

Effects of Migrating Corrosion Inhibitors on Reinforced Lightweight and Common Mortars

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ABSTRACT

In reinforced landmark, historical buildings, a series of mortars are commonly used for rendering of horizontal elements or filling of vertical ones. Corrosion of reinforcing steel represents the most important cause of concrete structure deterioration. This paper studies the protective effect of the reinforcement mortars, against rebars corrosion in mortar specimens containing corrosion inhibitors as admixture or as impregnation agent.

The migrating corrosion effectiveness was assessed in lightweight concrete with Greek pumice stone and in common mortar specimens. The inhibiting behavior of organic aminobased migrating corrosion inhibitors against steel corrosion was evaluated by specimens' immersion into 3,5%w.t. sodium chloride corrosive solution and by exposure to the atmosphere. The corrosion activity and inhibiting efficiencies (IE) were tested by measuring the rebars weight loss, their half - cell potential, carbonation depth and electrochemical measurements of chronicles corrosion rate of rebars in concrete specimens.

The results of our experiments have shown that the presence of the inhibiting protection increases in the mortars systems with the usage of migrating corrosion inhibitor compared to the reference specimens without corrosion inhibitor. Furthermore, common mortar specimens exhibited lower rebar corrosion rate than the lightweight concrete specimens. Finally, specimens with corrosion inhibitor exhibited the best corrosion protection results in corrosive conditions without chloride ions.

1. INTRODUCTION

Corrosion of reinforcing steel embedded in concrete is becoming a significant structural and financial problem. As it is known, in Greece, many historical buildings and structures are located in coastal regions (islands) where the weather is characterized by pollutants such as part particles Cl^- and carbon dioxide, CO_2 . This leads to an increased incidence of spalls, delamination and as a consequence the deterioration of concrete in reinforced structures.

In restorations, a series of traditional construction materials such as mortars, steel and grouts are commonly used for repairing and filling elements of structures. They are generally composed of cement, sand, lime and water or cement, sand, superplasticizer, and water [1]. Due to the fact, that the rest of the construction and the repair mortar have high porosity, the durability of these mortars is questionable as far as the corrosion of the reinforcement steel. This results in an attack from probably all sides as the water can penetrate either from the foundation and leakages in the roof or from porous walls [2]. As a result to a all above mentioned, many times the use of chemical admixture is essential due to blocking the ingress of chloride ions and oxygen, increasing the resistance of the passive film on the steel to breakdown by chloride ions.[3-4]

The use of chemical admixtures, which acts as corrosion inhibitors, is a method for preventing and delaying the onset of rebar corrosion. An ideal corrosion inhibitor has been defined as “a chemical compound, which, when added in adequate amounts to concrete, can prevent corrosion of embedded steel and has no adverse effect on the properties of concrete” [5]. Nowadays chemical corrosion inhibitors present an easily implemented solution to the growing problem of corrosion of reinforcing steel in concrete. However, to be considered viable, these additives should not only prevent or delay the onset of corrosion, they must not have any detrimental effect on the properties of the concrete itself, such as strength, setting time, workability and durability [6]. It must be clarified, that corrosion inhibitors do not totally stop corrosion, but rather increase the time to the onset of corrosion and reduce its eventual rate. Drawbacks of corrosion inhibiting admixtures are that they may not remain in the repair area, potentially reducing the concentration of the inhibitor bellowing necessary values and secondly, when used in a limited area long a continuous reinforcing bar, there is the potential for micro cell corrosion development [7].

The aim of this study is the examination of the performance, in chloride environment of two different sets of steel reinforced mortar specimens (lightweight and common mortar) together with corrosion inhibitor in an effort to lower the corrosion rate of steel reinforcement. Corrosion parameters such as corrosion rates, I_{corr} , R_p of reinforcing steel in mortar specimens from two differences types of mortar have been evaluated by electrochemical measurements and compared with that obtained from metal loss determination. Electrochemical corrosion measurements gives a snapshot of how the system mortar – steel behaved under corrosive environments versus time. Linear polarization, as well as

Tafel technique are not destructive methods for assessing the instantaneous corrosion current density. It has been widely used in monitoring corrosion of laboratory measurements and allowed to compare the performance of inhibitors in mortars specimens [8].

