The use of industrial and traditional limes for lime mortars

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ABSTRACT: In the testing program the research was focused on acquiring a better insight into the properties of lime-based mortars from industrial and traditional non-hydraulic limes available on the Slovenian market. The lime-based mortars were made from different types of sand and with or without the addition of small quantities of microsilica, metakaolin and cement for faster gain of strength, or with small amount of polypropylene fibres for better ductility of hardened mortars.

1 INTRODUCTION

Lime used to be traditional binder, used for a large variety of mortars for brickwork, stonework, renders and plasters in the ancient buildings of Europe. But for restoration purposes usually current materials and techniques are employed. These are often found to be ineffective and can cause damage. As a consequence there has been a renewed interest in ancient materials and technologies. These new developments are reflected in various recent Restoration Charters, which recommend the use of lime-based mortars for restoration works, because of their compatibility with the existing walls.

In the last few years the demands for the reintroduction of the lime-based mortars for restoration works have been more and more frequent also in Slovenia, although current materials and techniques are still too often used even in old town centres. For this reason some public laboratories and faculties have started to study and recommend lime technologies for the restoration works of ancient buildings. Our research team, Department of Research in Materials and Structures at the University of Ljubljana, has been involved in the research of lime-based mortars for clay bricklaying almost for a decade and for the last four years also in the research of lime-based renders and plasters. Our main field of interest is properties and characteristics of lime-based mortars from industrial and traditional non-hydraulic limes available on the Slovenian market, as well as the influence of possible pozzolanic additives for faster gain of strength and mikrofibres for better ductility of hardened mortars. In the sequel of the paper test results and experiences obtained with lime-based mortars from industrial hydrated lime and lime-putty as well as from traditional lime-putty are given and discussed. The lime-based mortars were made from different types of sand and with or without the addition of small quantities of microsilica, metakaolin and cement or with polypropylene fibres.

2 TESTING PROGRAMME

2.1 Materials and details of mixes

The testing programme encompassed tests of the characteristics of 12 mixes of fresh and hardened lime-based mortars and the determination of bond strength between the mortars and one type of solid clay bricks. The lime-based mortars were composed as follows:

- Mixes with type I sand
  - hydrated lime : sand 1:3 (HTI)
    (5 batches: HTIm-1, HTIm-2, HTIp-1, HTIp-2, HTIp-3)
  - hydrated lime : sand 1:3 with 10% of microsilica (HTI+s)
    (5 batches: HTIm+s-1, HTIm+s-2, HTIp+s-1, HTIp+s-2, HTIp+s-3)
- Mixes with type II sand
  - industrial lime-putty : sand 1:3 (PSII)
  - industrial lime-putty : sand 1:3 with 5% of metakaolin (PSII+m)
  - industrial lime-putty : sand 1:3 with 5% of cement (PSII+c)
  - industrial lime-putty : sand 1:3 with 3% of polypropylene fibres (PSII+v)
- Mixes with type III sand
  - industrial lime-putty : sand 1:3 (PSIII)
  - industrial lime-putty : sand 1:3 with 10% of metakaolin (PSIII+m)
  - industrial lime-putty : sand 1:3 with 10% of cement (PSIII+c)
  - traditional lime-putty : sand 1:3 (PPIII)
  - (2 batches: PPIII-1 and PPIII-2)
  - traditional lime-putty : sand 1:3 with 10% of metakaolin (PPIII+m)
  - traditional lime-putty : sand 1:3 with 3% of polypropylene fibres (PPIII+fibr)

The amount of added water was adjusted in order to obtain a flow value around 145mm and good workability determined by laboratory worker.

1:3 is volume proportion between hydrated lime or lime putty and sand. Mikrosilica (10%) was added with respect to the weight of the hydrated lime and cement (5% and 10%) and metakaolin (5% and 10%) with respect to the weight of the lime putty. Polypropylene fibres (3%) were added with respect to the volume of mortar.

The used non-hydraulic lime binders were hydrated lime produced by "IGM Zagorje ob Savi", the 3-month-old industrial lime-putty produced by "Solkanska industrija apna" and the 3 year old traditional lime-putty from the village Podpec near Ljubljana. The used sand types were mostly calcareous pebble-sand from the river Sava (type I), calcareous quarry-sand from the same quarry as the limestone for the industrial lime-putty (type II) and mostly siliceous pebble-sand from Puconci (type 3). The gradations of the 3 sands are given in Fig 1.

