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Electrochemical and Mechanical Properties of Lightweight Concrete Blocks with Expanded Polystyrene Foam

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Currently, the expanded polystyrene foam (EPS) is one of the industrial wastes that produces more pollution to the environment, since they do not break down or integrates to the nature. This paper presents the results of an experimental study on mechanical properties and corrosion effect with lightweight concrete with expanded polystyrene thermally modified (MEPS). The MEP received a heat-treatment maintaining the EPS in a hot air oven at 110 ºC for 10 minutes. 5 lightened concrete mixes were designed by replacing the gravel to the levels of 0%, 25%, 50%, 75% and 100% in volume by MEPS and a w/c ratio=0.65. The corrosion behavior was monitored for 105 days, under these conditions: 3.5% NaCl at a temperature of 23 °C. It was used the electrochemical corrosion potentials (E_{corr}) and resistance to linear polarization (Rp) techniques. Furthermore, the results were related to the technique of mechanical resistance (f'c), the ultrasonic pulse speed (VPU), and the capillary absorption coefficient (k). Under the conditions of this study it was observed a close relationship between the different techniques to infer the behavior of the lightweight concrete with MEPS, which determined that the concrete blocks lightened with the 75 and 100% of MEPS presented mechanical resistances lower than 15 MPa, but enough to the provisions of the Mexican standard NMX-C-404-ONNCCE-2005. It was also observed that when the blocks were submerged in the solution of 3.5 % NaCl they showed a better corrosion protection, helping to keep the reinforcing steel in a passive state.

Keywords: Lightened concrete, polystyrene thermally modified, linear polarization resistance, corrosion resistance, and mechanical strength.

1. INTRODUCTION

In many countries, the increase in costs and the continued reduction of natural resources makes that the use of waste as a building material can be considered as a viable alternative in the building industry. Moreover, the continued and ever increasing extraction of natural aggregates causes serious environmental problems [1-3], that can cause the destruction of ecosystems by soil erosion and permanently alter the topography of rural areas. In this scenario we find the concrete as the building material used globally. However, in recent times it has increased the use of lightweight concrete, both in structural and non-structural applications.

The lightweight concrete can be produced by introducing aluminum powder or foam, mineral lightweight aggregate such as perlite, vermiculite, pumice, expanded shale, slate, clay, etc., or by introducing plastic granules such as polystyrene, polymer materials or other aggregates [4,5].

Expanded polystyrene (EPS) is a stable, low density, and non-absorbent structure foam of hydrophobic nature [4-6]. Because of these characteristics, it can be used as ultra lightweight aggregate suitable for the development of concrete, both in structural and non-structural applications, by varying its volume percentage in concrete [7-9].

There are some publications that mention the use of EPS as a concrete aggregate in which the results showed specimens with a look that compromised the structural integrity of themselves [9], since the EPS has an extremely light density of 12-20 kg/m^3. Additionally, other publications only limited their scope of study to know some of the characteristics of the concrete mixtures added with inorganic material such as density, thermal conductivity, compression strength, absorption and freezing [9-12]. However, in 2009 it was developed a novel technique for densification of EPS by a simple heat treatment [13], generating a thermally modified polystyrene (MEPS), which provides a better accommodation of the particle within increasing the workability and compaction of lightweight concrete. Using this technique and considering that there are still no studies that evaluate the corrosion velocity in structures of lightweight concrete with MEPS, the present work shows the results of experimental evaluation of the electrochemical behavior of lightweight concrete with MEPS for 105 days in a solution of NaCl to 3.5% under controlled conditions, at a temperature of 23 °C and 100% HR. Electrochemical techniques were used for corrosion potentials (E_{corr}) and linear polarization resistance (Rp). Additionally, the results were associated with mechanical resistance (f'c), ultrasonic pulse velocity (UPV), and porosity coefficient (k) techniques.

2. EXPERIMENT PROGRAMME

2.1 Experimental design

An experimental design was developed to assess the effects would have on electrochemical and mechanical properties of lightweight concrete block after having substituted gravel for MEPS. The variables considered in this study were the number of MEPS (mixed type), test time (age) and media exposure (for electrochemical tests), keeping constant the ratio a/c = 0.65. Concerning to the variable levels of substitution, they were designed 5 lightened concrete mixtures replacing gravel levels of 0% (CTRL), 25% (25MEPS-75CA), 50% (50MEPS-50CA), 75% (75MEPS-25CA) and 100% (100MEPS-0CA) in volume by MEPS. Finally, in regard to the variable test time, it was considered from 14 to 28 days for the mechanical tests and 107 days for electrochemical tests. The response of these variables were the results of resistance to axial compression, ultrasonic pulse velocity, capillary absorption coefficient, the corrosion potential and corrosion rate. The details of the experimental design are shown in Table 1.

