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Effect of Zeolite Inclusion on Some Properties of Concrete and Corrosion Rate of Reinforcing Steel Bars Imbedded in Concrete

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Abstract: *In this paper, an experimental study has been conducted to evaluate the effect of zeolite inclusion as partial replacement on some properties of concrete containing zeolite and the effect of corrosion of reinforced steel bars imbedded in concrete .A total of 72 cubes were cast to determine compressive strength and 24 cylinder to determine the indirect tensile strength. Bond strength between reinforcing bars and concrete was determined by pullout test on 24 concrete blocks. Corrosion rate was studied and the results are presented. Different percentages of zeolite ,namely 5,10,15,20,25,30and 35% were used which resulted in seven mixes other than the control one .The optimum replacement value was 15%by weightof cement at which all the studied properties has been enhanced.*

I. Introduction

Concrete is the most widely used and versatile building material which is generally used to resist compressive forces. By addition of some pozzolanic materials, the various properties of concrete , workability, durability, strength, resistance to cracks and permeability can be improved. Many modern concrete mixes are modified with addition of admixtures, which improve the microstructure as well as decrease the calcium hydroxide concentration by consuming it through a pozzolanic reaction. The subsequent modification of the microstructure of cement composites improves the mechanical properties, durability and increases the service-life properties.

Some alternate or supplementary pozzolanic materials like Fly ash, silica fume, Rice husk ash, Ground Granulated Blast furnace Slag, High Reactive Metakaolin and zeolite can be used with cement as partial replacement in concrete and should lead to global sustainable development and lowest possible environmental impact and energy saving [1]. Many researchers showed that a part replacement of cement by mineral admixtures has improved the performance of concrete in strength and durability[2,12].

The incorporation of mineral admixtures such as silica fume in concrete is useful to increase the compressive strength , decrease the drying shrinkage, and the permeability [3,17]. Also the use of mineral admixtures in concrete is effective to increase the bond strength with the steel reinforcement [4], and abrasion resistance [5].

In this paper an attempt has been made to investigate the effect of zeolite powder on some mechanical properties such as compressive strength and bond strength. Moreover, the effect of zeolite powder on the corrosion of reinforcing steel bar imbedded in concrete was studied.

Natural zeolite which involves crystalline aluminosilicates in the types clinoptilolite, heulandite, analcime, chabazite and mordenite are uses in many fields :

*Agriculture: to install the resulting ammonia nitrogen in the soil sings due to its ability to ion exchange, it is used as fertilizer

* Industry: zeolite works as a catalyst material

* Water treatment: zeolite works as a filter and removing substances and impurities.

* Construction: zeolite improve the properties of fresh and hardened concrete.

II. Experimental Work

2.1. Materials

Cement and fillers: cement type CEM I 42.5 N meeting the requirements of ESS 2421/2007 was used table (1). The specific gravity of cement was 3.13 and the initial setting time was 90 min. at 27.5 percent water for standard consistency. Zeolite were delivered in 25-kg package with particle size 50µm table (2). Aggregates: natural siliceous sand having a fineness modulus of 2.54 and a specific gravity of 2.65 was used. Crushed dolomite with a maximum nominal size of 16 mm was used as coarse aggregate. The aggregate had a specific gravity of 2.65 and a crushing modulus of 23 percent. high tensile ribbed steel bars of 12 mm diameter were cut into 20 and 40 cm for corrosion and bond strength tests respectively. The water used was clean, fresh, free from impurities, and was taken from portable water supplies.

