The Corrosion Inhibition Effect of Forsterite (Mg$_2$SiO$_4$) Mine Tailings for Steel Rebar in Reinforced Concrete

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In this study, the usability of forsterite mine tailings (FOT) to provide steel reinforcing bar corrosion inhibition effect was assessed. To this end, C30 grade concrete specimens were produced with and without forsterite mine tailings. FOT were used with 5%, 10%, 20%, and 40% by volume in 150x150x150 mm cubic specimens, which then were subject to water curing for 28 days at 21±1ºC temperature. At the end of the curing, the specimens with FOT were tested under compression. It was seen the density and compressive strength of specimens with FOT were lower at different rates, depending on the amount of FOT. However, the specimens with 5%, 10%, and 20% FOT still exhibited higher compressive strengths than that of C30 grade concrete. The concrete mixes without and with 5%, 10%, and 20% FOT were poured into Ø50x100 mm molds with centrally embedded Ø10 mm flat steel reinforcing bars. The specimens were taken off the molds after 24 hours and subject to normal curing for 14 days. Then the specimens were placed into a 5% NaCl solution to enhance the corrosion in the reinforcing bars. Over the course of 17 weeks (approximately 120 days), the corrosion rate, Polarization resistance (Rp), Corrosion potential (E$_{(I=0)}$), and Corrosion current (Icor) values of the specimens were measured on a weekly basis by means of the Linear Polarization method. The results showed that the corrosion rate of the specimens with 5% and 10% forsterite mine tailings decreased compared to the reference specimens without forsterite tailings.

1. INTRODUCTION

Corrosion inhibitors are used as concrete additives in new buildings. However, they can also be used as patches within the concrete for protection purposes, or applied on the surface by spraying or painting [1,2].

The advantages of an inhibitor as a means of protection against corrosion is that it is evenly distributed within the concrete, protects all steel surfaces, and makes the concrete impermeable [3]. Corrosion inhibitors, in order to decrease corrosion rate, may increase the chloride threshold value or decrease the chloride permeability rate in the initial stage or during dispersion [4-7]. Ions such as hydroxide, citrate, and stannite are very effective inhibitors against steel corrosion in concrete-like environments formed using Portland pozzolana cement[8]. When 1-5% nitrite and phosphate-based-admixtures are used in OPC paste, the inhibitive effect is observed during the hardening stage, while chromate based admixtures become effective only after 28 days [9]. The most commonly used inhibitors in concrete are amino alcohols, calcium nitrites, and sodium monofluorophosphates [10].

In order to ensure environmental sustainability by minimizing the amount of CO_2 released into the atmosphere and the consumption of energy-natural resources, usage amount of the cement and concrete comprising industrial waste material increases day by day. This helps solve the waste storage problem, and also provides more durable concrete with enhanced mechanical properties, hence structures with longer service lives [11,12,13-15].

The specimens produced using the cement coded with CEM II 32.5 with 20% FA demonstrates the best behavior in terms of the DC power source applying fixed voltage of 30 V to the system which is the accelerated corrosion process [16]. The service lives obtained for specimens with 30% FA and 65% GGBFS, on the other hand, were 1761 and 1754 days, respectively [14]. This positive impact of fly ash against corrosion is due to the chloride binding capacity [17]. Furthermore, although there is no direct evidence, it is considered that stannous salts behave like a corrosion inhibitor for soft steel embedded within cement paste by binding to the corrosive products [18].

Olivine mining is relatively new in comparison to other minerals [19,20]. Although major olivine mines are found in Norway, it is also produced in Spain, Italy, and Turkey [21]. There are large dunite massives in Orhaneli, in northwestern Turkey [22]. The basic rocks containing the largest amount of olivine are dunites, named after the Dun Mountains in New Zealand. Dunites contain more than 90% olivine [23].

The total global olivine production is assumed to be around 8 million tons in the form of dunite or serpentine. In Turkey, the 2004, 2006, and 2008 forsteritic olivine production was 150.000, 150.000, and 200.000-500.000, respectively. In December 2010, the total forsteritic olivine production in Turkey was 590.000 tons [24].

Olivine that is widely used in steel production and the casting industry is also used in concrete production as aggregate [20]. Although there are many studies regarding the use of nanosilicate obtained from olivine in concrete [25-29], there are none about its direct use as a cement additive and its protective effect on reinforcement corrosion.

Olivine is a mineral with well-known dissolution kinetics. It dissolves quite quickly, especially in sea water at rates even higher than the theoretical estimates. When olivine is dissolved, the solution pH can reach up to 9-9.3. The major parameter that facilitates the dissolving of basic silicates is the pH of the ground solution that is in contact with minerals [30].

Contrary to the general view that Mg products caused by the dissolution of forsterite can result in expansion when used in concrete [31-33], the studies conducted by replacing the reactive MgO with cement during the production of precast concrete members matured by carbonation curing showed that

the combined effect of carbonation and reactive MgO results in a decrease in pore size and total pore volume, an increase in apparent density, and higher microhardness values. Chemical process and physical properties show that the dense inter-connected network structure composed of Ca and Mg carbonates is an influential factor affecting microhardness [34]. Furthermore, addition of 1wt. % of sodium hexametaphosphate reduces the water required for MgO/SF systems,which in turn improves the compressive strength in excess of 70 MPa [35].

