Retrofitting, Restoration and Rehabilitation of Structures with Geopolymers Technologies

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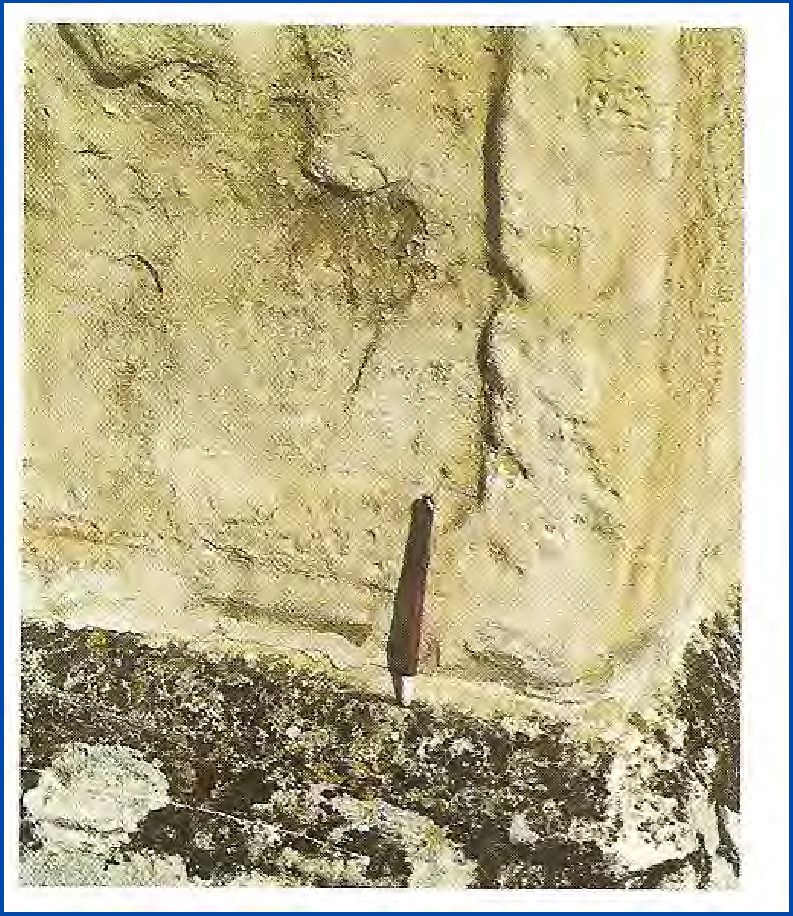
During their service life period, structures must present good levels of security, durability and functionality.

Nevertheless, several problems on design, construction and use can put some of these requirements at risk.

The great amount of damaged structures implies the increase of severity in the design codes and in the number of strengthening solutions.

Different type of structures can present pathologies:

