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SBR latex modified mortar rheology and mechanical behaviour

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Abstract

The paper deals with the influence of water-to-cement ratio (W/C) and percentage of polymer in the setting time, rheology and physical and mechanical properties of a Styrene–Butadiene–Rubber (SBR) Latex Modified Mortar (LMM).

An experimental test program including setting time and consistency in the fresh state and porosity, density, ultrasonic modulus and compressive and flexural strength in the hardened state of a LMM at different ages was performed. Several W/C and percentages of latex were studied.

The results obtained showed that both parameters interact in the properties in the fresh and the hardened states of the LMM. Multiple linear correlations among dosage parameters and physical and mechanical variables are presented. Linear approximations are acceptable (95% confidence level), taking into account the nature of the LMM.

Some dynamic compression tests were accomplished in order to determine some dynamic properties of SBR Latex Modified Mortar, as dynamic modulus (E_0) and loss tangent (tan δ).

Keywords: Rheology; Mechanical properties; SBR latex; Portland cement mortar

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1. Introduction

Nowadays, research on cement matrix materials is focused on the inclusion of additives, admixtures and short fibers, to improve certain physical and mechanical properties, although keeping its strength, low cost and capacity to fill almost any shape.

Adherence, permeability, thermal and acoustical insulation, ductility, flexural strength, fire performance and viscous damping are some of the main research lines on cement matrix materials.

Polymeric admixtures are defined as polymers used as a main ingredient effective at modifying or improving cement-based material properties[1–8]. Such a polymeric compound can be a polymer latex, redispersible polymer powder, water-soluble polymer or liquid polymer.

Among the different presentations of polymer admixtures, polymer latex is in most widespread use. Floor and bridge overlays, repairing mortars and bonding ceramic tile agents are some of the actual Latex Modified Mortar (LMM) uses. Recently, new uses have been proposed in precast elements and as precast elements joining material [9–12].

Polymer latex modification of cement mortar is governed by both cement hydration and polymer film formation processes in their binder phase. A co-matrix is formed by both processes [1,13,14].

Two different ways of adding polymers to cement composites have been described [6]:

- Keeping constant the water-to-cement ratio (W/C) to obtain a similar hydration of the cement paste. It is the typical laboratory procedure, with all the variables but one constant.
- Fitting the consistency of the composite, by adjusting the W/C or the inclusion of plasticizers. It is a trial-and-error procedure, but the results are of direct practical application.

The results obtained with both methods are different and cannot be compared. In general, the polymer modified

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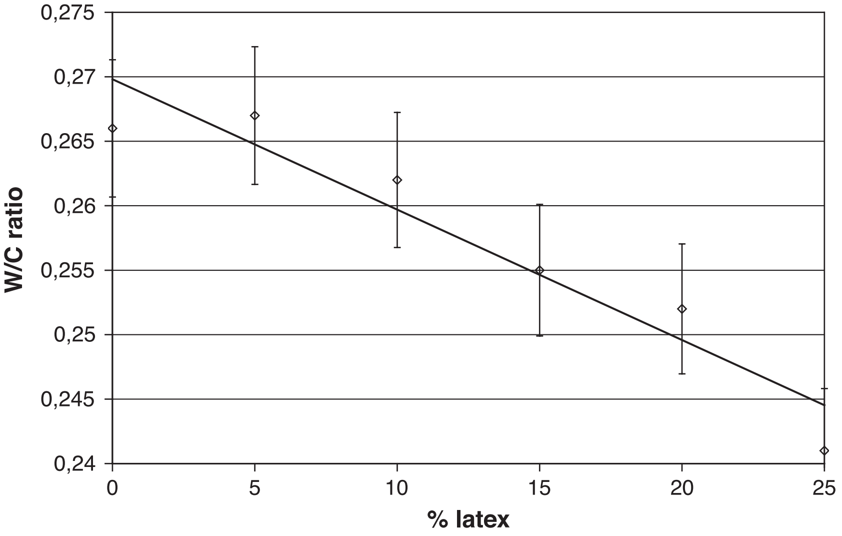

Fig. 1. W/C necessary to obtain the Vicat standard consistency of LMM with different percentages of latex.

mortar properties depend significantly on the polymer content rather than W/C, when compared to ordinary cement mortar [1,15]. Although, the inclusion of polymers, specially in latex form, improves the consistency of the mortar, due to the "ball bearing" action of polymer particles, the entrained air and the dispersing effect of surfactants [1]. Therefore, an important W/C reduction can be achieved.

In the hardened state, a noticeable increase in flexural strength and no improvement of compressive strength, compared to ordinary cement mortar, has been described [1]. An increase of the vibration damping capacity of cement paste modified with latex has also been described [7], though no reference of LMM dynamic behaviour has been found.