The current study aimed to determine the behavior of concrete produced using Forsterite Tailings(FOT), a by-product of olivine mining, as a cement substitute, in a corrosive environment from a durability perspective and its mechanical characteristics. Furthermore, the study aimed to reduce environmental pollution due to waste materials, to make a contribution to the country's economy, to prevent or retard the reinforcement corrosion, and to enhance durability.

2. EXPERIMENTAL

2.1 Materials

In this study, cement, aggregate, mixing water, reinforcement steel, reference electrode, counter electrode, and a NaCl solution were used. The properties of the materials used for this study are given in this section, with reference to the relevant standards.

In concrete mixtures, Portland cement coded with CEM I 42.5 R produced at Isparta Göltaş Cement Factory was used. The physical, chemical and mechanical characteristics of the EN 197-1-compliant cement are given in Table 1.

The 0-2 mm, 2-4 mm, and 4-8 mm crushed stone aggregates used in the specimens were sourced from the Atabey district of the city of Isparta. The aggregates were tested for the grain size distribution using EN 933-1, loose – compacted unit weight using ASTM C29-09, specific gravity, and water absorption capacity using ASTM C127-12, and organic matter content using EN 1744-1.

FOT to replace cement by volume in concrete mixtures were sourced from the Bursa-Orhaneli district's Setat Mining Inc. waste field. The chemical properties of the forsterite wastes are given in Table 1.

Suleyman Demirel University campus tap water was used for the concrete mixing water.

The physical properties and particle size distribution of the aggregates used in the mixture are given in Table 2 and Table 3, respectively.

To measure the corrosion, cylindrical reinforced specimens that were 50 mm in diameter and 100 mm in height were used. For specimen production, the ribbed reinforcing steel bars of 10 mm diameter were cut to 135 mm length. The surface of an end of the steel bar having 10 mm in length were planed and cleaned.

This part of the bar had the cylindrical area of 392 mm^2 that was left unpainted to allow corrosion. All other parts apart from this were painted with three layers of antirust paint. In order to connect the conductive wire to be used for the aim of electronic measurements, a groove of 1 mm

depth was cut at the other end of the reinforcing steel bar. The reinforcing bar used in the production of the reinforced concrete specimens can be seen in Fig. 1.
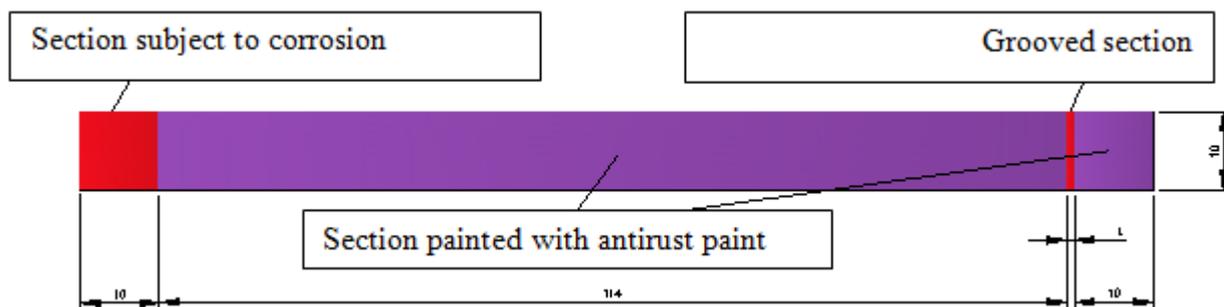

Figure 1. Schematic details of steel reinforcing bar within the concrete mixes

Table 1. Chemical compounds, and physical and mechanical properties of the cement and FOT

	Oxides (%)	CEM I 42,5 R	EN 197-1	FOT	ASTM C 618
	CaO	63.65	$(SiO_2+ CaO) \geq 50\%$	0.29	---
	SiO_2	19.87		43.68	$SiO_2+Al_2O_3+Fe_2O_3 >70$
	Al_2O_3	4.11	$\cong 6\%$	---	
	Fe_2O_3	3.44	$\cong 3\%$	10.60	
	MgO	1.61	$\leq 5\%$	45.35	
	SO_3	2.53	$\leq 4\%$	---	<4.0
	Na_2O	0.12	$(Na_2O+ K_2O) \leq 0.6\%$	---	
	K_2O	0.48		---	
	B_2O_3	---	---	---	
	Cl^-	0.004	$\leq 0.10\%$	---	
Main compounds	C_3S	65.52	$C_3S+ C_2S \geq 66.7\%$		
	C_2S	6.44			
	C_3A	5.04	-		
	C_4AF	10.47	-		
Physical Properties					
Specific gravity (gr/cm^3)		3.16	-	3.21-3.33	
Blaine fineness (cm^2/gr)		3440	2800-4000		
Initial setting time (min)		155	≥ 60		
Volumetric expansion (mm)		0.8	≤ 10		
Compressive strength (N/mm^2)					
2 days		23.6	≥ 20		
7 days		42.1	-		
28 days		50.2	≥ 42.5 ≤ 62.5		