Stone structures



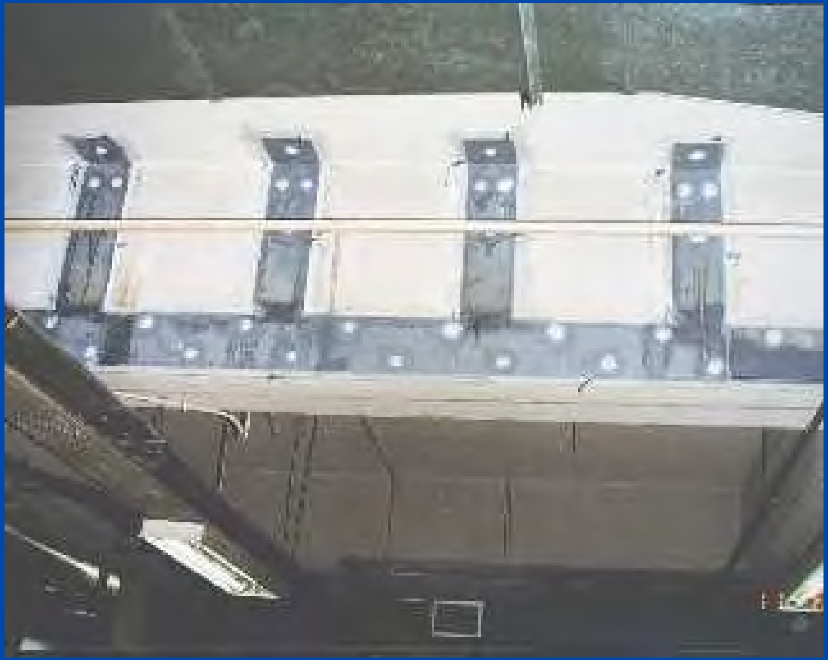
Timber structures

Steel structures

Masonry

The structures increasing decay are frequently combined with the need for upgrading.

The capacity of a structure can be enhanced using techniques of externally strengthening or section increase.



The materials for rehabilitation of structures

must be compatible:

- adequate mechanical strengths;
- adequate modulus of elasticity;
- similar coefficient of thermal expansion.

These materials must also present adequate

adhesion to the substrates and high durability

Commercial repair mortars

Examples

The repair mortars are supplied as pre-packed blend of graded aggregates with a maximum size 2mm, cement, silica fume, fibres and other additives.

A water/powder ratio of 0.16 is recommended for use in material R1 and 0,14 for R2.

The typical density of the fresh material is 2100 kg/m^3.

The repair products are ready for on-site mixing and use, requiring only the addition of clean water

Properties of commercial pre-pack mortars

	fc_{28d} (MPa)	**ft_{28d} (MPa)**	**Pull-off$_{14d}$ (MPa)**	**Pull-off$_{28d}$ (MPa)**
R1	45	9	2	**2**
R2	**49**	**8**	**1.5**	**1.8**

The cost of geopolymeric based concrete is one of the major factors which still remains a severe disadvantage over Portland cement based concrete explaining why this new product is not yet a current alternative.

Currently geopolymeric based concrete only becomes economically competitive for high performance structural purposes.

The above cited disadvantage means that the study of geopolymeric applications should focus on high cost materials such as, commercial concrete repair mortars.

A new development in the repair and strengthening of reinforced concrete systems is the use of carbon fiber reinforced polymers (CFRP) strips bonded to concrete substrate with epoxy resins.

Epoxy adhesive being used in the construction industry is very sensitive to temperature variations.

Results show that the epoxy temperature should not exceed 70 ºC in order to maintain the integrity between the CFRP and concrete.

It is noted that frequently exposure to direct sunlight causes temperatures higher than 70 ºC which causes malfunction of CFRP system.

Since geopolymers are known to possess high stability at high temperature, these materials can be an alternative to epoxy resins.

The geopolymers needs to be studied and adapted to this application

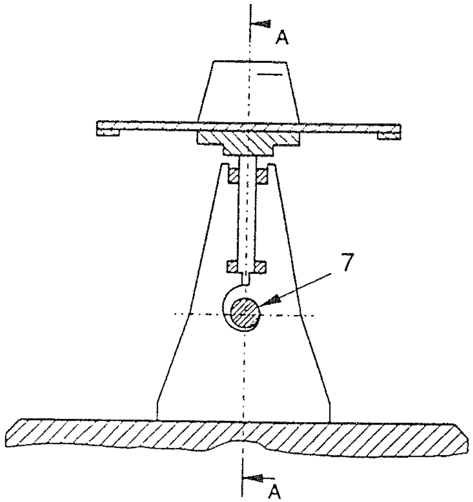
Properties at fresh state – viscosity – workability

Properties at hardened state – adhesion, mechanical strengths

and durability properties

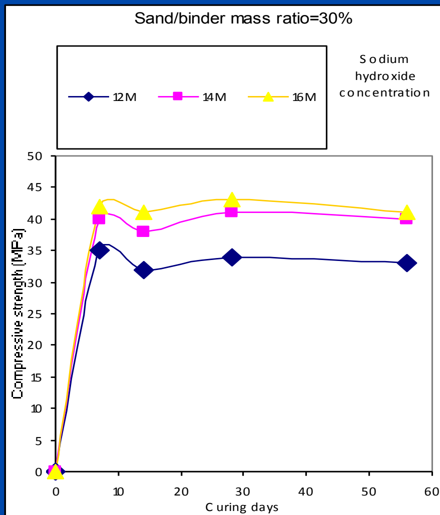
Determination of consistence of fresh mortar (by flow table)

