Utilization of repair mortar for the loss compensation of Hungarian porous limestone

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Abstract
Different ready-made, commercially available (in Hungary) stone repair mortars and laboratory mixed, newly designed mortars were tested under different conditions in the laboratory. The mortars had different aggregate and binder content. The aim of the research was to understand the influence of the different binders and various amounts of limestone aggregate on the properties of mortar. During the laboratory tests more than 550 specimens were analyzed according to the EN standards. Pure repair mortars have higher strength and lower capillary activity than the Hungarian porous limestones. Added aggregate can increase the compatibility of the commercially available mortars, but at some mortars it may result a drastic decrease in strength. Newly designed mortars have similar mechanical and hydrotechnical properties to the tested porous limestones.
Keywords: repair mortar, limestone, binder/aggregate ratio, compressive strength, compatibility

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1. Introduction

Repair mortars or artificial stones are often used for repair of stone monuments and artistic stone elements of facades, sculptures or statues. There is not a uniform terminology for the loss compensation of stones: the expressions of repair mortars or artificial stones are used by different authors [1-4].

Previous research in this field focused on loss compensation methods for stones [1,2]. Additional studies were made on the amount of filler added to cementitious materials and the performance of these materials was tested [5,6]. Mortars with specially selected fillers were also tested. Both natural and artificial inorganic materials were added to mortars to improve the physico-chemical and mechanical properties; workability or water retention was also analyzed [7-9]. In recent years, mechanical properties and fabric analyses were also made [3,10-13]. Chemical composition of the mortars were also analyzed [14-16]. Compatibility of the limestone and mortar was studied considering strength and durability characteristics such as mechanical resistance, water transfer properties, and physico-chemical properties [17-20].

Fig. 1. Loss compensation with incompatible repair mortar.
1. ábra Kőkiegészítés nem kompatibilis habarccsal.

Case studies have shown, that many of the commercially available (ready-mix) repair mortars can not be adequately used under certain conditions and are not compatible with porous limestone [17-18] (*Fig. 1*). Only limited data are available from the product properties in catalogues, safety data sheets, product specifications. There is not enough information about the porosity, fluid transport properties, pore-size distribution, long-term behaviour of the mortars and compatibility with porous limestones. Therefore, further information is needed to find the best performance and compatible mortar for the given stone. Repair mortars have been tested according to the European (EN) and American (ASTM) standards and performance in terms of strength, porosity, hydro-technical properties were measured [12-13].

2. Materials and methods

Commercially available repair mortars are commonly used for the restoration of stone structures made of Hungarian oolitic limestone. Practitioners use these ready-mix mortars since it is easy to work with them that allow a relatively fast repair. Furthermore, there are individual mortar recipes in the restoration practice. These two categories of mortars (pre-mixed and site-made) were tested under laboratory conditions. Their properties were compared with that of Hungarian porous limestone. Two lithologies were analyzed. The limestone was collected from Sóskút quarry, which is located app. 30 km from the capital of Hungary. The two tested lithologies are:

DMF: limestone with fine-grained micro-fabric (*Fig. 2a*),
DMD: limestone with coarse-grained micro-fabric (*Fig. 2b*).

Two groups of mortars were also tested. The first group is composed of different types of mortars that are commercially available repair mortars (M). The compounds of the mortars were made in Germany and test specimens from ready-mix mortars were prepared under laboratory conditions. 30 to 50 m% of limestone sand aggregate was added to the tested mortars to make the repair mortar more compatible with the coarse limestone. This mixing of mortar with limestone sand is a common method in the restoration practice in Hungary.

The abbreviations of the tested mortars are as follows:

- M: pure repair mortars (pre-mixed mortar + water),
- M30: pure mortar with 30 m% added limestone sand aggregate and
- M50: pure mortar with 50 m% added limestone sand aggregate.

Second group of tested mortars contained newly mixed repair mortars with two different compositions. Two types of cementitious binders were added to the mortars:

- PLM: mortar with Portland cement and hydrated lime binder,
- TLM: mortar with trass cement and hydrated lime binder.

The above mentioned limestone chippings (Sóskút quarry) were used for the aggregate sand. The maximum particles size of the aggregate was 2 mm in diameter. Fabric analysis of the tested materials was performed according to EN 12407:2000 European Standard by the analysis of thin-sections.

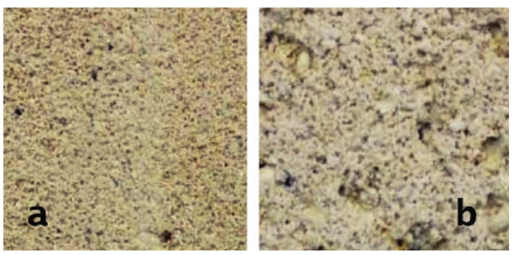

Fig. 2. Hugarian (Sóskút), Miocene, porous limestone: (a) fine-grained, (b) coarse-grained fabric.
2. ábra Sóskúti miocén korú durva mészkő: (a) finomszemű, (b) durvaszemű változata.