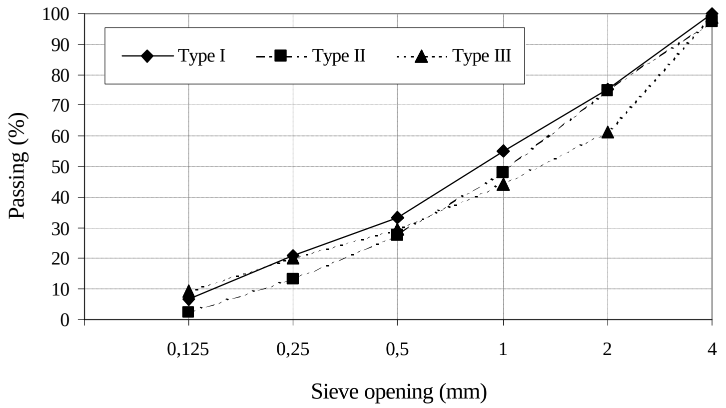

Figure 1 : Particle size distribution of used sands.

As additives were used microsilica in the form of water dispersion ($40\%_{mas}$ SiO_2 and $60\%_{mas}$ water) with trade name Cembinder 17 produced by Eka Chemicals, metakaolin MetaStar produced by IMERYS/ECC International and Portland cement CEM II/B-M 42.5 according to the EN 197-1 produced by Slovenian cement factory Salonit Anhovo. Polypropylene fibres for micro reinforcement of lime-based mortar were commercial fibres “Krenit”, produced by CEMFIBER from Denmark, with fibre length 12 mm, cross-section size 35x250-600 μm, ultimate stress 340-500 MPa, elastic modulus 8.5-12.5 GPa and ultimate strain 8-10%.

For the mortar mix from hydrated lime and type I sand denotations HTIm-1 and HTIm-2 mean two main batches from which only specimens for the determination of the hardened mortar properties were cast. On the other hand, denotations HTIp-1, HTIp-2 and HTIp-3 mean batches of the mix used first of all for the fabrication of walletes and panels for compressive, diagonal and shear tests of unreinforced clay masonry. From the batches also specimens for the determination of the mortar properties were cast. The hardened mortar properties were determined on the same day as the tests on walletes or panels were carried out (parallel tests). The same explanation is true also for the denotations of mortar batches in case of adding 10% of microsilica (HTIm+s-1, HTIm+s-2, HTIp+s-1, HTIp+s-2, HTIp+s-3).

2.2 Fabrication of specimens and tests specifications

After mixing particular batch of lime-based mortar, first the flow value (prEN 1015-3), air content (prEN 1015-7), density (prEN 1015-7) and water retentivity (prEN 1015-8) of fresh mortars were determined. Then, the specimens for the determination of the characteristics of hardened lime-based mortars were prepared. The compressive and flexural strength of the mortars were determined on prisms 4x4x16 cm^3 according to prEN 1015-11. For one batch of lime-based mortar at least three prisms were cast, which means at least three specimens for flexural test and at least six specimens for compressive test. Bond Wrench test of two-stack high masonry prisms was used for the estimation of bond strength between mortars and clay bricks in case of failure in the mortar-brick junction. In case of failure in the mortar joint, Bond Wrench test actually estimates the tensile strength of the mortar. The length of the level arm was first 540 mm and if this was not enough, the level arm with the length of 1080 mm was used. For one lime-based mortar at least three masonry prisms were made. For batches HTIm-1 and HTIm+s-1 of the mix HTI also the increase in strength of mortars with the age of specimens was studied, thus the compressive, flexural and Bond Wrench tests were carried out on 30, 60 and 90 day old specimens. The maximum age of the test specimens 90 days was chosen due to he supposition that compressive and flexural strengths of plain lime mortar prisms 4x4x16 cm^3 attain nearly final value at this age. For the other lime-based mortars the tests on hardened specimens were carried out on specimens aged between 90 and 300 days.