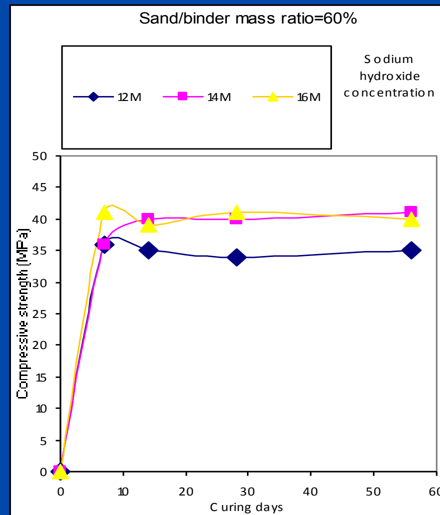
Constant flow of 160 mm (for example) – change the quantity of liquid

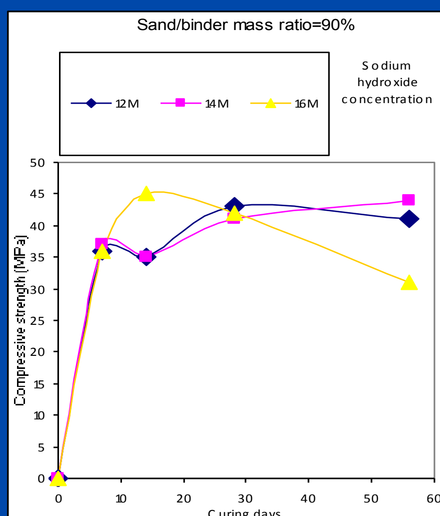


Key :		1	Stand
2	Horizontal shaft	3	Lifting spindle
4	Truncated conical mould	5	Disc
6	Rigid table plate	7	Lifting cam

