NOVEL GEOPOLYMERIC COMPOSITES FOR THE RESTORATION OF A ROMAN MOSAIC FRAGMENT

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AIM OF THE WORK

The target of this work was the design of engineered geopolymers to be used for restoration works. Thanks to a collaboration among the Archaeological Survey of Florence, the Institute for Restoration "Palazzo Spinelli" in Florence and Cnr-Istec of Faenza, specific mix-designs of geopolymeric composites were developed and then applied in the restoration of a fragment of Roman mosaic.

Two composites were created in order to operate into two specific ways:

1) reinforced geopolymeric support suitable to protect the fragment when on the outside and 2) colored geopolymeric tesserae for integration works.

History

In the 19th century during an excavation in S. Giovanni's Square in Florence, a two-toned mosaic was found (dated 1st century B.C. – 1st century A.D.). After ripping, during 1920's restoration works it was replaced on a concrete panel and then put in exposition into the outer room (XXI) of the Archaeological Museum in Florence.

Conservation status

The concrete panel was breaking into four parts and the presence of some iron pins had caused ferrous oxidation of tesserae and cement.

In the panel and in the mosaic many gaps were present. In addition, on the tesserae's surface there were micro fractures, biological attack and black crusts.

Restoration Intervention

Cleaning (1)

The panel and the tesserae have been cleaned by using mechanical and chemical methods (demineralized water / ammonium carbonate with E.D.T.A. / hydrogen peroxide 120 vol.)

Bonding (2)

Fracture bonding was made with epoxy resin with a 10-day exposure time. Subsequently, on the back of the concrete support, grooves were created to place aluminum bars treated with silver ions (GHA method).

Integration (3)

When possible, available in the original place of arrangement of the old Roman tesserae unearthed and glued with white cement adhesive.

(1)

(2)

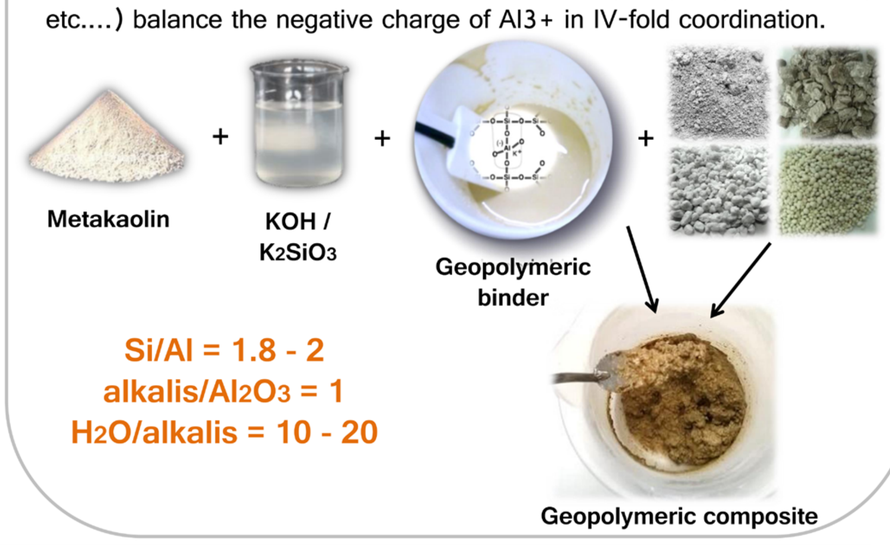
(3)

Geopolymeric materials

Geopolymers are artificial inorganic polymers synthesized by **alkali activation** of natural or artificial materials rich in SiO_2 and Al_2O_3.

The reaction, called geosynthesis or geopolymerization, takes place at low temperature and the sialate network consists of SiO4 and AlO4- tetrahedrons linked in an alternating sequence by sharing all of the interstitial oxygens.

Positive ions derived from the alkaline solution (Na+, K+, Li+, Ca++, etc....) balance the negative charge of Al3+ in IV-fold coordination.



Si/Al = 1.8 - 2
alkalis/Al_2O_3 = 1
H_2O/alkalis = 10 - 20

WORKING PLAN

STEP 1 - LAB TESTS – Design A) the right geopolymeric mixes in order to create a geopolymeric reinforced shell that can contain the entire mosaic fragment; B) the colored geopolymeric "pizza" to be cut for obtaining tesserae. N.B. Two layers of two different colors for a more controllable reversibility; lightening to allow vertical position and easier handling; steel network of structural reinforcement to improve the resistance of the shell.