Therefore, polymer admixtures produce effects in fresh and hardened state mortar properties.

This paper summarizes the results of an experimental test program on LMM with different W/C and percentages of latex in the fresh and hardened states. The aim of this study is to analyze the influence of dosage parameters on the physical and mechanical properties.

Multiple linear regressions among dosage parameters and physical and mechanical variables are presented.

Some dynamic compression tests were also performed, to determine some dynamic properties of SBR Latex

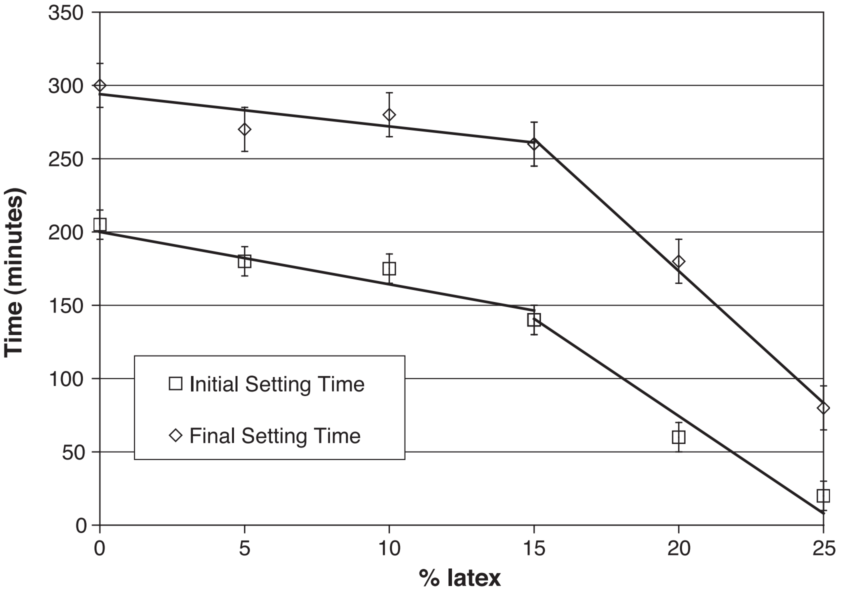

Fig. 2. Initial and final Vicat setting times of LMM with different percentages of latex.

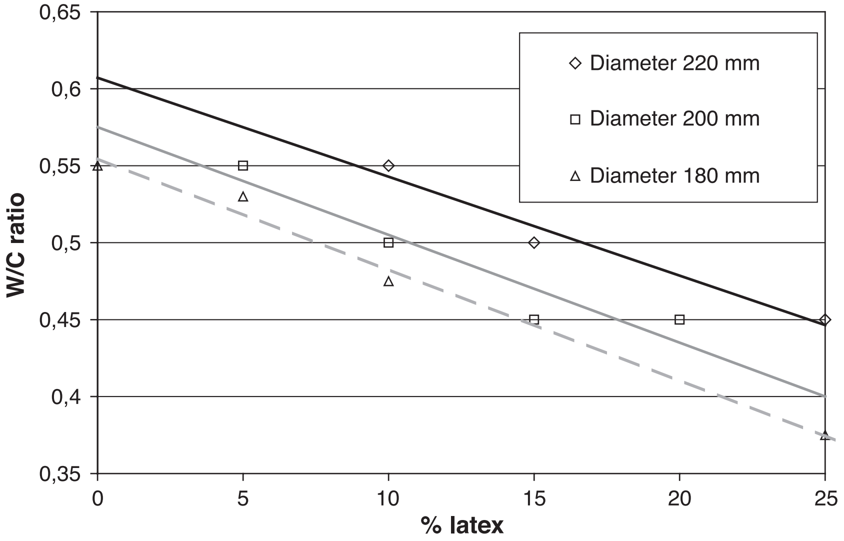

Fig. 3. W/C of LMM with different percentages of latex for flow table diameters of 180, 200 and 220 ± 10 mm.

Modified Mortar, as dynamic modulus (E_0) and loss tangent (tan δ).

2. Materials and mixture procedure

The materials used in the performance of the LMM specimens were:

- Cement type CEM II A/V 42,5 (ASLAND).
- Siliceous rolled sand with maximum size of 4 mm (100% passed 4 mm sieve).
- SBR latex (PCI-Emulsion of Bettor-MBT) with a pH of 8, 66% styrene and 34% butadiene, and a nominal solid content of 38% (39.47% solid content in the desiccation test). It contains an antifoaming agent in the commercial composition.

