

Mechanical Response of Portland Cement Mortars with added Expanded Polystyrene Spheres (EPS) under Accelerated Attack

W. Martinez Molina, E. M. Alonso Guzman, H. L. Chavez Garcia, C. Lara Gomez, F. M. Gonzalez Valdez, & O. R. Flores Lica

Department of Materials, Faculty of Civil Engineering
University of San Nicolas de Hidalgo
Morelia, Michoacan, Mexico
wilfridomartinezmolina@gmail.com;
eliamercedesalonso@gmail.com,
hchavezenerator@gmail.com, cindylago@hotmail.com,
laboratoriomaterialesfic@gmail.com,

A. A. Torres Acosta

Mexican Transport Research Institute
Ministry of Communications and Transports
Sanfandila, Pedro Escobedo, Queretaro, Mexico
atorres@imt.mx

W. Martinez Alonso

Division of Civil and Geomatics Engineering, Faculty of
Engineering, National Autonomous University of Mexico
Mexico City, Mexico and
Texas University, Austin, Texas, United States
wilfrido.martinez.alonso@gmail.com

J. A. Bedolla Arroyo

Faculty of Architecture
University of San Nicolas de Hidalgo
Morelia, Michoacan, Mexico
bedollaalberto@gmail.com

H. Hernandez Barrios

Department of Structures, Faculty of Civil Engineering
University of San Nicolas de Hidalgo
Morelia, Michoacan, Mexico
hugofernandezbarrios@yahoo.com.mx

Abstract—Mortars have many uses in construction: to lighten, sonic and thermal insulation, aesthetic purposes, to protect against environmental attack, repair, conservation, union masonry, etc. Mortar matrices may be Portland cement, lime, gypsum, clay and soil, asphalt or polymers. This work shows the result of the addition of areas of expanded polystyrene spheres (EPS) in three different percentages to the aggregate of a mixture of mortar. Physical and mechanical behaviour is evaluated to assess their behaviour under accelerated attack. The stone aggregate in the mortar was river sand; the cement used was ASTM C150 Type IV; the initial water-cement ratio by weight was 1.01 for each share; all blends met $105 \pm 5\%$ flow. The addition of expanded polystyrene spheres (EPS) replaced fine aggregate by 10%, 20% and 30% in each mixture. It was necessary to add a fluidizing agent in cases of adding expanded polystyrene spheres since the fluidity of the mortar decreased. Destructive testing such as simple compression and the accelerated attack took place; non-destructive testing included physical absorption as a percentage and specific gravity were also performed. It is concluded that the addition of expanded polystyrene improved resistance to chemical attack accelerated mortars and reduced the volume and weight, without detriment to the resistance.

Keywords—Mortar; Polystyrene; Attack

The authors acknowledge the financial support of the Coordination of Scientific Research of the Universidad Michoacana de San Nicolas de Hidalgo; Promed Thematic Network of the Ministry of Education, and CONACYT, National Council of Science and Technology of Mexico.

I. INTRODUCTION

The objective of this research was to develop mixtures of lightened mortars that will support aggressive chemical attack [1-3] and increase the strength of Portland cement-based coatings' resistance to environmental attacks such as efflorescence. These damages occur especially in structures in a marine environment with wet-dry cycles, as in the case of piers, bridge piers and rainwater containers. Many cases have been documented in which lightening corresponds to a decrease in resistance, but curing obviously favourably influences the properties of hardened concrete [4, 5].

The weight-reducing additive was expanded polystyrene in the form of spheres of diameters between 0.30 and 2.0 mm. The diameter of the spheres also influences the properties of the hardened materials and encourages the distribution heterogeneity in the Portland cement based matrix [6, 7]. Polystyrene is characterized by its low specific weight, 10 kg/m^3 .

As determined by its properties, the spheres are distributed uniformly in the matrix of the mortar. The first concrete/light mortars used to construct buildings emerged in the Roman Empire in 20 BC. At present, the demand for durable buildings with a high degree of security, which are subject to extreme weather stresses, provides decisive factors in its design.

The investigation began by performing a physical characterization with different percentages of additions of polymeric spheres that lightened the density, replacing the amount of sand [8-10], some percentages of additions caused a decrease in mechanical properties. At the end of the age test, the samples that showed the best performance under static load and accelerated attack were determined [7, 11].

