PAPER • OPEN ACCESS

Rheological and mechanical properties of lime-brick powder mortars with expanded clay aggregate

To cite this article: M Vysvaril *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **385** 012063

View the article online for updates and enhancements.

Rheological and mechanical properties of lime-brick powder mortars with expanded clay aggregate

M Vysvaril, T Zizlavsky and P Rovnanikova

Faculty of Civil Engineering, Brno University of Technology, Veveri 331/95, Brno 602 00, Czech Republic

Abstract. The rheological behaviour and mechanical properties of lightweight lime-brick powder mortars with combined expanded clay-sand aggregates are presented in this paper. The rheological investigation included the characterization of flow properties and viscoelastic properties of the fresh mortars. Flexural and compressive strengths were determined at 7 and 28 days. These mortars are Non-Newtonian thixotropic liquids with conversion from shear-thickening to shear-thinning behaviour depending on expanded clay aggregate (ECA) content. Yield stress and consistency coefficient of mortars significantly increase with decreasing amount of ECA; the mortars become more rigid and more viscous. Some of the mortars reached higher flexural strengths than similar lime mortars with metakaolin and higher compressive strengths than pure lime mortars. The lightweight lime-brick powder mortar with the mass ratio of 1:1 between gravelous sand and ECA was identified as the best among the analyzed mortars.

1. Introduction

Recently, the use of lightweight aggregates (LWA) in mortar composition to improve acoustic and thermal insulation, or fire resistance has been developed [1–5]. However, lowering the density produces a strength reduction, which can limit the direct exposition of the mortar to the environmental agents, requiring an external protection [6]. Expanded perlite, expanded glass, expanded clay and hollow micro-spheres are some lightweight materials that, because of their composition based on aluminosilicates, are potentially able to give pozzolanic reactions. They can therefore provide additional advantages in mortars by improving their mechanical strength. Expanded clay aggregate (ECA) has been successfully used as a component of lightweight concrete mixtures in the past [7–10]. The application of ECA as the LWA in lime mortars was newly reported [11].

Brick powder as a waste material is available from the development of building elements for the construction of low-energy houses, or from a demolition waste. Bricks waste is usually rich in glass and burned clays, consisting in dehydrated aluminosilicates not only in crystalline phase but also in amorphous state which is important for its pozzolanic reaction.

In this study, the influence of quantity of ECA on the rheological and mechanical properties of blended lime-brick powder mortars is monitored. As their supposed applications include the renovation of surface layers of historical buildings, brick powder is utilized as the pozzolanic admixture replacing cement. The rheological properties of lime or cement-lime mortars containing LWA was reported in common literature sources just in the very few cases [12]. The main ambition of this study is to partially contribute to filling the gap in the scientific knowledge in that respect. The knowledge of mortars rheology may contribute to understand the behaviour of fresh materials and can allow predicting their flow properties that are important in a rendering.

2. Materials

Hydrated lime CL 90-S (Carmeuse Czech Republic, s.r.o.) was used as the main binder in all studied mortars. The brick powder from skiving of heat-insulating bricks from the HELUZ Brickworks factory, v.o.s. was added as a material with good pozzolanic properties [13] which was supposed to improve the mechanical characteristics. Natural gravelous sand (the fine fraction 0/2 mm from Českomoravský štěrk, a.s., Hulín) and expanded clay (Lias Vintířov, LSM k.s.) were used as aggregates. The ECA was produced using clay expanded in a rotary kiln at the temperature of 1150 °C. According to the producer information, the final product has spherical grains and its internal porosity system is uniform, while the surface of spheres is sintered. Basic properties of the applied ECA, as given by the producer are presented in figure 1. The chemical composition of all raw materials is given in table 1. The phase compositions obtained by the X-ray diffraction analysis are presented in table 2. The granulometry of aggregates and binders is shown in figure 1.

Mortar mixtures were prepared using the correct amount of water required to obtain normal consistency and a good workability of the mortars (160 ± 5 mm; measured by the flow table test). The proportioning of the mortar mixtures is given in table 3. Fresh mixtures were cast into prismatic moulds of size 40 × 40 × 160 mm. Standard conditions of sample storage were 22 ± 2 °C and relative humidity of 50 ± 5%. After 7 and 28 days the bulk density, the flexural and compressive strengths were determined.

Table 1. Chemical composition of initial materials examined by XRF spectroscopy (mass %).