STEP 2 - SCALE UP – A) preparation of formwork to contain the mosaic fragment and geopolymeric shell; B) creation of shell by casting in to two steps and in two colors: deeping of fragment in the first geopolymeric layer; leveling of the system; C) integration with geopolymeric colored tesserae.

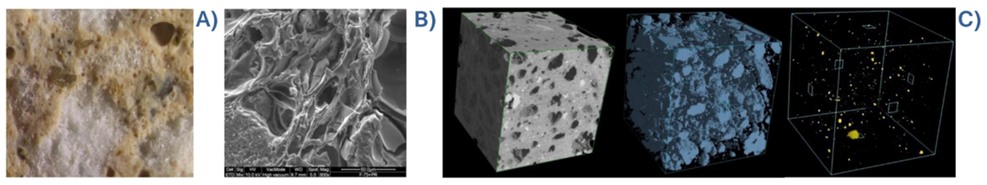
STEP 1 – A) Creation of mix designs

In order to obtain the most suitable formulations to create the multi-layers shell, different mixtures were designed and characterized by using bending (FS) and compression (CS) tests (after 28 days), water absorption (WA) and Bulk density (BD) and also optical and scanning electron microscopes. The best formulations were 6D and 6E.

Before the scaling up, some prototypes of definitive shell were produced in order to verify the stability of the composites characteristics, in particular the freeze-thaw resistance (UNI EN 539-2:2013).

GEO 6D (BOTTOM LAYER): 47.5% BINDER + 52.5% FILLER (fine sand+perlite)

GEO 6E (TOP LAYER): 47.5% BINDER + 52.5% FILLER (fine sand+perlite+$CaCO_3$)



Micrographs by A) optical microscope; B) SEM and C) micro-tomography of the selected composites showing a good distribution of the filler into the geo-binder.

Freeze-thaw test

Before — After 800 cycles

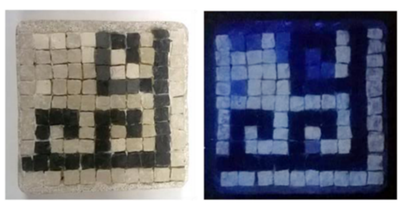
	Binder	6D	6E	Black	White
CS (MPa)	51.4 ± 10.0	25.7 ± 5.0	31.4 ± 7.0	46.9 ± 4.0	65.2 ± 9.0
FS (MPa)	7.6 ± 4.0	5.5 ± 0.5	7.7 ± 0.3	5.6 ± 1.0	8.7 ± 1.0
BD (g/cm^3)	1.5 – 1.6	1.1 – 1.2	1.1 – 1.2	1.5 – 1.6	1.5 – 1.6
WA (%)	8.6	21.00	27.2	24.4	17.7

The results of mechanical tests showed a very good structural product.

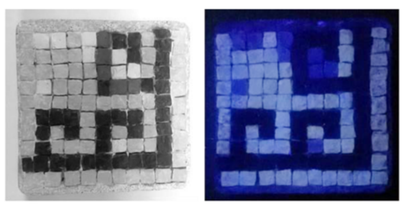
The perlite permitted to lighten the final product. The WA values underlined differences among geopolymeric samples. First of all, the presence of any aggregate provoked an increase in the WA values. The differences between composites 6D and 6E can be explained by considering the microporosity and the shape of the calcite grains. At the same way, the higher WA value of black geopolymer be related to the use of natural pigment derived from coal.

STEP 1 – B) Colored geopolymers

Black and white geopolymers were produced adding 10% (in wt.) of inorganic pigments (Vine black, Bianco di S. Giovanni). They were characterized by using mechanical tests and UV fluorescence lamp. Under UV lamp, the geo-tesserae don't fluoresce.



