Geopolymeric binder.
Study of an inorganic, cement free binder for concrete repair

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Introduction

Most historic reinforced concrete structures provide satisfactory performance over a hundred or more years of service life period. Concrete with no reinforced steel is a very durable material with a slow degradation rate. The introduction of reinforced steel allows cement structures that were previously impossible. The steel is protected from corrosion by the alkaline environment of the surrounding cement. When the decay of concrete takes place due to different causes (wrong mix-design, adverse environment condition, cracking, natural ageing), it results in an oxidation of the steel bars. Consequently, the steel increases in volume (rust is more than seven times greater) and subsequently spalling of the concrete that surrounds it. The cover is disrupted.
To protect the exposed steel bars patch repair is a common method. In order to create a repair compound that matches the building exactly, the conservator has to choose the right sand, gravel and mixture of cement. This is a time consuming process and the mechanical properties of the repair cannot be sufficiently evaluated. The use of pre-fabricated and proven products do guaranty the recommended standard EN 1504:2008, but industry-driven methods and materials do not take into account the usual conservation demands of aesthetics and historical respect, and can strongly deviate from the desired colour and texture. The aim of this interdisciplinary research is to evaluate the possibility of using a geopolymeric binder to create a cement-free mortar for use in the conservation of concrete heritage architecture. This binder consists of an aluminum silicate source (precursor) activated by an alkaline solution (activator) that forms a three-dimensional polymeric silicon-oxygen-aluminum framework.

Materials and methodology

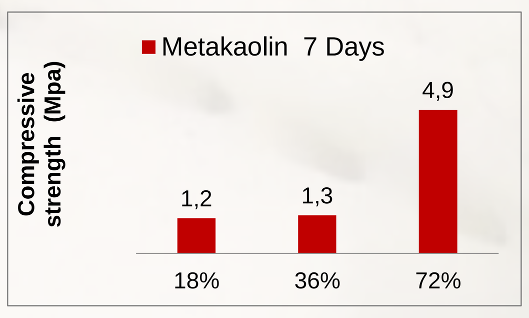
Precursor	Abbreviation	CaO %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	K_2O,Na_2O %	SO_3 %	TiO_2 %
Metakaolin	**MK**	0.3	55	40	1.4	-	0.8	-	1.5
Blast furnace Slag	**S**	39.2	40	13.5	1.8	3.6	0.6	0.2	-

Activator (A):
NaA: Sodium silicate 58.3 %, Sodium Hydroxide 13,3 %, Potassium Hydroxide 28.4 %
KA: Potassium silicate 58.3 %, Sodium Hydroxide 13,3 %, Potassium Hydroxide 28.4 %
(Sodium Hydroxide and Potassium Hydroxide were used at 8M)

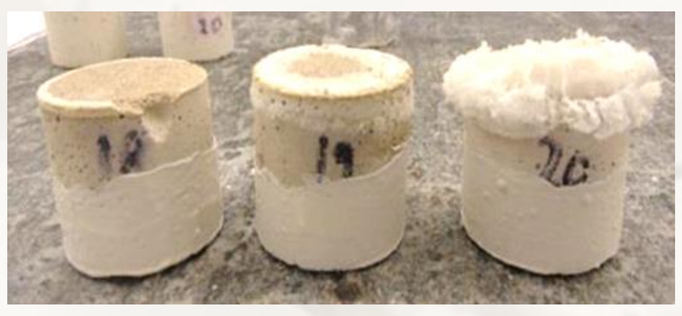
The current investigation involved mortars, realized with a base of metakaolin (MK), ground granulated blast-furnace slag (S), and mixtures of the two, activated with alkali activator and with the addition of sand. Siliceous sand and Precursor were mixed at a ratio of 1 to 2 (w:w)
The rheological and physical properties were investigated through mechanical and physical tests to evaluate the mortars in respect of the recommended standard value by EN 1504-3.
A total of 57different mixtures (552 specimens) were produced. The code-names used in this study (for example 20MK80S18NaA) describe the percentage of MK, S, the type (NaA, KA) and percentage of activator and eventually the presence of admixtures. The alkaline activator was prepared prior to use and additional water was added during the mixing.
In the application phase the liquid activators were replaced by dust activators to obtain a premixed binder, eliminating the difficulty of using the corrosive hydroxides liquids. Other samples were made to evaluate the possibility of reproducing the texture of the surface and aesthetic aspects of the original material.

Experimental procedure

The MK is a widely studied material in the field of geopolymers. Its particle size and the high specific surface result in the formation of a compact matrix but requires a lot of water in the mixture, which involves high shrinkage values. Its performance is related to the amount of activator and this is proportional to the salt efflorescence probability.

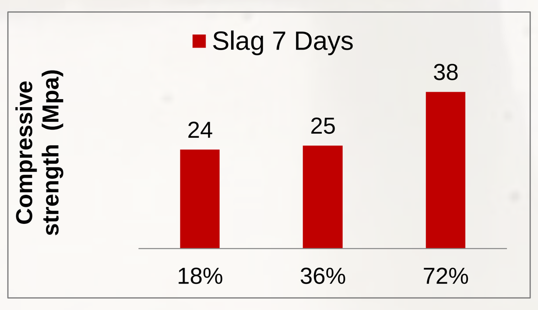


Picture 1:
Compressive strength of MK with different percentage of activator.