Table 2. Physical properties of the aggregate used in the mixture

Experiment		0-2 mm	2-4 mm	4-8 mm	Standards
Unit weight (kg/dm^3)	Loose	1643	1533	1520	ASTM C29
	Compacted	1842	1629	1635	ASTM C29
Specific Gravity (kg/m^3)		2530	2610	2660	ASTM C127
Water absorption (%)		3.43	2.01	0.74	ASTM C127
Impurities and Other Harmful Materials determination		NA	NA	NA	EN 1744-1

Chemical properties of reinforcing bar are given in Table 4.

Table 3. Particle size distribution of the aggregate used in the mixture

	Percent Passing		
Sieve Size (mm)	0-2 mm	2-4 mm	4-8 mm
8	100	100	100
4	100	100	0
2	100	0	0
1	63	0	0
0.5	35	0	0
0.25	25	0	0
PAN	0	0	0

Table 4. The chemical compounds of reinforcing steel

Oxides	C%	Si%	Mn%	P%	S%	Cu%
(%)	0.13	0.21	0.50	0.023	0.026	0.052

In corrosion measurements, a saturated calomel electrode (SCE) was used as reference electrode. As a counter electrode, a platinum electrode with a 200 mm^2 surface area was used. A copper wire was brazed and fixed on the platinum plate.

In order to obtain a corrosive environment that can expose to corrosion for reinforced concrete specimens and to provide conductivity in the potentiometric measurements, a solution of 5% NaCl was used.

2.2 Methods

In this study, firstly EN 206 compliant C30 grade concrete, which is widely used in the construction industry, was chosen as the target compressive strength class and the amounts of material required for these mixtures were calculated. During these calculations, the aggregate to be used for this

study was determined as d_{max} 8 mm. The aggregate interval was calculated using the Fuller Parabola equation as 0-2 mm 50%, 2-4 mm 20%, and 4-8 mm 30%. Then, the forsterite tailings (FOT) were ground using a ball mill until the grain size was 0-200 μ. The ground FOT was used to replace cement by 5%, 10%, 20%, and 40%. The water/cement ratio (W/C) in the concrete mixtures with FOT was chosen as 0.40. All materials were prepared and weighed, and then the concrete mixtures were prepared using a pan type mixer. For the aim of mechanical tests, a total of 30 specimens were produced; 6 of these were reference specimens, 3 of which were left to water curing for 7 days and the remaining 3 to water curing for 28 days. Among the remaining specimens, each 6 contained 5%, 10% and 40% FOT. These specimens were tested for density and compressive strength. At the end of these tests, cylindrical specimens of 50 mm diameter and 100 mm height were produced in order to use the specimens with 5%, 10%, and 20% FOT that reached the target mean strength. A total of 25 cylindrical corrosion specimens were prepared; five reference (without additives), and five each with 5%, 10%, and 20% substitute ratio. The proportions of the materials used in the mixture are given in Table 5.

The R prefix indicates the reference specimens cast in C30 strength class without any additives, while O5-O10-O20 and O40 prefixes indicate concrete specimens cast in C30 target strength class with 5%, 10%, 20%, and 40% FOT substitutes by volume.

In order to determine the effect of FOT on the consistency of fresh concrete, slump tests were carried out in accordance with the EN 12350-2 standard.

Table 5. 1m^3 of concrete mixture proportions

Material types in Concrete Mixing (kg/m^3)		R	O-5%	O-10%	O-20%	O-40%
8-4 mm Coarse Aggregate	30%	503	503	503	503	503
4-2 mm Fine Aggregate	20%	329	329	329	329	329
2-0 mm Fine Aggregate	50%	797	797	797	797	797
Ground Forsterite Tailings		0	22,5	45	90	180
Cement		475	449	427	379	284
Mixing Water		190	190	190	190	190

Concrete specimens that were kept within the curing pool for 7 and 28 days were removed from the pool and were brought into the SDS condition. Then, the ultimate load of each specimen was obtained using a compressive strength test device in accordance with EN 12390-3.

In order to determine the behavior of FOT used within the concrete specimens to provide a corrosion inhibition effect, a series of linear polarization resistance measurements were obtained, as has been widely done in similar studies [36-40].

Specimens produced for corrosion measurements were held in a normal curing environment at 20 ±2°C and 100% relative humidity for 14 days and then were subject to 5% NaCl for 17 weeks. During these 17 weeks, linear polarization resistance measurements were taken at regular intervals. These measurements provided the following values: I_{cor} (corrosion current), R_p (polarization resistance), $E_{(I=0)}$ (corrosion potential), and corrosion rate.