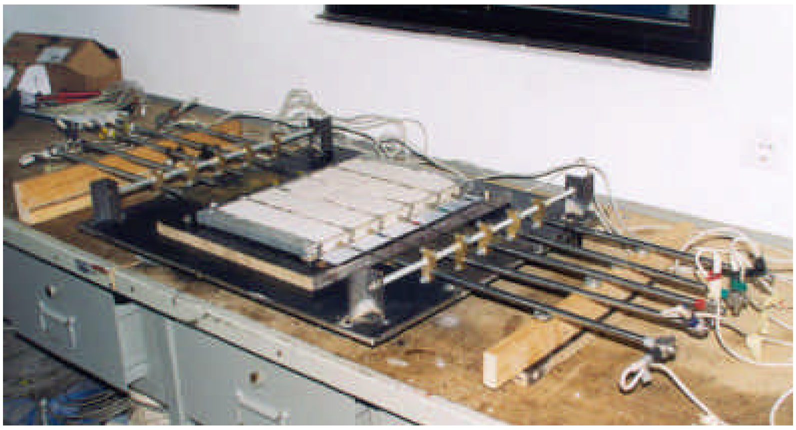

Figure 2 : Test set-up for shrinkage measurements of lime-mortars.

For the measurements of the deformations of lime-based mortars due to shrinkage, the equipment developed by our research group was used. The equipment consists of five moulds 2x6x25 cm^3 and ten LVDT’s (two for each specimen) with the accuracy of 10 μm and it should make possible to measure deformations of mortar from the moment, when the filling of moulds with mortar is finished (Fig. 2). The shrinkage tests were carried out only on 5 lime-based mortars made from type III sand (PPIII, PPIII+m, PPIII+v, PSIII and PSIII+c). During the tests the environmental conditions were as follows: temperature from 19 to 23ºC and relative humidity from 25 to 50%.

3 ANALYSIS OF TEST RESULTS

3.1 Properties of fresh lime-based mortars

Table 1 : Properties of fresh lime-based mortars from hydrated lime.

	HTIm-1	HTIm-2 and HTIp-1 to HTIp-3	HTIm+s-1	HTIm+s-2 and HTIp+s-1 to HTIp+s-3
number of specimens	16	8	16	7
flow value mm	149.5	149	151.5	148
C.V. %	2	2	1	3
air content %	3.4	4.2	2.9	3.8
C.V. %	12	33	10	34
density kg/m^3	2161	2130	2136	2100
C.V. %	0.5	2	0.3	2
number of specimens	5	8	5	7
water retentivity %	88.8	86.1	87.8	84.3
C.V. %	11	-	9	-

Table 2 : Properties of fresh lime-based mortars from industrial lime putty.

	PSII	PSIII	PSII +m	PSII +c	PSII + v	PSIII +m	PSIII +c
flow value mm	138	147	135	143	131	145	152
air content %	3.7	3.9	2.85	2.3	4.05	3.2	2.7
density kg/m^3	2046	2018	2082	2062	2058	2026	2032
water retentivity %	90.4	90.4	94.6	88.2	89.7	91.5	88.2

The test results of fresh mortar properties are given in Tab.1, Tab.2 and Tab.3. Higher coefficients of variation for group of batches HTIm-2, HTIp-1 to HTIp-3, compared to the batch HTIm-1, and for group of batches HTIm+s-2, HTIp+s-1 to HTIp+s-3, compared to the batch HTIm+s-1, are most probably due to workmanship: a few laboratory workers for the two groups of batches and single one for the batches HTIm-1 and HTIm+s-1. For mixes in Tab.2 and Tab.3 there was also single worker. However, for these mixes only one specimen was used for the determination of fresh properties of a particular mix. An exception is mortar mix PPII with two batches. Therefore, reliable conclusions about the influence of the used non-hydraulic limes, additives and fibres to the properties of fresh lime based mortars are difficult to be drawn.

However, it seems that the addition of cement, microsilica or metakaolin lowers the porosity of the mortar. The addition of cement or microsilica lowers also the water retentivity of the mortar. On the other hand, the addition of metakaolin seems to increase the water retentivity of the lime-based mortar. The addition of polypropylene fibres can slightly increase the air content of the mortar mix, but it has no influence on the water retentivity of the mortar.

Table 3 : Properties of fresh lime-based mortars from traditional lime putty.

