Construction and Building Materials 259 (2020) 120416

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Properties of a new material based on a gypsum matrix incorporating waste brick

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HIGHLIGHTS

- A new material based on a gypsum matrix incorporating waste brick is investigated.
- The water resistance of the mortars with waste brick is acceptable in decorative elements.
- Incorporation of the waste brick in the mortars has enhanced the adhesive strength.
- Adhesion test results with limestone substrate are better than those with brick substrate.

ARTICLE INFO

Article history:
Received 20 March 2020
Received in revised form 22 June 2020
Accepted 28 July 2020

Keywords:
Innovative material
Gypsum
Waste brick
Adhesion strength
Mortar

ABSTRACT

Many rehabilitation operations of historic buildings have not succeeded to utilize appropriate material for purpose of the project. Currently, the use of construction waste, especially the waste brick, is largely expanded in the world due to construction and rehabilitation of buildings. For efficient and sustainable use of such material in the rehabilitation of the architectural ornaments, an experimental study was conducted to examine the influence of the waste brick content on the physical and mechanical properties of the gypsum mortar. The materials used to prepare the gypsum mortar were gypsum, natural sand, waste brick, water and superplasticizer. The main variable in this study were the waste brick content (0% to 100%) and the type of the substrate (limestone and brick). The W/B ratio of all the mixtures was kept constant to maintain a similar level of the workability. Several tests were performed to assess the physical and the mechanical behaviour of the gypsum mortars including the adhesion test, XRD and the SEM analysis. The results found show that the adhesion strengths in the mortars are more important when the substrate is made from limestone with the regard to the substrate made with brick. However, excessive percentage of waste brick in the mortar can lead to adverse effects and reduce the adhesive strength. Gypsum mortars made with 75% of waste brick should be recommended for the rehabilitation of the architectural ornaments.

1. Introduction

Recently the conservation of buildings for the architectural heritage is gaining more attention from the urban planning experts, since it is considered as one of the most important landmarks for cities particularly in the Mediterranean dwelling buildings. This heritage occupies a significant value for real-estate value and contributes to the definition of the urban image of the cities. Most historic buildings are rich in decorative elements (ornaments) which provide a high architectural and aesthetical value. The architectural ornaments are made from stone, but most of their components contain gypsum [1]. It is reported that the deterioration of the ornaments is attributed to the penetration of water, biological colonization, micro and macro cracking [2]. A pathological study carried out on the architectural ornaments resulted in defining the causes of the debonding of these elements (partial and complete detachment), which are mainly linked to the mechanical behaviour [3].

Many rehabilitation operations of historic buildings have not succeeded to utilize appropriate material for the purpose of the design [4]. Currently, the use of construction and demolition waste

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https://doi.org/10.1016/j.conbuildmat.2020.120416
0950-0618/

(CDW), especially the waste brick, is globally accelerating due to construction and rehabilitation of buildings with approximately 45% of the total of CDW [5]. This waste is not biodegradable and does not deteriorate with other materials. Recycling these wastes becomes an efficient solution to decrease the large amount of waste, which is considered as innovative renewable and sustainable resources for the construction and civil engineering field. This results in a reduction of the extensive exploitation of the raw materials and landfill locations, leading to enormous environmental and economic benefits [6]. Alicia et al. [7] studied the feasibility of CDW in gypsum composites similar to the one used in the present study. They concluded that the incorporation of 50% of ceramic waste over the weight of gypsum keep the basic properties of gypsum, however it decreases the water absorption by capillary up to 23%.

Haoxin et al. [8] studied the utilization of waste brick in the production of cement used for the rehabilitation of decorative plaster. They showed that the water resistance of the plaster was not really affected, and all the mechanical behaviours (compression, flexural and adhesion strengths) of plaster were improved but the excessive amounts of waste brick decrease all these properties. In the same context, a study was undertaken using the lime mortars with different proportions of brick dust for the restoration of the architectural heritage [9]. The authors concluded that the incorporation of the brick dust in the lime mortars successfully generated a pozzolanic reaction, increased porosity and enhanced the flexural and compressive strength. Also, the authors using the difference in colour of the mortars evaluated the aesthetic compatibility between the historic substrate and the restoration mortar. Markssuel et al. [10] found another ecological alternative by replacing sand with rock waste in a gypsum mortar. The replacement of 25% to 50% causes an increase of the compressive strength from 1.89 MPa to 3.18 MPa.

Khalil et al. [11] have assessed recycled material from various industries and sources. They have analysed the feasibility of utilizing waste material through integration 0.2–10% of rice husk as agriculture waste to gypsum plaster. They concluded that it decreases the setting time and bulk density while it increases the apparent porosity and compressive strength. Some authors studied the effect to add a mixture of ceramic waste and Extruded Polystyrene (XPS) waste to the gypsum mortar on the physical and mechanical characteristics. They found that incorporating them combined in the mortars does not improve the mechanical strength and increases the superficial hardness compared with the reference gypsum [12]. Jiménez et al. [13] evaluated the feasibility of using fine recycled aggregates from ceramic waste in masonry mortar, where they prepared five mortars by replacing 0%, 5%, 10%, 20%, and 40% of the natural sand by a fine recycled waste ceramic. They showed that replacement ratios of up to 40% by volume did not significantly influence the properties of fresh and hardened mortar.

Otherwise, Eires [14] showed that incorporating granulated cork in mortars, offers a better cohesion and finishing appearance when applied on pressed gypsum boards. Recently, Jitka [15] demonstrated that the behaviour and the properties of gypsum mortars are related to the size and shape of the fine aggregates; the strength decreases with the increase of the surface roughness of the aggregate, but it does not deteriorate the adhesive strength. Hanifi et al. [16] showed using X-ray diffraction (XRD) analysis that the composition of mortar used in ancient binding in Al-Andalus with the presence of calcite, gypsum, quartz, and muscovite have high mechanical strengths.