Picture 2:
Efflorescence at 18 %, 36 %, 72 % of activator.

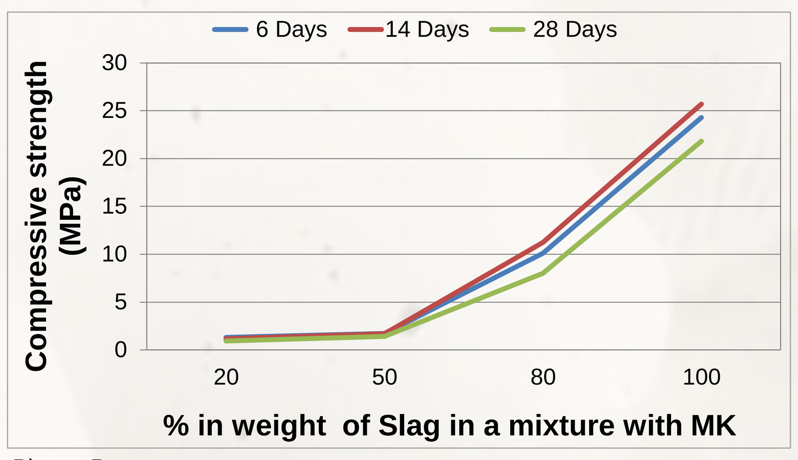
To reduce the amount of activators and achieve the rheological and physical characteristics indicated by the regulatory standards, a second precursor was introduced: the ground granulate blast furnace slag. It has a good compositional stability and is used to improve the mechanical and physical characteristics while introducing calcium oxide in the system. Its performance is related to the amount of activator but the probability of efflorescence is diminished. At a high percentage of the activator the setting time is too short and the mortar has no workability.



Picture 3:
Compressive strength of S with different percentage of activator.

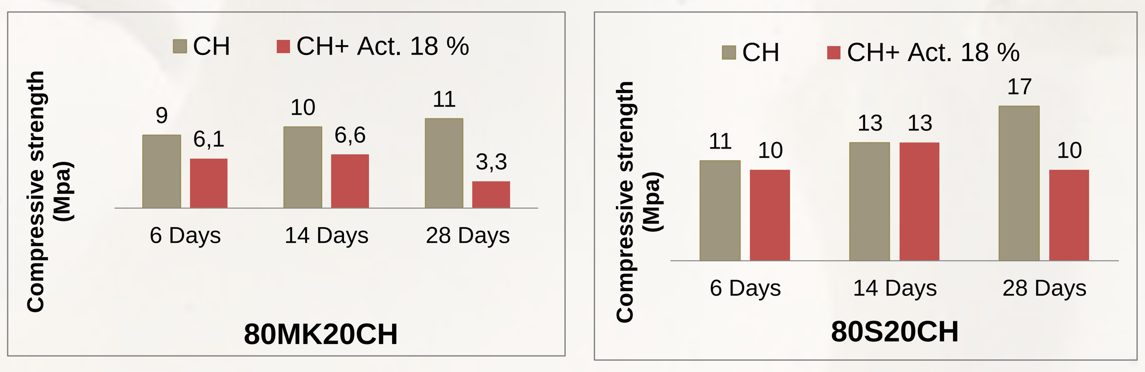
Picture 4:
Slag: No presence of efflorescence at 18 %, 36 %, 72 % of activator.

To combine their rheological features, different proportion mixtures of two precursors have been tested. The percentage of activator was kept at 18 % for all mixtures. Those exhibit a very low compressive strength of the MK that increases with the amount of slag in the mixture.



Picture 5:
Compressive strenght of different mixtures of MK-S.

The investigation evaluated the effect of calcium hydroxide on the performance of different mixtures. While the compressive strength increased with time in the mixtures without activator, it decreased in the presence of activator.



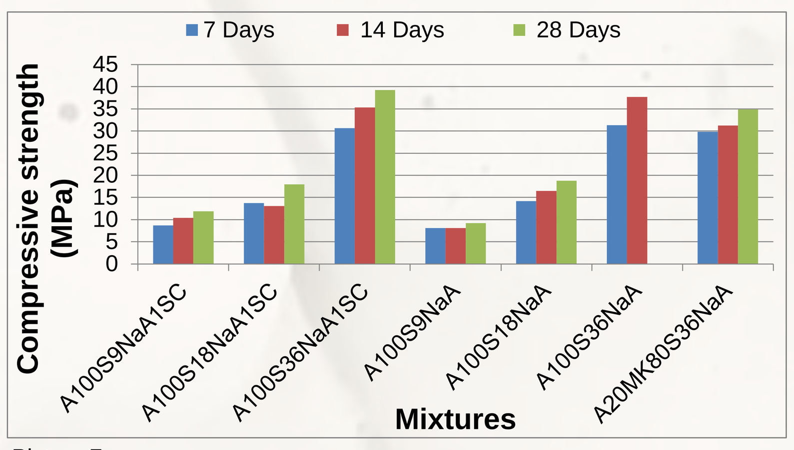
Picture 6:
Mixes with CH and Metakaolin or Slag with and without activator.