The dosage criteria used in the compositions of LMM were:

- Cement-to-sand ratio 1:3.
- Initial W/C 0.55. Afterwards, it was modified to obtain a fixed spread diameter, obtained using the flow table test for mortars [16].
- No plasticizer additive was used.
- 0%, 5%, 10%, 15%, 20% and 25% of latex, with regard to cement weight were included to the base mortar. The amount of water of the latex was taken into account in the W/C. These percentages of latex corresponded to 0%, 1.9%, 3.8%, 5.7&, 7.6% and 9.5% of polymer with regard to cement weight, respectively.

Table 1
W/C of LMM with different percentages of latex for a flow table diameter of 180 ± 10 mm

% Latex	0	5	10	15	20	25
W/C	0.55	0.53	0.475	0.425	0.4	0.375

The mixture of the mortar components was done using the prewetting method [17]. Water, cement and sand were mixed for 1 min in a vertical axis mixer at low speed (140 rpm). Afterwards, latex was added and the mixing process went on for 2 min more. The aim of this method is to reduce the amount of entrained air in the fresh mortar.

Sets of six prismatic standard specimens (4 × 4 × 16 cm) of each composition were prepared according to UNE-EN 196-1 [18]. Specimens were demolded 24 h after and air cured (20 °C and 50% RH) till tested, as recommended by Shaker et al. [8].

3. Experimental methods

Setting time and flow table tests were done on the SBR LMM in the fresh state. Latex percentages of 0%, 5%, 10%,

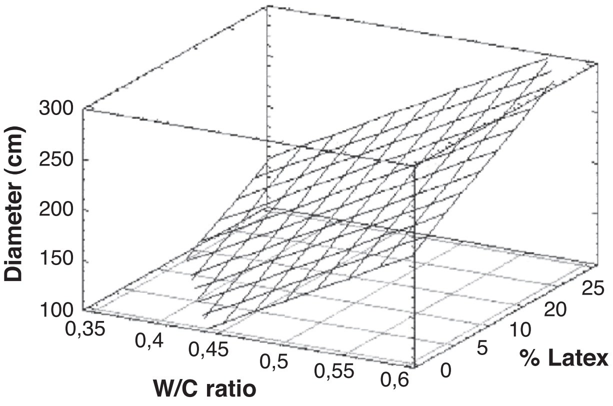

Fig. 4. Response surface of LMM consistency (flow table diameter) as function of W/C and percentage of latex.

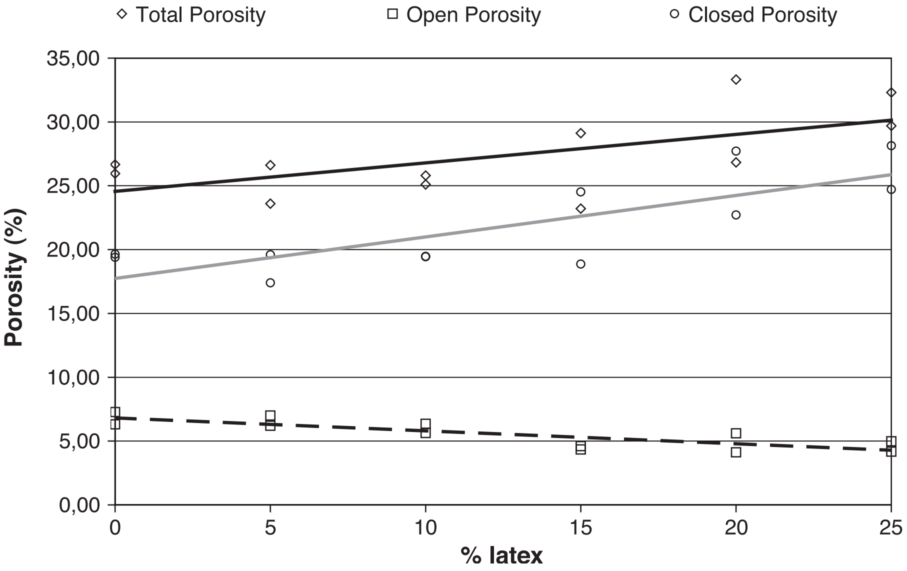

Fig. 5. Open, closed and total porosity of LMM with different percentages of latex.

15%, 20% and 25%, with respect to cement weight, were used.

Vicat needle apparatus was used to determine the initial and final setting times, according to UNE-EN 196-3 [19]. To obtain the standard consistency of each composition, the W/C had to be adjusted.

Consistency was measured using the flow table test, according to UNE-EN 1015-3 [16]. Several W/Cs for each percentage of latex were tested to obtain flow diameters of 180, 200 and 220 mm.

In the hardened state, dry, saturated and submerged weights, porosity, ultrasonic pulse velocity and bending and compression tests of different compositions at several ages (1, 7, 28 and 56 days) were performed.