2. MATERIALS AND EVALUATION METHODS

2.1. Materials

Greek Portlant cement was used for whole mortar specimens in this study. The chemical composition is given in Table 1.

Half of the test specimens were constructed with lightweight aggregate and the rest of them were with Greek sand. The use of the porous lightweight aggregates results in porosity increase, which could negatively affect the corrosion rate if steel rebars.

The lightweight aggregate used was a Greek porous pumice of 0 to 8mm diameter. The mean value of the sand grains diameter was $250_{\mu} < d < 4\text{mm}$. Round deform med reinforcing steel, nominally 12mm in diameter (ϕ_{12}) was used for all test specimens. Fabrication of the steel for the test specimens simply involved cutting to the consistent length of 100mm. Their chemical composition is given in Table 1.

Drinking water from Athens water supply network and INHIB-M, corrosion inhibitor alkanolamines based on, were used for the specimens' construction. The corrosion-inhibiting admixture was used according to the manufactures instructions regarding dose rate and mixing into the concrete. INHIB-M protects both the anodic and cathodic parts of the corrosion all. It's claimed to work by depositing a physical barrier in the form of the surface film that inhibits corrosion of the steel by preventing contact between moisture and oxygen. The inhibitor is able to diffuse through the concrete through either a vapor or liquid phase.

Table1: chemical composition % of OPC cement.

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	SO ₃	CaO _(f)	LOI
20.67	4.99	3.18	63.60	2.73	0.37	0.29	2.414	2.41	2.52

Table2: chemical composition % of steel rebars.

C	Mn	S	P	Si	Ni	Cr	Cu	V	Mo
0.18	0.99	0.047	0.023	0.15	0.09	0.09	0.21	0.002	0.021

2.2. Specimens Casting

The test specimens considered for the present study were 80mm long, 80mm wide and 100mm high. They contained four identical steel rebars in the position shown in figure 1. Copper wire cables were connected to each steel bar for electrochemical measurements. Prior to the preparation, the surface of the steel bars were washed with water, then immersed for 15 min in strong solution of HCl

with organic corrosion inhibitor washed thoroughly with distilled water to eliminate traces of the corrosion inhibitor and chloride ions. Following that, they were cleaned with alcohol and with acetone and then weighed to 0,1mg accuracy.

Thereafter, the bars were placed in moulds, as shown in figure 1, where the mortars was cast and stored at ambient conditions in the laboratory for 24 hours. After being demolded, were cured in tap water at 25 °C for 24 hours.

The specimens were stored for an additional 24h at ambient temperature and thereafter the part shown in Figure 1 was insulated with epoxy resin.

Finally half of them were partially immersed in 3.5% w.t NaCl solution up to 20mm from the bottom of the mortar specimens and the rest of them were exposed to the atmospheric conditions.