Figure 1: Flow table





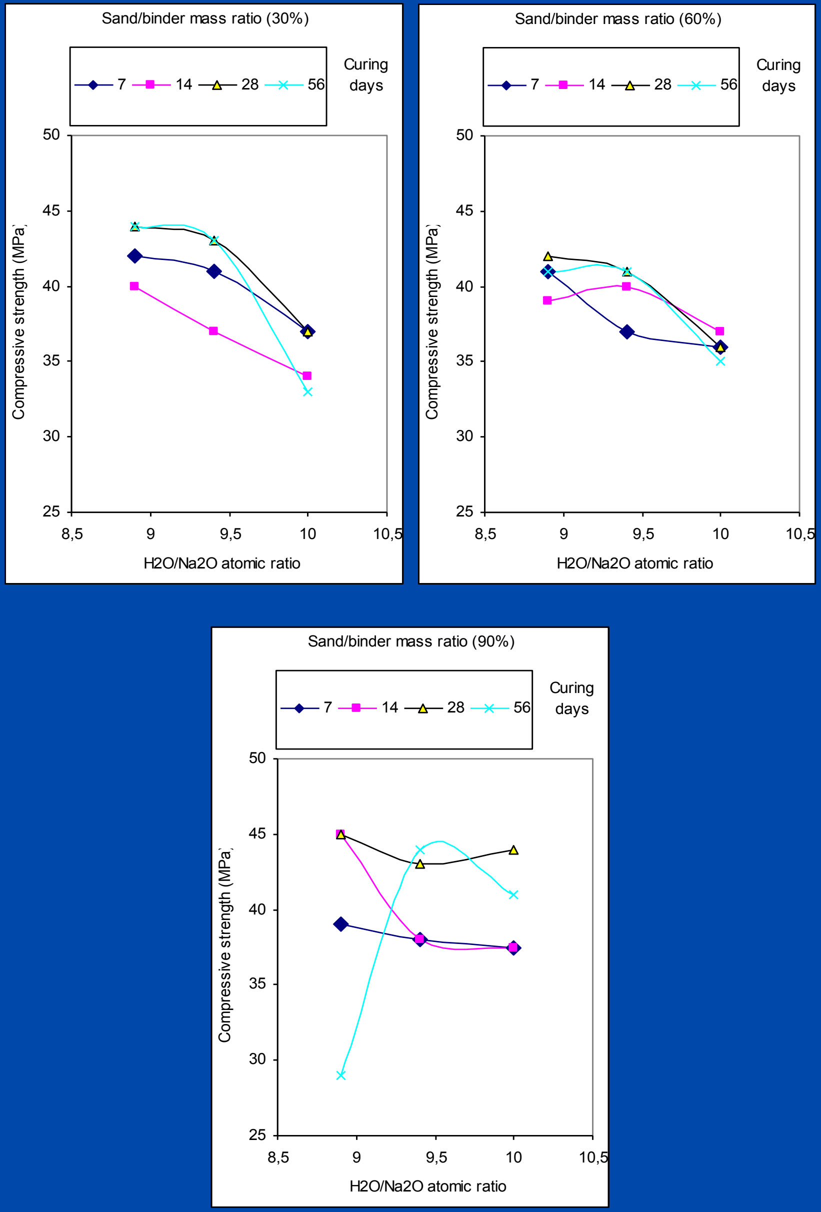


After 7 days curing all the mixtures present a compressive strength above 30MPa.

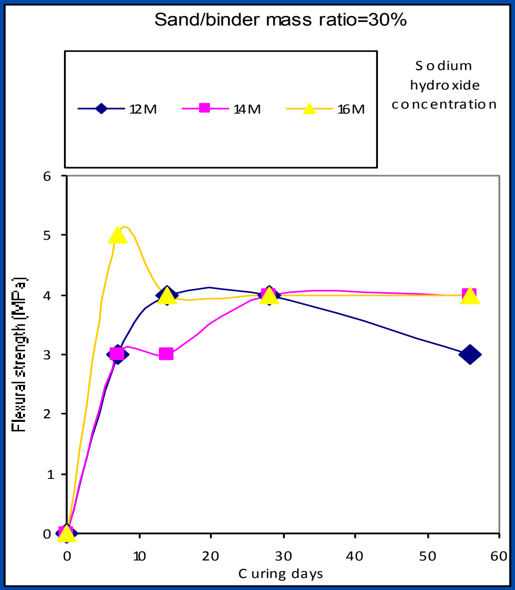
Higher sodium hydroxide concentrations lead to a compressive strength increase.

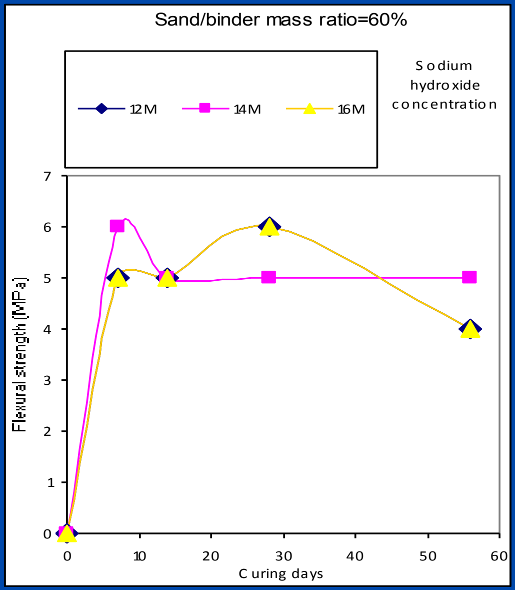
The higher concentrations of alkaline solution raises the pH which increases the dissolution and solubility of the aluminosilicate mineral waste and provides positive ions to balance the negative charge of the aluminate group.