The sample preparation was made under laboratory conditions (temperature 20±2°C, relative humidity of 50–55%). The initial curing environment was the same in all cases. More than 550 mortar specimens (30×30×30mm in size) were prepared for uniaxial compressive test (EN 1015-11:2000). For the microscopic analysis thin-sections were made (thickness of 30 µm). Prismatic samples of 40×40×80 mm in size were used for the capillary water uptake measurements, following the EN 1925:2000 standard. Cylindrical specimens of 10 mm in diameter were made for the pore size distribution analyses. The measurements were made with a Carlo Erba 2000 (GFZ Potsdam) porosimeter and the data evaluation was made by a Pascal software (version of 1.03). Samples were dried in oven to constant mass at 105°C.

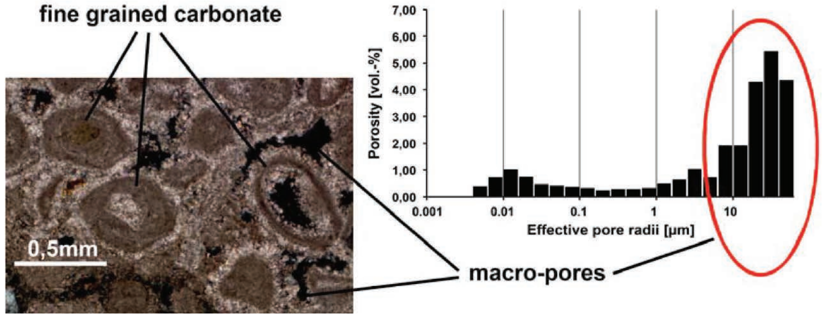

Fig. 3. Thin-section of the coarse-grained limestone (DMD) with the histogram of the pore size distribution of the limestone.
3. ábra Durvaszemű ooidos durva mészkő vékonycsiszolata és póruseloszlásának hisztogramja.

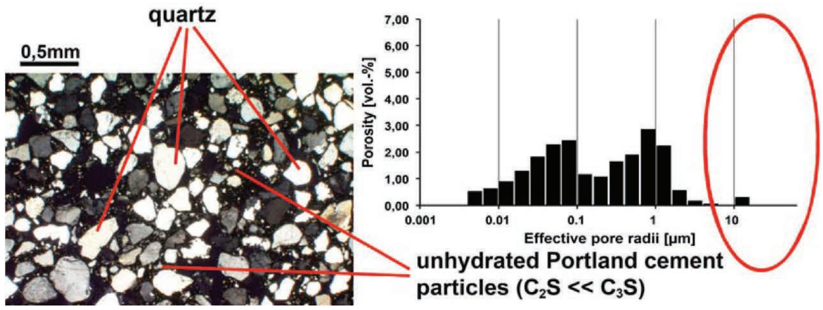

Fig. 4. Thin-section of the pure, commercial available repair mortar (M) with the histogram of the pore size distribution.
4. ábra Hazai kereskedelmi forgalomban kapható kőkiegészítő habarcs vékonycsiszolata és póruseloszlásának hisztogramja.

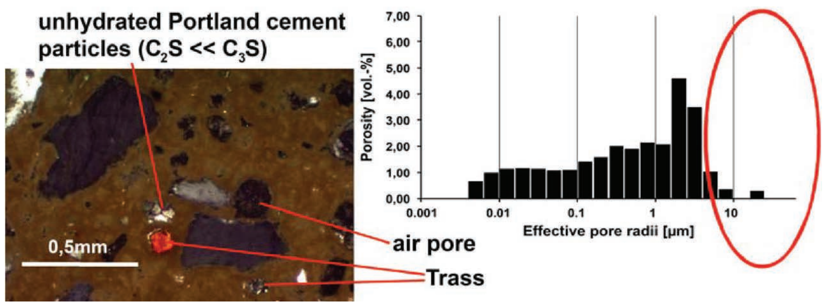

Fig. 5. Thin-section of the commercial available repair mortar (TLM) with the histogram of the pore size distribution.
5. ábra Kőkiegészítő habarcsban megjelenő trasz cement és légpórusok a vékonycsiszolatban, valamint a traszcement tartalmú habarcsok póruseloszlásának hisztogramja.