Apparent density (ρ_{app}) and open porosity (P_{open}) of each composition was calculated using the following equations:

$$\rho_{app} = \frac{W_{dry}}{W_{sat} - W_{sub}} \tag{1}$$

$$P_{open}(\%) = \frac{W_{sat} - W_{dry}}{W_{sat} - W_{sub}} \times 100 \tag{2}$$

where W_{dry} is the dry weight, W_{sat} is the saturated weight (specimen submerged in water for 24 h) and W_{sub} is the submerged weight (saturated specimen submerged in water and measured its weight with a hydrostatic scale).

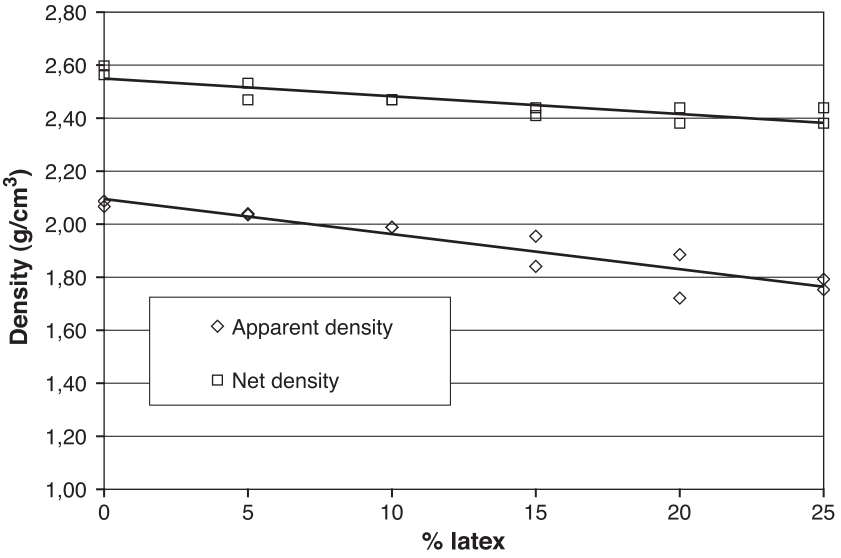

Fig. 6. Net and Apparent densities of LMM with different percentages of latex.

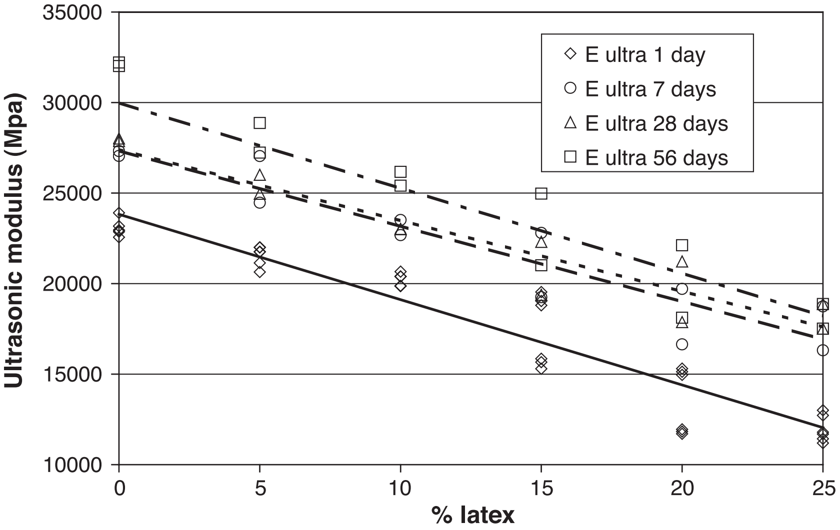

Fig. 7. Ultrasonic modulus of LMM with different percentages of latex at several ages.

Net density (ρ_{net}) was measured introducing milled samples of the different compositions of LMM, previously weighted, into a scaled pipe with water. The volume of water displaced by the sample of material corresponded to the volume of the sample. Total and closed porosity were calculated from net and apparent densities and open porosity.

Ultarsonic modulus (E_s) were calculated using the next equation [20]:

$$E_s = \rho v^2 \tag{3}$$

Where ρ is the density and v is the velocity of ultrasonic pulse propagation.

Standard bending and compression tests of LMM on different compositions were done, according to UNE-EN 196-1 [18].

Dynamic compression tests of LMM specimens with different percentages of latex and constant consistency (180 ± 10 mm of flow table diameter) at 0.5 Hz of frequency and room temperature (20 °C) were performed.