From the literature above, it can be seen that there is limited research on the effect of the CDW on the properties and behaviour of the gypsum mortar. So, it is worthwhile to investigate the impact of introducing the waste brick as sand in the gypsum mortar. The objective of this paper is to study a new material based on a gypsum matrix to be applied in the rehabilitation of architectural ornaments. The influence of the content of the waste brick on the physical and mechanical properties of the mortar is examined. These properties include the compressive strength, the flexural strength, the adhesion strength, the water absorption and the microstructure. The results obtained from this study may provide an alternative way for reusing the waste brick in the gypsum mortar used for the rehabilitation of ornaments.

2. Materials

The tests have been conducted in the Construction Materials Laboratory at the University of Minho (Portugal). The materials used in this experiment for the present composites are gypsum (G), superplasticizer (SP), natural sand (NS) and waste brick (WB).The gypsum employed is a commercial product used in construction, manufactured by SIVAL with high fineness and density of 2960 kg/m^3, additional details can be found at www.sival.pt. The superplasticizer employed is a GLENIUM SKY 617, with a density of 1050 kg/m^3 [17]. The sand has an average particle size of 439.9 μm and a density of 2600 kg/m^3. The crushed waste brick sand used in this investigation was obtained mechanically in a laboratory using a crushing device and then sieved to obtain a size similar to the NS. The grain size is shown in Fig. 1 and was determined by the sieving method [18].

The water absorption test was carried out on the natural sand and the waste brick according to standard. The objective was to know the water rate absorption of both materials. The bulk powder density WB were determined using flask and Kerosine liquid according to the previous standard [19]. It is found that the WB needs almost four times the amount of water than the natural sand (see Table 1). According to this observation, it is expected a difference in the rheological and mechanical behaviour of the mixture with and without waste brick. The chemical composition of the materials is showed in Table 1. The main chemical component of quartz sand is SiO_2, and its mass content is above 83.6% for NS and 39.55% for WB.

3. Methods

3.1. Sample preparation

A set of five different mortars were made with gypsum (G), natural sand (NS) and waste brick (WB). The waste brick was used as replacement by weight for the natural sand varying from 0% to 100%. A superplasticizer admixture (SP) was included in the mortar mixture at the proportion of 5% according to the literature [20].

The W/B ratio was fixed to maintain a similar level of workability comprised between 17 and 18 cm, in order to develop a mortar used in the rehabilitation of constructions in civil engineering. The workability was determined according to the standards [21] when the mortar took on a flow table after being vibrated for 25 s. The diameter was measured in two different directions. Details of the mixes are given in Table 2. Mortar prisms of 40 × 40 × 160 mm^3 were used to assess the physical and the mechanical behaviour of the gypsum mortars.

3.2. SEM/X-ray diffraction (XRD)

X- Ray diffraction (XRD) and Scanning Electron Microscopy (SEM) were used as analytical techniques to identify the mineralogical phases of the hardened five mortars and to realize a chemical, micro structural and crystallographic characterization at 28 days. Morphological analyses were realized in SEMAT

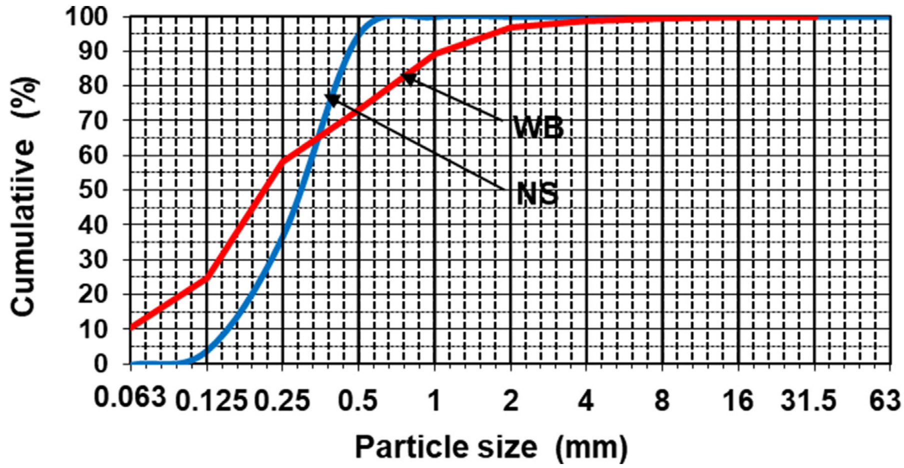


Fig. 1. Grain size of the sands.

Table 1
Chemical composition and characteristics of the materials used.

Component	Gypsum %	Natural sand %	Waste brick %
SiO_2	10.5	83,6	39.55
Al_2O_3	2.99	10.9	15.71
F_2O_3	1.55	0,433	14.05
CaO	26.90	0,058	12.88
MgO	3.09	/	3.29
K_2O	0.41	3,56	1.98
Na_2O	0.05	0,238	0.00
SO_3	30.33	/	0.48
Cl	0.01	/	/
TiO_2	/	0,82	/
P_2O_5	/	0,06	/
Density (kg/m^3)	2960	2600	2622
Water absorption (%)		5.10	20.22

(additional details can be found in www.semat.lab.uminho.pt) with Ultra-high resolution Field Emission Gun Scanning Electron Microscopy (FEG-SEM), NOVA 200 Nano SEM, FEI Company at an acceleration voltage between 10 and 15 kV. Chemical analyses were performed by X-ray microanalysis with Energy Dispersive Spectroscopy (EDS) technique, using an EDAX Si (Li) detector, integrated to the SEM, using an acceleration voltage of 25 kV. Powder X-ray diffraction (XRD) was conducted on a Bruker D8 Discover with Cu-Kα radiation (λ = 1,54060 Å) at 40 kV and 40 mA, in $\theta/2\theta$ mode. Each sample was scanned from 5° to 90° at a speed of 0.04°s-1. The analysis for phase identification was performed using analytical software EVA. The crystalline phases were indexed according the ICDD database (International Centre for Diffraction Data).