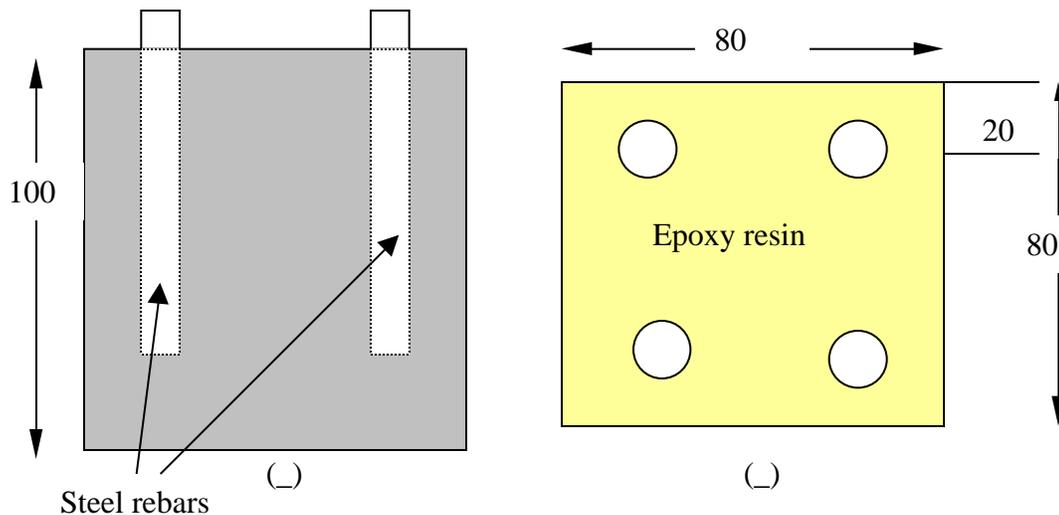


Figure 1: Schematic representation of reinforced mortar specimen (a) upper, (b) lateral view. Dimensions of specimens in mm

2.3. Evaluation Methods

The objective of these experiments was to investigate mortar with corrosion inhibitor as corrosion protection system and evaluate its performance in reference to specimens without any addition of admixtures.

The migrating corrosion effectiveness was assessed in lightweight concrete with Greek pumice stone and in common mortar specimens. The inhibiting behavior of organic alkanolamines based migrating corrosion inhibitors against steel corrosion was evaluated by specimens' immersion into 3,5%w.t NaCl corrosive solution and by exposure to the atmosphere. The code numbers and the composition for the different sets of specimens used in this study are shown in Table 3. The experimental duration of this study was 1year. Whole experimental procedure will be discontinued at the conclusion of two full years of testing.

Methods used to assess specimens' performance included the corrosion potential, carbonation depth, corrosion rate, and mass loss time dependence of the rebars measurements.

Specimens with all categories were immersed in 3.5% w.t NaCl solution and their electro chemical values were examined in order to evaluate the reinforcement corrosion in mortars. The test setup for both the Tafel plot as well as the linear polarization resistance techniques included a potentiostat / galvanostat, E.G & Model 263. Additionally, a computer program, Softcorr III developed by E.G & G Princeton Research was used for applying the potential scan, analyzing the parameters I_{corr} , R_p .

Half – cell potential measurements for each of the test specimens were recorded at regular intervals versus a saturated calomel reference electrode (SCE), for the duration of this experiment. Initially, these measurements were taken every day, until equilibrium conditions were established. Following, half – cell measurements were recorded every week. Twelve months after the start of this experiment the specimens were removed from the corrosive environment and broken in order to measure the carbonation depth and weight loss of steel rebars.

Table 3: Type and Composition of specimens

Specimens						
Composition ratio						
Code name	Cement	Pumice	Sand	Water	Corrosion inhibitor (lt/m³)	Remarks
K-I	1	3	-	1	-	<u>Category I:</u> <i>Immersed in 3,5%w.t NaCl</i>
KM-I	1	3	-	1	1.24	
S-I	1	-	3	0.6	-	
SM-I	1	-	3	0.6	1.24	
K-II	1	3	-	1	-	<u>Category II:</u> <i>Exposed in Atmosphere</i>
KM-II	1	3	-	1	1.24	
S-II	1	-	3	0.6	-	
SM-II	1	-	3	0.6	1.24	

The steel rebars were cleaned from rust according to above mention procedure, the metal loss was determined and the corrosion rates were calculated by the following equation.

$$\text{Corrosion rate } (m/y) = 8.76 \times 10^7 W / (A * T * D) \quad (1)$$

W : metal loss in [g], A : area of steel in [cm²], T : time of exposure in [h], D : density of steel in [g/cm³]

The carbonation of the specimens was determined by the method recommended by RILEM CPC-18, on broken mortar pieces. The carbonation depth of mortar was calculated in the interval section of the specimen using phenolphalein and by measuring the area where the colour did not change to red.

