4	84.39
3	5.11	97.6	-541.8	59.81
4	6.93	4.1	-19.8	81.10

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Table5: The Corrosion Parameters of Four Fire Steel Fiber Samples 2ml in Diameter in 3.5%Nacl, Solution.

Sample No.	I_{corr} µA/cm^2	Tafel Slopes β_a mV	β_c	Corrosion rate µm/y
1	3.30	82.6	-313.9	38.66
2	2.48	19.9	-35.3	29.11
3	1.80	117.6	-236.3	21.15
4	2.10	133.6	-162.9	24.65

Table 6: The Corrosion Parameters of Four Drawn Steel Fiber Samples 1ml in Diameter In 3.5%Nacl, Solution.

Sample No.	I_{corr} $\mu A/cm^2$	Tafel Slopes β_a mV β_c		Corrosion rate µm/y
1	2.37	728.1	-304.0	27.73
2	2.33	11.6	-14.8	27.34
3	2.17	127.4	-489.0	25.40
4	2.25	46.5	-40.0	26.32

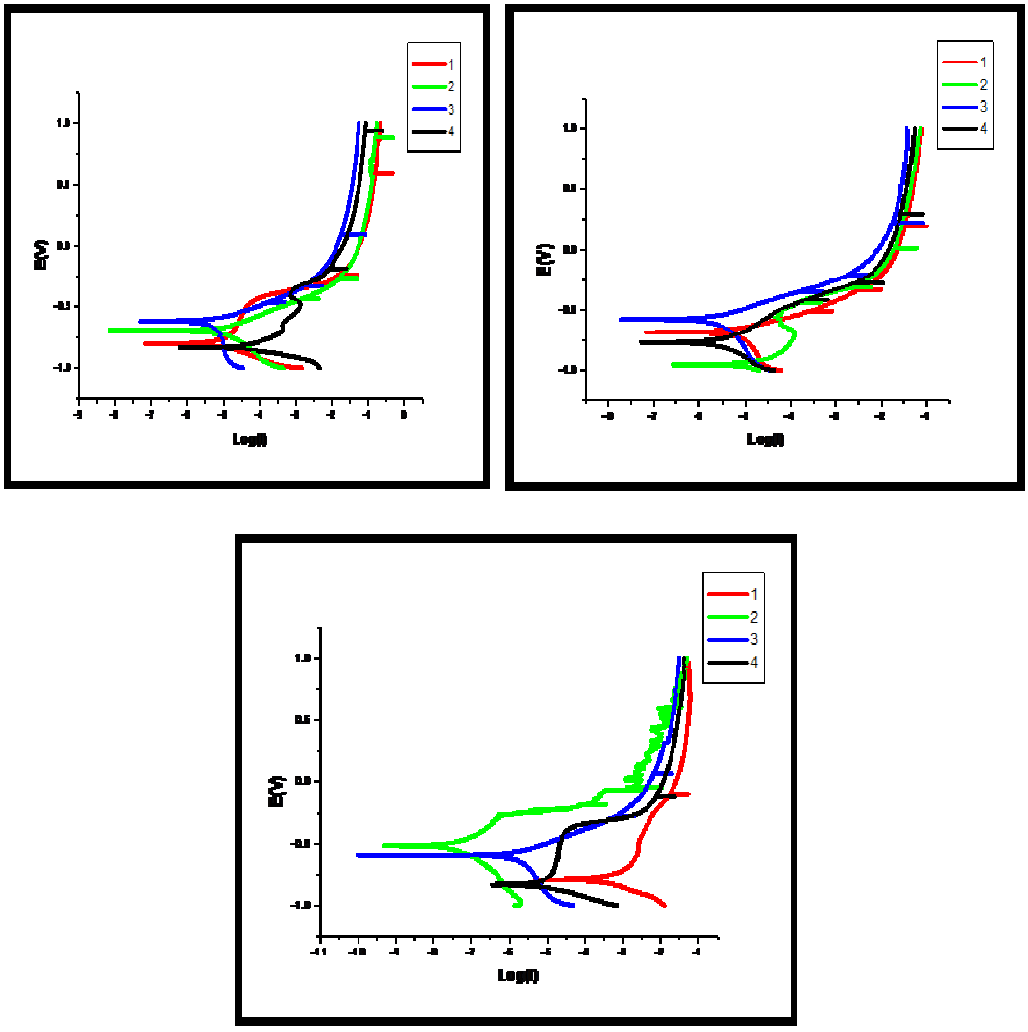


Figure.2: Anodic and Cathodic Polarization Curves

- Four fire steel fiber samples, 1 ml in diameter in 3.5 %NaCl solution
- Four fire steel fiber 2 ml in diameter in 3.5 %NaCl solution.
- Four withdraw steel fiber 1 ml in diameter in 3.5 %NaCl solution.