Results

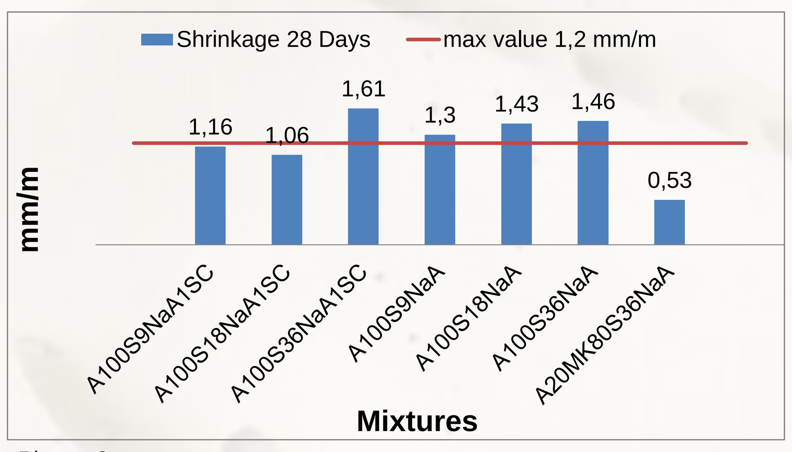
We found that it was not possible to use uniquely MK in the repair mortar, as the resulting compressive strength was too low. Moreover, in the cases where the activator was increased, efflorescence appeared. It is more effective to use MK in a mixture with slag.
The introduction of calcium hydroxide reduced the mechanical properties of the mortar mixture.

The arising issues of the selected mixtures were a too much limited setting time and a too high shrinkage, above the maximum value of 1.2 mm/m. The addition of 1 % of sodium carbonate increased the setting time to the desirable value of around one to two hours, depending of the amount of activator.

Different admixtures were used to reduce plastic shrinkage: Calcium oxide, glass fibre alkali resistant, modified cellulose and starches. The effect on compressive strength and on shrinkage was evaluated.



Picture 7:
The effect of admixtures on compressive strength.



Picture 8:
The effect of admixtures on shrinkage.

Mixture selected

Mix	Compressive strength (MPa)	Flexural strength (MPa)	Elastic Moduls (MPa)	Adhesion (MPa)	Shrinkage 28 days (mm/m)	Water absorbtion (%)
A20MK80S 36NaA	34,88	3,28	12307	>1.43	0,53	13

Application Phase

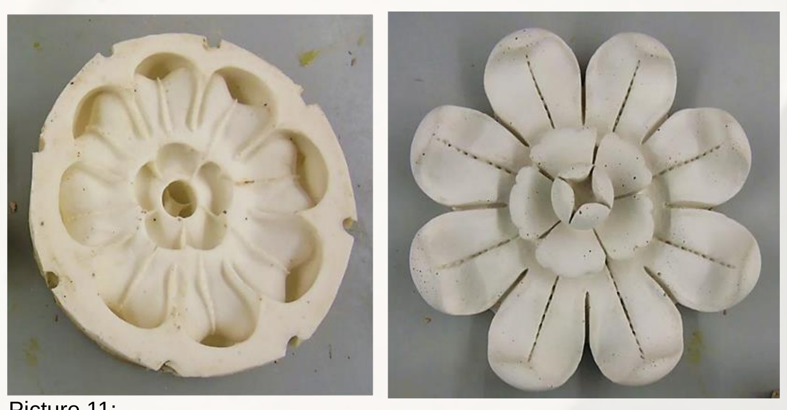
Picture 9:
Mortars with different aggregate (grain size and typology),filler and pigments.

An application of this mortar, in the thickness from 0.2 cm to 3 cm, was produced to evaluate the use as a coat mortar and for the reconstruction of three-dimensional losses.

After 72 days, no crack has appeared.

Picture 10:
Application of this mortar, in the thickness from 0.2 cm to 3 cm.

For the realization of decorative elements the binders available on the market are cement (white cement if the pasta must be colored) or two-component resins. Geopolymers may be used as a new binder in these situations.



Picture 11:
Reproduction of original decoration can be cast with this mortars, using a mold rubber.

Conclusion

The performance of the selected mixtures matches the required standards. Their adaptability to different textures and colours allows to achieve reinstatement as similar as possible to the original and ensures the durability of the added material. In regards to the possible leaching of the alkaline ions, we did not observe any efflorescence during the tests performed. The working properties allow an easy application with the appropriate setting time and the possibility of varying thickness maintaining the same performance characteristics. This means that it can be used as coarse mortar for reconstruction of volumes, fine mortar for gaps, abrasions or recostruction of serial punched decorations. This reduces the processing time and intervention costs.
This new material in the field of heritage conservation can be respectful of the aesthetic aspects of the original material, and ensures the absence of pollute materials. It allows for restoration with minimal environmental impact: Through reduction of CO_2 emissions, recycling of industrial by-products and reduced use of environmental resources.

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