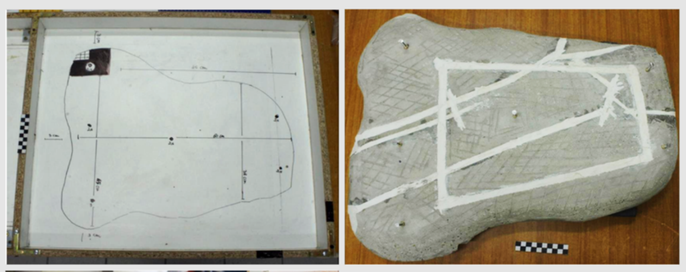
RGB image — UV image: 365 nm



B/W image — UV image: 254 nm

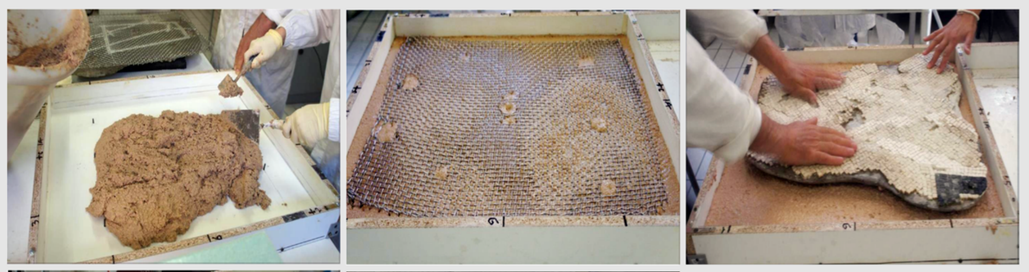
STEP 2 – SCALE UP

A) Preparation of formwork and fragment



- Steel screws were put back into the cement to guarantee a perfect flatness
- An etchings net was created into the cement to facilitate the anchorage of geopolymer
- The cement support was kept wet

B) Operative sequence- casting



- A steel net (1mm wire diameter; 10mm mesh) was placed over the first layer of geopolymeric composite
- The mosaic fragment was placed into the first layer
- The second mixture was poured up to cover the cement support

C) Integration with geopolymeric tesserae

- After 90 days curing, colored geopolymeric tesserae were placed into the lacunae.
- At first the lacunae inside the fragment;
- After over geopolymeric layer to re-create the original mosaic draw.

CONCLUSIVE REMARKS

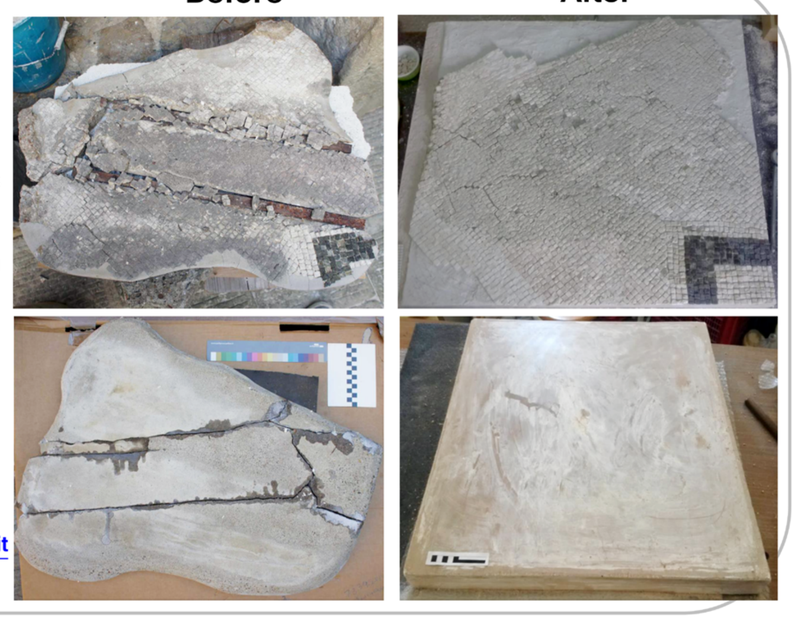
Novel materials

- **Geopolymeric composites are a very stable product in terms of weather and mechanical resistance**
- **The geopolymeric shell makes easy to handle the artwork and also permits its placement in upright**
- **The two opportunely made different in colors geopolymeric layers guarantee any removal intervention. One of the layer was thought to be a sacrifice surface**
- **The colored geopolymeric "pizza" is easy to be cut in suitable shapes. The tesserae can be used for "ton sur ton" restoration interventions. Their inorganic nature prevents any biological attacks**
- **Under UV fluorescence radiations, geopolymeric materials don't fluoresce, so it is easy to be recognized**

Innovation in the restoration intervention

- **The geopolymeric shell is not a pre-casted support**
- **It is tailored in order to be compatible with pre-existent cement support**
- **The mosaic fragment is directly placed on the fresh geopolymeric composite**

Before — **After**



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