4. Fresh state test results

The W/C necessary to obtain the Vicat standard consistency of LMM with different percentages of latex are summarized in Fig. 1. The increase of latex in the LMM

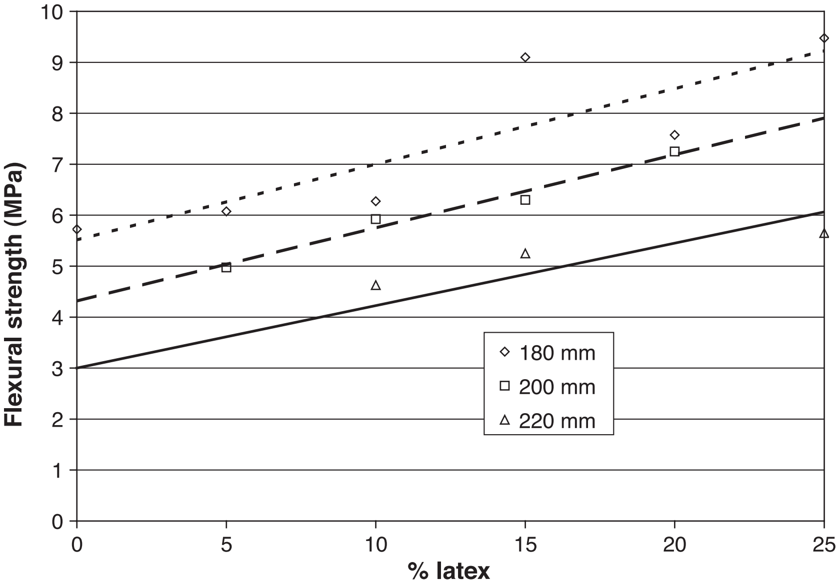

Fig. 8. Flexural strength of LMM with different percentages of latex and several fixed consistencies (flow table diameters of 180, 200 and 220 ± 10 mm).

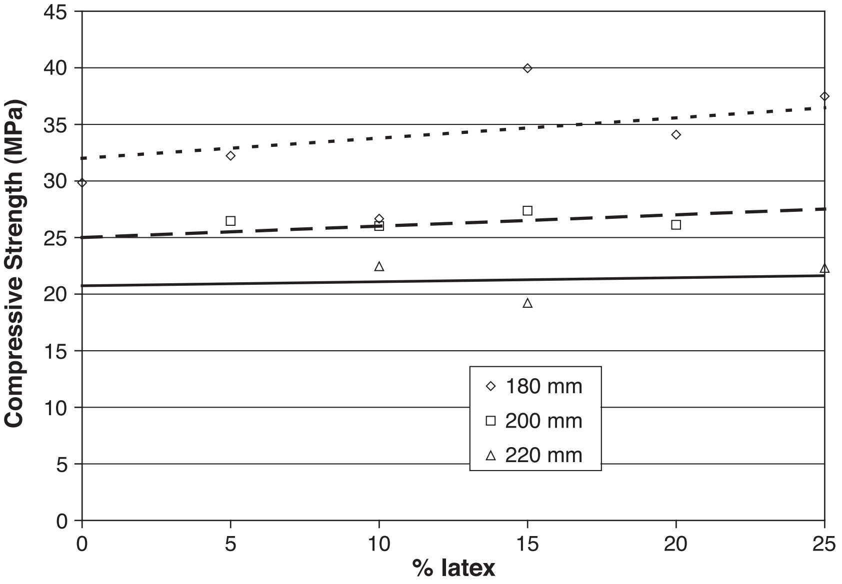

Fig. 9. Compressive strength of LMM with different percentages of latex and several fixed consistencies (flow table diameters of 180, 200 and 220 ± 10 mm).

meant a reduction of the water necessary to obtain the fixed consistency due to the plasticizer effect of the latex [1].

Initial and final setting times are presented in Fig. 2. The inclusion of latex reduced both setting times. A change on the tendency of the reduction at 15% of latex can be observed. Above it, a decrease on the setting time (time between initial and final setting time) occurred.

Fig. 3 presents the W/C of LMM with different percentages of latex for flow table diameters of 180, 200 and 220 ± 10 mm. A dependence of consistency on both parameters can be observed. Table 1 summarizes W/C for 180 ± 10 mm flow table diameter of LMM with all the percentages of latex under study. These values were used for dynamic test specimens dosage.

A multiple linear regression analysis was performed on consistency with both parameters. Fig. 4 presents the response surface of this parametrical analysis (95% level of confidence).