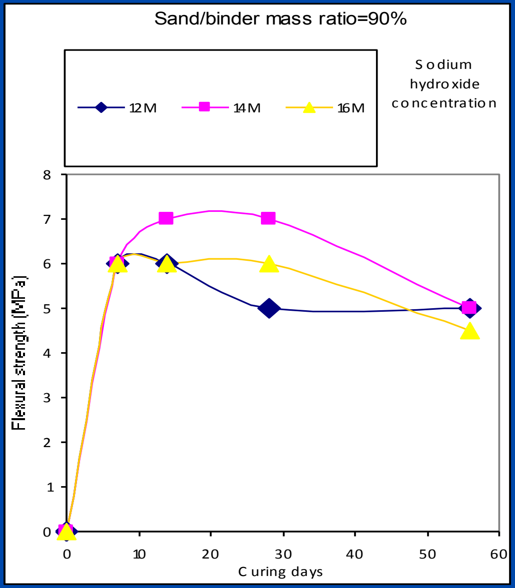
Compressive strength according to curing days for geopolymeric mortar mixtures with several sodium hydroxide concentrations (12M, 14M, 16M) and several sand/binder mass ratios (30%; 60%, 90%)



Compressive strength versus H_2O/ Na_2O atomic ratio according to curing days for geopolymeric mortars with several sand/binder mass ratio (30%; 60%, 90%)







The results represent 10-15% of the compressive strength.

This is quite similar to the behavior observed for ordinary Portland cement based mortar.

An explanation is related to the possibility of the occurrence of shrinkage cracking near the aggregates, originating a clear tensile strength reduction.

Flexural strength according to curing days for geopolymeric mortar mixtures with several sodium hydroxide concentrations (12M, 14M, 16M) and several sand/binder mass ratio (30%; 60%, 90%)

OPC concrete substrate

Mix proportions and main properties of the OPC concrete substract

Components	Mix
Cement II 32.5 (Kg/m^3)	400
Fine river sand	578
Coarse aggregate	1066
W/C ratio	0.53
$fc_{28d}{}^{a}$ (MPa)	20.3

[a]Average value of three specimens (150×150×150mm^3)

concrete slabs were cast into moulds with 300×200×50mm.

As for beams they have 850×100×80mm.