Table 1. Variables tested in this study.

Mechanical Properties				
Variable	Level	Description	Repetitions	Response
Type of Concrete	5	CTRL (100CA) 25MEPS-75CA 50MEPS-50CA 25MEPS-75CA 100MEPS-0CA	5	Compressive Strength (f'c) Ultrasonic Pulse Velocity (UPV) Capillary Absorption Coefficient (k)
Time Elapsed Since Production	2	7 and 14 days		
Exposure medium	1	Curing room at 90% relative humidity and 23ºC		
Electrochemical Characterization				
Variable	Level	Description	Repetitions	Response
Type of Concrete	5	CTRL (100CA) 25MEPS-75CA 50MEPS-50CA 25MEPS-75CA 100MEPS-0CA	2	Corrosion Potential (E_{corr}) Corrosion Density (i_{corr})
Time Elapsed Since Production	14	Distributed in 107 days		
Exposure medium	1	Aqueous solution contains 3.5% NaCl and 23ºC		

2.2 Materials

It was used Portland cement (CPC 30R type) according to the NMX-C-414-2004-ONNCCE [14] rules. Water was obtained from the municipal water network, which meet the NMX-C-2004-ONNCCE requirements. Fine aggregate was obtained from Atliyac River in Paso de Ovejas Veracruz, Mexico, and coarse aggregate limestone material was obtained from the central zone of the Gulf of

Mexico in the state of Veracruz. Both aggregates met the specifications of NMX-C-111-2004 [15] (see Table 2).

Table 2. Physical characteristics of aggregates used in the mixes

Physical Property	19 mm Agg	Sand
Specific Gravity (g/cm^3)	2.66	2.60
Dry-rodded weith (kg/m^3)	1380	- - -
Absorption (%)	4.00	3.8
Fineness Modulus	- - -	2.4
Maximum Aggregate Size	¾"	- - -

The MEPS used as an aggregate was obtained from EPS waste, which were heat treated under controlled laboratory conditions [13]. Some characteristics of MEPS can be seen in Table 3.

Table 3. Physical characteristics of MEPS

Average specifications of MEPS	
Density (kg/m^3)	205
Compressive strength (MPa)	7.69
Thermal conductivity (w/mk)	0.059
Absorption by volume (S_h) (%)	0.58
Absorption by weight (S_a) (%)	4.10

Table 4. Mix details of concrete tested (for 1 m^3)

	Cement		Water		19 mm Agg		19 mm MEPS		Sand		Fresh concrete	
Concrete Code	kg	m^3	kg	m^3	kg	m^3	kg	m^3	kg	m^3	Slump (cm)	Unit weigth (kg/m^3)
CTRL (100CA)	402	0.127	261.31	0.261	1010.6	0.38	0	0	551.2	0.212	22	2276.7
25MEPS-75CA	402	0.127	261.31	0.261	758.1	0.285	19.47	0.95	551.2	0.212	20	1978.6
50MEPS-50CA	402	0.127	261.31	0.261	505.4	0.19	38.95	0.19	551.2	0.212	19	1786.5
75MEPS-25CA	402	0.127	261.31	0.261	252.7	0.095	58.425	0.285	551.2	0.212	16	1644.9
100MEPS-0CA	402	0.127	261.31	0.261	0	0	77.9	0.38	551.2	0.212	12	1441.3

The method for the proportioning of the concrete mixtures was established by ACI 213 R87 [16], which primarily relies on the physical characteristics of the materials and the aggregates used in the mixtures. It is very important to pay special attention to the preparation of the mixtures with MEPS because it is quite difficult to make them homogeneous. The MEPS supplied for replacing the coarse aggregate was used in 25%, 50%, 75% and 100% by volume of aggregate. Furthermore the unit weight and concrete slump was determined immediately after homogenizing the mixture (see Table 4).

2.3 Mechanical properties

To determine the axial compressive strength of concrete blocks, they were manufactured lightened blocks of 12x15x30 cm with MEPS, and were tested according to the NMX-C-036-ONNCCE-2004 [17]. The evaluation criterion was performed according to standard NMX-C-404-ONNCCE-2005 [18], which sets out the minimum compressive strength of 10 MPa for concrete blocks and for Sand-Lime Bricks of 6 MPa.