Table (1): Properties of Cement Type (CEM I 42.5 N)

Properties		Measured Values	Limits of the E.S.S*
Fineness (cm^2/gm)		3290	
Specific Gravity		3.15	
Expansion (mm)		1.2	Not more than 10
Initial Setting Time (min)		180	Not less than 60 min
Final Setting Time (min)		230	Not less than 10 hrs
Compressive Strength (N/mm^2)	**2 days**	22.4	
	7 days	33.7	-
	28 days	56.8	Not less than 42.5 and not more than 62.5
Chemical Compositions	**SiO_2**	20.36 %	
	Al_2O_3	5.12 %	
	Fe_2O_3	3.64 %	
	CaO	63.39 %	
	MgO	1.03 %	
	SO_3	2.21 %	
	Loss ignition %	1.3	

- ***Egyptian Standard no: 4756-1 /2007***

Table (2) Chemical composition of Zeolite admixtures

Test/ Result	rcentage
SiO_2	**63.9413**
CaO	**2.9563**
MgO	**0.5211**
Na_2O	**1.9606**
K_2O	**0.8247**
Fe2O3	**2.3314**
Al_2O_3	**13.2221**
SO_3	**0.0413**
Cl^-	**0.0145**
L.O.I	**13.8208**
TOTAL %	**99.6337**
Thermal Conductivity(W/m.k)	**0.31**

2.2. Preparation of test specimen

Different concrete mixedused are illustrated in table (3).

All batches were mixed using the same procedure in adrum pan mixer. The mixing sequence was placing the weighted coarse aggregate and fine aggregate in the mixer and mixed for 30 s., the cementatious materials were then added and mixed for few seconds to obtain a homogeneous mix. Then water and S.P were added and the mixing continued for 3 min more. The consistency and workability of the concrete mixes was evaluated using the slump test . Nine cubes of 150mm side length and twenty four cylinder's15*30cm were prepared and compacted using a compacting rod. The concrete specimens were demoulded after 24 hours and keep in water curing tank until the age of testing. The specimens were tested in saturated surface dry condition. table (3) shows the Concrete Mix Proportions

Table (3) Concrete Mixes used

Mix	Cement (Kg/m^3)	Dolomite (Kg/m^3)	Sand (Kg/m^3)	Zeolite%	W/Cm	Superplasticizer %
M0	350	1260	635	0	0.5	3
M1	332.5			5%		
M2	315			10%		
M3	297.5			15%		
M4	280			20%		
M5	262.5			25%		
M6	245			30%		
M7	227.5			35%		

2.3.Fresh concrete test

The consistency and workability of the concrete mixes was evaluated using the slump test. Table (4) shows the slumpvalues of different mixes.

Table (4) slump test of concrete

MIX	M0	M1	M2	M3	M4	M5	M6	M7
Slump (cm)	**17**	**15**	**14**	**13**	**10**	**8**	**6**	**4**

2.4 Hardened concrete

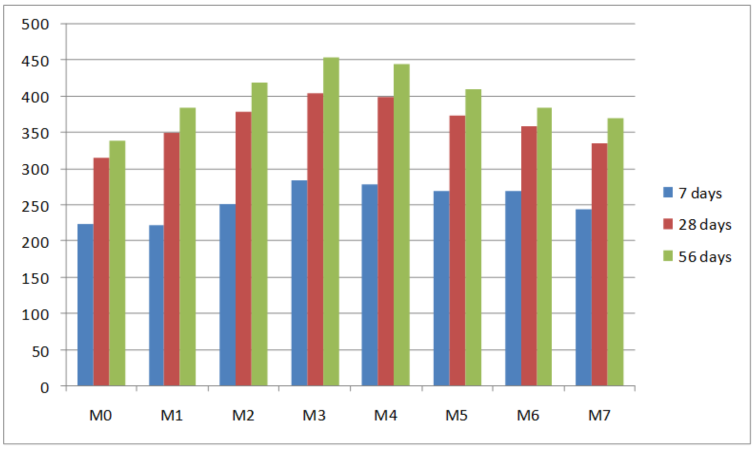
*2.4.*1 Compressive strength

Compressive strength tests were conducted on cured cube specimen at 7, 28 and 56 days age using a compression testing machine of 200 tons capacity. The cubes were fitted at centre in compression testing machine and a very small load was applied to keep the cube in position. The load was then slowly applied to the tested cube until failure.Both of table (5) and figure (1) show theconcrete cube compressive strength in different ages fore concrete mix and mixes containing different zeolite persentages.