II. EXPERIMENTAL DEVELOPMENT

The sand was taken from the Huajúbaro River located in Zinapécuaro, Mexico, 19°42 'north latitude and 100°33 ' west longitude, it is a quartz sand or Canada silica sand. The sampled material was moved to the Laboratory Ing. Luis Silva Ruelas in the Department of Materials, Faculty of Civil Engineering of the University of Michoacan, where it was characterized. All tests indicated were performed in triplicate and the values shown are the product of three quantifications, and all the results did not differ in more than 10%, if they did, the test must be repeated. See Table I for a summary of tests performed, the result is the average of the 3 values.

TABLE I. PHYSICAL TESTS ON THE FINE STONE AGGREGATE FOR USE IN MORTARS

Tests for Fine Aggregates	Standard	Result
Sampling	ASTM D75	750 kg
Absorption percentage	ASTM C128	3.73
Relative density or specific gravity	ASTM C128	2.3
Surface moisture (%)	ASTM C128	0.74
Bulk density (unit weight) and voids	ASTM C29/C29M	1.23
Bulk density (unit weight)	ASTM C29/C29M	1.33
Organic impurities	ASTM C40	scale 3
Sand equivalent value	ASTMD 2419	97.50%
Materials finer than 75- μ m (No. 200) sieve	ASTM C117	1.98%
Sieve analysis	ASTM C136	2.19

The dosage of mortar was one part cement and 2.75 parts by weight of sand, 1: 2.75. The dried solids were first mixed; the necessary amount of water was added to the mortar to present a fluidity of 105% \pm 5%, ASTM 109M-12 C. In mixtures spiked with polymer spheres, additions such as agglutinated fresh mixtures were used [12, 13] to achieve a fluidizing flow. In 10% and 20% substitutions of silica sand by polystyrene spheres, 8 g of plasticizer per kg cement was used and for the 30% substitution of sand by spheres, 10 g/kg cement was used. The fluidizing additive was able to reduce the mixing water from 32% to 40% to yield the fluidity/workability mentioned.

All results were compared against the values obtained for the mortar mix control without additions or plasticizer. Mixing was performed mechanically.

A. Preparation of specimens.

To prepare the admixture, first the weight dry materials are mixed: cement, sand and expanded polystyrene spheres, after adding the water, and quantify the fluidity, before fill in the moulds.

To prepare specimens, steel moulds that meet the dimensions specified by ASTM C 109M for buckets and ASTM C 192 / C 192M for cylinders were used.

The moulds were coated with the oily material to prevent adhesions. For filling of the specimens, the procedure described by Navarro Sánchez, Martínez Molina, and Espinosa Mandujano (2010) was followed [14].

The removal of the specimens from their moulds was carried out at 48 \pm 8 hr; then came the fluidizing delayed curing. Curing was performed by immersion ASTM-C511.

B. Tests on cured state mortar specimens.

Tests carried on cured state mortars can be classified as destructive [15]. The tests are listed in Table II. The specimens were tested at the ages of 7, 14, 28, 45, 90, 150, 210 and 300 days. The tests were compared against the control admixture.

Before testing, the specimens were taken from the immersion and dried superficially; then the non-destructive tests were conducted, at the end of which the destructive tests were performed.

TABLE II. MECHANICAL TESTS ON SPECIMENS OF MORTAR

Test	Standard	Specimen Sizes
Compressive strength	ASTM C109	Cubes 5cm x 5cm x 5cm
Absorption percentage	ASTM C128	Cubes 5cm x 5cm x 5cm
Relative density or specific gravity	ASTM C128	Cubes 5cm x 5cm x 5cm
Accelerated attack or soundness of concrete samples by use of sodium sulphate	ASTM C88	Cylinders 5cm \varnothing x 10cm high

III. RESULTS AND DISCUSSION

The results were compared against the control mortar. The summarized results are shown in graphical form.

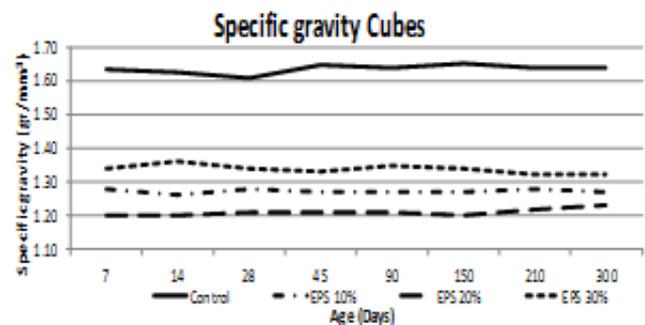


Fig. 1. Test results for specific gravity, in cubes

A. *Specific gravity.*

The results presented in the specific gravity test for additions are below the value of the control mortar

B. *Absorption.*

The absorption was measured as an indirect measure of the volumetric weight or density, resistivity, and mechanical strength.