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	TiO_2	SO_3	MnO
Lime	–	–	–	99.2	0.6	–	–	–	–	0.1	–
Brick powder	57.4	14.6	5.5	9.8	4.0	2.8	1.4	0.1	0.3	1.2	–
Sand	86.8	6.5	1.2	0.5	0.3	2.3	0.9	–	0.2	0.1	–
ECA	42.9	30.6	11.3	4.4	2.4	2.5	0.8	0.3	3.4	0.8	0.2

Table 2. Phase composition of initial materials (mass %).

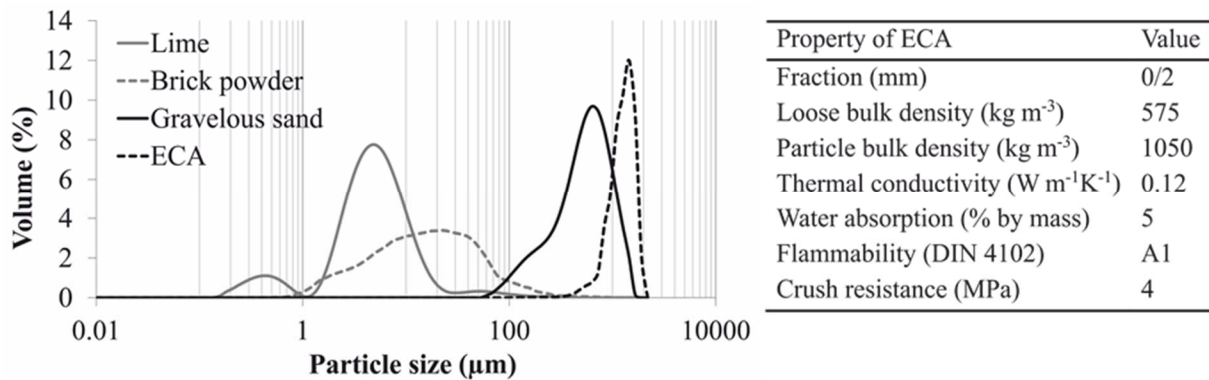| Mineral	Lime	Brick powder	Gravelous sand	ECA
Albite	–	13.5	–	–
Anatase	–	2.8	–	–
Anorthite	–	–	–	7.8
Biotite	–	–	3.0	–
Calcite	1.8	–	–	–
Diopside	–	–	–	3.0
Epidote	–	–	3.6	–
Gypsum	–	–	–	0.8
Hematite	–	3.1	0.7	–
Hercynite	–	–	–	12.2
Microcline	–	12.4	3.9	–
Mullite	–	–	–	7.9
Muscovite	–	8.9	–	–
Orthoclase	–	2.9	3.0	–
Portlandite	98.1	–	–	–
Quartz	–	31.2	75.6	2.9
Rutile	–	3.1	0.1	–
Sanidine	–	2.4	–	–
Staurolite	–	–	6.1	–
Amorphous phases	–	19.6	–	64.7

Figure 1. Particle size distribution of initial materials and properties of the expanded clay aggregate.

3. Experimental procedures

Rheological tests were carried out on the hybrid rheometer Discovery HR-1 (TA Instruments). The experimental conditions, the technique of flow and oscillation measurements and the data evaluation were identical as in the previous studies [14,15]. The Herschel-Bulkley model was applied to descending branches of flow curves to fit the experimental data and used to describe the mortars rheological behaviour. Thixotropy of the mortars was determined by the TRIOS software as an area between flow curves [16]. The strain of 0.003% used in the frequency sweep oscillation tests was lower than the critical strain for all studied mortars (table 4; γ_c).

Flexural strengths of the samples were determined using a standard three-point-bending test and compressive strengths were measured on the far edge of both residual pieces obtained from the flexural test according to EN 1015-11. The flexural and compressive strengths were obtained after curing times of 7 and 28 d. The coefficients of variation were below 15%. The water absorption of mortars was measured according to EN 13755 after curing times of 28 d.

Table 3. Composition of mixtures.