The Ultrasonic Pulse Velocity (UPV) was performed according to NMX-C-275-0NNCCE-2004 standard [19], using a Schaffner brand device, model PUNDIT 6 with a vibration frequency of 50 kHz, the used ratio for obtaining the ultrasonic Pulse Velocity was: $UVP = L/T$, where L is the length of specimen (30 cm), T is the time at which the signal travels from transmitter to receiver. To determine the quality of mixing from the velocity of ultrasonic pulse they were used Leslie Cheesman parameters, where UPV <2130 m/s is for a very poor condition concrete; 2130 m/s <UPV <3050 m/s, for a poor concrete condition; 3050 m/s <UPV <3650 m/s, for normal or doubtful concrete condition; 3650 m/s <UPV <4750 m/s, for a good condition concrete, and UPV> 4750 m/s for an excellent condition concrete NMX-C-275-0NNCCE-2004.

The results of the mechanical strength and Ultrasonic Pulse Velocity were related to the capillary absorption coefficient (k) of each concrete. This test was performed according to NC: 345:2005 [20] and Fagerlund test.

2.4 Electrochemical techniques

It is not only important to meet the strength requirements, but also meet the necessary specifications to achieve the durability of concrete exposed to different environments. For this reason it was evaluated the corrosion protection that provide lightweight concrete with MEPS to the reinforcement steel bar. They were designed small prismatic specimens of 9×15×15 cm, as shown in Fig 1, four were designed with concrete lightened with MEPS and 1 as CTRL, with two embedded steel bars that were used as working electrode (WT) and auxiliary electrode (CE) for electrochemical measurements. They were exposed in a solution of 3.5% NaCl and put up in a curing room at a temperature of 23 ° C and 90% relative humidity for 107 days.

The electrochemical behavior was evaluated with a potentiostat / galvanostat-ZRA, ACM Instrument brand. The following techniques were used:

(a) Corrosion potential (E_{corr})

E_{corr} values were used to determine the corrosion probability. According to ASTM C876-99, for E_{cor}r<–0.350 mV vs. $Cu/CuSO_4$, there is High probability of corrosion (~90%); for –0.350

mV<E_{corr}<–0.200 mV vs. $Cu/CuSO_4$, there is uncertainty of corrosion; and for E_{corr}> –0.200 mV vs. $Cu/CuSO_4$ there is a 10% probability of corrosion [21].

(b) Linear polarization resistance (Rp) ($R_p = \frac{\Delta E}{\Delta I}$)

According to Stern-Geary equation [22], $i_{corr} = \frac{B}{R_p}$ administering ΔE±20 mV, with a scan rate of 0.16 mV s^{-1}, the constant B was 26 mV. The corrosion rates were defined according to Durar network specifications [23], for values among i_{corr}<0.1 μA cm^{-2} it can be considered a passivity state, whereas for values 0.1 μA cm–2<i_{corr}<0.5 μA cm^{-2} it can be considered a moderate corrosion state; for values of 0.5 μA cm^{-2}<i_{corr}<1.0 μA cm^{-2} it is a high corrosion state, whereas for values up to i_{corr}>1.0 μA cm^{-2} it represents a very high corrosion state.