CFRP sheets and epoxy adhesive

CFRP sheets were provided in rolls by BASF and were composed by

unidirectional carbon fibres with a commercial reference MBrace CF130

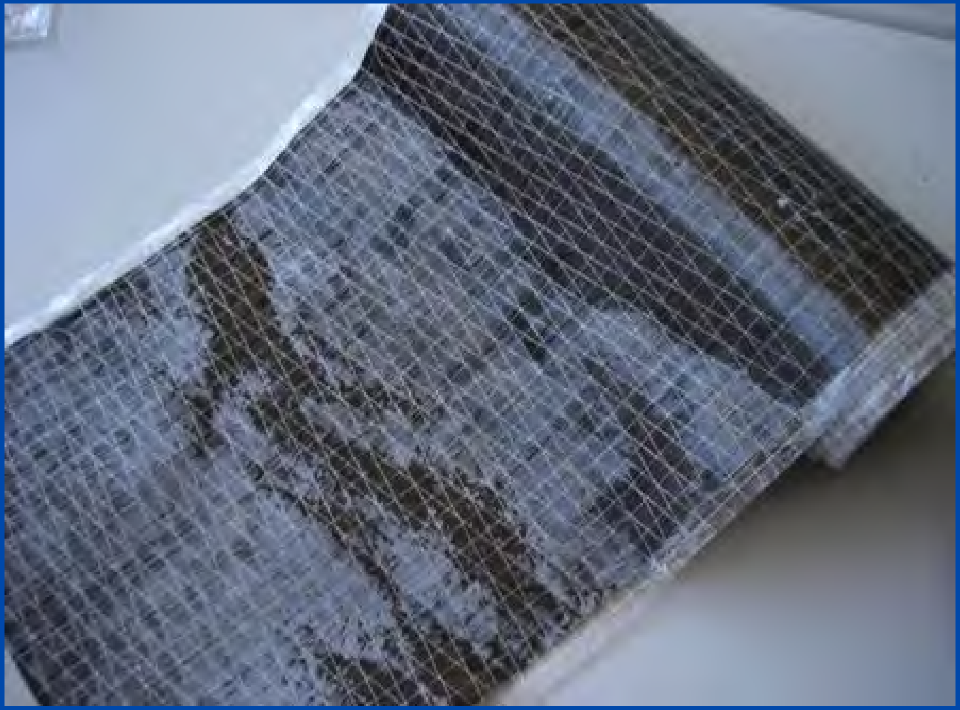


Figure 3 - CFRP strips

Table 4 - Properties of CFRP sheets

Properties	CF130
Thickness (mm)	0.176
Width (mm)	300
Length (m)	50
Specific surface(g/cm^2)	300
Tensile strength (MPa)	4900
Young modulus (GPa)	230
Elongation at break (%)	2.1

The epoxy adhesive used to bond the CFRP strips to concrete is a two components system with a commercial reference MapWrap 31.

After mixing the two components the mixtures remains workable during 40 minutes at 23 ºC.

Table 5 - Properties of epoxy adhesive

Properties	MapeWrape 31
Tensile strength (MPa)	30MPa
Flexural strength (MPa)	70MPa
Compressive strength (MPa)	80MPa
Young modulus in flexion (GPa)	3.8
Young modulus in compression (GPa)	3.0

OPC concrete specimen preparation

The process starts with surface roughening operations to remove grease, oils, free particles, laitance and also producing an irregular surface.

Then a geopolymeric mortar are applied followed by the CFRP sheets with 800 mm and a second layer of geopolymeric mortar.

Figure 5 – OPC concrete beams preparation: a) surface roughening ; b) CFRP sheets impregnation; c) Placing the CFRP sheet over the geopolymeric mortar; d)Applying a second layer of geopolymeric mortar

Pull-off

The adhesion strength was assess by pull-off test according to EN 1015- 12.

This test uses a Proceq Dyna Z15 device and an epoxy adhesive with a commercial reference Icosit K101 from Sika.

The adhesion strength was obtained from an average of 6 pull-off test specimens.