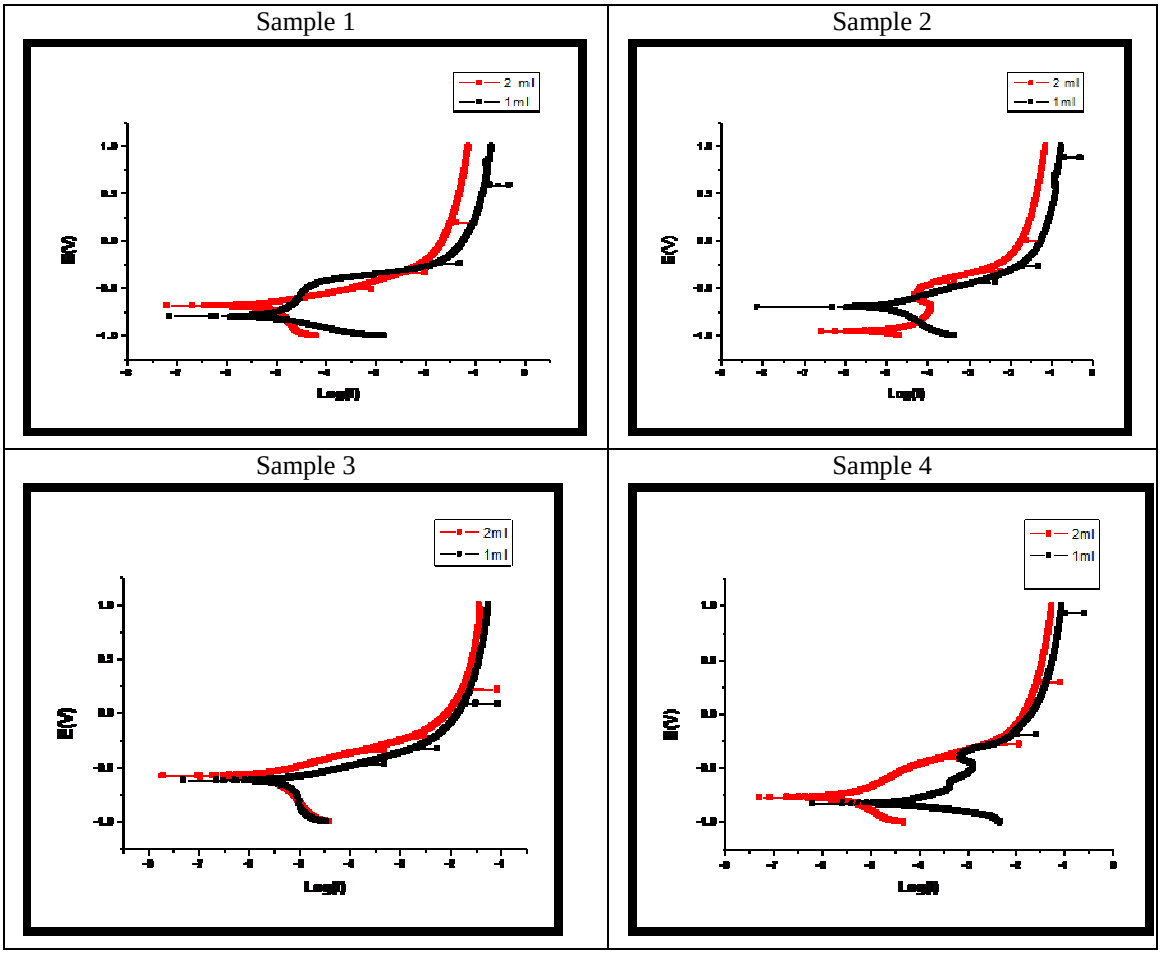
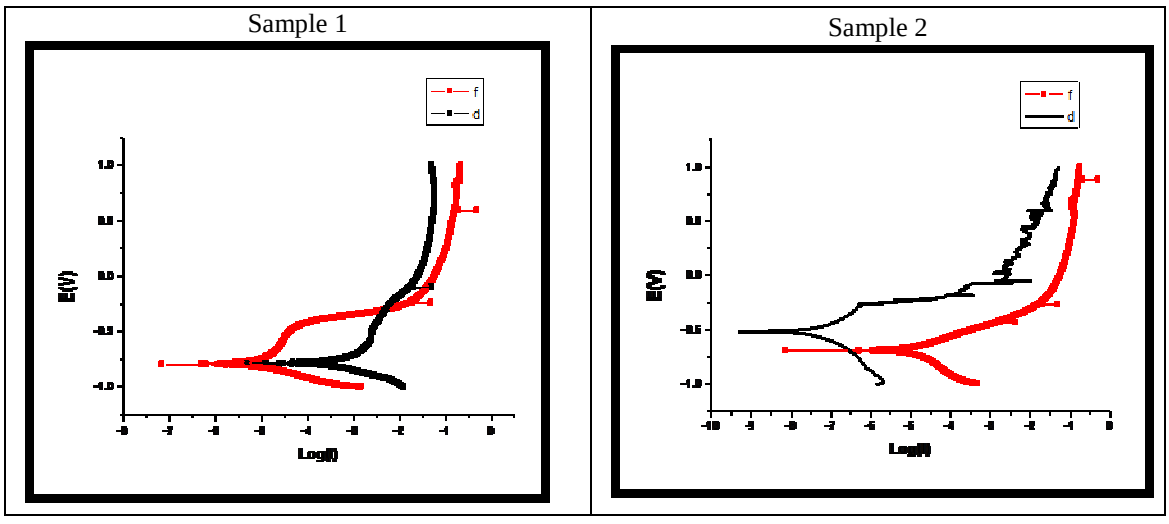