3.3. Flexural and compressive strength

For the five mixtures, 60 prismatic specimens with 40 × 40 × 160 mm^3 were prepared (twelve for each mixture) and were demoulded after being cured for 1 day following European Standard EN 1015-11 [22]. The flexural strength and compressive strength values were measured by LR50K machine with digital readout and self-centring planets for 7, 14 and 28 days. The two broken prism pieces obtained after the flexural strength testing, were then used for determination of the compressive strength (three specimens for each mixture), and the others for water absorption by capillarity and immersion.

3.4. Water absorption

The aforesaid broken prism pieces (6 for each 5 mixtures) were placed in the oven at a temperature of 60 °C ± 5 °C in order to remove water until to obtain a constant weight. Three specimens for each mixture were sealed with epoxy resin. Then after, they were immersed in water with a depth of 5 mm according to Standard EN 1015-18:2002 [23] and the other three were immersed for absorption by immersion test. The quantification of the absorbed water was performed by conducting consecutive weightings in specimens at 5, 10, 20, 30, 60 and 1440 min according to the same standard

3.5. Adhesion strength

Pertaining to the adhesion tests, five mixtures will be applied on two kinds of substrates, one made from limestone and the other made from waste brick. The thickness of the mortar is around 15 mm. There were 6 holes with dimensions of 50 × 50 mm^2. A metal disc of Ø50 mm is glued with an epoxy resin in these holes after 24 h. The procedure for the preparation of the samples is illustrated in Fig. 2. The process of test was performed in accordance to standard EN 1015-12 [24]. The adhesion strength was measured by the same machine used to measure the compressive strength (LR50K machine). Their average values were calculated by using equation A = F/S, where A is the adhesion strength; F is the maximum force; and S is the area of the mortar holes.

Table 2
Constitution of the five mixtures for 1 m^3.

	NS%:WB%	W/G	G (g)	NS (g)	WB(g)	SP(g)	W (g)
M 1	100:0	0.40	800	976,20	0.00	40	270,67
M 2	75:25	0.45	800	650,14	216,71	40	283,02
M 3	50:50	0.50	800	381,21	381,21	40	297,52
M 4	75:25	0.52	800	180,16	540,48	40	303,48
M 5	0:100	0.55	800	0.00	660,74	40	306,40

Fig. 2. Procedure of preparation of the samples.

During the adhesion test, an optical inspection was done on the surface of the substrate where the gypsum mortar was applied on the purpose to assess the failure mode between the mortar and the substrate. Two kinds of substrates were used: the brick and the limestone. The choice of the type of the substrates is related to the majority of the walls decorated with ornaments and made with masonry of brick and limestone in the countries of the Mediterranean southern and northern shore [25].

4. Results and discussion

4.1. Characterisation of the materials

4.1.1. Particle size distribution

As shown in Fig. 1, the particles of both materials pass through the sieve of 4.74 mm and more than 50% of them are smaller than 0.74 µm, which lead to consider the materials as fine sand. According to their coefficient of uniformity and curvity (Cu, Cc), WB presents a well graded material with the regard to the NS. This will generate a good distribution of the particles in the mortar mix and create less empty pores. It can be expected a fair mechanical behaviour for the mortar made with WB.

4.1.2. Water absorption by immersion

Water absorption by immersion of the gypsum mortars is plotted in Fig. 3 as function of the waste brick content. The amount of water absorbed by immersion in the gypsum mortars increases with the introduction of the waste brick content. The rate of increase is around 20% in the first and second replacement rate and 6% for the third and fourth replacement levels. This progression is initially excessive between M1/M2 and M2/M3; furthermore it becomes low between M3/M4 and M4/ M5. Although the density of the brick waste is similar to that of sand, the gypsum

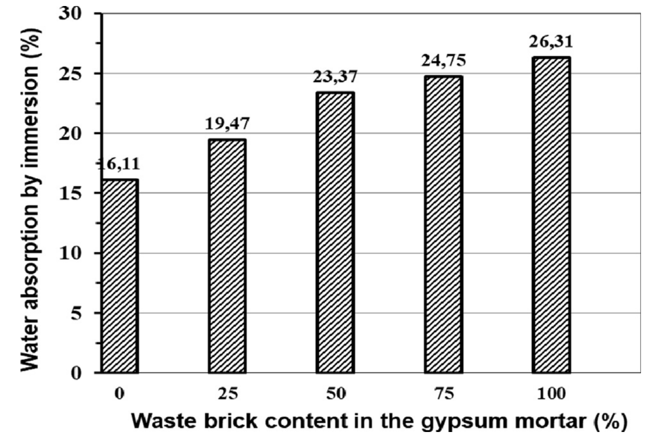


Fig. 3. Water absorption by immersion of the gypsum mortars as a function of WB content.

mortar made with only the natural sand (M1) and the gypsum mortar made with the brick waste do not display the same absorption value. This absorption is associated with the porous structure of the WB granulate compared to that of the NS.

4.1.3. Water absorption by capillarity

The variation of the water absorption by capillarity of the different gypsum mortars as function of the time (expressed here in square root of the time) is shown in Fig. 4. The sample M1 (control mortar) indicates the fast time of saturation with 120 min. This time increases with the introduction of 25% of WB and becomes

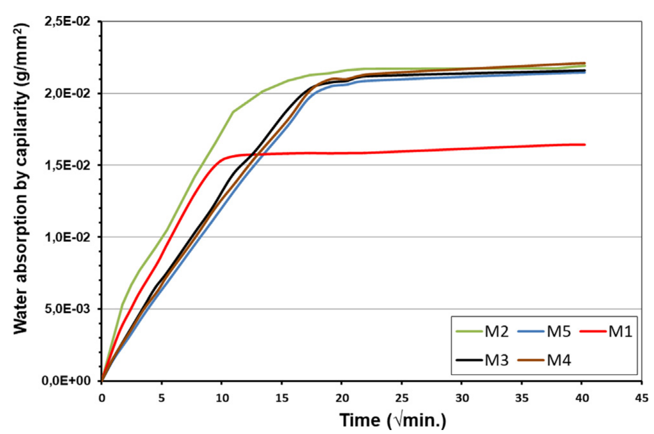


Fig. 4. Water absorption by capillarity as function of the time.