The electrochemical technique of polarization resistance is used to measure absolute corrosion rates, usually expressed in milli-inches per year (mpy). The corrosion current can be related directly to the corrosion rate through the following equation[54]:

$$\text{Corrosion rate}(\text{milli}-\text{inches/year}) = 0.13\frac{I_{corr}(\text{E.W})}{d} \tag{1}$$

As stated by Khatri et al. [14], in studies dealing with reinforced concrete reinforcement corrosion, polarization resistance gives better results than the half-cell potential technique. The corrosion measurements were made with the three electrodes method using a PAR brand potentiostat device. In the test set-up used for corrosion measurements, a 5% NaCl solution was used for the corrosive and conductive environment, while platinum was used as the counter electrode and a saturated calomel electrode (SCE) was used as the reference electrode. Finally, steel reinforcement bars that were centrally embedded into the cylindrical concrete specimen were used as the working electrode.

3. RESULTS AND DISCUSSION

3.1 Slump test

With the slump test that was conducted on fresh concrete, 60 mm, 75 mm, 75 mm, 70 mm and 75 mm were measured respectively for R, O5, O10, O20, and O40 specimens. When the amount of water was kept constant within the mixtures, the use of FOT increased the slump value by approximately 15 mm in comparison to the R specimen and slump values did not change based on the waste substitute amount.

3.2 Hardened concrete density

The density values obtained for the reference specimen and specimens with the FOT addition using EN 12390-7 are given in Fig. 2.
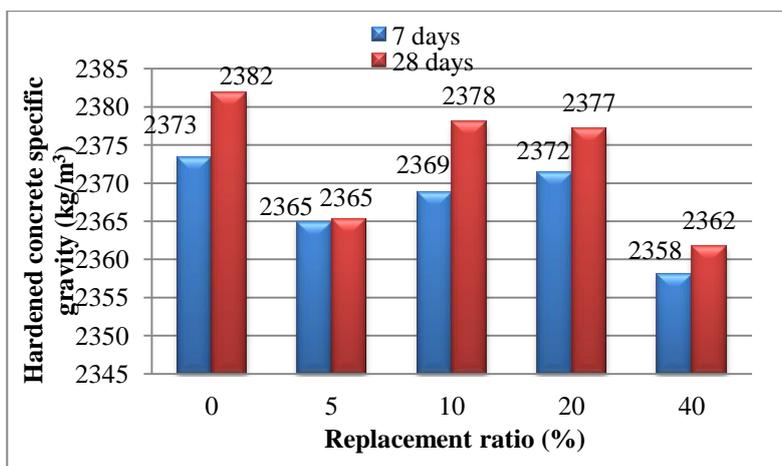
Figure 2. Densities of hardened concrete specimens

When the density values obtained for specimens with FOT were compared against those obtained for reference specimens, it is seen that there was a decrease of 0.36%, 0.19%, 0.08%, 0.65% in the 7 day specimens of O5, O10, O20, and O40, respectively. The density rates decreased for the 28 day specimens of O5, O10, O20, O40, at rates of 0.69%, 0.15%, 0.19%, and 0.84%, respectively. There was also a mild trending decrease in concrete density with increasing amounts of FOT, however the difference was not significant [40]. This is thought to be because the CSH gels formed by SiO_2 that are present in cement compounds and forsterite as a result of pozzolanic reactions are lighter than portlandite and pure silica [40,41].

3.3 Compressive strength

Hardened concrete reference specimens and those containing FOT were tested for compressive strength in accordance with EN 12390-3 at the age of 7 and 28 days. The obtained results are shown in Fig. 3.
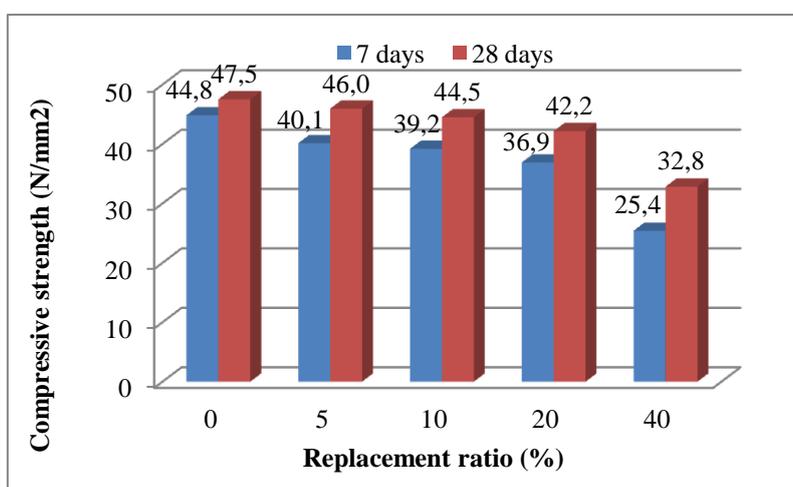

Figure 3. The compressive strength of hardened concrete specimens (N/mm^2)

When the obtained values are compared to each other, it was seen that as the amount of waste used in FOT specimens increased, the compressive strength decreased. The compressive strength values obtained for the 7 day specimens of O5-O10-O20-O40 were less than that of the reference specimen by 10.48%, 12.60%, 17.71%, and 43.35%, respectively. In the 28 day specimens with 5%, 10%, 20%, and 40% FOT additions, on the other hand, the compressive strength values decreased by 3.32%, 6.37%, 11.26%, and 30.95%, respectively. As can be seen, the strength reduction ratio was approximately 2 times when the FOT amount was increased from 5% to 20%, while this value was more than 3 times when the FOT amount was changed from 20% to 40%.