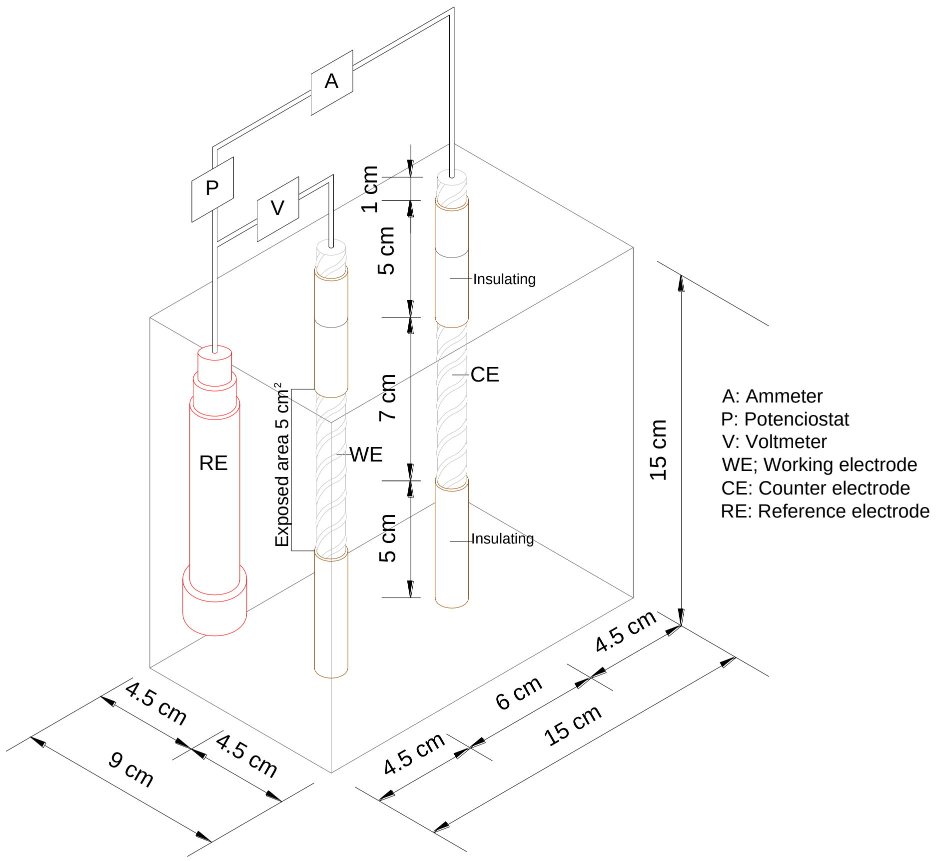

Figure 1. Outline of the prismatic specimen and measuring cell used for E_{corr} and R_p.

3. RESULTS

Fig 2 shows a cross section of lightened concrete cylinders, displayed in lighter colors MEPS adequate distribution within the concrete matrix. Likewise, the relative density is decreased if the substitution of coarse aggregate by MEPS is greater, can thus be considered as lightweight concretes [24]; as shown in table 5. After 28 days in cured the CTRL concrete (100CA) had a relative density of 2276 kg/m^3 and the lightened concrete 100MEPS-0CA decreased 63.3% compared to the previous one.

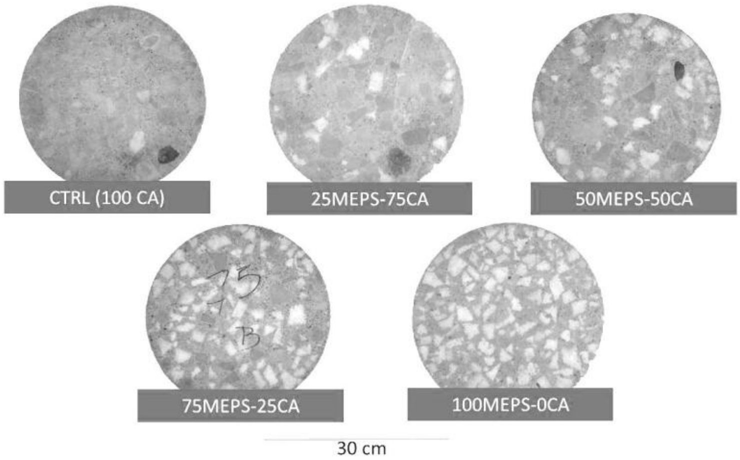

Figure 2. Cross-section cylinders (30 cm diameter) of CTRL (100CA), 25MEPS-75CA, 50MEPS-50CA, 75MEPS-25CA, 100MEPS-0CA concrete.

Table 5. Relative density for lightweighted concretes (ASTM C642-06) [25]

Concrete Code	Relative Density (kg/m^3)
CTRL (100CA)	2276.7
25MEPS-75CA	1978.6
50MEPS-50CA	1786.5
75MEPS-25CA	1644.9
100MEPS-0CA	1441.3

Table 6. Compressive strength results of saturated blocks (MPa).