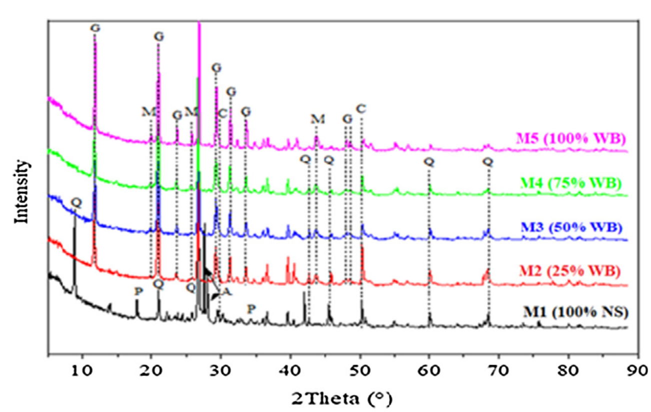
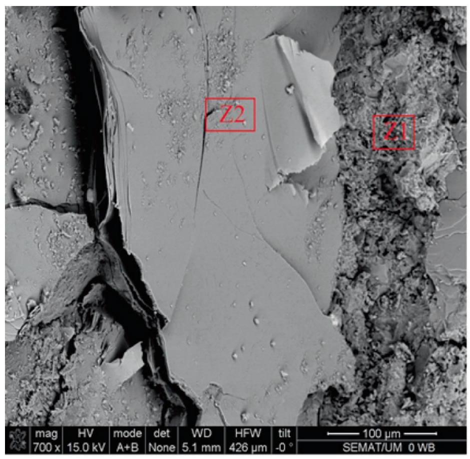


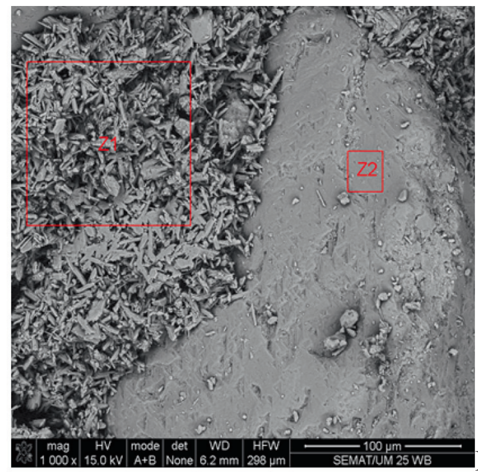
Fig. 5. X ray diffraction analysis for the mortar samples.

240 min for the mortar M2, while M3, M4 and M5 display approximately the same absorption rate with around 360 min. It is to be noted that the control mortar needs 120 min to achieve the saturation; however the mortar with 100% WB needs 360 min to reach the saturation level despite the difference in the saturation level. The difference of the water absorption by capillarity between the mortar with and without WB is around 37%. Although this will affect the mechanical behaviour of the gypsum mortars, the mortars incorporating WB present a water resistance quite acceptable to be used for the decorative elements according to some authors [7]. The rate of absorption expressed by the slope of the water absorption in Fig. 5 is more pronounced for the sample M1 and M2 than for the others, which may reflect the water resistance of the mortars made with high amount of WB.



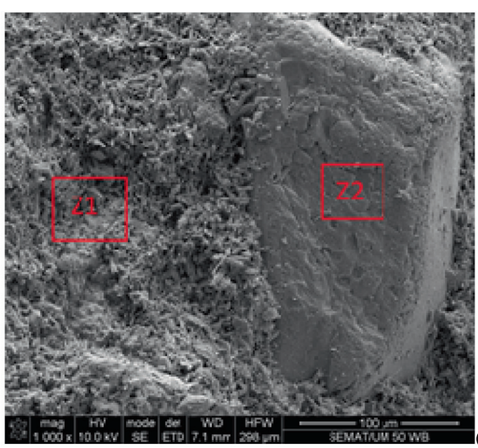
A

M1 Gypsum mortar with 100% NS



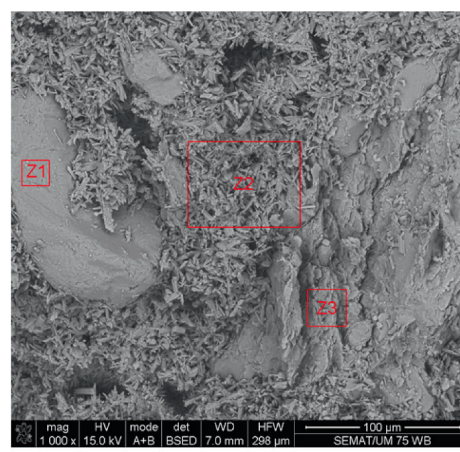
B

M2 Gypsum mortar with 25% WB



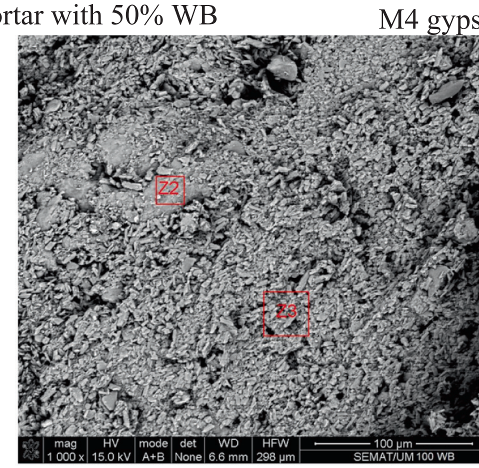
C

M3 gypsum mortar with 50% WB



D

M4 gypsum mortar with 75% WB



E

M5 gypsum mortar with 100% WB

Fig. 6. SEM images of the five samples incorporating various amounts of WB.