Figure.3: Comparison between Fire Steel Fiber (1 And 2ml) In Diameter at 25C^0



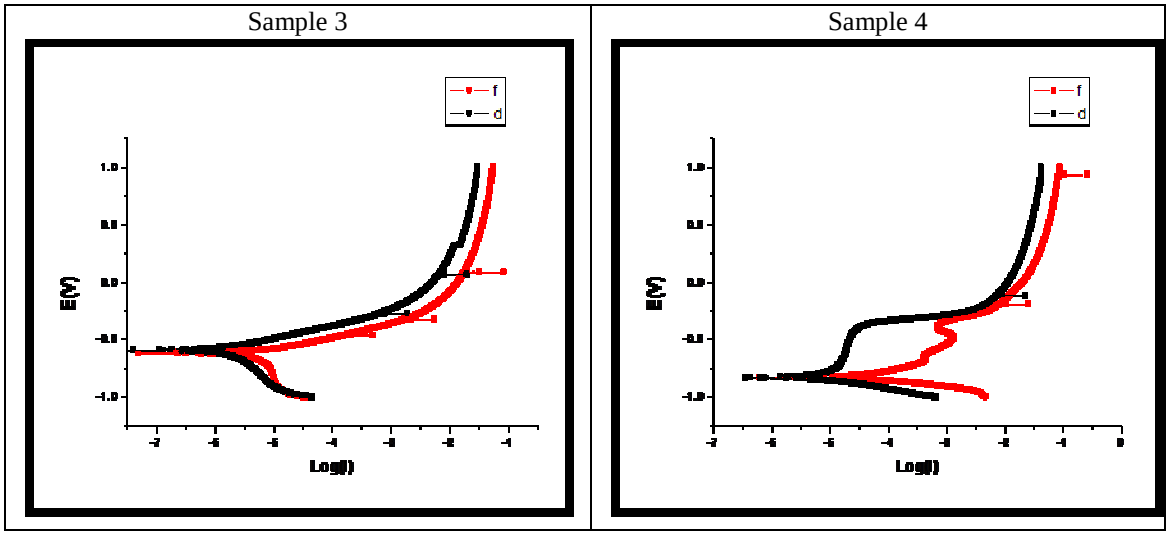


Figure.4: Comparison between Fire (F) and Drawn (D) Steel Fiber Samples at 25C^0

Potentiodynamic Cyclic Anodic Polarization Measurements

Cyclic polarization can provides a **qualitative** view of pitting corrosion mechanisms and can determine the tendency of a metal to undergo surface pitting or crevicing when placed in a special corrosive environment.

Figure 5 **represent** the potentiodynamic cyclic anodic polarization measurements for samples (a), (b) for 1,2ml fire and (c) withdraw steel fibers in 3.5% NaCl solution using scan rate 5mV/sec in potential range from -1000 to 1000 mV at 250C..

The current rises suddenly without any sign of oxygen evolution for samples 1and 2, denoting break down of the passive layer, when the polarization potential reaches a certain critical potential (Epit).

For samples 3 and 4, in 3.5% NaCl solution, the cyclic polarization curves don't have a hysteresis loop where the forwards scan current density are higher than backwords at the same potential, indicating the good stability and self repairing ability of the passive film. For the rest samples, the hysteresis loops were observed.

