Nano-reinforced ternary lime-based composites for structural health monitoring of Cultural Heritage Monuments

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Outline

1. Theoretical background and motivation
2. Experimental procedure
3. Results
4. Conclusions

Motivation

- Most historical buildings are suffering from damage due to natural weathering, earthquakes, pollution and urgently need restoration interventions.
- Typical building materials that need to be restored are NOT ordinary cement / concrete, but mostly stone, limestone.
- The compatibility problem between the original building materials and the restoration mortars is the main issue in order to achieve long-lasting restoration interventions.

Therefore, due to <u>incompatibility</u> it is impossible to restore historical buildings with modern building materials.

Cracks due to the incompatibility of the original material and the restoration mortar

Schueremans, L., Cizer, Ö., Janssens, E., Serré, G. & Balen, K. Van. Characterization of repair mortars for the assessment of their compatibility in restoration projects : Research and practice. Constr. Build. Mater. ***25****, 4338–4350 (2011).*

Graphene nanoPlatelets (GnPs)

- Nanostructures at the nano level (i.e., 1 - 20 nm).
- Possess increased mechanical, thermal and electrical properties.
- Exhibit low production cost compared to other carbon nanomaterials.
- Can refine the matrix microstructure and can create a denser matrix.
- Can attribute to the restoration material piezo-resistive properties to give useful information of the stress/strain condition or detect potential damage.

next slide

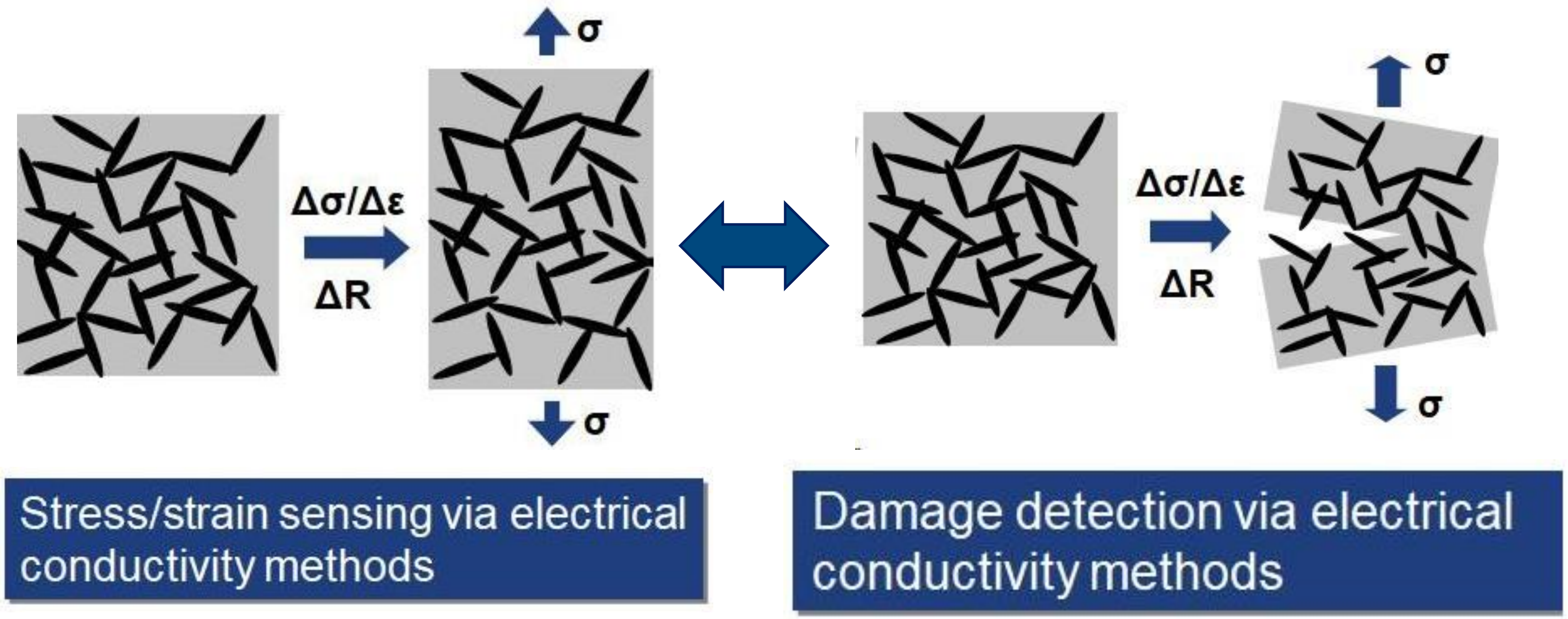
GNPs nanostructure

“Mu, S.; Yue, J.; Wang, Y.; Feng, C. Electrical, Piezoresistive and Electromagnetic Properties of Graphene Reinforced Cement Composites: A Review. Nanomaterials 2021, 11, 3220.