Table (5) Compressive strength tests of concrete mixes

MIX	M0	M1	M2	M3	M4	M5	M6	M7
Comp.st at7 days *Kg/cm²*	225	235	251	285	280	270	270	245
Comp.st. at28days *Kg/cm²*	315	350	380	405	400	375	360	335
Comp.st at56days *Kg/cm²*	340	385	420	455	445	410	385	370

Comp.
Strength
Kg/cm2



Mix no

Figure(1) Effect of zeolite inclusion in different percentages on cube compressive strength of concrete

2.4.2. Tensile strength

Indirect tensile strength tests on cured cylindrical concrete specimen of 28 days age(ft) were performed using a compression testing machine. The cylinder's were fitted in compression testing machine with a steel bar on each side of the concrete cylinder to achieve line load. Table (6) shows the Tensile strength valuesof specimens containing different zeolite percentages.

Table (6) Indirect tensile strength results for different concrete mixes

MIX	**M0**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
ft (Kg/cm^2)	**42**	**44**	**46**	**51**	**49**	**47**	**44**	**46**

2.4. 3 Bond strength

The bond strength of steel substrate with concrete structure was evaluated. After curing of the block, load versus slip was observed with the help of a tensile testing machine (100 KN make tensile testing machine), fitted with an appropriate precession slip measuring device. The average bond strength was computed as the following:

$$\tau = \frac{p_{\max}}{\pi . d . l} \qquad (1)$$

Where τ is the bond strength; P_{max} is the maximum pullout load; d is the bar diameter; and L is embedment length of bar.

Table (7) Bond strength results for different concrete mixes

MIX	**M0**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
bond.st. at28days Kg/cm^2	**55**	**57**	**60**	**67**	**66**	**63**	**58**	**55**

2.4.4 Corrosion tests

A- Weight loss method

Immersion corrosion tests as shown in **Figure**.2 were carried out at room temperature according to ASTM G1 and G31 [7]. Concrete cubes of size 15×15×15 cm were cast with partial replacement of cement by zeolite by different amounts. High tensile ribbed steel bars was embedded at a cover of 25 mm in the cube. Initially the steel bars were cleaned in HCl acid solution (3.5%) for 5 minutes, degreased with acetone and washed with distilled water and dried. The initial weight of the steel bars was(W_0) taken before casting using q digital balance for the original weight (W_0). After immersion in 3.5 wt.% NaCl solution for 60 days , At the end of the exposure period, the concrete specimens were broken and the rebar specimens were removed and cleaned with HNO_3 solution for 3 min and dried. The specimens were reweighed and the loss in weight was calculated. The corrosion rate CR (from the mass loss) was calculated using the following equation [7]:

$$CR = \frac{K \cdot W}{A \cdot D \cdot T} \qquad (1)$$

where CR is the corrosion rate expressed in mils per year (mpy), K is a constant (3.45×10^6), T is the time of exposure (h), A is the area (cm^2), W is the weight loss in the nearest 1 mg and D is the density of the material (g/cm^3).

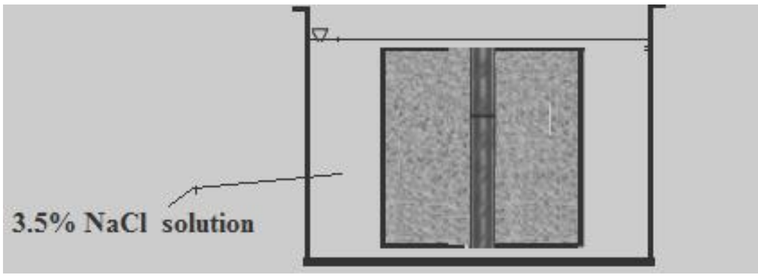


Fig.2 Experimental setup for immersion corrosion tests

B- Electrochemical technique

Cubic specimens with an edge of 150 mm were prepared. The rebar was positioned in the centre of the mould. Steel bar and concrete are only bonded in half length of the cubic specimen, in order to exclude an eventual confinement of the concrete surrounding the rebar due to the stress distribution on the specimen surface in contact with testing rig. During the specimen casting, concrete was placed in the moulds in the perpendicular direction of the rebars, so-called "rebars casted in the horizontal".