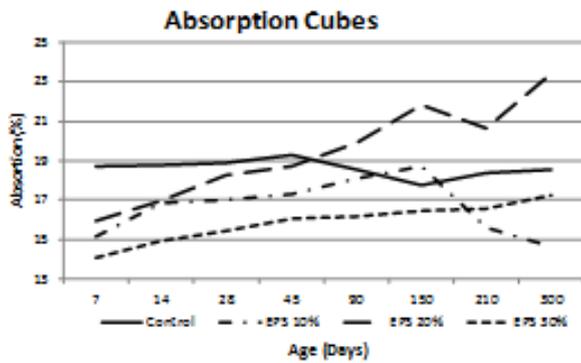


Fig. 2. Test results for percentage of absorption, in cubes

C. *Destructive testing.*

Compression. The results of the compression testing of mortars with the addition of two sphere replacement ratios, 10% and 20%, show that the resistance is below our control mortar. With the 30% addition of polystyrene beads, resistance to simple compression increased, achieving above the control mortar.

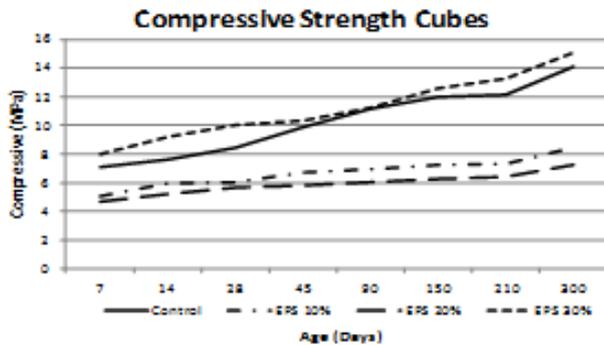


Fig. 3. Test results for compression, in cubes

Sulphate attack or accelerated chemical attack. The accelerated attack test, ASTM C88, is simulated by subjecting the specimens to five cycles in a saturated solution anhydrous sodium sulphate, to qualify its durability [16]. After each cycle, the integrity of the specimen under compression was tested to determine the loss of cohesion in the cement matrix. All EPS mortars resisted five test cycles.

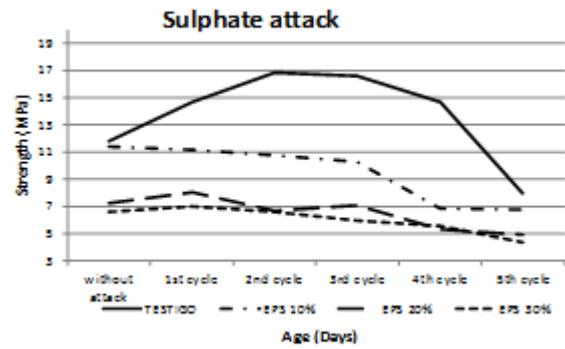


Fig. 4. Test results for compression in cylinders for five cycles of the test anhydrous sodium sulphate accelerated attack.

IV. CONCLUSIONS

With the addition of the polymeric spheres, the fresh mortar mix coalesced and it was necessary to modify the water/cement ratio with the fluidizing aid. One of the main objectives of adding the spheres was to lighten the material, which was significantly achieved by replacing the stone aggregate with polystyrene spheres. Lightweight concrete meets aesthetic functions, decreasing the masses applied to structures under stresses of vertical and horizontal loads.

In the testing attack by sulphates, the results indicate a good preventive measure to this design, the use of cement made with the special characteristic being resistant to sulphates (RS). In addition to spheres, the results obtained in the development of test cycles generally demonstrate its use: it allows the matrix within the element more space for recrystallization to occur and the cement paste does not damage micro fractures caused by expansion due to recrystallization of salts. This was demonstrated since the control specimens and mortar enhanced with spheres resisted five test cycles, so the addition of polystyrene beads is good way to avoid damage from sodium sulphate attack, which is the case of concrete/mortar subjected to contaminated ground water, water with salt/chloride, freezing and thawing, and wet and dry cycles.