In situ detection via electrical conductivity method

An **electrically conductive** matrix:

- Allows health monitoring in nanocomposites
- Improves detectability of matrix dominated failure mechanisms



A restoration demonstrator in Korais Library in Chios island

Research concept

Research goal is to develop a restoration binder in lab-scale. The restoration binder should possess self-sensing properties.

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However, building materials do not possess such properties.

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Nanomaterials

GnPs (nanomaterials) will be efficiently incorporated in matrix so that **the final composite material are enhanced with piezoresistive properties.**

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Flowchart of the experimental procedure

<u>nano-reinforced materials</u>

Lime + Metakaolin + White CEM* + Dispersion


+

+

+


mixing ASTM C305

casting into molds

Cure the specimens in water for 28 days

Testing of the mechanical properties:
1) Bending tests (4-point bending)
2) Compression tests

*www.aalborgwhite.com

Building materials

The examined binder (of commercially-available **Hydrated Lime (L)**, **Metakaolin (MK)** and **White Cement (CEM)**) consists of 35 wt%, 35 wt%, 30 wt% concentrations of the components, to address the compatibility issue.

($Ca(OH)_2$ – Commercial Aerial Lime CaO Hellas)[*1]

Density (volumetric weight): ~ 2240 kg / m^3
EU A.3: Relative density

Aalborg White®
CEM I 52,5 R - SR 5
(Made in Denmark)

Density (volumetric weight):
~ 1050 kg/m^3

(Metakaolin ARGICAL™ -M1000)[*2]

Density (volumetric weight): ~ 2000 to 3000 kg / m^3

[*1] https://caohellas.gr/products/?lang=enm
[*2] https://roseofjericho.co.uk/product/argical-m1000/

Aqueous dispersion of the nanomaterials

- *Graphene nanoplatelets type N008-100-P40 (Angstron Materials Inc. Dayton, OH, USA)*
- *Superplastisizer Sika® ViscoCrete®-5600 HS (**to enhance the GnPs dispersion**)*
- Water of specific characteristics (VIKOS S.A. bottled water)

↓

Ultrasonication to break the GnPs agglomerates

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Fine dispersion of GnPs aqueous solution at water mix

The energy generator was the VCX-500 model and the nozzle model was CV-334 model (SONICS & MATERIAL®)

GnPs agglomerates

- As the **ultrasonic energy increases, the dispersion becomes more uniform** with lower size of agglomerates.
- Nevertheless, at high energy level the ultrasonication:
  1. destroys the surface groups of the GnPs-particles
  2. decreases their lateral size
  3. tend to re-agglomerate.
- An intermediate concentration of GnPs is suggested (about 0.15 wt% of the binder materials) as optimal for the specific engineering application, ultrasonicated at approximately 65 kJ.

Dispersion before ultrasonication (left) and after (right).

Dimou, A., Maistros, G., Poulin, P. & Alexopoulos, N. In situ control of graphene oxide dispersions with a small impedance sensor. Nanotechnology (2021)

The nanocomposites studied

	Aqueous solution	Ratio SP/GnPs
1.	0 %wt SP_0 %wt GnPs	0
2.	0.15 %wt SP_0.15 %wt GnPs	1/1
3.	0.30 %wt SP_0.15 %wt GnPs	2/1
4.	0.0 %wt SP_1.0 %wt GnPs	0
5.	1.0 %wt SP_1.0 %wt GnPs	1/1
6.	2.0 %wt SP_1.0 %wt GnPs	2/1

(1–3) ***jointing*** *application*

(4–6) ***grouts*** *application*

Mixing proportions *of the components of the dispersions in the nanoreinforced pastes*

According to the standard **EN 1015-3:** Methods of test for mortar for masonry – Part 3: Determination of consistence of fresh mortar (by flow table); 1999.

