Lime-metakaolin mortars – properties and applications

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ABSTRACT: Lime is the most sustainable binder due to lower production energy needs, lower CO_2 emission during production and CO_2 absorption by carbonation. For centuries it was used in both mortars and concretes until it was replaced by Portland cement, due to faster hardening, higher strength and apparent longevity. However, in building conservation actions, the use of lime-based renders may be a necessity in order to achieve the required compatibility with ancient renders and substrates. With the purpose of developing mortars for this application, metakaolin was added to lime mortars allowing for a faster application and hardening and, possibly higher durability whilst maintaining compatibility requisites. Metakaolin from two different producers was characterised and mortars containing air-lime, metakaolin and siliceous sand were formulated with different compositions. A testing campaign for determination of mechanical strength and capillary absorption was carried out. Following the obtained results, application of lime-metakaolin mortars both in conservation and in new build, as a sustainable alternative, is discussed.

1 INTRODUCTION

Metakaolin is obtained from the calcination of kaolinitic clays at temperatures in the range of 700-800ºC (Badogiannis 2005, Sabir 2001), high enough to allow for loss of hydroxyls but below temperatures that cause the formation of a vitreous phase and crystallization of other phases such as mullite. The raw-material for its production is available in Portugal, especially in the north and centre of the country (Ferraz 2004, Gomes 1990), although many quarries are no longer active due to lack of demand. However, a growing scientific interest in the use of metakaolin in mortars and concretes, in order to improve mechanical strength or reduce alkali-silica reaction (Fortes-Revilla 2006, Kim 2007, Ramochlan 2000, Silva 2006), together with the prospective lack of traditional pozzolanic materials such as fly ash and silica fume, are inducing the industrial sector towards metakaolin production.

In building conservation practice, there is some difficulty in formulating compatible mortars for use in renders and joints, due to requisites of low elastic modulus, sufficient flexural strength and adequate behaviour in terms of water intake and drying. Chemically, materials must also guarantee compatibility issues. For these reasons air lime is the most adequate binder, however it encloses some problems such as slow setting, inability to harden under water and lack of durability. The use of pozzolans in lime mortars is a matter of recent studies (Fortes-Revilla 2006, Velosa 2006) and results suggest that, in adequate proportions, they produce an increase in mechanical strength and durability of mortars, meeting water intake and drying requirements. Additionally, these mortars have low cracking susceptibility (Veiga, in press), a factor of major importance, crucial in terms of efficiency towards limiting water absorption of walls and increasing durability.

Although formulations were made focusing on conservation mortars, these products (air lime and metakaolin) may also be used for mortars to be applied in new build, if formulations are altered to meet different requirements. The use of air lime in mortars is a contribution towards sustainability, due to lower temperatures used in the production process and lower CO_2 emissions; additionally, during the carbonation process, CO_2 is absorbed from the atmosphere (Holmes, 1997).

2 MATERIALS, MORTAR COMPOSITIONS AND CONDITIONING

Mortars were formulated with powdered commercial air-lime, a siliceous river sand and metakaolin from two different sources: commercialized, very pure, metakaolin of a white colour (K1) and a nationally produced metakaolin with light orange colouring (K2), described in Table 1. These products were characterized in terms of X-Ray Diffraction (XRD) and results revealed a similar composition of quartz, feldspars and muscovite, with an evident content of amorphous material.

Table 1: Characterization of metakaolin

Product	Colour	Apparent density (kg/m^3)
K1	White	315,0
K2	Light orange	638,8

Table 2 shows mortar compositions (in volume) and water/dry mortar ratio (W/M) in which both binders and aggregates are considered. Added water was calculated in terms of an adequate consistency, producing similar flow values (around 130), correspondent to adequate workability for this type of mortar. A lime mortar with a lime/sand volumetric ratio of 1:3 was used as comparison mortar. Ratios 1:1:4 (lime: pozzolan: sand) and 1:0,5:2,5 (lime :pozzolan: sand) were used taking into account that it does not act totally as a binder and results from other studies relative to lime consumption (Moropoulou 2004, Sabir 2001). Only one ratio was tested with MK1, whilst two different ratios were tested with MK2.