Mixture	Lime (g)	Brick powder (g)	ECA (g)	Gravelous sand (g)	Water (ml)
LV-I	100	100	100	0	240
LV-II	100	100	75	25	210
LV-III	100	100	50	50	180
LV-IV	100	100	25	75	150

4. Results and discussion

4.1. Rheological properties

4.1.1. Flow properties.

Figure 2 illustrates the flow curves of fresh mortars. The shape of curves indicates the lime-brick mortars as Non-Newtonian liquids with gradual conversion from shear-thickening to shear-thinning suspension for decreasing ECA content. It is also confirmed by diminishing flow index values, n, (table 4). The shear-thickening behaviour of lime mortars is very unusual especially with such high doses of mixing water and spherical grains of ECA, conversely to typical shear-thickening behaviour of lime-metakaolin mortars where the dilatant properties can be explained by considering the plate like and angular shape of metakaolin particles. All of the mortars exhibited a thixotropic (time-dependent shear thinning) character with an increasing tendency for decreasing ECA content in the mortar (table 4). It is apparent that the yield stress and the consistency coefficient of mortars significantly increased with decreasing amount of ECA (table 4). This was expected because the lower mixing water amount in mortar drops off the solubility of the lime and brick particles, the structure of the mortar is denser, and the mortar is less fluid with higher plasticity.
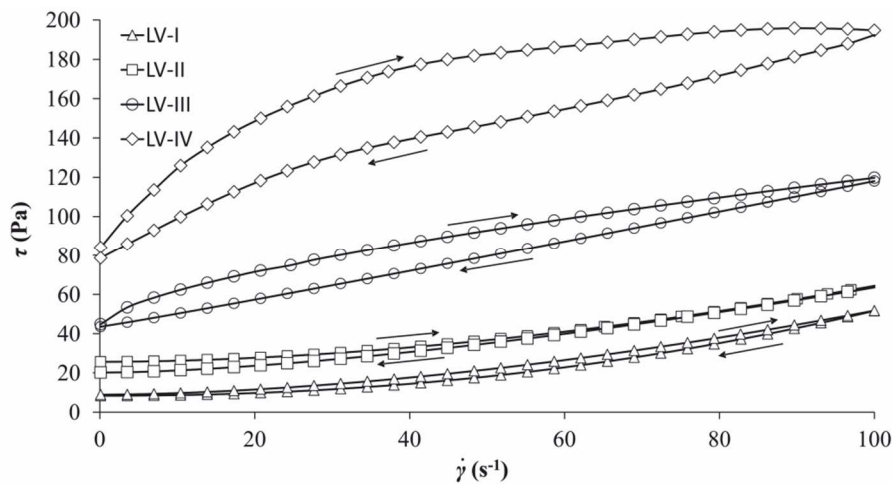
Figure 2. Flow curves of lime-brick powder mortars.

Table 4. Comparison of bulk density (28 d) and rheological parameters of lime-brick powder mortars.

Mixture	ρ_b (kg m^{-3})	τ_0 (Pa)	k (Pa s)	n (-)	Thixotropy (Pa s)	γ_c (%)	γ_f (%)	G^* (Pa)	η^* (Pa s)	tan δ (-)
LV-I	790	8.35	0.002	2.14	242.5	0.005	0.359	14501	2308	0.296
LV-II	930	20.00	0.036	1.54	226.5	0.005	0.841	13872	2208	0.280
LV-III	1120	43.45	0.602	1.05	1043.0	0.006	5.778	39135	6229	0.212
LV-IV	1250	75.44	6.152	0.63	2670.2	0.008	15.08	57750	9191	0.138

4.1.2. Viscoelastic properties

A linear viscoelastic (LVE) range was determined for mortars by applying varying strain amplitude oscillatory test and measuring the dynamic moduli, G' and G'', (figure 3). The LV-IV mortar exhibited the largest LVE range ending at a critical strain, γ_c, at which the decrease of G' is observed, but the variations were quite small (table 4). All mortars have G' greater than G'' in the LVE range, where the structure of the system is not disturbed; this indicates that the mortars are composed of a strongly multi-connected network of particles. Decreasing amount of ECA in the mortars leads to an increase of the storage modulus (G'), indicating an increase of the material cohesion.
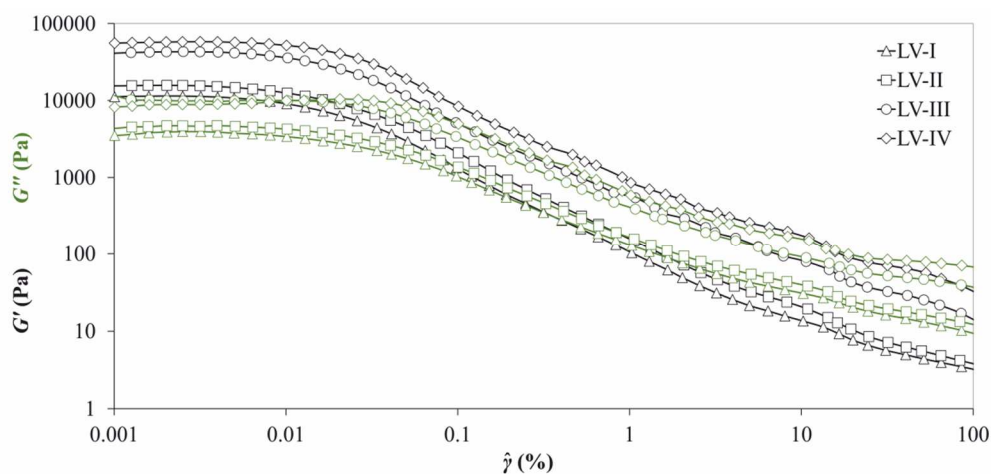