3. MEASUREMENTS AND RESULTS

3.1. Category-I: Specimens immersed in 3.5%w.t NaCl

Half-cell potential measurements given in figure 2 came out from the first category of specimens that were immersed in 3.5%w.t NaCl solution. According to the standard test method ASTM C 876, Standard test method for Half Cell Potentials of reinforcing Steel in Concrete, the more negative the voltmeter reading, the greater the probability of active corrosion. Values less than -350mV , have as a result 90% probability of active corrosion. It is obvious that for all the specimens there is a tendency for the reduction of their potential value from the range of -300mV to -650mV . these measurements suggests a high probability of an active stage of corrosion throughout the test period.

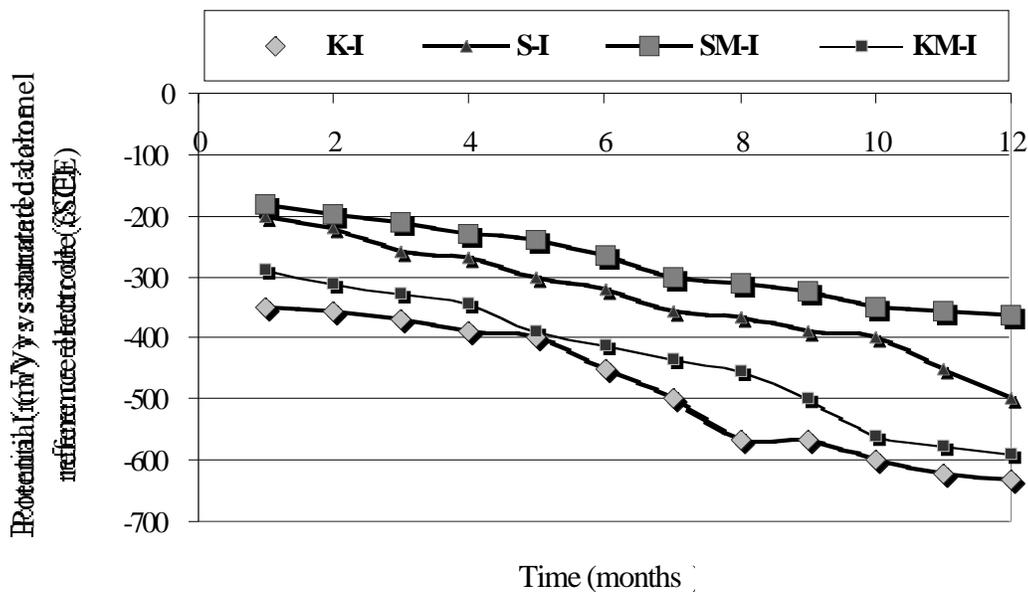


Figure 2: Half- cell potential measurements vs immersion time.

The results of mass loss measurements of reinforcing steel, after twelve months of exposure in chlorides solution are given in figure 3. It is obvious that mass loss differences are higher when lightweight mortars are compared to common mortars that contain as aggregate sand. From these results, the improvement of the mortars properties and consequently of the corrosion performance of steel rebars when the aminobased corrosion inhibitor added is evident. The INHIB-M, lowering the steel rebar mass loss after twelve months of exposed by about 45% in lightweight mortar and 50% in common mortar specimens.