Table 2: Mortar composition

Product	Lime	K1	K2	Sand	W/M (% weight)
L	1	-	-	3	15
MK1	1	1	-	4	21
MK2A	1	-	1	4	15
MK2B	1	-	0,5	2,5	15

No cement mortars were included in this test programme, but a comparison was made with a cement mortar, C, with a volumetric ratio 1 : 4 (cement : sand), tested in a previous study [Veiga, 2003], following the same test methods.

Mortar specimens were prepared and conditioned in a climatic chamber following standard NP EN1015-11: Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar. Specimens were stored for the first 7 days at 20±2ºC, in a plastic bag and then maintained at the same temperature, but with a relative humidity of 65±5%. Mortars with no pozzolanic addition (L) were not stored initially in a plastic bag, as previous attempts to implement this, by the authors and by other researchers[1], resulted in a retarded hardening of pure lime mortars.

3 RESULTS AND DISCUSSION

Compressive and flexural strength testing was performed following standard NP EN1015-11: Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar. The dynamic modulus of elasticity was determined following Report LNEC 427/05-NRI and capillary absorption was tested following NP EN 1015-18: Meth-

[1] These results are not yet published.

ods of test for mortar for masonry – Part 18: Determination of water absorption coefficient due to capillary action of hardened mortar.

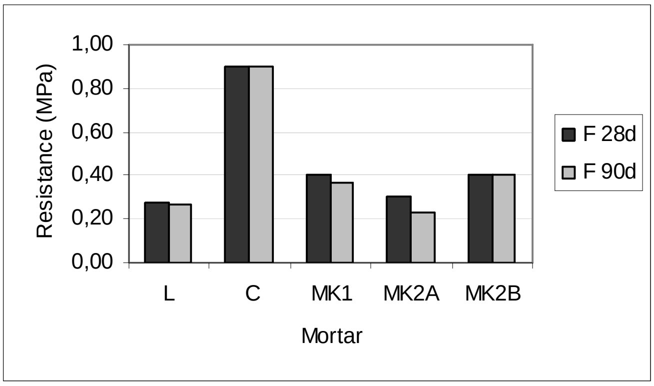

Figure 1: Flexural strength of mortars at 28 and 90 days

Results of the flexural resistance test indicate an increase in strength of mortars MK1 and MK2B in relation to lime mortar with no addition. However, results of MK2A, with a 1:1:4 ratio in volume were very similar to those of lime mortar. The decrease in flexural strength from the age of 28 days to the age of 90 days is a phenomenon that has been observed in other mortars, namely those containing pozzolans; reasons for this are unclear but may be linked with microcracking due to shrinkage, to which flexural strength is very sensitive (Veiga & Carvalho, 1994). The higher flexural strength displayed by mortar MK2B is due to the action of metakaolin as a binder, increasing binder/aggregate relation. Results achieved by cement mortar C, with a lower binder ratio, are significantly higher from the others.