On the other hand, for all concrete specimens except for the one containing 40% FOT (5%, 10%, 20%), the targeted compressive strength value, C30, was obtained. When the relationship between strength reduction and fresh concrete slump value is examined, although the effect of mixture water is constant, the amount of FOT does not change slump values. Therefore, a correlation between the amount of forsterite waste used within the specimens and reduction in compressive strength could not be concluded. In a similar study, Yiğiter [42] reported that reduced compressive strength values were obtained in comparison to values obtained for reference concrete in case of 15-30-45-60% FA and blast furnace slag substitution. In this case, however, the sufficient pozzolanicity expected to be obtained with the use of FOTs as a substitute of cement to ameliorate the mechanical characteristics of the concrete could not be obtained. This is thought to be due to the fact that long term curing was not applied to ensure pozzolanic properties to clearly appear.

3.4 Linear polarization measurements

Because the specimens containing FOT by 40% fell short of the targeted C30 strength, cylindrical specimens with reinforcement bars were produced using O5, O10, and O20 mixtures. Findings obtained from these specimens are given in this section.

3.4.1 Corrosion rate

The results obtained from the corrosion rate testing of the specimens containing FOT that were subject to an environment with 5% NaCl for 17 weeks and the arithmetic means of these results are given in Fig. 4 and Fig. 5, respectively.

When Fig. 4 is examined, one will see that the specimens containing FOT follow a similar trend as reference specimens in terms of corrosion rate. Specimens containing 5% FOT exhibited the best performance among all, while specimens with 10% FOT exhibited a better performance than the reference specimens but resulted in a higher corrosion rate than specimens with 5% FOT. The specimens containing 20% FOT, on the other hand, exhibited a better performance than the reference specimens between week 6 and week 13; however, they resulted in an increasing corrosion rate from week 14 onwards.
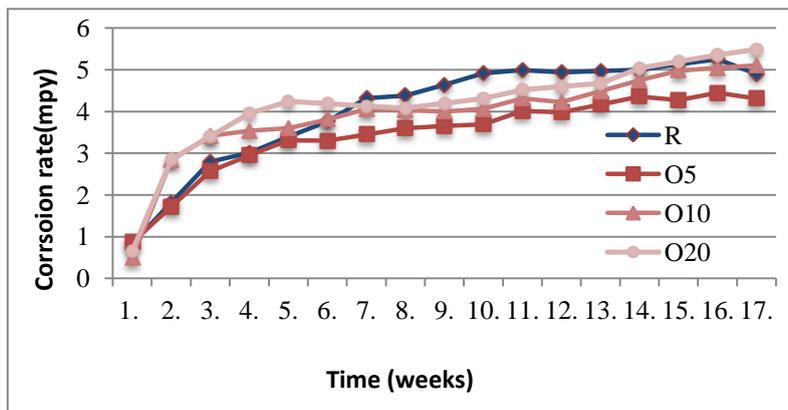
Figure 4. Relation of corrosion rate-FOT replacement ratio depending on time

The mean corrosion rate values obtained at the end of the 17 weeks corrosion process of specimens with FOT within a corrosive environment are given in Fig. 5.
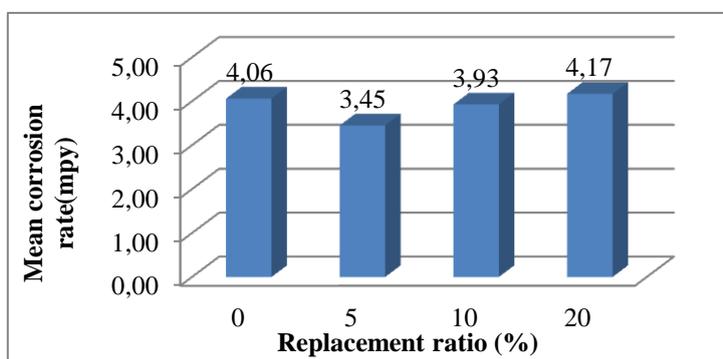

Figure 5. Mean corrosion rates for 17 weeks, depending on FOT ratio in samples

As seen in Fig. 5, the specimens containing 5% and 10% resulted in a lower corrosion rate by 15.05 and 3.20%, respectively, than the R specimens. When 20% FOT was used was a cement substitute, the corrosion rate increased by 2.71% in comparison to the R specimens. It can be concluded that use of 5% and 10% FOT can reduce the corrosion rate, and thus contribute to concrete durability. Therefore, it can be said that use of FOT by less than 10% will have an inhibitive effect. The corrosion inhibition mechanism provided by FOT is considered to be caused by C-S-H gels, formed as a result of the pozzolanic reaction between SiO_2 that is present in its chemical composition with CaOH inside the cement, resulting in a more impermeable microstructure [6,25,26,43-50].