The corrosion analysis was performed by A Potentiostat/Galvanostat (EG&G model 273). A three-electrode cell composed of a specimen as a working electrode, Pt counter electrode, and Ag/AgCl reference electrode were used for the tests (Fig3).

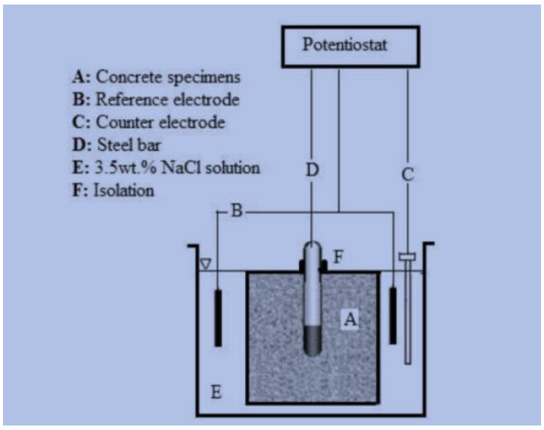


Fig.3 Experimental setup for electrochemical technique

Polarization tests were carried out at a scan rate of 0.5 mV/s at room temperature. Specimens with exposed surface area of 20 cm^2 were used as a working electrode. The PAR Calc Tafel Analysis routine statistically fits the experimental data to the Stern-Geary model for a corroding system. The routine automatically selects the data that lies within the Tafel region (± 250 m_V with respect to the corrosion potential). It then calculates the corrosion current and the corrosion rate. The solutions were prepared using analytical reagent grade chemicals and distilled water. The volume of the test solution was 5 liters.

2.4. 5 Microstructure

Scanning electron microscope (SEM) was used to observe the microstructure of concrete with and without zeolite particles additives. All samples were coated with gold to improve the appearance of microstructure.

III. Results and Discussions

3.4.Effect of zeolite on microstructure of concrete

Fig. 4(a) shows, the(SEM) slide of the ordinary Portland cement concrete without Zeolite. It has independently formed a C-SH gel, mutually linked needle-shaped hydrates (ettringite), and many $Ca(OH)_2$ crystals, showing a sparse internal structure with non-crystal hydrates. Figure. 4(b- e) shows the structure of concrete with different amounts of Zeolite. It can be seen that the crystals of $Ca(OH)_2$ decreases with increasing Zeolite up to 15wt.%. Beyond this value it increases again. This behavior is attributed to agglomeration of zeolite particles which exert more voids in concrete and decreases C_3S content.