Additions of polystyrene spheres allowed decreases in the mass in the order of 20%, which significantly lightened the mixture, an important feature in areas of high seismicity where the decline of the mass, even in cases of large acceleration, results in lower forces acting.

The goal here is the addition of expanded polystyrene spheres to avoid accelerated attack, not only to diminish weight of concrete. The diminish of the weight of course conduce to lower cost in the construction, but the resistance under accelerated attack means lower costs in the maintenance of the concrete structures.

REFERENCES

[1] F.G. Branco, and L. Godinho, "On the use of lightweight mortars for the minimization of impact sound transmission", *Constr. Build. Mater.* vol. 45, pp. 184–191, 2013.

- [2] D. Saradhi Babua, T.K. Ganesh Babub, and T.H. Weea, "Properties of lightweight expanded polystyrene aggregate concretes containing fly ash", *Cem. Concr. Res.* vol. 35, pp. 1218–1223, 2005.
- [3] D. Saradhi Babua, T.K. Ganesh Babub, and T.H. Weea, "Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete", *Cem. Concr. Comp.* vol. 28, pp. 520–527, 2006.
- [4] W.C. Tang, H.Z. Cui, and M. Wua, "Creep and creep recovery properties of polystyrene aggregate concrete", *Constr. Build. Mater.* vol. 51, pp. 338–343, 2006.
- [5] I.H. Ling, and D.C.L. Teo, "Properties of EPS RHA lightweight concrete bricks under different curing conditions", *Constr. Build. Mater.* vol. 25, pp. 3648–3655, 2011.
- [6] A. Laukaitis, R. Zurauskas, and J. Kerien, "The effect of foam polystyrene granules on cement composite properties", *Cem. Concr. Comp.* vol. 27, pp. 41–47, 2005.
- [7] N. Liu, and B. Chen, "Experimental study of the influence of EPS particle size on the mechanical properties of EPS lightweight concrete", *Constr. Build. Mater.* vol. 68, pp. 227–232, 2014.
- [8] D. Bouvard, J.M. Chaix, R. Dendievel, A. Fazekas, J.M. Létang, G. Peix, and D. Quenard, "Characterization and simulation of microstructure and properties of EPS lightweight concrete", *Cem. Concr. Res.* vol. 37, pp. 1666–1673, 2007.
- [9] V. Ferrandiz-Mas, T. Bond, E. Garcia-Alcocel, and C.R. Cheeseman, "Lightweight mortars containing expanded polystyrene and paper sludge ash", *Constr. Build. Mater.* vol. 61, pp. 285–292, 2014.
- [10] W.C. Tang, T.Y. Lo, and R.V. Balendran, "Bond performance of polystyrene aggregate concrete (PAC) reinforced with glass-fibre-reinforced polymer (GFRP) bars", *Build. Envir.* vol. 43, pp. 98–107, 2014.
- [11] V. Kilar, D. Koren, and V. Bokan-Bosiljkov, "Evaluation of the performance of extruded polystyrene boards and implications for their application in earthquake engineering", *Polym. Test.* vol. 40, pp. 234–244, 2014.
- [12] R. Madandoust, M. Muhammad Ranjbar, and S. Yasin Mousavi, "An investigation on the fresh properties of self-compacted lightweight concrete containing expanded polystyrene", *Constr. Build. Mater.* vol. 25, pp. 3721–3731, 2011.
- [13] A. Sadrmomtazi, J. Sobhani, M.A. Mirgozar, and M. Najimi, "Properties of multi-strength grade EPS concrete containing silica fume and rice husk ash", *Constr. Build. Mater.* vol. 35, pp. 211–219, 2012.
- [14] L.M. Navarro Sánchez, W. Martínez Molina, and J.A. Espinosa Mandujano, *Análisis de Materiales*. ISBN 978-970-703-551-5. México: Universidad Michoacana de San Nicolás de Hidalgo, 2010.
- [15] X. Yi, L. Jiang, J. Xu, and Y. Li, "Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick", *Constr. Build. Mater.* vol. 27, pp. 32–38, 2012.
- [16] V. Ferrandiz-Mas, and E. García-Alcocel, "Durability of expanded polystyrene mortars", *Constr. Build. Mater.* vol. 46, pp. 175–182, 2013.