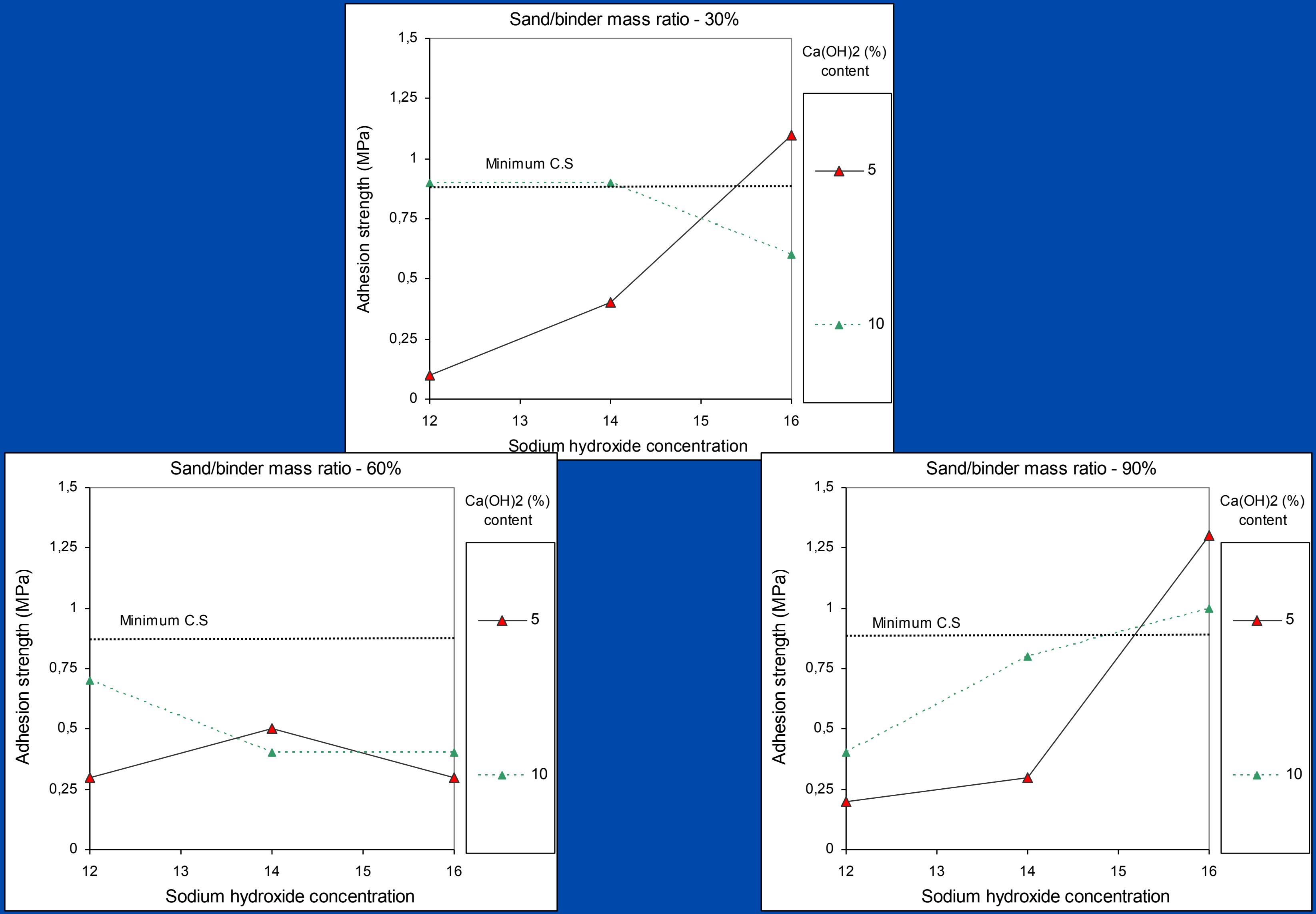


Figure 9 – Adhesion strength between OPC concrete specimens and geopolymeric mortar mixtures according to the sodium hydroxide concentration (12M, 14M, 16M) and the sand/binder mass ratio (30%; 60%, 90%)

All the mixtures have adhesion strength lower

than the minimum recommended (1.5 MPa).

The adhesion strength is lower than the one obtained with cement base

repair mortars (1.5 – 2.0 MPa).

The explanation could be due to the fact that the mortars

present a high shrinkage behavior that was

observed in this work because the surface of the specimens with a lower

sand content presented a high level of microcracks.

a)

b)

c)

Figure 10 – Influence of sand/binder mass ratio on the shrinkage performance: a) 30%; b) 60%; c) 90%

Flexural strength of concrete specimens uses 850×100×80mm beams reinforced by CFRP sheets and is done according to EN 12390-5.

The flexural tests were conducted with an electro-hydraulic universal testing machine, at a controlled rate of axial displacement.

The supports were placed 25mm from the beginning of the beams.