Concrete	CTRL (100CA)		25MEPS-75CA		50MEPS-50CA		75MEPS-25CA		100MEPS-0CA	
Elapsed time	14	28	14	28	14	28	14	28	14	28
1	35.3	37.4	22.3	22.8	17.3	17.2	15.5	14.2	10.0	11.1
2	34.8	36.2	21.6	20.8	16.2	16.7	14.3	14.3	11.8	10.9
3	34.6	37.3	20.9	21.6	16.0	16.3	13.9	16.0	10.6	11.4
4	35.3	38.3	21.3	20.5	16.4	17.3	14.8	14.6	11.2	10.9
5	34.4	37.8	21.3	22.3	16.7	16.5	14.7	14.7	11.0	10.8
Mean (MPa)	34.9	37.4	21.5	21.6	16.5	16.8	14.6	14.8	10.9	11.0
SD (MPa)	0.41	0.78	0.52	0.97	0.51	0.44	0.60	0.72	0.67	0.24
CV (%)	1.17	2.08	2.43	4.50	3.07	2.59	4.09	4.90	6.16	2.17

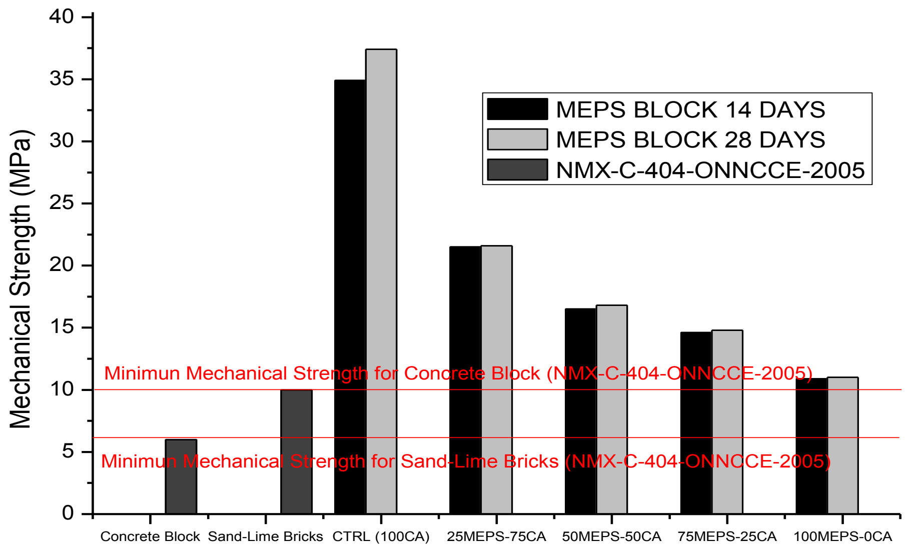

Figure 3. Compressive strength for specimens: CTRL (100CA), 25MEPS-75CA, 50MEPS-50CA, 75MEPS-25CA, 100MEPS-0CA, after 14 and 28 days of ageing.

Table 6 lists the test results of the compressive strength of each specimen tested. It also shows the average result of each studied series. It can be seen that the specimen CTRL (100CA) shows the largest mechanical strength (34.9 and 37.4 MPa at 14 and 28 days respectively) and as coarse aggregate substitution by MEPS is increased resistance to compression values decreases, This phenomenon can be attributed to the thermal resistivity of EPS concrete which retained the heat of hydration and increased the cement reaction [26]. The lowest compressive strengths were obtained by the 100MEPS specimen (10.9 and 11.0 MPa at 14 and 28 days respectively). This can be attributed to the substantial difference in specific gravity between materials, the coarse aggregate 2660 kg/m^3 and 205 kg/m^3 of MEPS.

Table 7. Ultrasonic Pulse Valocity (m/s)

Concrete	CTRL (100CA)		25MEPS-75CA		50MEPS-50CA		75MEPS-25CA		100MEPS-0CA	
Elapsed time	14	28	14	28	14	28	14	28	14	28
1	3811.3	3880.9	3703.7	3456.9	3311.2	3408.1	3222.4	3375	2818.5	2910.0
2	3838.8	3951.3	3607.2	3629.3	3194	3630.3	3216	3315.3	2802.9	2961.0
3	3818.0	3824.2	3561.4	3793.1	3568.4	3382.8	3181.3	3144.3	2552.6	2820.4
4	3885.2	3852.3	3659.2	3648.3	3360.2	3499.2	3207.1	3262.8	2735.1	2895.8
5	3757.1	3932.9	3590.1	3612.4	3371.5	3449.4	3204.7	3293.4	2716.6	2900.2
Mean (MPa)	3822.1	3888.3	3624.3	3628.0	3361.1	3473.9	3206.3	3278.2	2725.1	2897.5
SD (MPa)	46.42	53.43	56.88	119.57	135.55	97.89	15.66	85.36	105.72	50.36
CV (%)	1.21	1.37	1.57	3.296	4.03	2.82	0.489	2.60	3.88	1.74

Mexican standard NMX-C-404-2005-ONNCCE "bricks and breeze block for structural purposes - Specifications and test methods" specifies the minimum necessary strengths that should meet these structural elements, where the minimum required for Sand-Lime Bricks is 60 MPa and for Concrete Blocks is 100 Mpa. In Figure 3, it can be seen that according to these limits, the lightweight concrete with MEPS meet this criterion. The mechanical behavior of the concrete specimens containing EPS aggregates is quite different from that of the normal concrete [5, 27, 28]. The failure mode of EPS concrete under compression exhibits more gradual instead of the typical brittle failure.