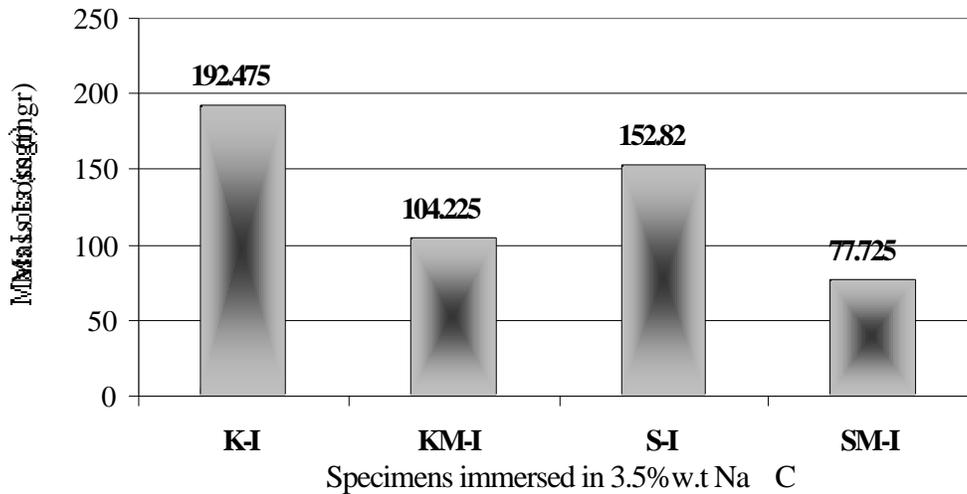


Figure 3: Mass loss measurements of lightweight and common mortars after 12 months of partially immerse to NaCl 3.5% w.t.

Carbonation of specimens versus time is shown in figure 4. Between mortars with sand and mortars with Greek pumice as an aggregate, it is observed that the specimens, which exhibit carbonation, were the latter mortars. Lightweight specimens without corrosion inhibitor, exhibit 3.5 times higher carbonation depth values than those with corrosion inhibitor. From these results, it seemed that the corrosion inhibitor addition in the lightweight mortars protect steel by a mechanism that seem to influence to carbon dioxide access.

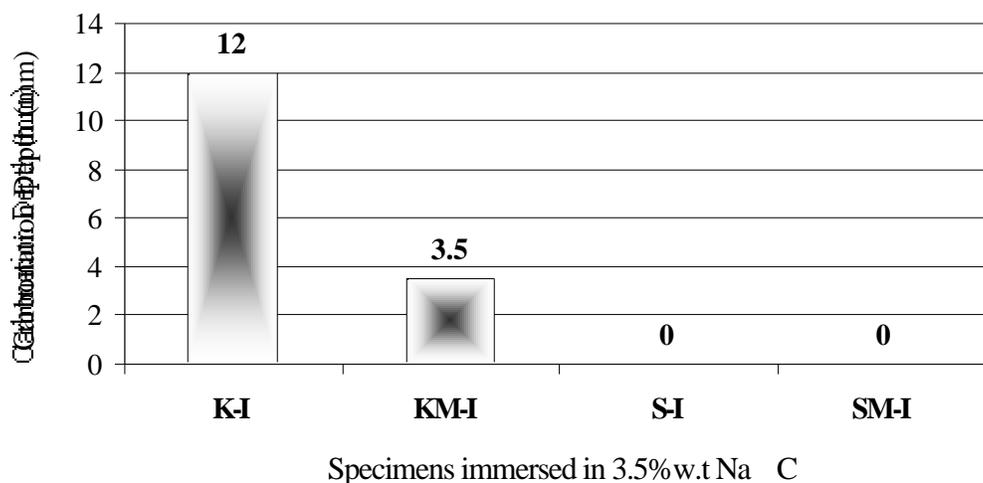


Figure 4: Carbonation depth of lightweight and common mortars after 12 months of exposure to NaCl 3.5% w.t.

In Tafel plot technique, a potential scan was applied to the specimens starting from E_{CORR} and extending to 250mV either in the cathodic or anodic direction. The

current measurements in this case were the difference between anodic and cathodic currents. Figure 5 gives the Tafel curves generated at chloride level of 3.5% w.t.in solution that specimens were been immerse. In linear polarization technique, a controlled potential scan was applied to the specimens in a range much smaller than that used in the Tafel plot. It was from $E_{corr}-25mV$ to $E_{corr}+25mV$. The R_p polarization resistance, which is the slope of the potential current curve at E_{corr} is related to I_{corr} . Table 4 is a comparison of the corrosion rate values from electrochemical techniques with those from the mass loss determination technique.