OPC concrete beams characteristics

<table>
<tr><th rowspan="2">Ref</th><th rowspan="2">Description</th><th colspan="3">Geopolymeric mortar composition</th></tr>
<tr><th>Sodium hydroxide concentration</th><th>Calcium hydroxide content (%)</th><th>Sand/binder mass ratio (%)</th></tr>
<tr><td>CFRP0</td><td>Plain concrete</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>CFRP1</td><td>Concrete reinforced with CFRP and epoxy adhesive</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>CFRP2</td><td rowspan="3">Concrete reinforced with CFRP and geopolymeric mortar</td><td rowspan="3">14M</td><td rowspan="3">10</td><td>30</td></tr>
<tr><td>CFRP3</td><td>60</td></tr>
<tr><td>CFRP5</td><td>90</td></tr>
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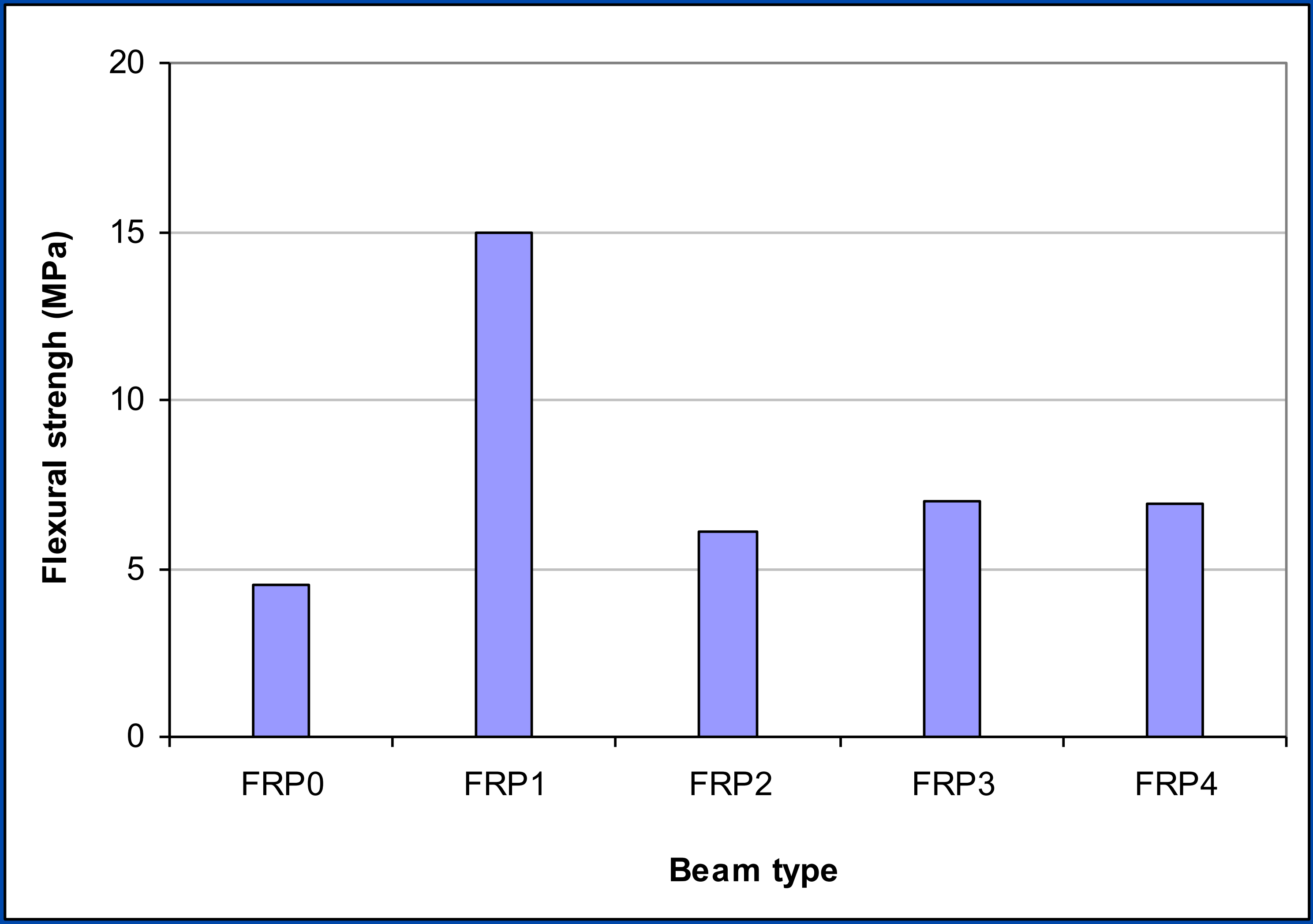

Figure 11 – Flexural strength of OPC concrete beams reinforced with geopolymeric mortars and CFRP

The results of flexural strength of concrete beams reinforced with CFRP confirm that using a epoxy adhesive (FRP1) is a better option to insure the adhesion between concrete and FRP compared to use of geopolymeric mortars.

The explanation is probably related to the shrinkage behavior of the metakaolin mortars.

Another explanation maybe due to the fact that the geopolymeric mortar mixture was not optimized.

Conclusions

The materials for rehabilitation of structures must be compatible with the existing materials

The geopolymers needs to de studied and adapted for the different applications

Important properties are:
workability
adhesion