With the Ultrasonic Pulse Velocity test it can be observed that the content of MEPS and coarse aggregate was the primary source of variance in both speed and strength, as shown in Table 7. Statistical analysis showed that much of the variation in results can be attributed to the difference in homogeneity between the different parts of the specimen due to the buoyancy of the MEPS and the difficulty of mixing it.

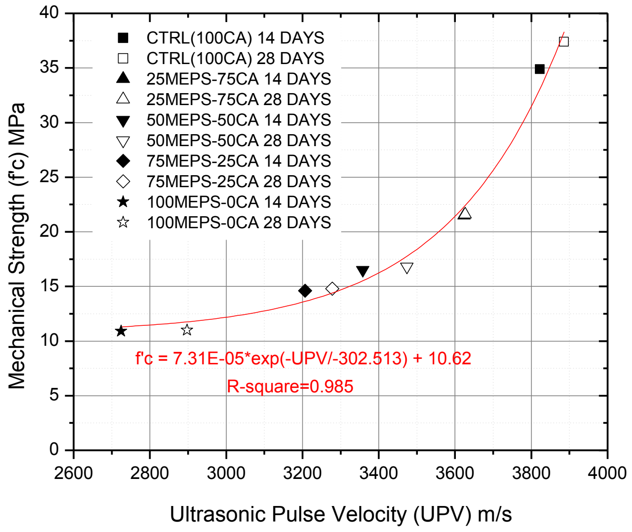

Figure 4. Data and curve-fitting speed of compressive strength for specimens CTRL (100CA), 25MEPS-75CA, 50MEPS-50CA, 75MEPS-25CA, 100MEPS-0CA after 14 and 28 days of ageing.

However, the specimens showed a very close relationship with the results of the compressive strength. It also showed that for Ultrasonic Velocities greater than 3800 m/s there are the highest strengths. For this case study, the Ultrasonic Velocities were greater than 35 MPa, and for speeds below 2800 m/s they were associated with strengths close to 10 MPa.

Figure 4 shows a curve with the exponential regression model: $f'c = 7.31E - 05 * \exp(-UPV / 302.513) + 10.52$ and R= 0.985. This obtained coefficient explains a strong relationship between the Ultrasonic Pulse Velocity variable and the resistance to compression one, which in engineering terms means that the dispersion of the experimental data obtained from the model is very small, which means that it can be exclusively applied to study the homogeneity of concrete lightened with MEPS and for predicting the mechanical behavior of this type of concrete under the described conditions of this study.

It can be seen the very fitted model is for the relation between UPV and compressive strength. However, it is well known that the compressive strength and elastic modulus may be influenced differently, depending on the concrete composition. Therefore, the relation between UPV and fc is not unique and can be affected by factors such as the type and size of aggregate, physical properties of the cement paste, curing conditions, mixture composition, concrete age and moisture content [29-34]. So far, the correlation between fc and UPV must be calibrated for each specific concrete mix. Moreover, the heterogeneous nature of concrete caused by the introduction of polystyrene aggregate and results in increased scatter, i.e., dispersive properties.

The potentials and the corrosion rates of the MEPS concretes were not reported hitherto in literature. Figure 5 shows the results obtained with the technique of corrosion potentials (E_{corr}). It was observed that all concrete studied have 90% probability of corrosion. However concrete CTRL (100CA), since day 36, is the one which has the most negative values from 541 mV vs. $Cu/CuSO_4$ up to -617 mV vs. $Cu/CuSO_4$. Additionally, it was seen that all lightweight concrete with MEPS show more positive values than the CTR (100CA). The lightweight concrete that showed better performance during the evaluation period was the 100MEPS-0CA.