Water/Binder ratio = 0.55

All GnPs dispersions were ultrasonicated at 65 kJ


Flow table test

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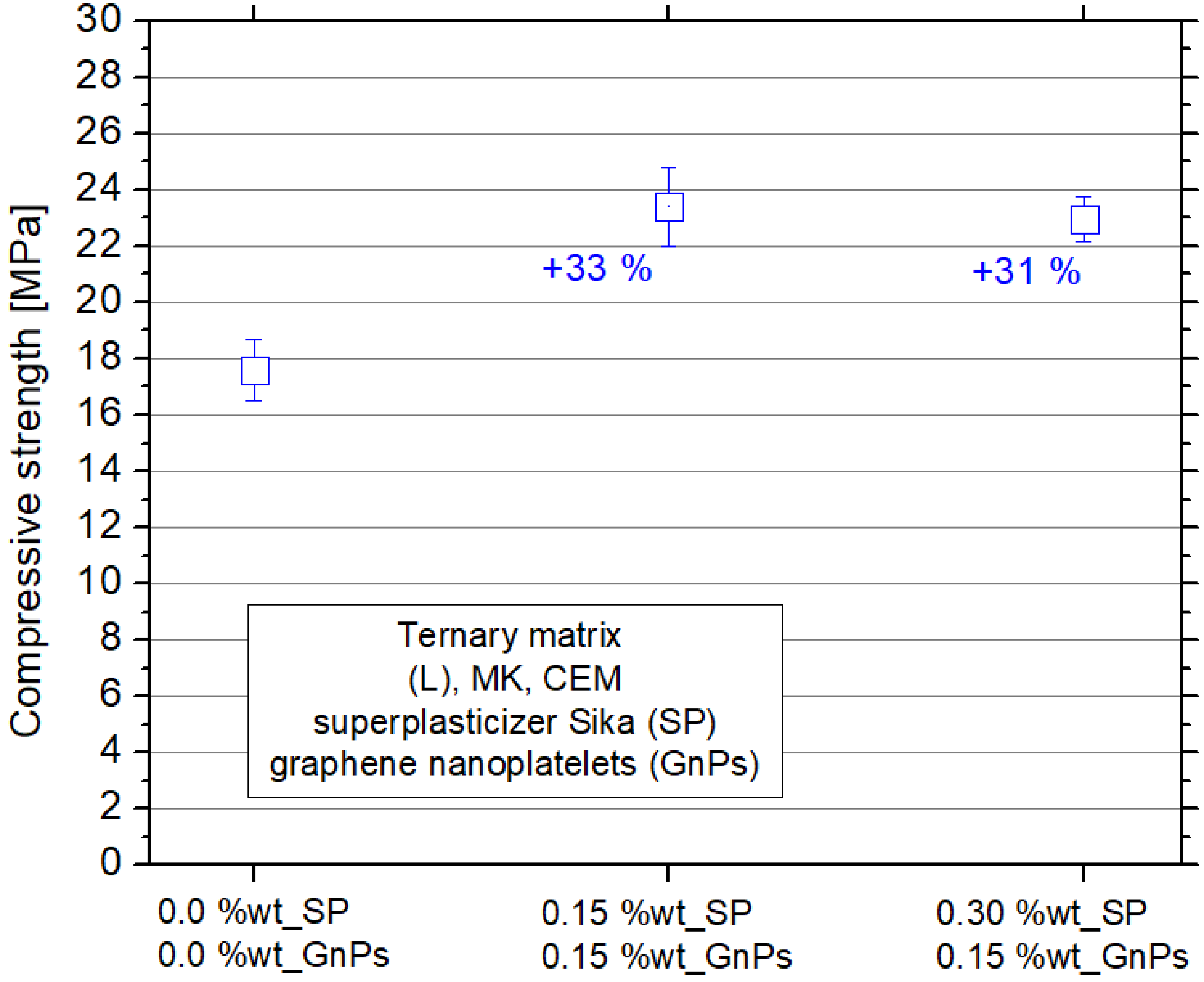
Results: compressiion tests (1)