4.1.4. X-ray diffraction analysis

The results of X-ray diffraction of the 5 samples after 28 days of curing are presented in Fig. 5. The diffraction patterns of M1 (100% NS) present some mineral phases, namely the Quartz, Albite, Portlandite and Calcite as the main crystalline phases. The other 4 mixtures exhibit the disappearance of the main quartz reflection with the decreasing of the natural sand content in the samples. The gypsum phase reflection was present in the specimens incorporating WB while it was not present in the sample with sand. This can be explained by the presence of the sand which marks the reflection of gypsum. The samples also present the reflection of the calcite and the Muscovite phase, which are probably the major phases of the waste brick. The increase of their reflection by the increase of the amount of the waste brick in the mixture can possibly explain better the adhesion results found later. The appearance of the portlandite phase in the mortar with only natural sand and its disappearance in the mortar with WB indicates that this phase was consumed by the waste brick giving additional C-S-H phase. This observation may probably indicate the pozzolanic behaviour of the waste brick. However, the C-S-H phase was not detected in the XRD features, which may lead to two assumptions; either C-S-H formed is amorphous, or the quantity of CSH is so weak to be detected by the XRD analysis. On the other hand, the X-ray diffraction of the samples made with WB did not show any trace of other crystalline new phases; therefore, it is fair to say that the waste brick did not have a chemical reaction with the gypsum after mixing.

4.1.5. SEM analysis

SEM images of the hardened mortars at 28 days made with different amounts of WB are shown in Fig. 6. The samples display various zones with different aspects. One can observe that the structure of the zone Z1 is different to that of the zone Z2. When increasing the WB content, the surface of the Z2 increases and the surface Z1 decreases simultaneously (see Fig. 6A & B). The image C displays a new zone named Z3 in addition to Z1 and Z2, the zone Z1 is still reducing. The sample with 75% of WB displays only the Zone Z3 and a small surface of Z2 (see Fig. 6D). It is deduced that as the mortar contains more WB content, the microstructure becomes denser, because probably of the different particle size distributions of the WB. The particles of WB probably fill the voids and pores and make the gypsum mortars more compact. The compact and dense microstructure may be the result of the formation of the zone Z2 and Z3, which may influence the mechanical strength of the mortars made with WB.

4.2. Flexural strength results

The evolution of the flexural strength of the gypsum mortars with the WB content at different ages is illustrated in Fig. 7. It seems that when the replacement level of the waste brick is less than 50%, no clear effect of the presence of the waste brick is observed on the flexural behaviour of the mortars. Over this percentage, the gypsum mortars start to show a correlation between the rate of WB and the flexural strength particularly at 28 days.

4.3. Compression strength results

The development of the compressive strength of the gypsum mortars as function of the waste brick content for the different ages is shown in Fig. 8. The increase of the waste brick content leads to the increase of the compressive strength for the gypsum mortars at all the ages. Replacing 25% of natural sand by 25% of waste brick in the gypsum mortars improves the compressive

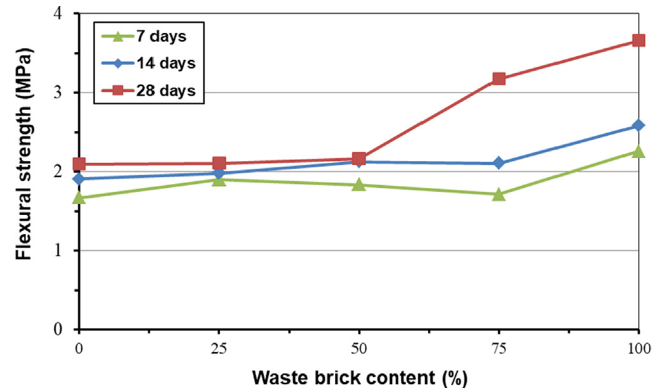


Fig. 7. Flexural strength of the mortars as function of the waste brick content at different ages.

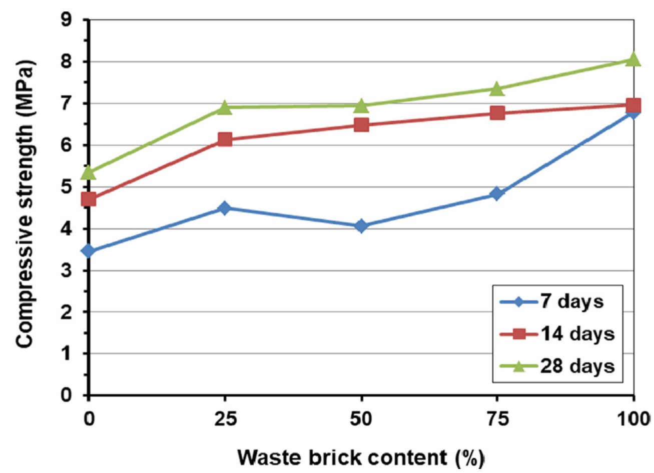


Fig. 8. Compressive strength of the mortars as a function of the waste brick content at different ages.

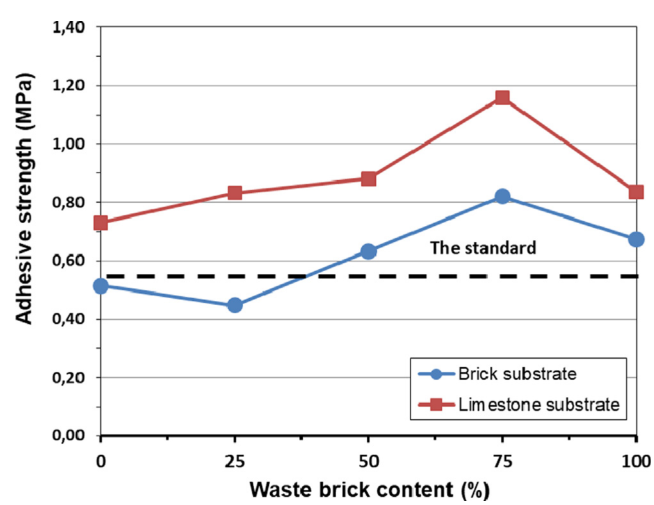


Fig. 9. Adhesive strength of the gypsum mortars for the brick and limestone substrate.