	PPII	PPIII	PPIII +m	PPIII +v
flow value mm	148	152.5	138	135
air content %	3.3	3	2.8	3.2
density kg/m^3	2084	2048	2050	2048
water retentivity %	85.6	85.6	91.5	86.2

3.2 Properties of hardened lime-based mortars

Table 4 : Properties of plain lime mortars from hydrated lime.

	HTIm-1	HTIm-1	HTIm-1	HTIm-2	HTIp -1	HTIp -2	HTIp -3
age of specimens days	30	60	90	160	150	150	300
number of specimens	12	12	12	30	12	12	18
compressive strength MPa	0.85	1.44	1.46	1.24	2.09	1.92	1.13
C.V. %	19	10	9	5	5	7	10
number of specimens	6	6	5	15	6	6	9
flexural strength MPa	<0.29	<0.29	0.52	0.57	0.58	0.5	0.37
C.V. %	-	-	25	11	8	18	27
number of specimens	5	5	4	-	6	6	8
Bond Wrench MPa	0.06	0.07	0.11	-	0.12	0.19	0.13
C.V. %	5	17	9	-	47	18	24

The influences of age of the specimens, different batches of the same mix and workmanship on the properties of hardened plain lime mortar were studied only on the mortar mix HTI (Tab.4). From the results given in Tab. 4 we can see that compressive strength of the mortar batch HTIm-1 at 30 and 60 days is around 60 and 98% of its 90-day strength. It seems that the prisms from hydrated lime attained their final compressive strength at approximately 60 days of age. Flexural strength of the same batch was obtained only for 90-day-old specimens, since at 30 and 60 days specimens were not even able to carry the weight of used testing equipment. The comparison with results obtained on different batches of the mix HTI at specimens' age 90 days or more shows, that flexural strength of the mortar obtained at 90 days is a good approximation of final flexural strength of the mortar. From the same results we can see the important influence of different batches and workmanship on compressive strength of the mortar HTI. The obtained values are between 1.13 MPa and 2.09 MPa with average value equal to 1.51 MPa. The influence of the same parameters to the flexural strength of the mortar is less important, since the obtained values are between 0.37 and 0.58 MPa with average value of 0.51 MPa. The same is true also for the results of Bond Wrench tests, where the obtained strengths are between 0.11 and 0.19 MPa with average value of 0.14 MPa.

Table 5 : Properties of plain lime mortars from lime-putty.

	PSII	PSIII	PPIII-1	PPIII-2
age of specimens days	90	120	90	120
number of specimens	28	12	17	12
compressive strength MPa	1.16	0.95	2.03	1.63
C.V. %	10	10	4	22
number of specimens	14	6	9	6
flexural strength MPa	0.56	0.572	0.52	0.7
C.V. %	16	32	27	72
number of specimens	3	3	3	3
Bond Wrench MPa	0.09	0.10	0.12	0.24
C.V. %	29	7	47	49

The properties of hardened plain lime mortars from lime-putties at specimens' age of 90 days or more are given in Tab.5. For the mix HTI average compressive, flexural and Bond Wrench strength are given above. The obtained results show that the lowest compressive strength was obtained for mortars from industrial lime-putty (PSII and PSIII), higher average compressive strength for the mortar from industrial hydrated lime (HTI) and the highest compressive strength for mortar from traditional lime-putty (PPIII). It is true that plain lime mortar mixes were from three different types of sand, but from the results in this paper (PSII and PSIII) and results obtained by other authors (Bosiljkov 2000, Kosovel 2000) we can conclude that the influence of sand type with particles size distribution in the range of the three used sands (Fig.1) on compressive strength of lime mortars is not very important. The obtained compressive strengths between 0.95 and 2.09 MPa are in good correlation with the results reported by Giorgi (1998), where compressive strengths obtained on replicas of ancient mortars from different non-hydraulic lime-putties and different types of sand were between 0.8 and 1.4 MPa. Despite relatively large interval of compressive strengths obtained during our tests, average flexural strengths of plain lime mortars are in very narrow interval, mostly between 0.51 and 0.57 MPa. Exceptions are batch HTIp-3 of the mortar HTI with average flexural strength of 0.37 MPa and second batch of the mortar PPIII with average flexural strength 0.7 MPa. However, coefficient of variation of the batch PPIII-2 is extremely high (72%) compared to the other plain lime mortars batches (8 to 32%).