5. Hardened state test results

Open, closed and total porosity of LMM varies with the inclusion of latex, as shown in Fig. 5. The increase of latex

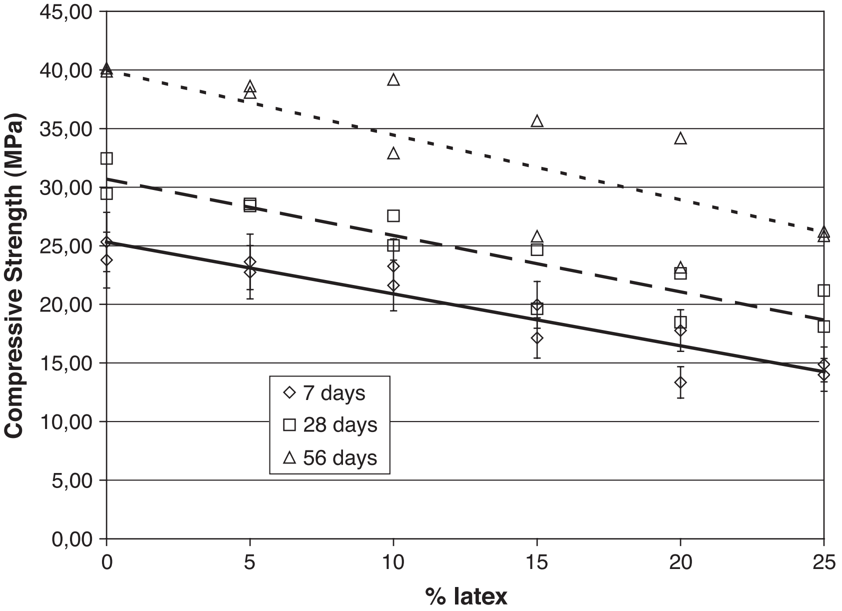

Fig. 10. Compressive strength of LMM with different percentages of latex and constant W/C (0.55) at several ages.

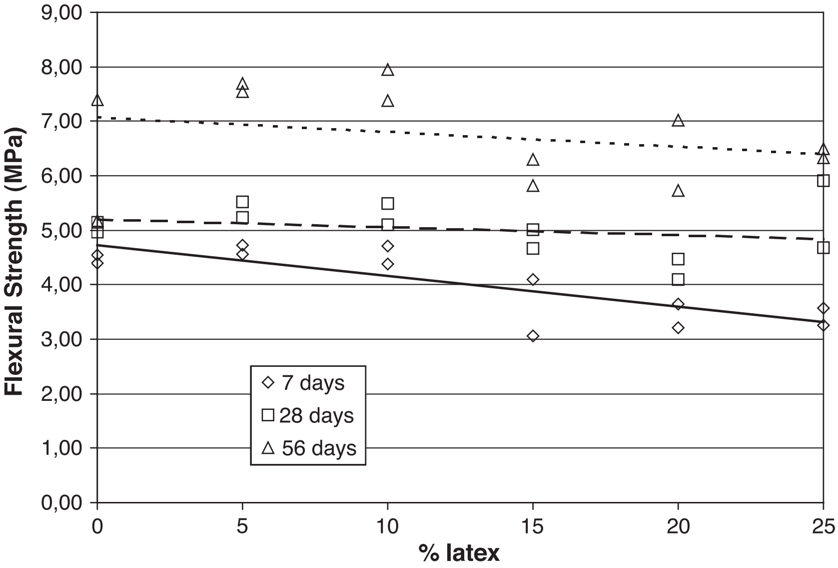

Fig. 11. Flexural strength of LMM with different percentages of latex and constant W/C (0.55) at several ages.

percentage increased closed and total porosity and decreased open porosity, for a constant W/C.

Consequently, with porosity, apparent and real densities decreased with the increase of latex, due to the lower density of latex with regard to mortar density (Fig. 6).

Fig. 7 summarizes ultrasonic modulus (E_s) LMM with different percentages of latex and W/C constant (0.55), at several ages. E_s decreased when percentage of latex increased, though it increased with age.

Bending and compression test results of LMM with several fixed flow table diameters in the fresh state at 28 days are presented in Figs. 8 and 9, respectively. Flexural strength increased with the percentage of latex and decreased for larger flow table diameters. Compressive strength was practically constant for any percentage of latex, though decreased for larger flow table diameters.

For constant W/C (0.55), flexural strength remained constant for any latex percentage, though increased with age (Fig. 10). Compressive strength decreased when latex percentage increased and increased with age (Fig. 11).

Dosage variables and physical and nondestructive variables can be related with mechanical properties through parametrical studies using multiple linear regression analysis (Figs. 12 and 13). The results of this analysis are hyperplane response surfaces, with 95% of confidence level. These parametric relations are useful to predict the mechanical behaviour of SBR LMM.