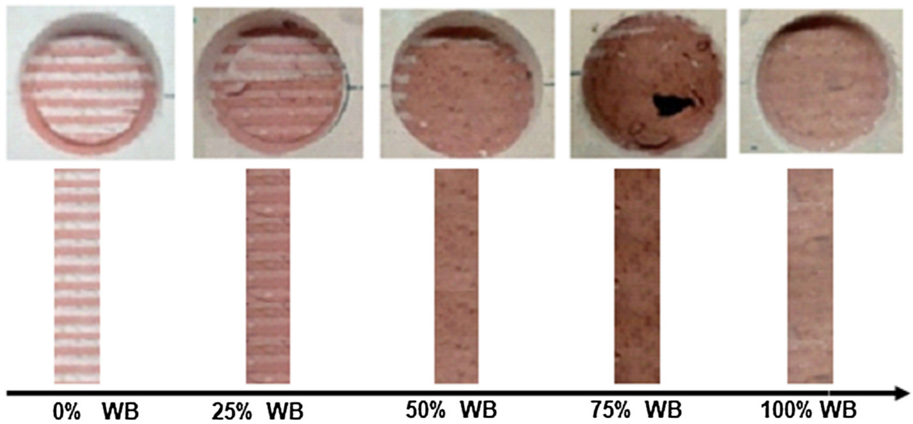


Fig. 10. Colour assessment chart of mortars.

strength by approximately 30%. This positive contribution may be attributed to the different phases of the waste brick (as mentioned in XRD analysis) and probably to the particle size distribution. According to the compressive strength results, it is possible to substitute entirely NS by WB without any unfair effects. It is thought that a compressive strength of around 8 MPa at 28 days is sufficient to resist at the ornament compressive stresses.

4.4. Adhesion strength results

Adhesion strength is known to be one of the most important properties of the mechanical performances for the gypsum-plaster used as decorative material. In Fig. 9, it is plotted the adhesion strength as function of the waste brick content. The adhesive strength for the gypsum mortars increases with the increase of the replacement level of the waste brick for both substrates. The maximum adhesive strength value is reached at the rate of 75% for both substrates. The adhesion strengths in the mortars are more important when the substrate is made from limestone with the regard to the substrate made with brick. However, excessive percentage of WB in the mortar can lead to adverse effects and reduce the adhesive strength (100% WB).

In general, all the adhesive strength results obtained are quite satisfactory, since they exceed the corresponding value required for decorative gypsum plaster (0.57 MPa) [8] except for the mortar M1 and M2 when the substrate is made from brick. The presence of the waste brick has enhanced the adhesive strength of the gypsum mortar, which may result in improving the crack resistance in the gypsum mortar. It is to be concluded that 75% of WB is the optimum value for the replacement level of the waste brick to get a mortar suitable for the rehabilitation of the architectural ornaments.

4.5. Physical appearance

In order to evaluate the failure that occurs between the gypsum mortars (aged 28 days) and the substrate during the adhesion test, we need to estimate the amount of substrate or mortar that has separated from each other. The colour of the interface area between the two elements (left after the adhesion test) may provide an idea about the type of the failure. A chart colour is drawn in Fig. 10 to assess the colour of the trace corresponding to the failure adhesion. The colour of the interface depends on the adhesion strength of the mortar, which is influenced by the waste brick incorporated in the gypsum mortar. In Fig. 11, it is represented a view of the interface mortar/brick substrate after adhesion test for the gypsum mortars with different waste brick content. It is noticed that the higher the replacement rate of the brick waste, the darker the colour of the trace left after the adhesion test. It seems that the colour of the M1/substrate interface is mostly that of the gypsum mortar, which may indicate that the adhesion strength between the two elements is weak (see Fig. 11(a)). However, with the introduction of the waste brick in the gypsum mortar (with 25% WB), a small piece is detached from the substrate and sealed with the mortar (as shown in Fig. 11(b)), which may reflect the increase of the adhesion strength in the mortar M2.