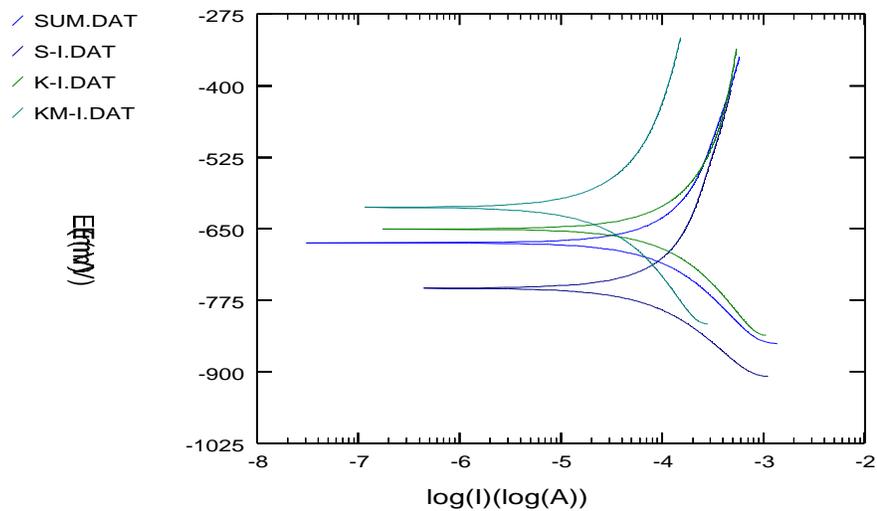


Figure 5: Tafel plots curves for reinforcing steel in common mortar and lightweight specimens immersed in 3.5% w.t. NaCl

Table 4: Corrosion rates of reinforcing steel in mortars with and without corrosion inhibitor, calculated by different techniques.

Code name	Tafel plot technique			Linear polarization technique			Weight loss determination	
	Rp (Ohms)	Icorr (___)	Corrosion rate (mpy)	Rp (Ohms)	Icorr (___)	Corrosion rate (mpy)	Mass loss (mg)	Corrosion rate (mpy)
K-I	371.6	58.44	1.715	386.1	56.24	1.650	192.475	0.71193
KM-I	538.5	40.32	1.183	438.5	49.52	1.453	104.225	0.3855
S-I	460	47.20	1.384	480	45.15	1.325	152.82	0.5652
SM-I	1379	15.75	0.4617	1481	14.66	0.4298	77.725	0.2874

1.2. Category-II: Specimens exposed in atmosphere.

The results of mass loss measurements of reinforcing steel, after twelve months of exposure in atmosphere are given in figure 6. The INHIB-M, lowering the steel rebar mass loss after twelve months of exposed by about 44% in lightweight mortar and 45% in common mortar specimens.