3.4.2 Polarization resistance (R_p)

The polarization resistance (R_p) measurements taken from the specimens containing FOT, which were subject to a corrosive environment for 17 weeks, and the arithmetic means of these results are given in Fig. 6 and Fig. 7, respectively.
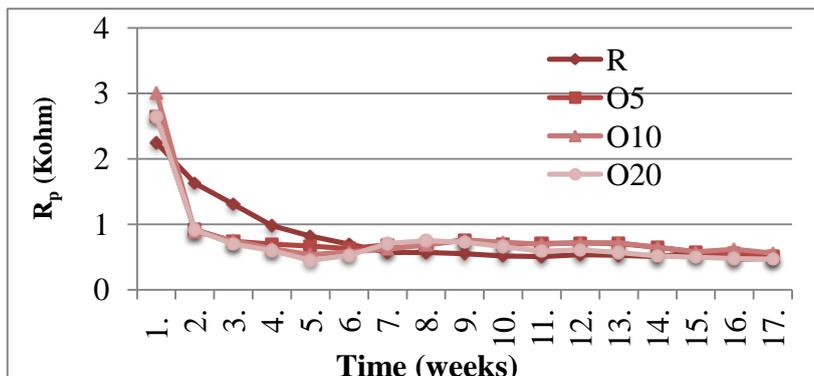
Figure 6. The relation of polarization resistance (R_p)-FOT ratios depending on time

When Fig. 6 is examined, it is seen that the polarization resistance of all specimens decrease over time, following a similar overall trend.
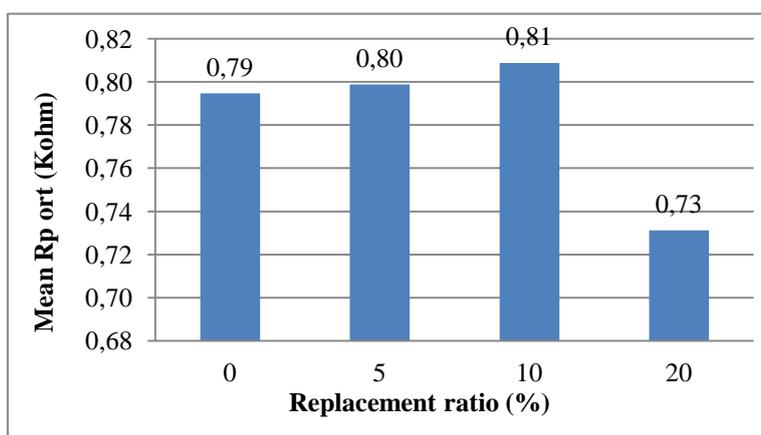

Figure 7. Mean polarization resistance for 17 weeks, depending on FOT ratio (R_p)

Fig. 7 shows that specimens containing FOT show a smaller variation in polarization resistance than Rs. Polarization resistance of 5% FOT specimens was lower by only 1.27% compared to that of Rs, while these values were 2.53% and 7.59% respectively for specimens containing 10% and 20% FOT. According to the electrochemical measurements, the corrosion rates are expected to decrease with increasing values of polarization resistance [12,14,15,38,51-53]. The findings obtained here, on the other hand, demonstrate that although there is a correlation between corrosion rate and polarization resistance, polarization resistance values are not positively affected by FOT usage as corrosion rate values. The reason for this may be that the specimen sizes are too small or more specimens, hence more measurements are required. The difference between the values calculated using two different methods is always quite likely. Because of this contradiction between the values obtained from electrochemical tests, it is a good decision to conduct a "gravimetric test," although it is a destructive test, before concluding that FOTs can be used as reinforcement bar corrosion inhibitors. When the results obtained from electrochemical tests and gravimetric tests are compared to each other, it is seen

that those given by potentiostatic LP technique are more realistic than those given by galvanostatic techniques and closer to the actual weight loss determined in the laboratory environment [54].