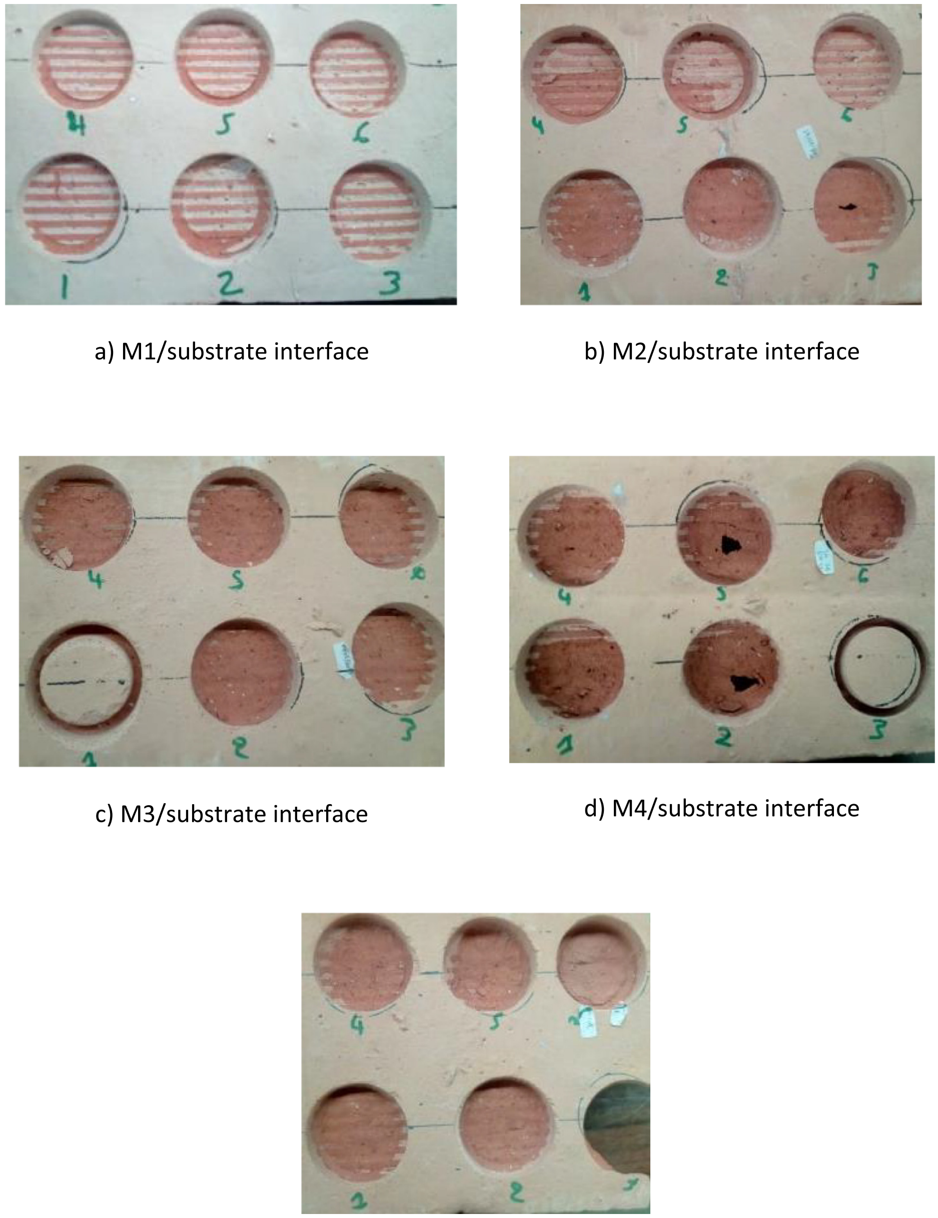
Beyond 50% of replacement rate of the waste brick, the colour of the interface becomes very dark, which look likes the colour of the brick substrate as shown in Fig. 11(d). This interface also presents a black hole in some samples, which reveals the enhancement of the adhesion strength. It is to be thought that the adhesion strength is so great that the debonding is deeper, which has probably lead to the appearance of a black hole in the substrate and a very dark colour. At 100% replacement rate, the colour of the interface (M5/substrate) is dark but not as the previous interface (M4/substrate), which may indicate that the adhesion strength in the mortar (M5) is less pronounced than that of the mortar (M4). The visual observation results agree fairly with those of the adhesion strength found above.

It is worth noting that all the failures caused by the adhesion test occur between the substrate and the mortar (named adhesive failure) and no failure happens within the mortar (named cohesive failure). This is to confirm that incorporating waste brick in the gypsum mortar has enhanced the adhesive strength. This constitutes one of the solutions to use in order to fight against the debonding of the architectural ornaments.

5. Conclusion

An experimental study was conducted on a new material based on a gypsum matrix to be used for the rehabilitation of decorative ornaments. The influence of the content of the waste brick on the physical and mechanical properties of the mortar is evaluated. The important conclusions are summarized as follows:

- The results of the absorption by capillarity show that the gypsum mortars incorporating waste brick present a water resistance quite acceptable to be used for the decorative elements.
- Samples made with waste brick did not show any trace of other crystalline new phases. It is thought that the waste brick did not have a chemical reaction with the gypsum after mixing and its effect is only physical.



a) M1/substrate interface

b) M2/substrate interface

c) M3/substrate interface

d) M4/substrate interface

e) M5/substrate interface

View of the interface mortar brick substrate after adhesion test

Fig. 11. View of the interface mortar brick substrate after adhesion test.

- The SEM analysis proves that the microstructure of the sample with waste brick is dense and compact as much as the amount of brick waste is important in the sample, which may explain the improvement in the mechanical behaviour of the gypsum mortar made with waste brick.
- The presence of the waste brick in the gypsum mortar has enhanced the adhesive strength of the sample, which may result in improving the crack resistance. The 75% of waste brick is the optimum value for the replacement level of the waste brick to get a mortar suitable for a possible use in the rehabilitation of the architectural ornaments. The adhesion strength results with limestone as substrate are better than those with brick substrate.

CRediT authorship contribution statement

Said Beldjilali: Investigation, Writing - original draft, Writing - review & editing. **Abdelkader Bougara:** Supervision, Conceptualization, Writing - review & editing. **José Aguiar:** Resources, Conceptualization, Methodology. **Nasr-Eddine Bouhamou:** Writing - review & editing. **Rawia Dabbebi:** Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the General Directorate of the Scientific Research and Technological Development in Algeria for its support and contribution.