Figure 3. The evolution of G' and G'' as a function of strain amplitude.

A flow strain γ_f at a flow point (when G′ = G″, the gel-like character of the sample is changed to the liquid state) increases with decreasing ECA content; this confirms the more fluid character of LV-I and LV-II mortars.

The results of frequency sweep tests proved the relationship between the amount of ECA and the stiffness of lime mortars; the ratio between dissipation and elasticity increased (growing G^*) with decreasing amount of ECA and the mortars became more rigid and more viscous (figure 4). Since the ratio between viscosity and elasticity (loss factor, tan δ) varies below 1 (table 4), the mortars show a higher proportion of the elastic component (G') than the viscous one (G''), suggesting that the mortars have a strong structure resistant to external interference.
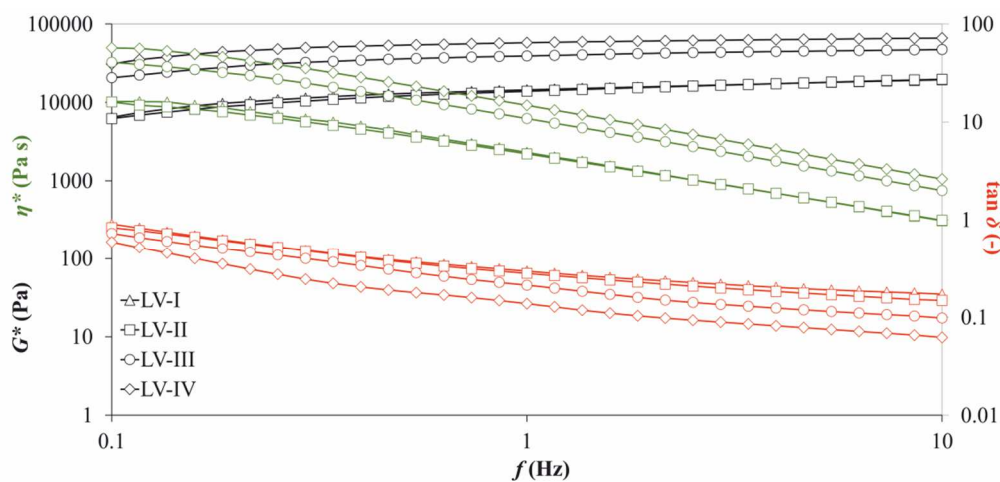

Figure 4. Evolution of G^*, η^* and tan δ as a function of frequency.