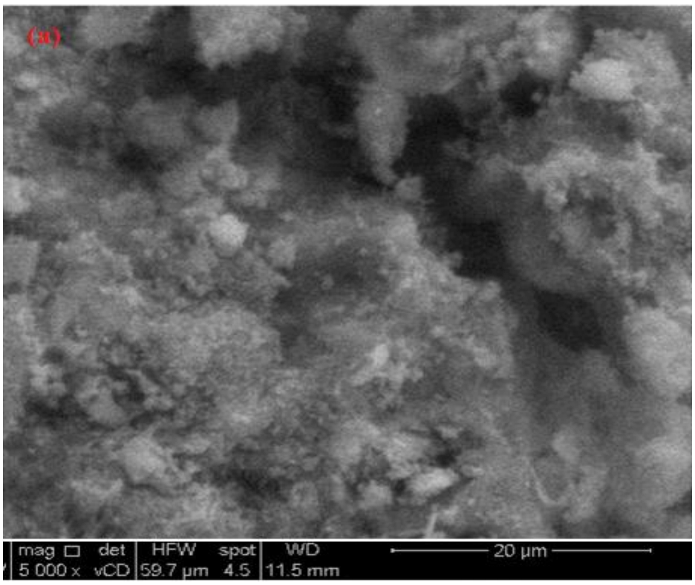


Fig.4.a Microstructure of concrete without zeolite

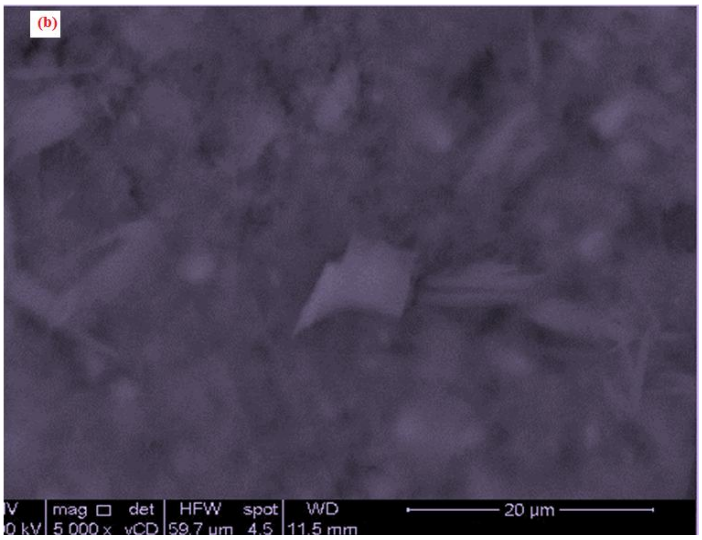


Fig.4b. Microstructure of concrete with replacement of-5wt.%

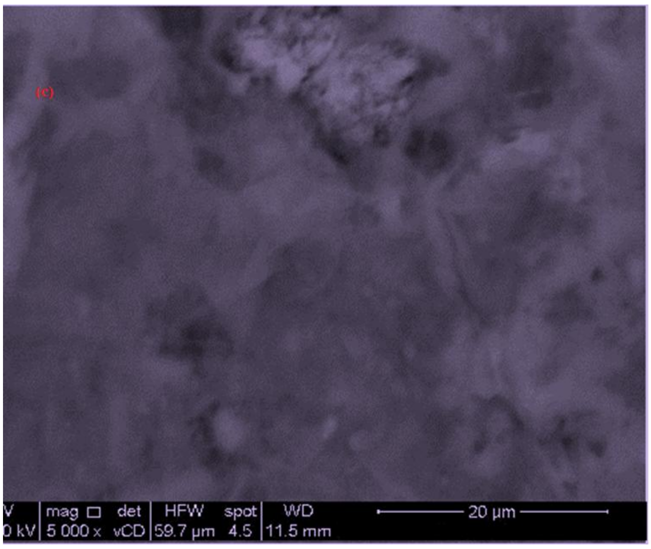


Fig.4c. Microstructure of concrete with replacement of-10wt.%

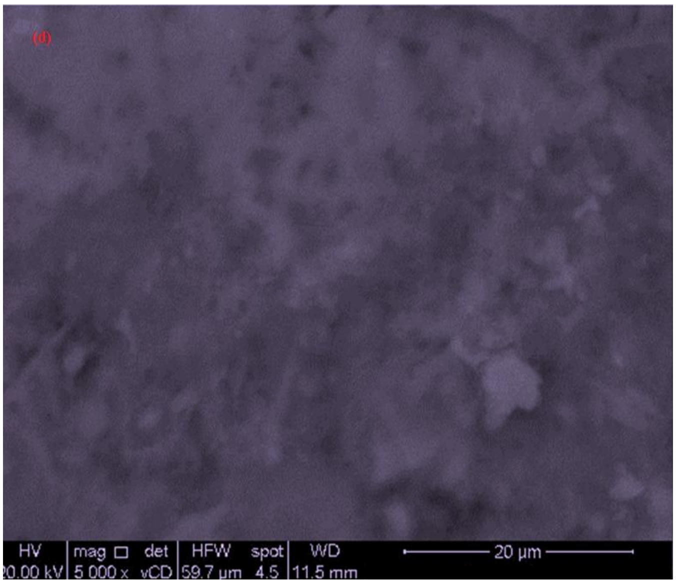


Fig.4d. Microstructure of concrete with replacement of-15wt.%

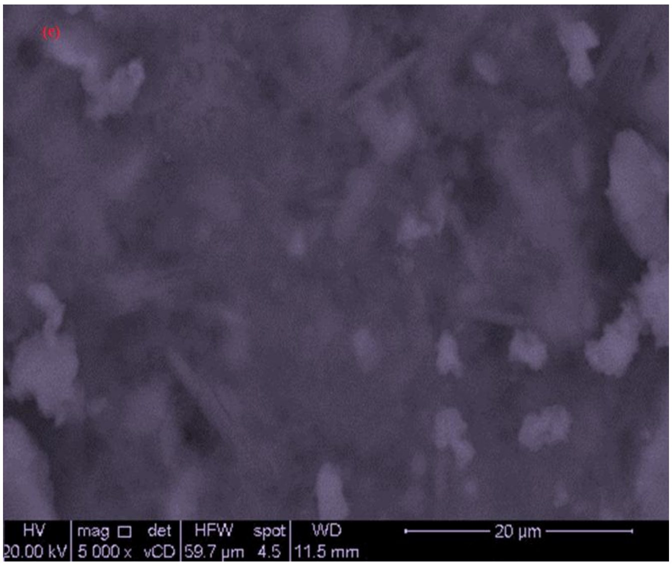
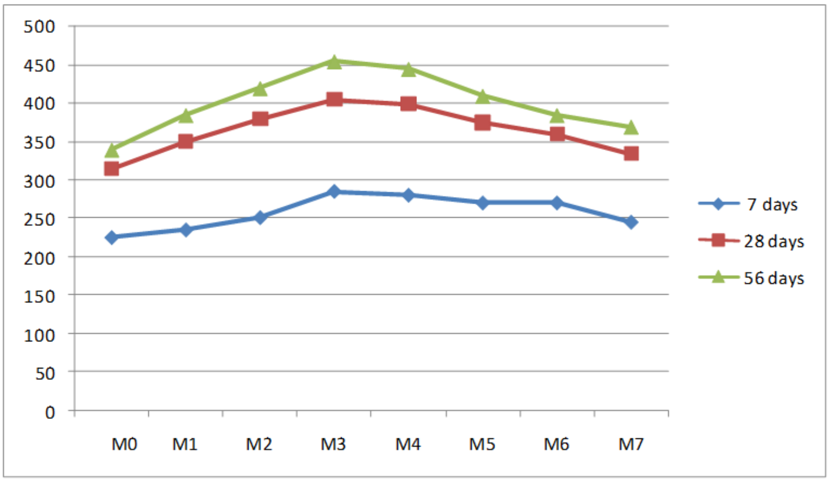


Fig.4e. Microstructure of concrete with replacement of20wt.%

3.1. Effect of zeolite on compressive strength of concrete

The compressive strengths have been evaluated from the peak load obtained by crushing the specimen. The compressive strengths after 7, 28 and 56 days are shown in Figure.(5) It can be seen that the compressive strength was developed in concretes containing zeolite in every case higher than the concrete specimen. of without that. The difference in the strength development of the mixtures can be attributed to pozzolanic reaction. Strength enhancement of SiO_2 can be attributed to reduction in the content of $Ca(OH)_2$ which has not any cementing property and production of hydrated calcium silicate (CSH) that plays a vital role in mechanical properties of concrete [8,9,10]. Therefore, in this procedure, the SiO_2 admixture can be filled among the cement particles to make hardened concrete compact and to improve the interface structure and performance. Moreover, Figure 5 indicate that the compressive strength increases with increasing zeolite content from 0 to 15 wt.% replacement of cement beyond this amount the strength decreases. This behavior is attributed to agglomeration of zeolite particles which exert more voids in concrete. Fig. 4a-c displays microstructure of concrete with and without zeolite additions. It can be seen from Figure. 4b that the concrete with 15wt. % of zeolite addition has less voids and its structure is more denser and large amounts of hydrate crystallizations were noticed. On the other hand Fig. 4c indicates that concrete with 35% of zeolite had more voids and small amounts of crystallizations were noticed.