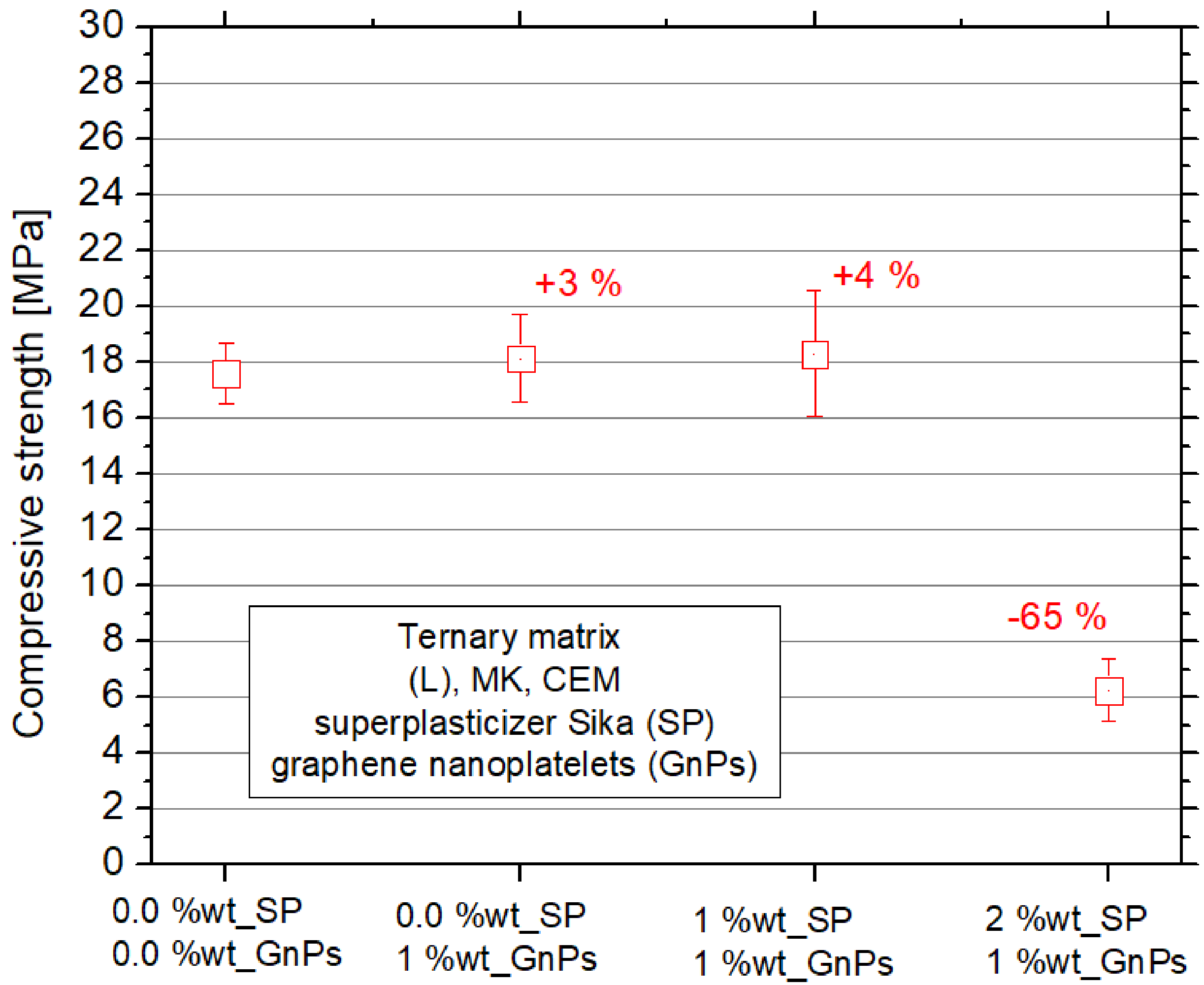


Reference samples:
17.6 MPa
Reinforced samples:
23.1 MPa

- The incorporation of GnPs in the matrix improves the compressive strength in both ratios of superplasticizer/GnPs.
- Similar increase (+28 %) by adding graphene oxide (GO) and reduced graphene oxide (rGO) in ternary pastes 📖.