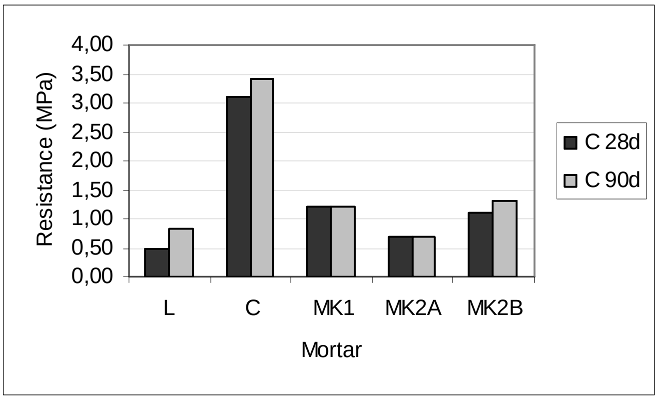

Figure 2: Compressive strength of mortars at 28 and 90 days

Compressive strength results show similarities with those of flexural strength, with a clear strength increase in mortars MK1 and MK2B in relation to mortar L, with no metakaolin, whilst mortar MK2A reveals an early strength increase in relation to mortar L, but attained strength stabilizes until the age of 90 days. At this age, compressive resistance of MK2A is lower that that of the comparison lime mortar. This property, in mortars with a 1:1:4 ratio (MK1 and MK2A) has no variation between the ages of 28 days and 90 days, probably due to partial action of metakaolin as an aggregate. Again, results attained by cement mortar reveal higher mechanical strength compared to those with other binders.

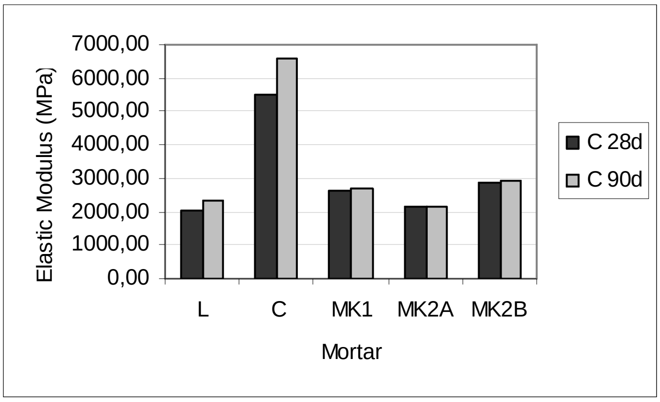

Figure 3: Elastic Modulus of mortars at 28 and 90 days

Elastic Modulus of all tested mortars with a lime binder is low, as desired, ranging from 2000MPa to 3000MPa, and variations from 28 days to 90 days are not significant. Using a cement binder the Elastic Modulus rises to values surrounding 6000MPa.

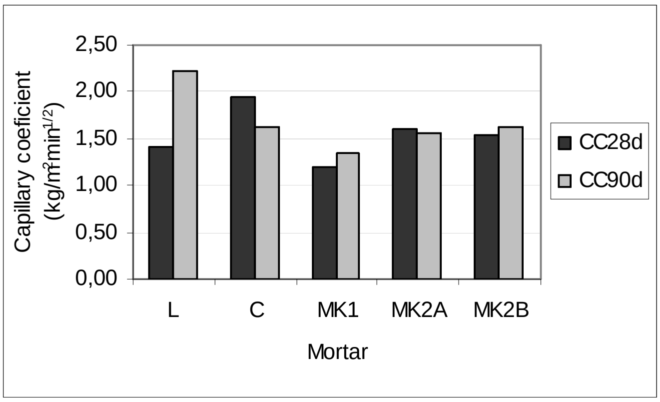

Figure 4: Capillary coefficient at 28 and 90 days

Initial capillary absorption of all mortars with metakaolin is similar, and with values lower than comparison mortars. At 90 days, possibly due to the development of a different pore structure in lime with pozzolan mortars in relation to mortars with no additions, capillary coefficient of mortar L is significantly higher than the others (Figure 4). The formation of products from pozzolanic reaction, with a different structure may induce this phenomenon. Capillary coefficient gives an indication on initial water absorption rate. Additionally, Figures 5 and 6 show that total water intake of mortar MK2B, at 90 days, is significantly lower than that of mortar L and drying is also faster.