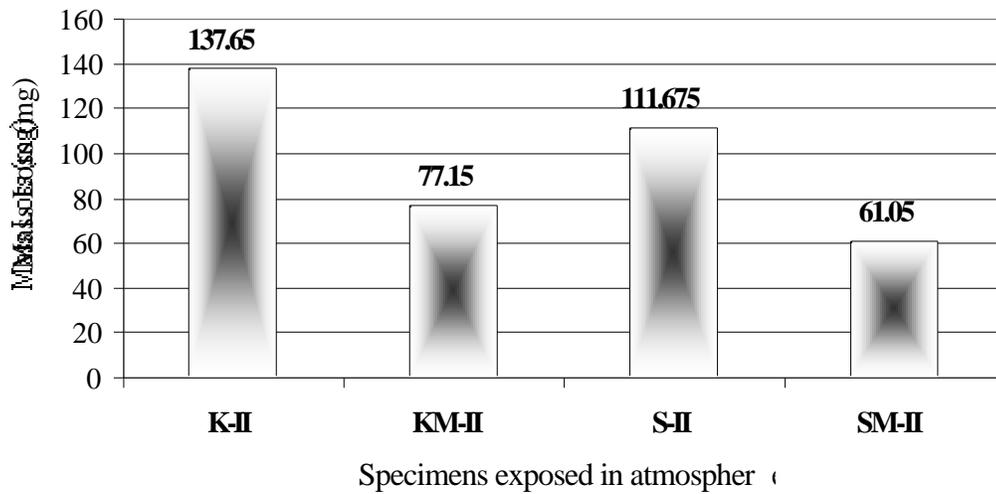


Figure 6: Mass loss measurements of lightweight and common mortars after 12 months of exposure to atmosphere.

Carbonation of specimens versus time is shown in figure 7. From these results, it seemed that the corrosion inhibitor addition in mortars protect steel by a mechanism that does not seem to influence to carbon dioxide access. The carbonation depth in lightweight mortars is definitely higher than those in mortars with sand as aggregates.

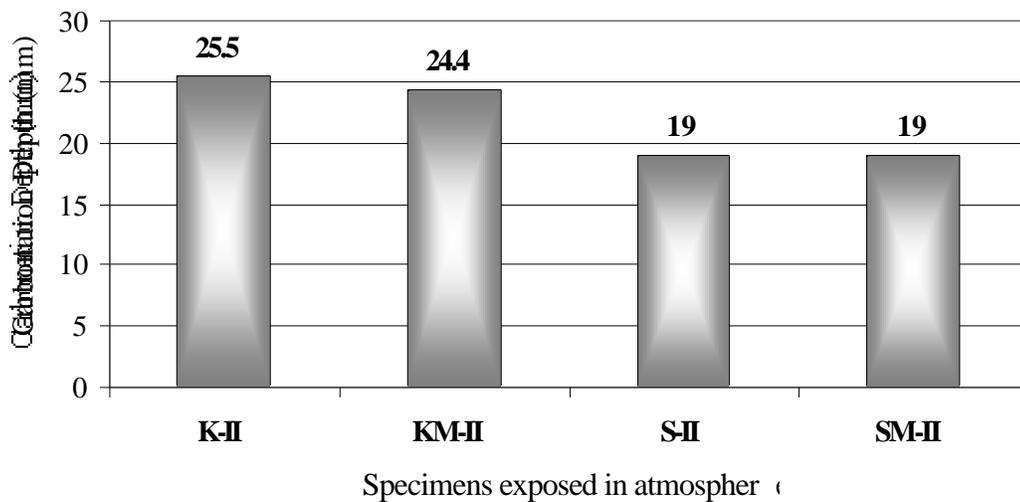


Figure 7: Carbonation depth of lightweight and common mortars after 12 months of exposure to atmosphere.

4. CONCLUSIONS

The usage of corrosion inhibitors has decreased corrosion both in the specimens that were partially immersed in 3.5%w.t NaCl as well as in those that were exposed in atmospheric conditions exposed for about 45% and 50% respectively.

The results of the electrochemical measurements for calculating the corrosion rate in order to have a first estimation of the corrosion of the mortar specimens that were partially immersed in 3.5%w.t NaCl solution are certified and confirmed by the results of the calculations of the reinforcements mass loss in the mortars for a twelve month corrosion period.

The carbonisation with a high porosity aggregates is by far larger when compared with the one in the specimens that were mortars made with common sand. The corrosion in the lightweight mortars has reached the surface of the reinforcements in a about a year's time and in that case the corrosion inhibitor has decreased the reinforcements corrosion for about 45%. As a result the conclusions of this study are in line with the confession that the usage of corrosion inhibitors is doubling the lifetime of the constructions.

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