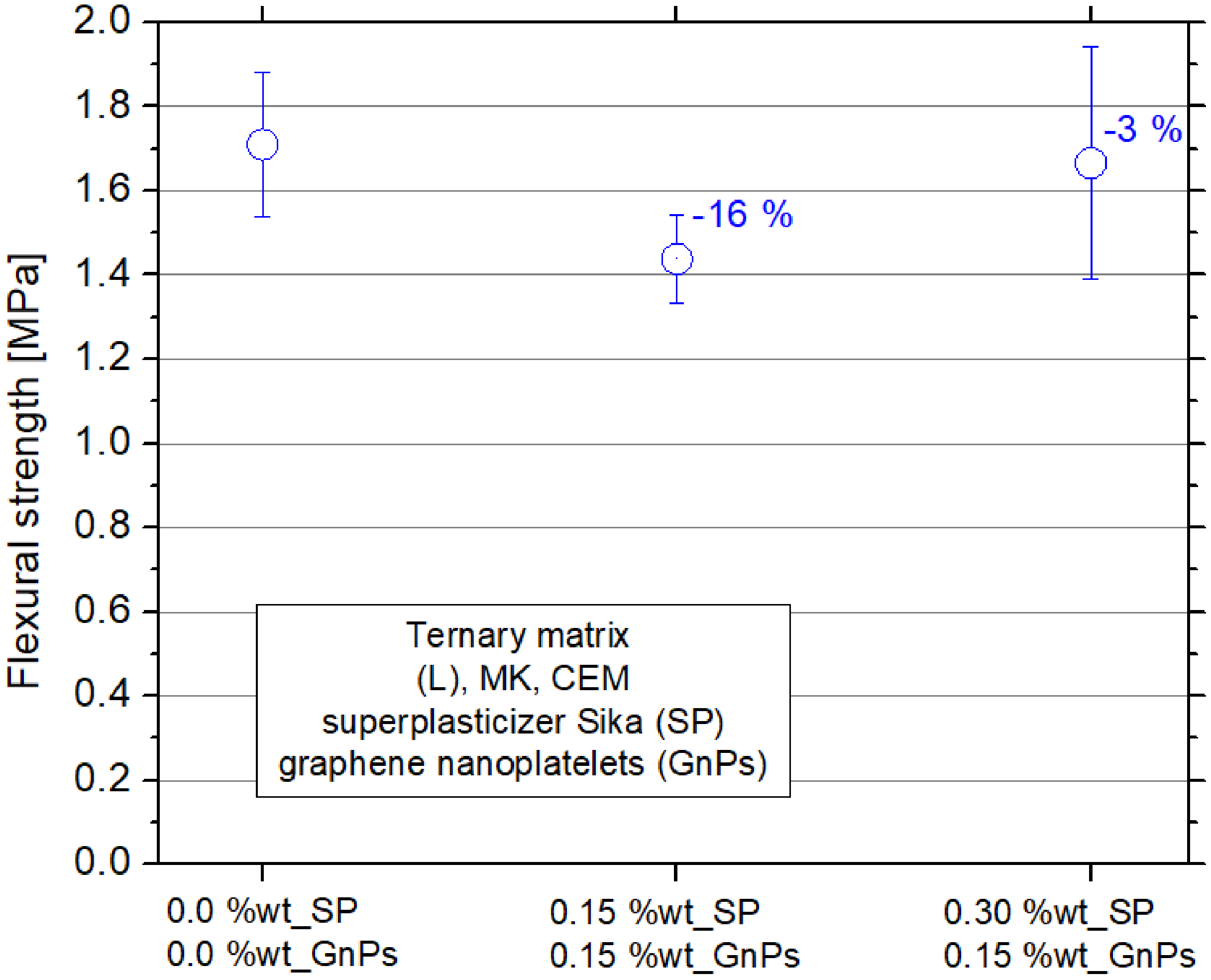
📖 *Dimou AE et al. Developments in the Built Environment 10 (2022) 100068*

Results: compression tests (2)