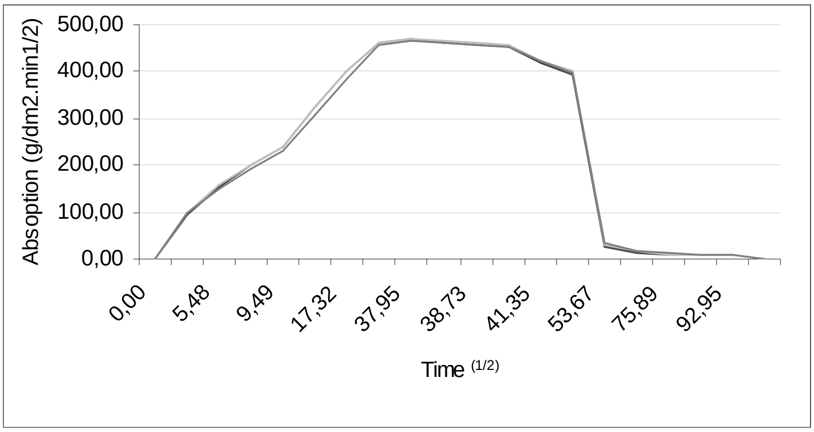

Figure 5: Capillary absorption and drying of lime mortar (L) at 90 days

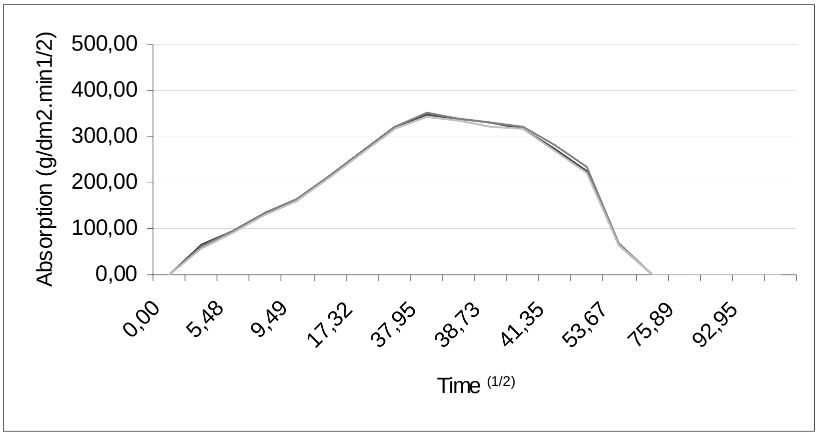

Figure 6: Capillary absorption and drying of MK2B mortar at 90 days

Although it is expected that pozzolanic additions increase mechanical strength of mortars, this did not occur with mortar MK2A. A possible explanation for this is that MK2 acted partially as an aggregate. In fact, taking into account the apparent density of lime (430kg/m^3) and of MK2 (638kg/m^3) and the fact that some of the lime will be used by carbonation and some by pozzolanic reaction, some of the pozzolan will not be involved in pozzolanic reaction due to lack of lime (CH), acting as an aggregate in the 1:1:4 (lime: pozzolan: sand) mix, and therefore increasing aggregate/binder ratio.

The obtained results were consistent, revealing an increase in mechanical strength of lime mortars with pozzolanic additions in all mortars except for MK2A and adequate behaviour in terms of water intake and drying.

4 CONCLUSIONS

Metakaolin is an adequate pozzolanic addition for lime mortars, providing adequate mechanical and water behaviour characteristics for application in conservation mortars. For this particular application cement mortars are inadequate, due to excessive elastic modulus and high content in soluble salts [Teutónico et al., 1994; Veiga et al., 2004; Moropoulou et al., 2005]. A further advantage of lime/pozzolan mortars is their lower environmental impact, when compared to cement mortars, due to lower CO_2 emission during production and CO_2 absorption by carbonation.

Further studies, taking into account cracking susceptibility and durability (climate and salts) must be undertaken.

An important conclusion that arises is that the use of greater percentages of pozzolan in a mortar doesn't necessarily imply improved characteristics. For each particular pozzolanic product there are specific formulations that produce better results for the application that is being considered.

ACKNOWLEDGEMENTS

The authors wish to acknowledge CERÂMICA CONDESTÁVEL for its assistance. They also acknowledge the financial support of FCT (the Portuguese Foundation for Science and Technology) through the Project POCI/HEC/57890/2004 "Study of Compatible mortars for the building heritage"

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