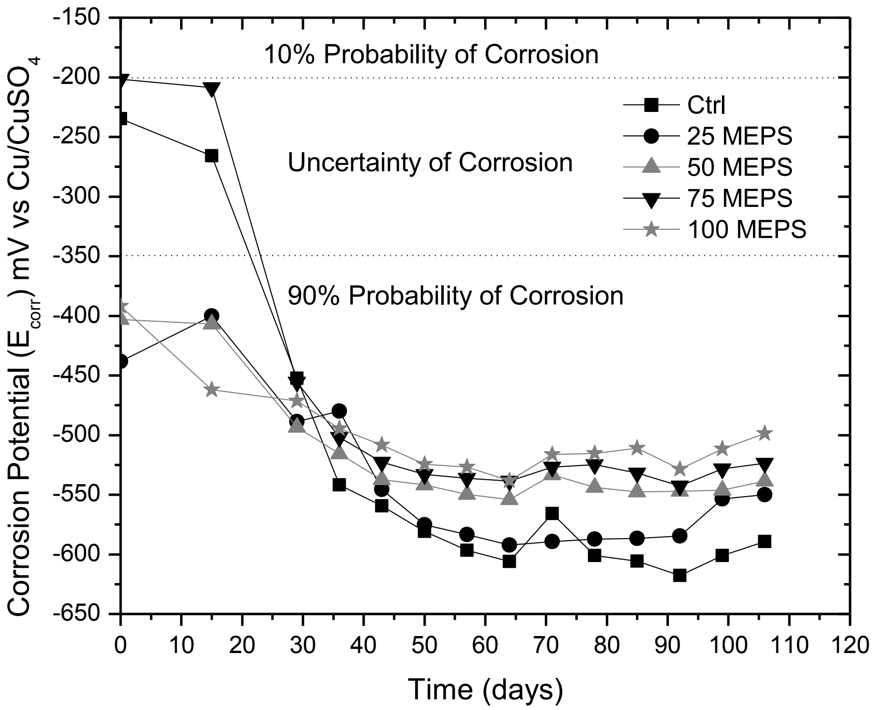

Figure 5. Corrosion potential (E_{corr}) versus time for Steel embedded in concrete CTRL (100CA) and lightweighted concretes 25MEPS-75CA, 50MEPS-50CA, 75MEPS-25CA, 100MEPS-0CA. The specimens were immersed in a 3.5% NaCl solution.

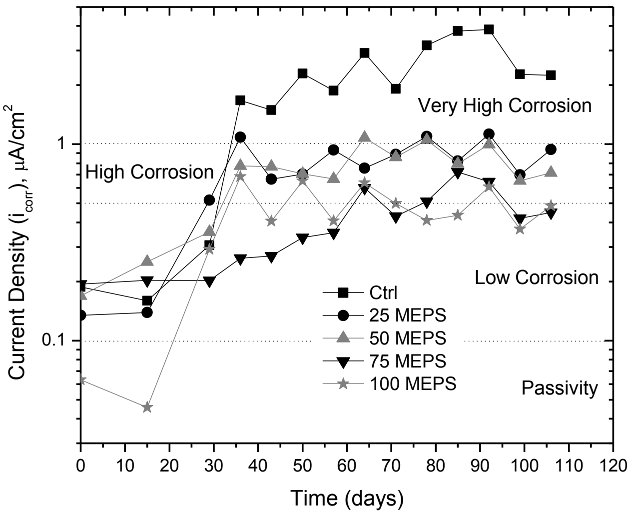

Figure 6. Current density ($i_{corr,}$ μA cm^{-2}) versus time for Steel embedded in concrete CTRL (100CA) and lightweighted concretes 25MEPS-75CA, 50MEPS-50CA, 75MEPS-25CA, 100MEPS-0CA. The specimens were immersed in a 3.5% NaCl solution. Current density values were determined using R_p measurements.

Figure 6 presents the results of corrosion density obtained by the technique of Rp, where concrete CTR (100CA), the first day of exposure, showed values of 0.187μA cm^{-2} (moderate corrosion) but from day 36, it increased current density values up to 3.84μA cm^{-2}, which means a very high corrosion level. It was also observed the performance of concretes lightened in proportion to the replacement of coarse aggregate by MEPS considering corrosion. In the case of the specimen 100MEPS-0CA, the first day of valuation it showed passivity values, which increased to moderate corrosion from day 43 to day 107 when this values became stabilized, with values of 0.401, 0.685 and 0.187 μA cm^{-2}. In this sense it can be said that the lightweight concrete with MEPS can decrease the corrosion rate of reinforcing steel exposed in saline environments with NaCl.