4.2. Mechanical properties

Obviously, because of mortar hardening, the mechanical strengths of mortars increased with curing time (figure 5). It can be stated that the mortars with higher content of ECA (LV-I and LV-II) are much weaker than LV-III and LV-IV. The latter mortars reached higher flexural strengths than similar lime mortars with metakaolin [11]. The effect of ECA amount on the values of compressive strength was contradictory to the previous findings [11]. The compressive strength of LV-III and LV-IV was much higher than for pure lime mortars and if the reduced bulk density (table 4) is taken into account, the LV-III mortar represents a suitable variation of lightweight lime-brick powder mortars for practical utilization. The differences in strengths properties and water absorption between LV-III and LV-IV are insignificant but the difference in bulk density is fundamental.
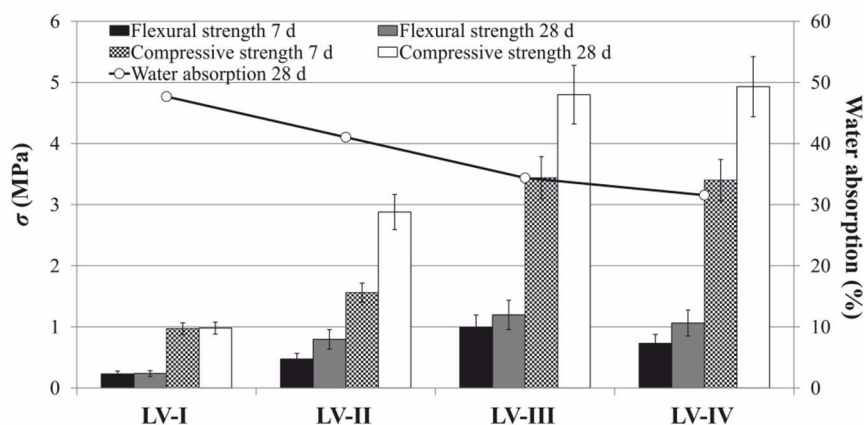

Figure 5. Strength characteristics and water absorption of lime-brick powder mortars.

5. Conclusions

Lightweight lime-brick powder mortars with combined expanded clay-sand aggregates were investigated in this paper. The effect of quantity of expanded clay aggregate (ECA) on the rheological and mechanical properties of mortars was determined. The main conclusions are as follows:

- The lime-brick powder mortars were Non-Newtonian liquids with gradual conversion from shear-thickening to shear-thinning behaviour for decreasing ECA content. All of the mortars exhibited a thixotropic character with an increasing tendency for decreasing ECA content in the mortar.
- The yield stress and the consistency coefficient of mortars significantly increased with decreasing amount of ECA because of the diminishing amount of mixing water required for the same consistency.
- Decreasing amount of ECA in the mortars led to the growth of the storage modulus (G') and complex modulus ($G*$) indicating the material cohesion increase; the mortars became more rigid and more viscous.
- The mortars with high content of ECA were weak in strengths. Some of the mortars reached higher flexural strengths than similar lime mortars with metakaolin and higher compressive strengths than pure lime mortars.
- The lightweight lime-brick powder mortar with the mass ratio of 1:1 between gravelous sand and ECA, which was identified as the best among the analyzed mortars, has a very good potential for practical applications because its properties are significantly enhanced, as compared with the common lime plaster with silica aggregates.

References

[1]   Silva L M, Ribeiro R A, Labrincha J A and Ferreira V M 2010 *Cem. Concr. Compos.* **32** 19
[2]   Torres M L and García-Ruiz P A 2009 *Cem. Concr. Compos.* **31** 114
[3]   Zach J, Hela R, Hroudová J and Sedlmajer M 2011 *Adv. Mater. Res.* **335–336** 1199
[4]   Brás A, Gonçalves F and Faustino P 2014 *Energy Build.* **72** 296
[5]   Mazhoud B, Collet F, Pretot S and Chamoin J 2016 *Build. Environ.* **96** 206
[6]   Palomar I, Barluenga G and Puentes J 2015 *Constr. Build. Mater.* **75** 306
[7]   Lo T Y and Cui H Z 2004 *Mater. Lett.* **58/6** 916
[8]   Kong L, Zhang B, Ge Y and Yuan J 2009 *J. Wuhan Univ. Technol. Mater. Sci. Ed.* **24/1** 145
[9]   Dilli M E, Atahan H N and Şengül C 2015 *Constr. Build. Mater.* **101** 260
[10] Ke Y, Beaucour A, Ortola S, Dumontet H and Cabrillac R 2009 *Constr. Build. Mater.* **23/8** 2821
[11] Konakova D, Cachova M, Vejmelkova E, Keppert M, Jerman M, Bayer P, Rovnanikova P and Cerny R 2017 *Cem. Concr. Compos.* **83** 374
[12] Pereira de Oliveira L A, Castro Gomes J P and Nepomuceno M C S 2013 *Appl. Rheol.* **23** 15505
[13] Navratilova E and Rovnanakova P 2016 *Constr. Build. Mater.* **120** 530
[14] Vysvaril M and Zizlavsky T 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **251** 1
[15] Vysvaril M, Hegrova M and Zizlavsky T 2018 *Key Eng. Mater.* **760** 257
[16] Bohac M and Necas R 2016 *Procedia Eng.* **151** 34