The influence of microsilica on the properties of hardened lime-based mortar was studied on 5 batches of the mortar MTI+s (Tab. 6). The results obtained on batch HTIm+s-1 at specimens age of 30, 60 and 90 days show increase in compressive as well as flexural strength due to the addition of microsilica. The highest increase in compressive strength, by 210%, was obtained at 30 days and the highest increase in flexural strength, by more than 13%, at 60 days.

The comparison between compressive strengths of different batches of the mortar HTI+s at specimens' age of 90 days or more also shows that the addition of 10% of microsilica increases compressive strength of the mortar compared to the plain lime mortar HTI. However, the strength increase differs a lot between individual batches. The minimum increase of 20% was obtained for batches HTIm+s-2 and HTIp+s-3 and the maximum increase of around 190% for batches HTIm+s-1 and HTIp+s-2. It is very realistic to conclude that the obtained great difference in results is mostly due to no uniform distribution of particles of microsilica in the lime based mortar and of course also due to the influence of different batches and workmanship. Regarding flexural strength of the specimens aged 90 days or more we can see that the addition of microsilica increased only flexural strength in the case of the batch HTIm+s-1 (by about 50%), had almost no influence at batches HTIp+s-1 and HTIp+s-2 and decreased flexural strengths in the case of batches HTIp+s-2 and HTIp+s-3 (by 16 and 19%). Again, no homogeneity of the lime-based mortars can be predominantly responsible for the obtained results.

Considering that the failure obtained at Bond Wrench test for the mortar mix HTI was always in the mortar joint and for the mix HTI+s always in the mortar brick junction, we can see (Tab.4 and Tab.6) that the addition of microsilica can extremely decrease bond strength between mortar joint and solid clay brick. On the other hand, potential increase in bond strength is only up to 50%.

Table 6 : Properties of lime-based mortars from hydrated lime with additives.

	HTIm +s-1	HTIm +s-1	HTIm +s-1	HTIm +s-2	HTIp +s -1	HTIp +s -2	HTIp +s -3
age of specimens days	30	60	90	160	150	150	300
number of specimens	12	12	12	30	12	12	18
compressive strength MPa	2.66	3.37	4.23	1.49	3.78	5.68	1.35
C.V. %	4	4	3	4	9	10	6
number of specimens	6	6	6	15	6	6	9
flexural strength MPa	0.53	0.66	0.77	0.48	0.57	0.52	0.3
C.V. %	9	2	1	18	2	28	-
number of specimens	3	5	4	-	6	6	8
Bond Wrench MPa	0.06	0.11	0.17	-	0.03	0.003	0.16
C.V. %	37	1	27	-	103	173	58

Properties of hardened mortars made from lime-putties with additive or microfibres at specimens' age of 90 days or more are given in Tab.7. From the results in the table we can see that the addition of metakaolin improves the compressive strength of the lime-based mortar compared to the plain lime mortar. Improvement in the strength is much lower for lower content of added metakaolin (75% for mortar PSII+m) than for higher content of metakaolin (245 and 290% for mortars PSIII+m and PPIII+m). The addition of higher content of metakaolin increased also the flexural strength of the lime-based mortars (by 33 and 180% for mortars PSIII+m and PPIII+m). On the other hand, lower content of metakaolin had almost no influence on the flexural strength of the lime-based mortar. The influence of metakaolin on the strength obtained by Bond Wrench tests seems to depend on the type of used lime-putty. For industrial lime-putty it is very likely that metakaolin has improved strength of bond between mortar joint and clay brick. Failure modes obtained at mortars PSII and PSIII were partially in the mortar joint and partially in the mortar-brick junction. Thus the obtained values present actually the estimation of the bond strength between mortar joint and clay brick and are for mortars PSII+m and PSIII+m by 33 and 210% higher than for mortars PSII and PSIII. On the other hand, for the traditional lime-putty the addition of metakaolin lowered bond strength by more than 25%, since failure mode of the mortar PPIII was always in the mortar joint and for the mortar PPIII+m always in the mortar-brick junction.