3.4.3 Corrosion potential results ($E_{(I=0)}$)

The corrosion potential ($E_{(I=0)}$) measurements obtained with a potentiostat device from the specimens containing FOT that were subject to a corrosive environment with 5% NaCl for 17 weeks are given in this section. For the experimental results obtained at the end of these measurements, see Fig. 8 and 9.
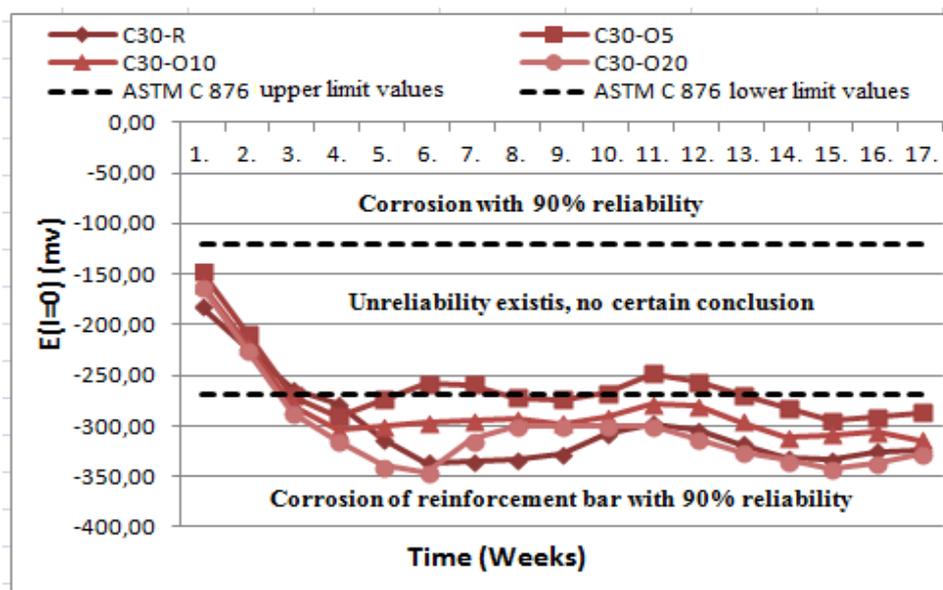

Figure 8. Relation of corrosion potential ($E_{(I=0)}$) -FOT ratio on specimens
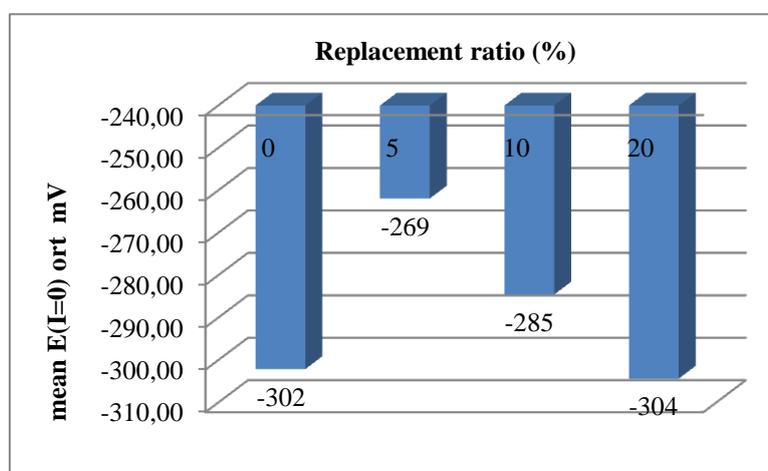

Figure 9. Mean corrosion potential ($E_{(I=0)}$) values for 17-week exposure

When Fig. 8 is examined, it is seen that all values are found in the corrosion within the 90% reliability area; however, the corrosion potential ($E_{(I=0)}$) decreases in comparison to the reference specimens with 5% and 10% FOT, and increases with 20% FOT.

Fig. 9 shows that FOT decreases corrosion potential ($E_{(I=0)}$) by 13.51% and 5.82% when used by 5% and 10% respectively, and 20% FOT increases corrosion potential by 0.75%.

Similarly, Sancak and Şimşek [46] reported that 10% silica fume and 20% super-plasticizers used to substitute cement by weight in load-bearing lightweight pumice concrete and normal aggregate concretes tended to decrease the corrosion potential of the reinforcement bars within the concrete specimens at the end of 17 wetting-drying cycles.

Keleştemur and Demirel [55], on the other hand, reported that the corrosion potential increased when concrete specimens produced by substituting cement by 5%, 10%, 15%, and 20% pumice by weight were left in 3% NaCl solution for 160 days. The same study concluded that corrosion potential decreased when the cement was substituted by 5%, 10%, 15%, and 20% finely ground pumice and 10% silica fume.

3.4.4 Corrosion current results (I_{cor})

The corrosion current densities (I_{cor}) of the specimens containing FOT, which were subject to corrosion for 17 weeks, were measured. For the experimental results obtained at the end of these measurements, see Fig. 10 and 11.
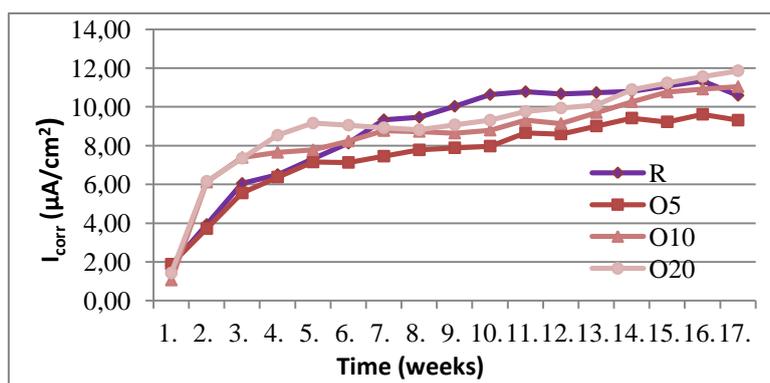