Ganesh and Saradhi [35], reported that the corrosion rates of all the EPS concretes showed values around 0.4–0.5 mpy, which is significantly lower than that for the normal concretes, and obtained similar results to this job.

Table 8. Capillary absorption coefficient (k) and effective porosity (ε_e) after 28 days.

Concrete	CTRL (100CA)		25MEPS-75CA		50MEPS-50CA		75MEPS-25CA		100MEPS-0CA	
Elapsed time	K	ε_e	K	ε_e	K	ε_e	K	ε_e	K	ε_e
	(kg/m^2 S$^{0.5}$)	(%)	(kg/m^2 S$^{0.5}$)	(%)	(kg/m^2 S$^{0.5}$)	(%)	(kg/m^2 S$^{0.5}$)	(%)	(kg/m^2 S$^{0.5}$)	(%)
1	0.46	17.4	0.41	17.7	0.36	17.74	0.34	16.38	0.36	16.72
2	0.48	19.0	0.35	15.9	0.39	17.10	0.34	16.38	0.29	14.13
3	0.46	18.9	0.41	16.9	0.38	19.26	0.35	16.84	0.28	13.75
Mean (MPa)	0.47	18.48	0.39	16.88	0.38	18.04	0.34	16.53	0.31	14.86

This behavior can be attributed to values of capillary absorption coefficient (k) and effective porosity (εe) of the matrix of lightweight concretes. As shown in Table 8 the greater the substitution of coarse aggregate for MEPS, the capillary absorption coefficient decreased from 0.47 kg/m^2 $S^{0.5}$ for concrete CTRL (100CA) to 0.31 kg/m^2 $S^{0.5}$ for lightened concrete 100MPES-0CA.

Additionally, it can be seen that the behavior of effective porosity of specimen CTRL (100CA) was 18.48%, whereas the value of effective porosity for concrete lightened with higher content of MEPS decreased, for instance the value for 100MPES-0CA specimen was 14.86%. This behavior is possibly due to the expanded polystyrene is not hygroscopic. Even completely immersing the material in water, its absorption levels are minimal with values ranging between 1% and 3% by volume (test by immersion after 28 days).

4. CONCLUSION

This paper shows that lightweight concrete blocks with expanded polystyrene foam with a relative density of 1,441.3 to 1978.6 kg/m3 and a compressive strength of 11–21.6 MPa can be made by partially replacing coarse aggregate from the control concrete with MEPS. The main findings of this study are listed as follows:

1. By visual observation, the polystyrene aggregate showed an even distribution in concrete matrix. In general, lightweight concrete blocks with MEPS showed difference in homogeneity between the different parts of the specimen due to the buoyancy of the MEPS and the difficulty of mixing it.
2. The MEPS is an excellent lightening material, as long as it is properly thermally treated for modification.
3. The mechanical strength declines significantly as the substitution of coarse aggregate for MEPS in concrete is greater. However, for using it as a structural masonry block in bearing walls can be used properly due to it showed strengths superior to those provided by the current regulations regarding Concrete Blocks. Due to its low specific thermal capacity, the concretes with MEPS showed higher strength acceleration at early ages than the control concrete with increasing significance in particular at high MEPS contents
4. The density and strength of the lightweight concrete blocks with MEPS decreased considerably with increase of MEPS content in the mix. The compressive and splitting failures of the concrete specimens containing polystyrene aggregates showed a large
compressibility of the material and did not exhibit a brittle failure.
5. The specimens showed a very close relationship with the results of the compressive strength and Ultrasonic Pulse Velocity test, a model was obtained with a and R= 0.985, affirm this relationship; which means that it can be exclusively applied to study the homogeneity of concrete lightened with MEPS and for predicting the mechanical behavior of this type of concrete under the described conditions of this study.
6. The performance of corrosion protection of these concrete has been extremely superior to those of a conventional concrete with a 100% stone aggregate.

7. The corrosion rate is decreased proportional to the amount of substitution by MEPS gravel, concrete lightened so that it better corrosion protection presented in the 107 days of the evaluation was that 100 had a substitution of MEPS.
8. The corrosion rate decreased proportional to the amount of substitution of gravel for MEPS. Finally, the lightened concrete that showed better performance of corrosion protection during the 107 days of the evaluation period was the one which had a substitution of 100% MEPS.
9. the value of effective porosity for concrete lightened with higher content of MEPS decreased, This behavior is possibly due to the expanded polystyrene is not hygroscopic.

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