Dynamic parameters obtained from dynamic compression tests at 28 days and room temperature (20 °C and 50% RH) are summarized in Table 2. An increase of loss tangent (tan δ) and a decrease of dynamic modulus (E_0) when latex percentage increased can be observed.

6. Discussion of results

In the fresh state, the larger the amount of latex, the shorter the setting time. Above 15% of latex, a change of the tendency was observed. The change can be explained taking into account the co-matrix formation (cement hydration and

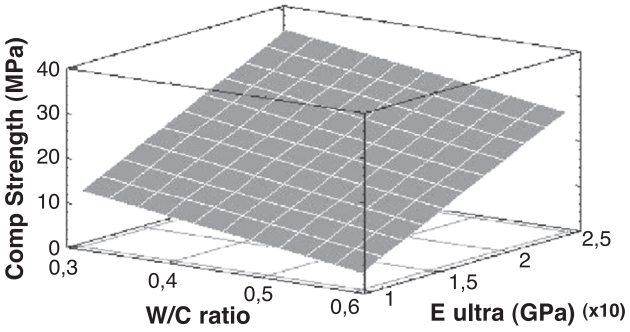

Fig. 12. Multiple linear regression analysis of LMM compressive strength at 28 days related to percentage of latex and ultrasonic modulus.

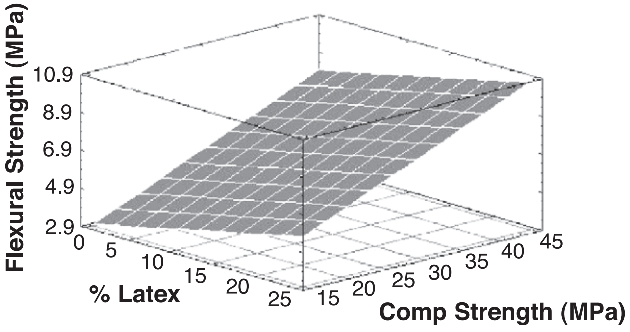

Fig. 13. Multiple linear regression analysis of LMM flexural strength at 28 days related to compressive strength at 28 days and W/C.

Table 2
LMM dynamic parameters for different percentages of latex, 0.5 Hz of frequency, at 28 days and room temperature (20 °C and 50% RH)

% Latex	E_0 (GPa)	δ (°)	tan δ	E' (GPa)	E'' (GPa)
0	1.12	7.61	0.13	1.11	0.15
5	1.08	9.44	0.17	1.07	0.18
10	0.98	10.31	0.18	0.96	0.18
15	0.78	11.53	0.20	0.76	0.16
20	0.69	13.96	0.25	0.67	0.17
25	0.54	14.74	0.26	0.52	0.14

polymer film formation). Under 15% of latex, setting process is governed by cement hydration and, above 15%, polymer film formation governs it.

In the hardened state, a decrease of apparent density and ultrasonic modulus due to the increase of latex occurred. Although, open porosity decreased due to a reduction of permeability [4,8]. On the other hand, total porosity increased with latex, due to the entrained air generated in the mixing process.

LMM stiffness decreased with latex, as shown in Fig. 7. Latex stiffness is lower than mortar stiffness, so LMM stiffness decreased with the increase of latex. E_s increased with age, due to the differed formation of cement paste hydration products.

The inclusion of SBR latex in cement mortar produces a decrease of compressive strength, due to the lower mechanical capacity of latex with regard to cement mortar, for a fixed consistency. This decrease is compensated by the reduction of W/C due to the plasticizer effect of latex. Both phenomena together maintain compressive strength constant for any percentage of latex.

Dynamic compression test results pointed out a decrease of the dynamic stiffness and an increase of phase angle (δ) as the amount of latex increased. The phase angle relates the time shift between the load wave and the displacement wave of a specimen subjected to cyclic load. The loss tangent (tan δ) relates the storage or static young modulus (E′) and the loss modulus (E″) by the next equations [21]:

$$E^* = E' + iE''$$

$$E' = E_0 \cos\delta$$

$$E'' = E_0 \sin\delta$$

$$|E^*| = E_0 \tag{4}$$

E' and E'' are, respectively, the real and imaginary components of the complex Young's modulus (E^*) [22]. It can be observed that the absolute value of the complex Young's modulus ($|E^*|$) coincides with the value of the dynamic Young's modulus (E_0).

The increase of the loss tangent (tan δ), due to the increase of latex in the LMM, does not mean an increase of loss modulus, because of its dependence on dynamic modulus [7]. The results obtained show that it can be considered constant.

It has to be taken into account that only one frequency (0.5 Hz) and temperature (20 °C) were tested and the behaviour of this kind of material depends on both frequency and temperature [22].