As clear from Tables (7-9), for all samples the corrosion current, I corr. decreased and pitting potential, Epit. Increased in case of chemical treated steel fiber. The value of corrosion rate for sample No. 3 and 4 are 44.68 µm/y and 50.65 µm/y while the value of Epit are 0.15 mV and 0.14 mV for fire steel fiber 1 ml in diameter respectively.

The data reveal that, the value of Epit for all samples in test NaCl solution follows the sequence

Samples 3>4>2>1

This sequence reflects the beneficial effect of (galvanized and ZnPh conversion) in the corrosion resistance of steel fibers sample.

From the Tables we can also observed that the corrosion resistance increases as the diameter increase from 1ml to 2ml for fire steel fibers. While the corrosion resistance for withdraw steel fibers is higher than that of fire steel fiber. Which the value of corrosion rate for sample No. 1 = 60.26 µm/y for 1ml fire steel fiber 52.20 µm/y for 2 ml fire steel fiber and 43.86 µm/y for 1 ml withdraw steel fiber.

Table7: The Corrosion Parameters of Four Fire Steel Fiber Samples 1ml in Diameter in 3.5% Nacl Solution at 25C^0

Sample No.	E_{pit}(mV)	I_{corr}µA/cm^2	Corrosion rate µm/y
1	0.10	5.2	60.26
2	0.13	4.62	54.05
3	0.15	3.82	44.68
4	0.14	4.33	50.65

Table 8: The Corrosion Parameters of Four Fire Steel Fiber Samples 2ml in Diameter In 3.5%Nacl Solution at 25C0

Sample No.	E_{pit}(mV)	I_{corr}µA/cm^2	Corrosion rate µm/y
1	0.19	4.46	52.20
2	0.22	4.22	49.42
3	0.25	3.41	39.99
4	0.23	4.02	47.06

Table 9: The Corrosion Parameters of Four Withdraw Steel Fiber Samples 1ml in Diameter In 3.5% Nacl Solution at 25C0

Sample No.	E_{pit}(mV)	I_{corr}µA/cm^2	Corrosion rate µm/y
1	0.20	3.8	43.86
2	0.24	2.85	33.44
3	0.34	2.45	28.17
4	0.29	2.66	31.12

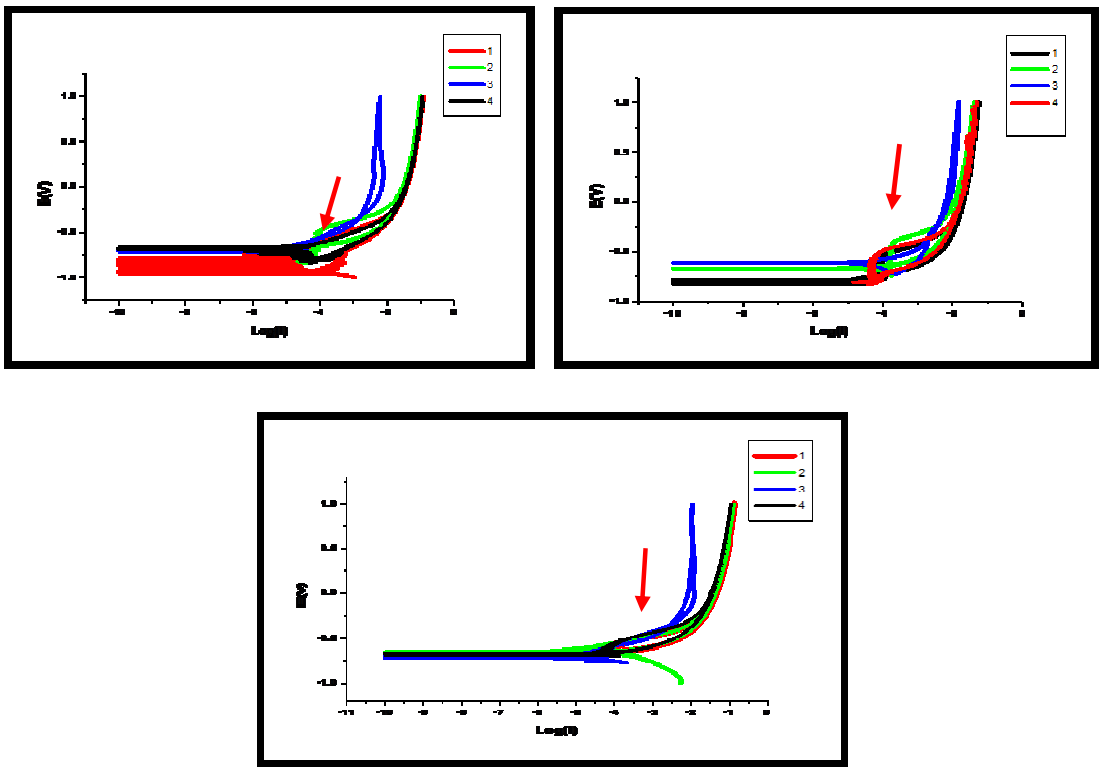


Figure 5: Cyclic Anodic Polarization Curves For (A, B), 1, 2 Ml Fire Steel Fiber and (C) 1ml Withdraw Steel Fiber in 3.5%Nacl Solution at 25C^0.