Comp.
Strength
Kg/cm2



Mix no

Fig. 5 Effect of zeolite ratio on compressive strength of concrete

3.2. Effect of zeolite on bond strength of concrete

The results obtained are given in table7. It can be seen that most of the concrete mixes with zeolite performed better as compared to normal concrete. Most of this could be attributed to the reaction between zeolite and calcium hydroxide released from the hydration process leading to the formation of further calcium–silicate–hydrate (C–S–H), which enhances the interfacial bond strength between rinforcing bars and cement matrix. It coud be seen from table(7) that the optimum increase in bond between reinforcing bars and concrete is 21.8 % which achieved at replacing 15% by weight of cement by zeolite powder. Figure (3) indicates that the bond strength increases with increasing zeolite content from 0% to 15 wt. % replacement of cement beyond this amount the bond strength decreases this behavior attributed to agglomeration of zeolite which causes more voids with increasing zeolite more than 15 wt. % replacement of cement.

3.3. Effect of of **zeolite on corrosion of reinforced steel bars imbedded in concrete**

A- Immersion Tests

The corrosion rate of steel imbedded in concrete with and without zeolite was studied by weight loss method in 3.5 wt. % NaCl solution. Fig.6 shows that with increasing the zeolite replacement to 15 wt. %, the corrosion rate decreases. This may be due to decreasing of Ca(OH)2 crystals which have bad effect on concrete. When the amount of zeolite goes beyond 15 wt. %, the zeolite particles agglomerate and increase the voids in concrete. Increasing voids in concrete leads to penetrating large amount of water and hence increasing the chemical reaction.

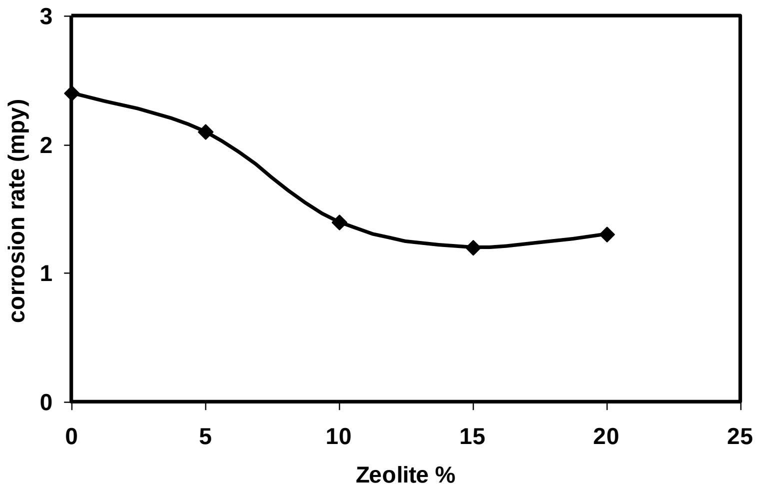


Fig. 6. Effect of zeolite on the corrosion rate of steel imbedded in concrete in 3.5wt. % NaCl solution using weight loss method

B- Electrochemical technique

In order to investigate the effect of zeolite additives on passive stability and corrosion of steel imbedded in concrete contaminated with chloride ions, polarization tests were performed. Figure(7) shows Tafel polarization curves of steel imbedded in concrete with and without zeolite additives in 3.5 wt. % NaCl solution. All the samples were immersed in the solution for about 20 days before polarization tests to achieve their stable potential values. It can be seen that the anodic current densities decreased with increasing zeolite additives to 15%wt. This behavior is due to concrete prevent chloride ions to penetrate the pores and attack the passive film on the steel surface and cause corrosion. Beyond this value more voids appear and allow chloride ions to penetrate and and contact with steel bars. Therefore electrochemical reaction occurs and increases with increasing voids. Electrochemical parameters obtained from potentiodynamic polarization can be presented in Table 8