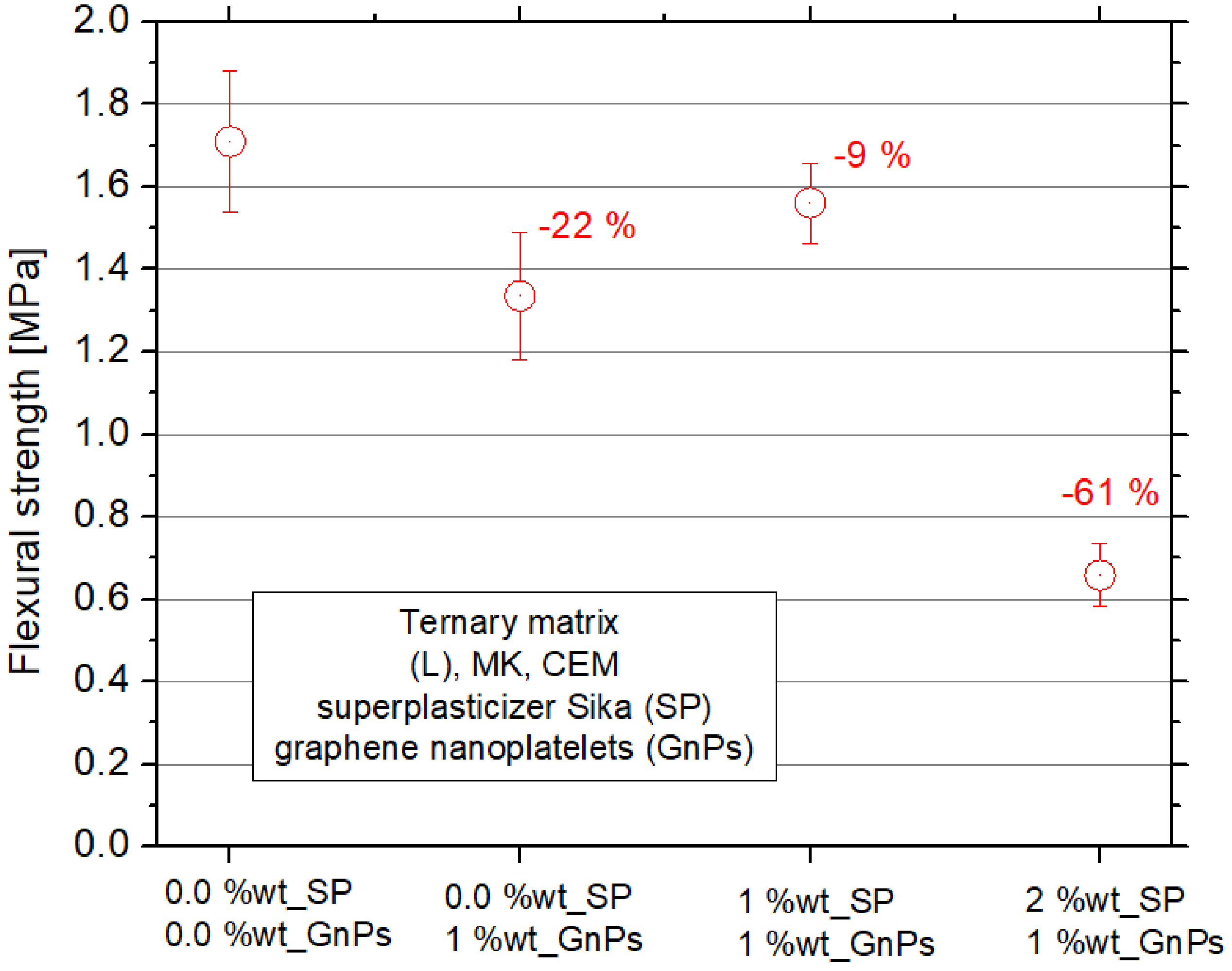
- Adding higher GnPs concentration for grouts (1 wt %) in the matrix leads to marginal (~ 3 %) increase of the compressive strength.
- The presence of SP at SP/GnPs ratio equal to 1 is not highly beneficial for the compressive strength.
- A dramatic reduction of the compressive strength is noticed for SP/GnPs ratio equal to 2 due to de-mixing from the high SP content.

Results: bending tests (1)



- The reference pastes display 1.7 MPa flexural strength.
- Adding GnPs (0.15 wt %) in the matrix leads to a small reduction of flexural strength due to the platelet size of the GnPs.
- When the ratio SP/GnPs increases from 1 to 2, the flexural strength increases due to better GnPs dispersion (approximately the same value with reference material).

Results: bending tests (2)



- Adding GnPs (1 wt %) without SP leads to a - 22 % reduction of flexural strength due to GnPs agglomerates.
- Addition of SP at the same GnPs concentration increased the GnPs dispersion and the flexural strength is increased.
- When the ratio SP/GnPs increases from 1 to 2 the flexural strength is essentially decreased to - 61 % due to de-mixing.

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Conclusions

- The addition of GnPs increases the compressive strength and reduces the flexural strength of the nanocomposites.
- The addition of superplasticizer in low concentrations (0.15 %wt) is beneficial as it promotes the higher efficiency for GnPs dispersion in the matrix.
- Higher superplasticizer concentration decreases significantly the mechanical properties of the restoration material due to de-mixing.

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Thank you for your attention!

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