SPECTROSCOPIC SURFACE EXAMINATION

Scanning Electron Microscope (SEM).

To confirm the results obtained after potentiodynamic polarization measurements, the tested steel fiber samples were observed under the scanning electron microscope (SEM).Figures (6,7)illustrates the morphology surface of steel fiber samples after potentiodynamic polarization in 3.5 % NaCl solution. Fig.(6a) which belong to the sample No.1(as received) in 3.5% NaCl solution showed that, the surface of the sample was highly corroded. While Figure. (6 b and c) for samples No. 3 and 4 show no evidence of corrosion attack and formation of passive film on steel surfaces. This observation indicates that samples No.3 and 4 which undergo chemical treatment have excellent corrosion resistance due to the presence of a very thin protective passive film on the surface of the samples. Fig (7 a, b and c) show SEM for withdraw steel fiber samples 1, 3 and 4 which has less corrosion than fire steel fiber.

The influence of ZnPh in the active – dissolution region has been related to the original smooth surface of the steel fibers to be modified into a rough topographical feature by precipitating ZnPh crystals on the fiber. These observations are in good agreement with the previous observations where the surfaces of the treated fibers were examined in details using SEM [5].

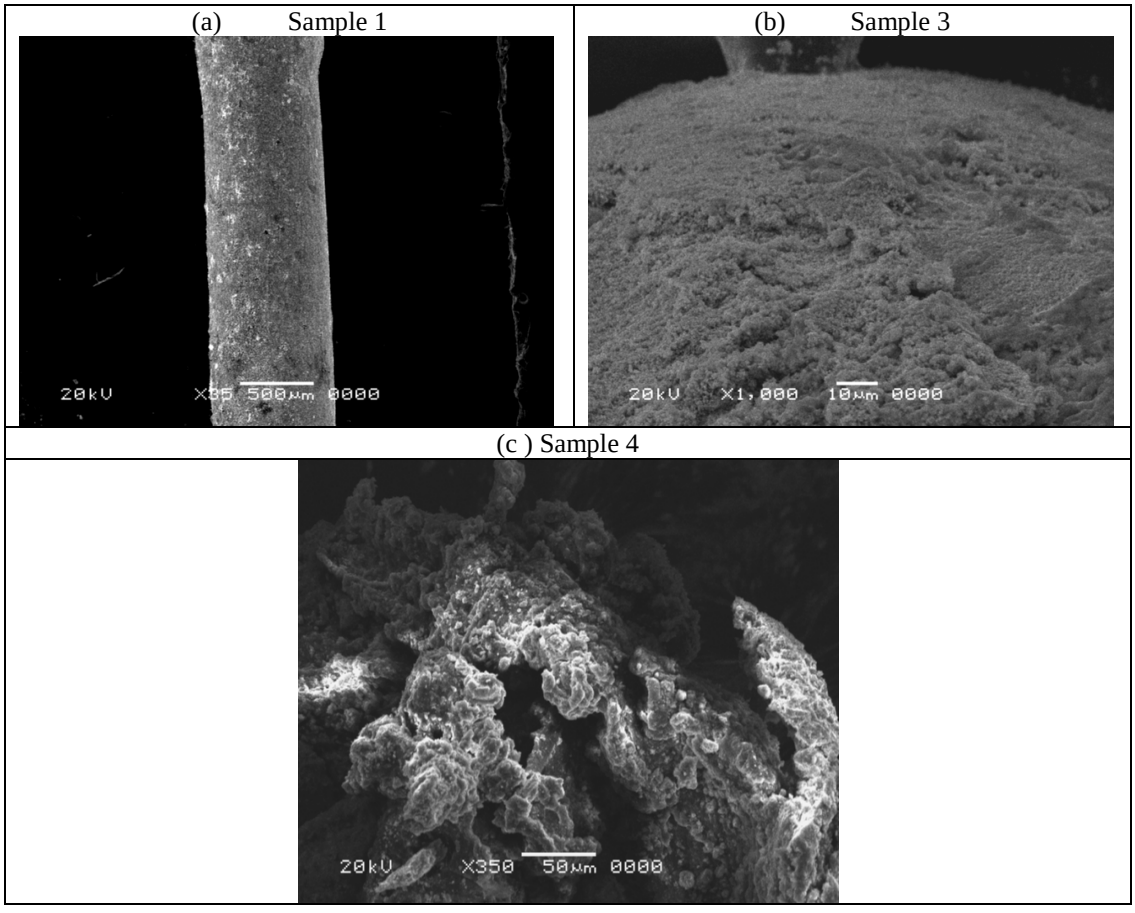


Figure.6: Surface Morphology of Three Fire Steel Fiber Samples In 3.5% Nacl Solution.