The addition of 5 or 10% of cement to lime mortar has negative influence on the properties of hardened mortar. This was not expected despite some information that the addition of small amount of cement to lime mortar worsens its properties (Holmström 1995). The compressive strength of the mortars PSII+c and PSIII+c is by 60 and 39% lower, flexural strength is by at least 48 and 50% lower and bond strength is lower (by 33 % for PSII+c) or approximately the same (PSII+c) as for the mortars PSII and PSIII, respectively.

The incorporation of polypropylene micro fibres in the mortars PSII and PPIII resulted in the same (PSII+v) or lower (by 32% for PPIII+v) compressive strength, lower flexural strength (by 43 and at least 31% for mortars PSII+v and PPIII+v) and lower strength obtained at Bond

Wrench test (by 33 and 58% for mortars PSII+v and PPIII+v), compared to the mortars PSII and PPIII. Due to fact that for mortars with incorporated microfibres failures at Bond Wrench test were not only in the mortar joint but also in the mortar-brick junction, we can conclude that also bond strength is lower at micro reinforced lime mortars than at plain lime mortars. Since the properties of fresh mortar mixes were almost not changed due to the addition of small amount of fibres (Tab.2 and Tab.3), lower strengths could be the result of compaction of fibre-reinforced mortars that was not so effective as at plain lime mortars. Unfortunately, none of the used tests for strength characteristics of lime-based mortars can estimate the improvement in ductility of the mortar due to incorporated fibres. However, already not instantaneous but progressive failure obtained at Bond Wrench test indicates that ductility of such mortars is significantly improved.

Table 7 : Properties of lime-based mortars from lime-putty with additives.

	PSII +m	PSII +c	PSII +v	PSIII +m	PSIII +c	PPIII +m	PPIII +v
age of specimens days	90	90	90	120	120	120	120
number of specimens	17	18	15	6	12	6	6
compressive strength MPa	2.03	0.45	1.2	3.28	0.58	7.21	1.25
C.V. %	4	11	7	7	5	3	23
number of specimens	9	9	8	3	6	3	3
flexural strength MPa	0.52	<0.29	0.32	0.76	<0.29	1.73	0.418[i] <0.29[ii]
C.V. %	27	-	13	21	-	10	-
number of specimens	3	3	3	3	3	3	3
Bond Wrench MPa	0.12	0.06	0.06	0.31	0.1	0.14	0.08
C.V. %	47	21	13	42	14	34	18

i – result obtained on one specimen, ii – results obtained on two specimens

3.3 Shrinkage of lime-based mortars

The results of shrinkage measurements of lime-based mortars carried out with equipment (Fig. 2) developed by our research group show (Fig. 3) that in three days after mixing of lime-based mortar most of the deformations due to shrinkage occur and can be after three days as high as 1%. In case of standard shrinkage test on prisms 4x4x16 cm^3 according to JUS B.C8.029 (former Yugoslav standard) we have to leave the lime-mortar specimens in moulds for at least three days to gain sufficiently high strength of the specimens, which prevents failure of the specimens during demoulding. According to the results obtained by Bosiljkov (2000) from the age of pure lime mortar specimens of three days on we can expect gain in deformations due to shrinkage only up to around 0.02% in two months. Therefore, testing method capable of measuring the deformations of lime-based mortars due to shrinkage from the very beginning on can be very useful.

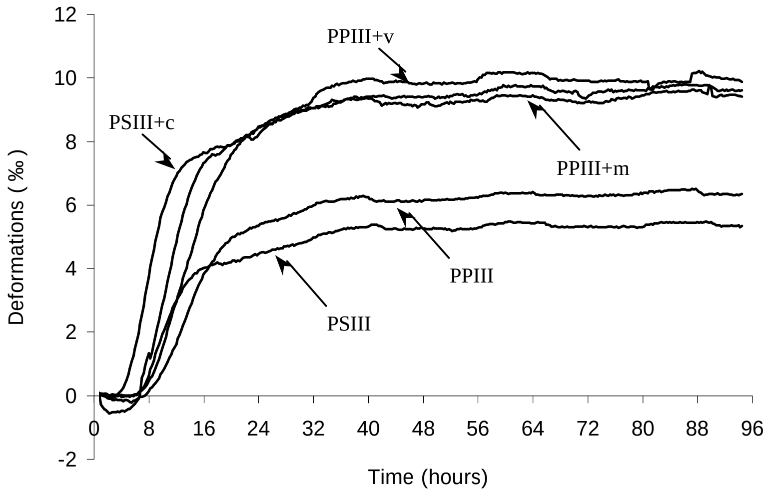

Figure 3 : Average deformations due to shrinkage of lime-based mortars.