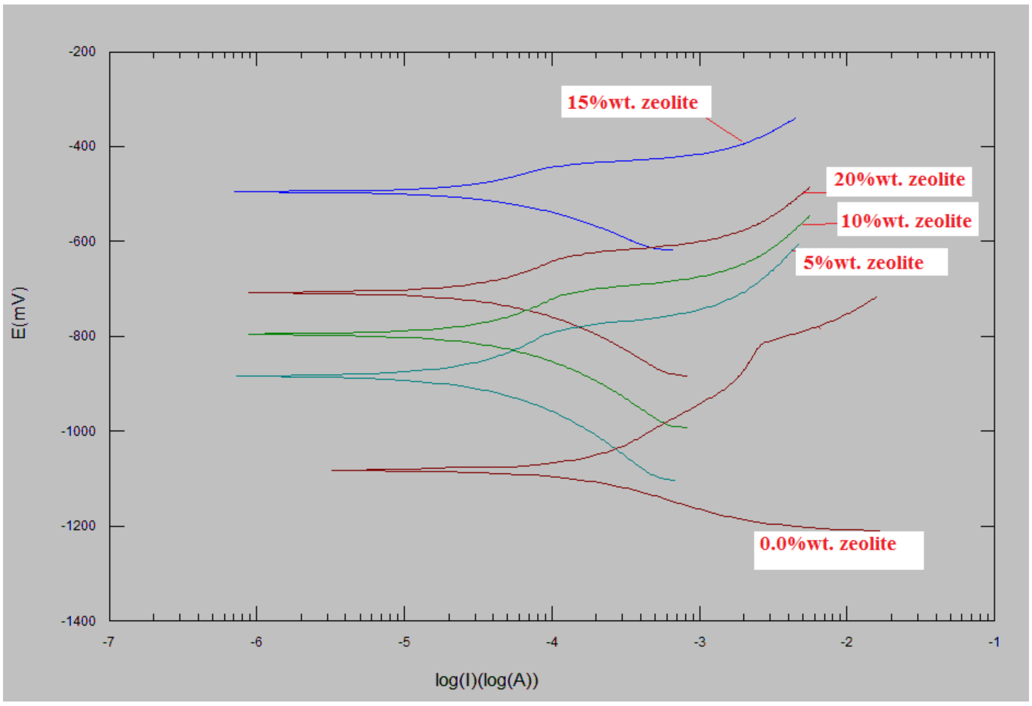


Fig. 7. Tafel polarization curves of steel imbedded in concrete with and without zeolite additives in 3.5 wt. % NaCl solution

Table 8. Electrochemical parameters obtained from potentiodynamic polarization measurements for the corrosion of reinforced steel bar in concrete immersed in 3.5 wt. % NaCl

SiO_2 Wt.%	$E_{cor.}$ (mV)	i_{cor} (A/cm^2)	β_c (mV/dec)	β_a (mV/dec)
0.0	-1250	$8.2*10^{-5}$	245	345
5	-920	$3.3*10^{-5}$	244	345
10	-780	$5.5*10^{-6}$	230	346
15	-450	$3.4*10^{-6}$	241	356
20	-750	$5.2*10^{-5}$	230	352

IV. Conclusions

This study investigated the effect of zeolite on compressive strength, bond strength, tensile strength and microstructure of concrete as well as corrosion of reinforcement. The results showed that the compressive strength, bond strength and corrosion resistance was increased with increasing zeolite content up to 15 wt. % as partial replacement of cement. Beyond this value, zeolite powder has smaller effect on these properties .The following conclusions could be drawn:

1- Maximum increase in compressive strength at 28 days accured at the replacement ratio of 15%was 28.6%compared with control specimen.
2- Maximum increase in tensile strength accured at 28 days at the replacement ratio15%was 21.4%compared with control specimen.
3- Maximum increase of bond strength at 28 days at the replacement ratio15%was 21.8%compared with control specimen.
4- Maximum decreas of corrosion rate was at the zeolite replacement percentage of 15 wt. %by weight.It reached about 1.1 mpy compared to about 2.4 for the control specimen.

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