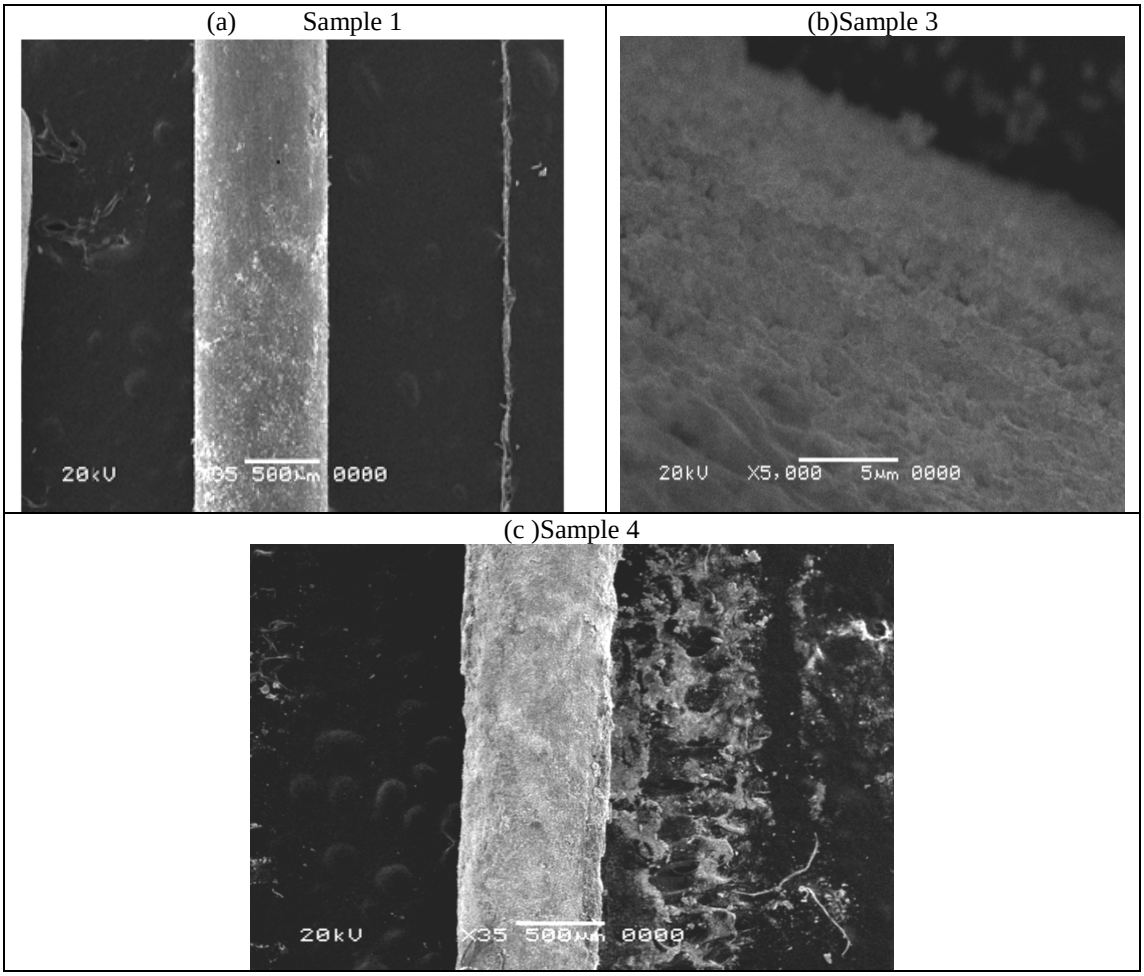


Figure.7: Surface Morphology of Three Samples of Steel Fiber (Withdraw) In 3.5% Nacl Solution.