Figure 10. Relation of Corrosion current (I_{corr})-FOT ratio on concrete specimens

When Fig. 10 is examined, it is seen that the variation in the corrosion current values obtained from specimens with 5% FOT are parallel to the variation observed in reference specimens for the first five weeks, whereas from the seventh week onwards the corrosion current density values of specimens with 5%, 10%, and 20% FOT drop below reference specimens. After the 14th week in the corrosion process, the lowest corrosion currents were obtained from specimens containing 5% and 10% FOT, while the reference specimens and specimens with 20% FOT exhibited higher corrosion current values.
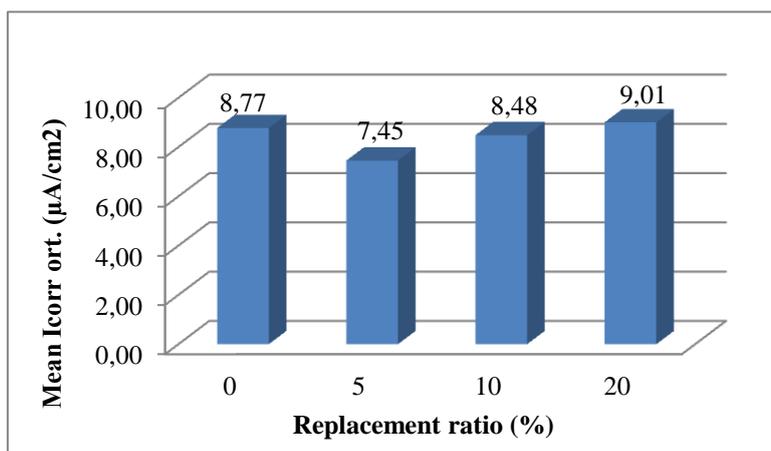
Figure 11. Change of mean corrosion current (I_{corr}) -FOT ratio for 17 weeks

Fig. 11 shows that the corrosion current values (I_{cor}) obtained from specimens with 5% and 10% FOT were 15.05% and 3.31%, respectively, lower than those obtained from reference specimens. This positive impact is thought to be because of the high chloride binding capacity of the C-S-H gels formed as a result of the puzzolanic reaction between SiO_2 compounds found in FOTs and CaOH [9,17,56-58], which help bind chloride infiltrating within concrete. Therefore, the specimens containing FOT reduce electric conductivity, hence reinforcement corrosion current, and create an effect to inhibit corrosion. It is also seen that FOT use by 20% increases corrosion current by 2.74%.

Similar results were obtained by Baradan and Yiğiter [59], who reported that when the high performance concrete specimens produced using 40% FA and 10% SF to substitute cement were subject to 3.5% NaCl solution for up to 200 wetting-drying cycles, 40% FA usage gave better results than 10% silica fume and decreased corrosion current in comparison to specimens produced without any additives.

4. CONCLUSIONS

The current study investigated the inhibitive effect of forsterite tailings used as a cement substitute on reinforcement corrosion. The results obtained from the tests are summarized below:

Increasing FOT amounts resulted in an approximately 1% decrease in the hardened concrete density in comparison to the density of reference specimen.

The compressive strength values obtained for concrete specimens containing FOT tended to decreases with increasing additive amounts. But, all specimens apart from those containing 40% (5%, 10%, and 20%) appeared to have compressive strengths above the targeted C30 grade concrete.

The corrosion rate mean values obtained for specimens containing 5%-10% FOT are lower than those obtained for reference specimens.

Because the use of 5% and 10% FOT as cement substitute results in an increase in the Rp value, gravimetric methods should also be employed before drawing the conclusion that FOT can protect the reinforcing bars within the concrete at least as much as reference concrete.

The corrosion potential values ($E_{(I=0)}$) obtained from specimens with or without FOT content are found within the uncertain zone for the first three weeks of the corrosion process. FOT usage of 5% and 10% decrease the corrosion potential ($E_{(I=0)}$), while 20% FOT resulted in similar values as reference specimen.

The lowest corrosion current values were obtained from the specimens containing 5% and 10% FOT, while specimens with 20% FOT exhibited higher corrosion current values at the 14th week of corrosion process. Due to this positive behavior, corrosion current decreases with 5% and 10% FOT usage.

When the results are used for an overall assessment, it can be said that a new method for waste disposal and reduction in need for clinker as well as energy savings can be provided, as using 5% forsterite tailings as a cement substitute has been demonstrated to have a positive impact on reinforcement corrosion.

Abbreviations

d_{max} Largest grain size, mm

$E_{(I=0)}$ Corrosion potential, mV

I_{cor} Corrosion current density, $\mu A/cm^2$

Rp   Polarization resistance,

Ø   Reinforcing bar diameter, mm

E.W. = equivalent weight of the corroding species, g.

d = density of the corroding species, g/cm^2.

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