The obtained average time-dependent deformations due to shrinkage from the very beginning on are shown in Fig. 3. From the results we can see that gain in shrinkage deformations of the lime-based mortars starts in three to six hours after mixing of the mortar. The observed several hours long "resting" period of lime-based mortars could be the result of high water retentivity of the lime-based mortars or not high enough cohesion between mortars and inserted ripped bolts connected with LVDT's. The real source of the "resting" period will be shown only by a precise validation of the used test method, since up to now only comparison between the results obtained with LVDT's and change of length of the specimens determined with vernier calliper after demoulding have been carried out. These two values for particular mortar mix were in good correlation.

From the results in Fig. 3 we can see that the addition of cement had important influence on the beginning of shrinkage, which started approximately three hours after mixing of the mortar PSIII+c. About one hour later started also the shrinkage of the mortar PPIII+m, but for this mortar also relatively high swelling was detected. Since for mortars PSIII, PPIII and PPIII+v the beginning of shrinkage was approximately the same (after about six hours), the earlier start of shrinkage for the mortars PSII+c and PPIII+m could be the result of cement hydration and pozzolanic reaction, respectively.

After four days of shrinkage measurements the obtained average shrinkage deformations were for the plain lime mortars PSIII and PPIII about 5‰ (C.V. 10%) and 6‰ (C.V. 30%), respectively and for the mortars PSIII+c, PPIII+m and PPIII+v about 9.5‰ (C.V. 18%), 9.3‰ (C.V: 10%) and 9.8‰ (C.V. 5%), respectively. That means that the addition of cement to the mortar PSIII increased the average shrinkage deformation by about 80% and the addition of metakaolin and fibres to the mortar PPIII increased this deformation by about 50 and 67%, respectively. The obtained higher shrinkage at the mortars PSIII+c and PPIII+m, compared to the plain lime mortars, could be due to chemical reactions in the mortars or physical phenomena connected with pore structure of the mortars. On the other hand, higher shrinkage of the mortar PPIII+v could be the consequence of smaller amount of micro cracks in the mortar, since the fibres do not influence the process of lime hardening (at least not importantly). Obviously the used fibres increase also the strain capacity of the mortar in the "green" state. This limits the formation and growth of micro cracks and can results in higher shrinkage deformations. Important information at this stage is that almost no visible cracks could be detected on the tested specimens after demoulding.

4 CONCLUSIONS

The main conclusions drawn from the analysis of the test results are as follows:

- Different batches of the same lime-based mortar and workmanship have big influence on the compressive strength of the mortar. The influence of the same parameters to the flexural and Bond Wrench strength is less important.
- Obtained final compressive strengths of plain lime mortars are between 0.95 and 2.09 MPa, flexural strengths between 0.37 and 0.7 MPa and Bond Wrench strengths between 0.09 and 0.24 MPa.
- Addition of small amount of microsilica or metakaolin always increases compressive strength of the lime-based mortar and can increase or decrease its flexural strength and strength of bond between mortar joint and solid clay brick. The height of the increase (or decrease) of the individual strength depends first of all on the type and amount of added pozzolanic material and probably also on uniformity of pozzolanic particles distribution in the mortar.
- Addition of small amount of cement has negative influence on the final strength properties of lime-based mortar.
- Obtained lower strength properties of the lime mortars with polypropylene fibres are most probably the result of the ineffective compaction of the fresh mortars. However, ductility of such mortars is highly improved.
- Shrinkage deformations of lime-based mortars obtained with the developed equipment are 5 and 6‰ for plain lime mortars and around 9.5‰ for lime-based mortars with used additives or fibres. Since precise validation of the used test method will be carried out in the future, the test method could still underestimate the actual overall shrinkage deformations, if the obtained “resting” period is the result of too low cohesion between inserted ripped bolts and mortars.

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