Energy Dispersive X-ray Analysis (EDAX)

It is important to take into consideration the percentage of elements and oxide formed on the surface of the samples. This percentage was obtained from analyzed element composition by energy dispersive X-ray analysis (EDAX). The observed spectra Fig. (8) Indicated the presence of Fe, and S in fire steel fiber. The presence of chloride ion on the passive film is known to create a concentration gradient that facilitates its diffusion into the film, where it undergoes hydrolysis and reduces the local pH, causing dissolution of the film [14].Fig. (9) Indicated the presences of lower percentage of chloride ion which indicate that withdraw steel fibers are lower corrosion rate than fire steel fibers.

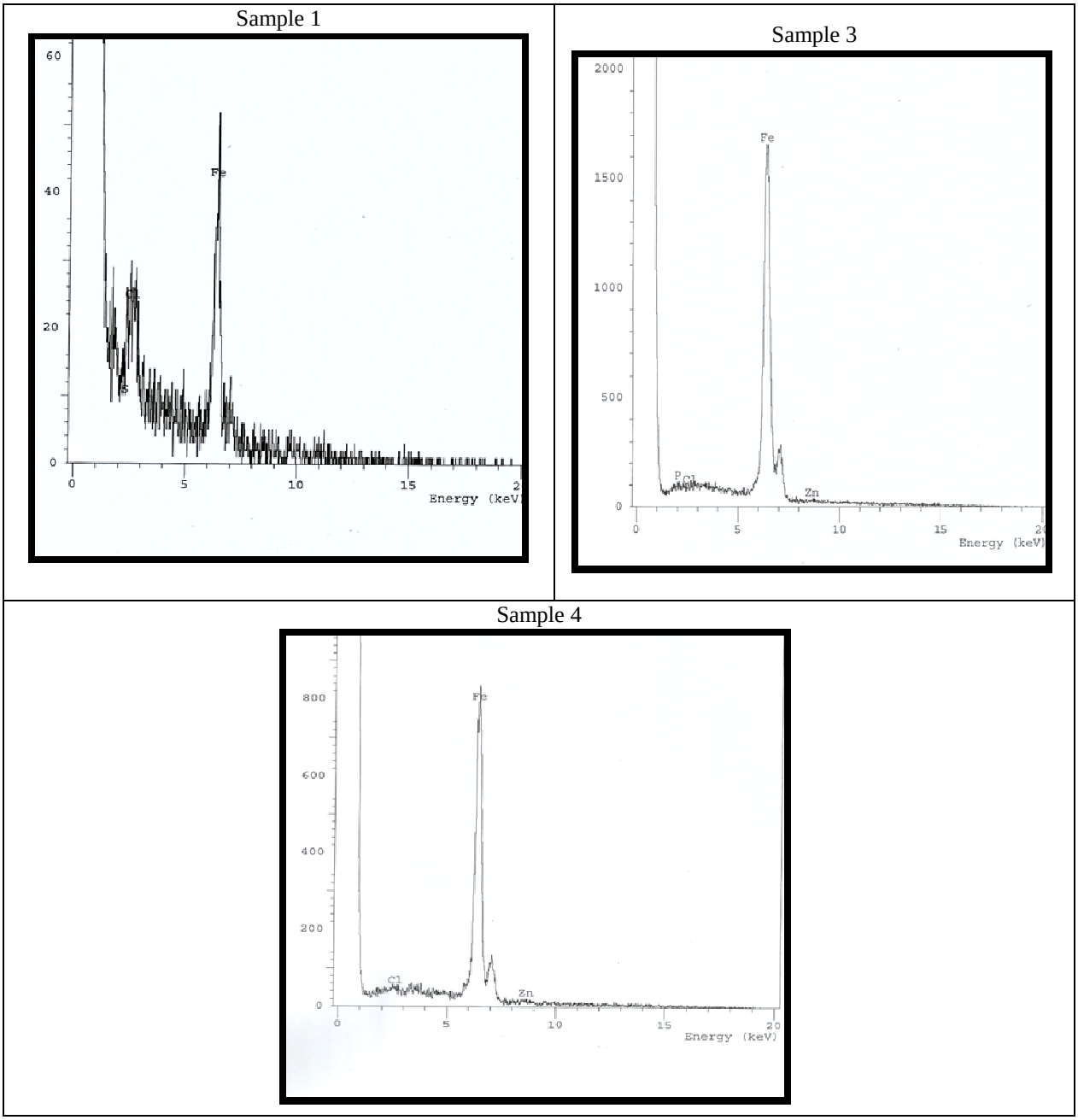


Figure.8: EDAX Spectra of Fire Steel Fiber In 3.5 % Nacl Solution.