7. Conclusions

The consistency of SBR Latex Modified Mortar (LMM) depends on both water-to-cement ratio (W/C) and percentage of latex (PL). The parametric study presented allows prediction of the consistency as a function of both dosage parameters.

The SBR LMM experimental results showed that the mechanical properties depend also on dosage parameters and the results obtained by keeping constant W/C or consistency cannot be compared. In the first case, compressive strength decreased as PL increased and the flexural strength does not depend on PL. In the second case, compressive strength does not depend on PL and flexural strength increased with PL.

The mechanical properties of LMM can be predicted as a function of dosage parameters and physical properties obtained using nondestructive test methods such as the ultrasonic velocity pulse test.

Dynamic modulus decreases and loss tangent increases when PL in SBR LMM increases. Both variables define SBR LMM dynamic behaviour.

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References

[1] Y. Ohama, Polymer-based admixtures, Cem. Concr. Compos. 20 (1998) 189–212.

[2] J. Colville, A.M. Amde, M. Miltenberger, Tensile bond strength of polymer modified mortar, J. Mater. Civ. Eng. 11 (1) (1999) 1–5.

[3] I. Ray, A.P. Gupta, M. Biswas, Effect of latex and superplasticiser on Portland cement mortar in the fresh state, Cem. Concr. Compos. 16 (1994) 309–316.

[4] I. Ray, A.P. Gupta, M. Biswas, Effect of latex and superplasticiser on

Portland cement mortar in the hardened state, Cem. Concr. Compos. 17 (1995) 9–21.

[5] J. Schulze, Influence of water-to-cement ratio and cement content on the properties of polymer-modified mortars, Cem. Concr. Res. 29 (1999) 909–915.

[6] L. Bureau, A. Alliche, P.H. Pilvin, S. Pascal, Mechanical characterization of a styrene–butadiene modified mortar, Mater. Sci. Eng. A308 (2001) 233–240.

[7] X. Fu, D.L.L. Chung, Vibration damping admixtures for concrete, Cem. Concr. Res. 26 (1) (1996) 69–75.

[8] F.A. Shaker, A.S. El-Dieb, M.M. Reda, Durability of styrene–butadiene latex modified concrete, Cem. Concr. Res. 27 (5) (1997) 711–720.

[9] G. Barluenga; The joint in building systems of elements for façade: Constructive, aesthetic and structural functions, PhD thesis, Department of Building and Building Technology, School of Architecture, Polytechnic University of Madrid, 2002, in Spanish.

[10] G. Barluenga, F. Hernández-Olivares, R.T. Leon, Seismic response of a new design of vertical joint for architectural panels, Eng. Struct. 25 (2003) 1655–1664.

[11] Y. Ohama, Recent progress in concrete–polymer composites, Adv. Cem. Based Mater. 5 (1997) 31–40.

[12] D.W. Fowler, Polymers in concrete: A vision for the 21st century, Cem. Concr. Compos. 21 (1999) 449–452.

[13] E. Sakai, J. Sugita, Composite mechanism of polymer modified cement, Cem. Concr. Res. 25 (1) (1995) 127–135.

[14] R. Ollitrault-Fichet, C. Gauthier, G. Clamen, P. Boch, Microstructural aspects in a polymer-modified cement, Cem. Concr. Res. 28 (12) (1998) 1687–1693.

[15] D.A. Silva, V.M. John, J.L.D. Ribeiro, H.R. Roman, Pore size distribution of hydrated cement pastes modified with polymers, Cem. Concr. Res. 31 (2001) 1177–1184.

[16] UNE-EN 1015-3; Métodos de ensayo de morteros de albañilería. Parte 3: Determinación de la consistencia del mortero fresco (por la mesa de sacudidas), 2000.

[17] J.-H. Kim, R.E. Robertson, Prevention of air void formation in polymer-modified cement mortar by prewetting, Cem. Concr. Res. 27 (2) (1997) 171–176.

[18] UNE-EN 196-1; Métodos de ensayo de cementos. Parte 1: Determinación de resistencias mecánicas, 1996.

[19] UNE-EN 196-3; Métodos de ensayo de cementos. Parte 3: Determinación de tiempos de fraguado y de la estabilidad de volumen, 1996.

[20] J.C. Wang, Young's modulus of porous materials, J. Mater. Sci. 19 (1984) 809–814.

[21] N.G. McCrum, B.E.Y. Read, G. Williams, Anelastic and dielectric effects in polymeric solids, Dover Publications, New York, 1991.

[22] F. Hernández-Olivares, G. Barluenga, M. Bollati, B. Witozsek; Static and dynamic behaviour of recycled tyre rubber-filled concrete, Cem. Concr. Res. 32 (2002) 1587–1596.