References

[1] W. Bartz, T. Filar, Mineralogical characterization of rendering mortars from decorative details of a baroque building in Kożuchów (SW Poland), Mater. Charact. 61 (2009) 105–115, https://doi.org/10.1016/j.matchar.2009.10.013.
[2] H. Cotrim, M. do R. Veiga, J. de Brito, Freixo palace: rehabilitation of decorative gypsum plasters, Constr. Build. Mater. 22 (2008) 41–49. https://doi.org/10.1016/j.conbuildmat.2006.05.060.
[3] S. Beldjilali, S. Beldjilali, Architectural ornaments of colonial towns in Algeria: the case of Mostaganem, Int. Soc. Study Vernac. Settkements. 7 (2020) 1–11.
[4] M.T. Freire, A. Santos Silva, M. do R. Veiga, J. de Brito, Studies in ancient gypsum based plasters towards their repair: mineralogy and microstructure, Constr. Build. Mater. 196 (2019) 512–529. https://doi.org/10.1016/j.conbuildmat.2018.11.037.
[5] C.L. Hwang, M. Damtie Yehualaw, D.H. Vo, T.P. Huynh, Development of high-strength alkali-activated pastes containing high volumes of waste brick and ceramic powders, Constr. Build. Mater. 218 (2019) 519–529, https://doi.org/10.1016/j.conbuildmat.2019.05.143.
[6] P.O. Akadiri, E.A. Chinyio, P.O. Olomolaiye, Design of a sustainable building: a conceptual framework for implementing sustainability in the building sector, Buildings 2 (2012) 126–152, https://doi.org/10.3390/buildings2020126.
[7] A. San-Antonio-Gonzalez, R. Santos Jimenez, M. del Rio Merino, M. Gonzalez Cortina, C. Vinas Arrebola, Feasibility of recycling CDW as raw material in gypsum composites, Athens J. Technology Eng. 2 (2019) 149–160.
[8] H. Li, L. Dong, Z. Jiang, X. Yang, Z. Yang, Study on utilization of red brick waste powder in the production of cement-based red decorative plaster for walls, J. Clean. Prod. 133 (2016) 1017–1026, https://doi.org/10.1016/j.jclepro.2016.05.149.
[9] I. Aalil, D. Badreddine, K. Beck, X. Brunetaud, K. Cherkaoui, A. Chaaba, M. Al-Mukhtar, Valorization of crushed bricks in lime-based mortars, Constr. Build. Mater. 226 (2019) 555–563, https://doi.org/10.1016/j.conbuildmat.2019.07.265.
[10] M.T. Marvila, A.R.G. Azevedo, L.S. Barroso, M.Z. Barbosa, J. de Brito, Gypsum plaster using rock waste: a proposal to repair the renderings of historical buildings in Brazil, Constr. Build. Mater. 250 (2020) 118786, https://doi.org/10.1016/j.conbuildmat.2020.118786.
[11] A.A. Khalil, A. Tawfik, A.A. Hegazy, M.F. El-Shahat, Effect of some waste additives on the physical and mechanical properties of gypsum plaster composites, Constr. Build. Mater. 68 (2014) 580–586, https://doi.org/10.1016/j.conbuildmat.2014.06.081.
[12] M. del Río Merino, J. Santa Cruz Astorqui, P. Villoria Sáez, R. Santos Jiménez, M. González Cortina, Eco plaster mortars with addition of waste for high hardness coatings, Constr. Build. Mater. 158 (2018) 649–656. https://doi.org/10.1016/j.conbuildmat.2017.10.037.
[13] J.R. Jiménez, J. Ayuso, M. López, J.M. Fernández, J. De Brito, Use of fine recycled aggregates from ceramic waste in masonry mortar manufacturing, Constr. Build. Mater. 40 (2013) 679–690, https://doi.org/10.1016/j.conbuildmat.2012.11.036.
[14] R. Eires, A. Camões, S. Jalali, Eco-friendly construction materials using gypsum and industrial wastes, Challenge Ind. New Millenn. Proc. Sustain. Constr. Mater. Pract. Conf. (Portugal SB07), Lisboa, Port. 2007 (2007) 942–949. http://hdl.handle.net/1822/7576.
[15] J. Krejsová, M. Doleželová, R. Pernicová, P. Svora, A. Vimmrová, The influence of different aggregates on the behavior and properties of gypsum mortars, Cem. Concr. Compos. 92 (2018) 188–197, https://doi.org/10.1016/j.cemconcomp.2018.06.007.
[16] H. Binici, S. Kapur, The physical, chemical, and microscopic properties of masonry mortars from Alhambra Palace (Spain) in reference to their earthquake resistance, Front. Archit. Res. 5 (2016) 101–110, https://doi.org/10.1016/j.foar.2015.10.003.
[17] GLENIUM_SKY_617_FICHA TÉCNICA.pdf, (n.d.).
[18] BSI, BS EN 933-1:1997 Tests for geometrical properties of aggregates Part 1: Determination of Particle Size Distribution - Sieving Method, Br. Stand. Inst. 3 (2005) 1–7. https://bsol.bsigroup.com/en/Bsol-Item-Detail-Page/?pid=000000000030117183.
[19] ASTM C188-17, Standard Test Method for Density of Hydraulic Cement, 95 (2017) 1–3. https://doi.org/10.1520/C0188-17.
[20] N. Flores Medina, M.M. Barbero-Barrera, Mechanical and physical enhancement of gypsum composites through a synergic work of polypropylene fiber and recycled isostatic graphite filler, Constr. Build. Mater. 131 (2017) 165–177, https://doi.org/10.1016/j.conbuildmat.2016.11.073.
[21] E.C. for S.E. 1015-3:2004 (CEN), Methods of Test for Mortar for Masonry – Part 3: Determination of Consistence of Fresh Mortar (by Flow Table), 200, 2004.
[22] E. 1015-11:1999 European Committee for Standardization (CEN), Methods of Test for Mortar for Masonry – Part 11: Determination of Flexural and Compressive Strength of Hardened Mortar (1999).
[23] EN 1015-18, Determination of water absorption coefficient due to capillary action of hardened mortar, 3 (2002).
[24] European Committee for Standardization (CEN), Methods of Test for Mortar for Masonry – Part 12: Determination of Adhesive Strength of Hardened Rendering and Plastering Mortars on Substrates, 2000.
[25] J. Cassar, A. Torpiano, T. Zammit, A. Micallef, Proposal for the nomination of Lower Globigerina Limestone of the Maltese Islands as a "Global Heritage Stone Resource," Episodes 40 (2017) 221–231. https://doi.org/10.18814/epiiugs/2017/v40i3/017025.