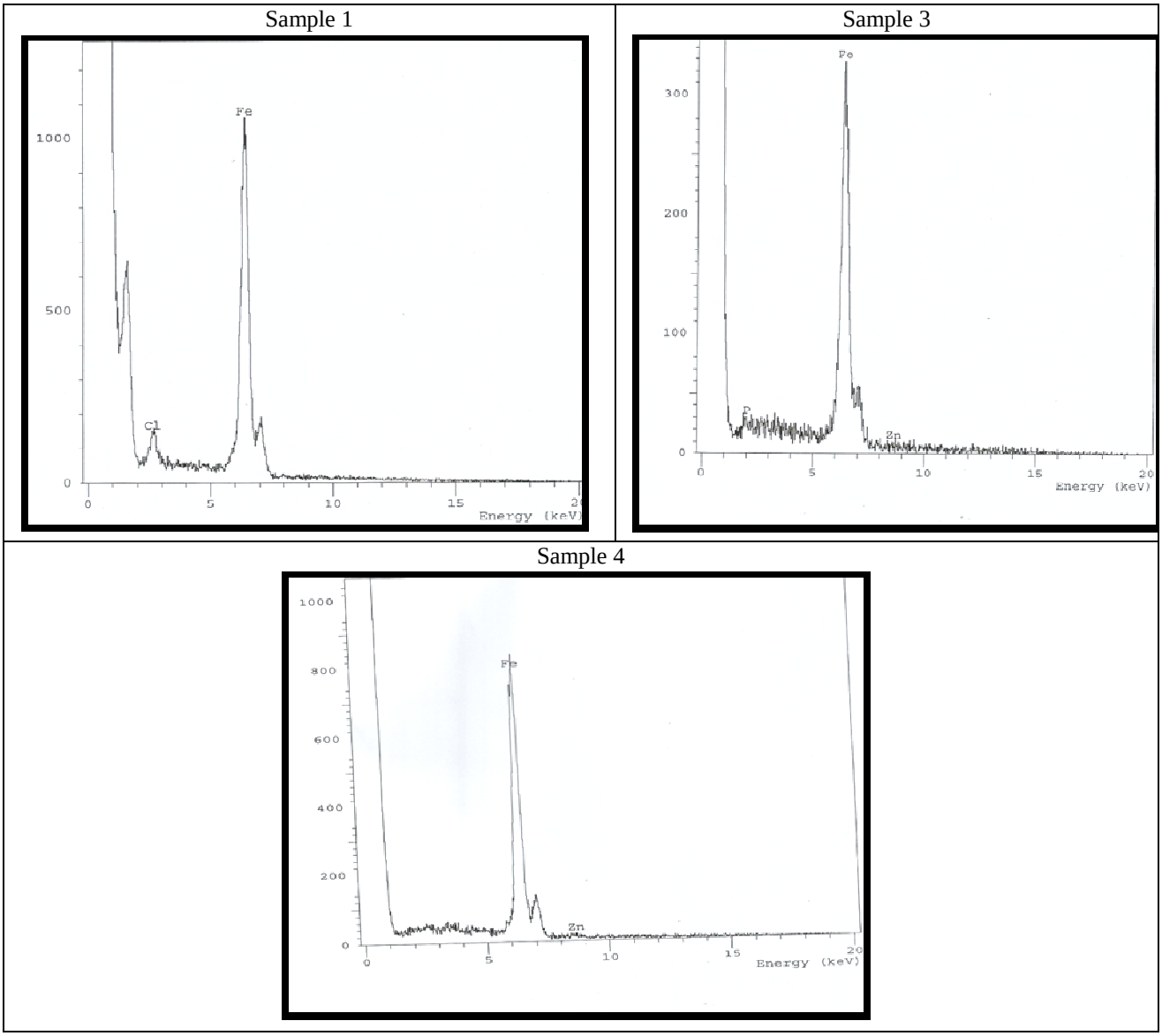


Figure 9: EDAX Spectra of Draw Steel Fiber In 3.5% Nacl Solution.

CONCLUSIONS

The corrosion attack was found to be retarded by chemical treatment:**.** From potentiodynamic polarization and potentiodynamic cyclic anodic polarization techniques the corrosion resistance increase in the order samples 3> 4 > 2 >1

.ZnPh addition to steel fiber promotes the passivation. Phosphatized steel fibers have lower corrosion rate than galvanized steel fibers. Phosphatized and galvanized steel fibers have a lower corrosion rate than as received steel fibers. The corrosion resistance of fire steel fibers is lower than that of withdraw steel fibers**..** The corrosion resistance is shown to be increased with increasing the diameter. **.** From SEM examination, the samples No.3 and 4 which undergo to chemical treatment have excellent corrosion resistance due to the presence of a very thin protective passive film on the surface of the samples**..** SEM and EDAX analysis are in good agreement with two electrochemical techniques used.

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