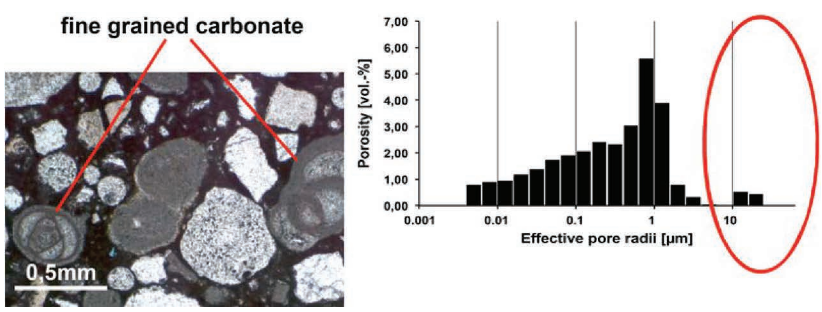

Fig. 6. Thin section of the commercial available repair mortar with 50m% added limestone sand aggregate (M50) with the histogram of the pore size distribution.
6. ábra Hazai kereskedelmi forgalomban kapható kőkiegészítő habarcsba kevert mészkő zúzalék (50m%) vékonycsiszolata és póruseloszlásának hisztogramja.

3. Results

3.1 Fabric

Limestone: The micro-fabric is characterized by the presence of ooids, and the microfacies of the stone is an ooid-grainstone to packstone. Large and visible macro pores of different size were visualized in both selected limestones (DMD and DMF). The porosity is characterized by the presence of intra- and inter-granular pores. According to the pore size distribution, the main pores were detected in the range of macro-pore size (10-100 μm) (*Fig. 3*).

Mortars (M): The binder is mostly calcitic, and the aggregate is mostly given by small rounded quartz grains of 10–500 μm. The hydraulic binder content of the samples (white portland cement) is clearly demonstrated by the unhydrated cement particles. Hydrated alite (C_3S - mostly), and small amounts of belite (C_2S) was also observed, furthermore a mixture of slaked lime was present in all of the four commercially available repair mortars (*Figs. 4* to *6*).

Mortars (M, PLM, TLM): Only very small visible pores were detected under the microscope. When 30 or 50 m% of limestone sand is added to the repair mortars, the proportion of the binder-to-aggregate ratio is shifted towards the grain dominance.

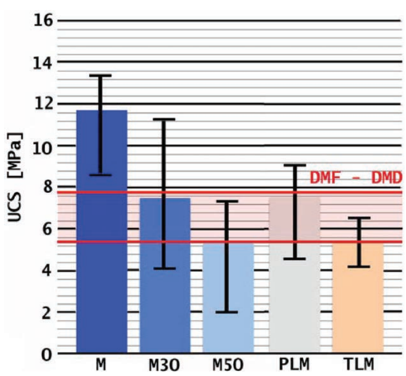

Fig. 7. Average value with the standard deviation of the compressive strength of the tested mortars. All the values measured for the limestones are shown in the zone indicated in red colour.

7. ábra Habarcsok átlagos egyirányú nyomószilárdsága és szórása. A piros sávban vltak mérhetők a kétféle mészkövön a nyomószilárdsági értékek.

Abbreviation	UCS [MPa] day 3	day 7	day 14	day 28	day 90	Water absorption [%]	av. real density (g/cm³)
M	6.89	8.86	9.76	10.39	11.66	9.1	2.72
M30	4.28	5.54	6.42	7.21	7.54	11.7	2.67
M50	2.41	4.06	4.9	5.48	5.31	13.4	2.61
PLM	3.64	5.88	6.94	7.43	6.32	5,56	2.7
TLM	3.28	4.35	5.56	5.08	5.02	13.4	2.66
DMF	7.60 (dev 2.5)					20.5	2.69
DMD	5.56 (dev 2.2)					14.6	2.73

Table 1. Uniaxial compressive strength (UCS), water absorption and density of the tested materials (for abbreviations see the text).

1. táblázat A vizsgált anyagok egyirányú nyomószilárdága, vízfelvétele és anyagsűrűsége (anyagok rövidítése a szövegben).

3.2 Strength

Pure repair mortars (without limestone sand aggregate) have more than double of the strength than that of the tested porous limestones. Added limestone sand aggregate can reduce the strength of the mortars and it becomes closer to the strength of limestone (*Fig. 7* and *Table 1*).

The tests have demonstrated that newly designed repair mortars 28 days after curing (mostly TLM) have similar strength to that of porous limestone, but on a longer-term the strength of mortar specimens has been gradually decreased.

3.3 Water absorption

The capillary water uptake of the tested limestones is much faster than that of the tested repair mortars (*Fig. 8*). The slow water uptake of the pure repair mortars are proportionally increased, when limestone aggregate was added. The biggest increase in capillary water uptake was measured at mortars made with trass cement binder. Smaller increase was detected in water uptake at commercial available mortars with limestone aggregate (M30, M50).

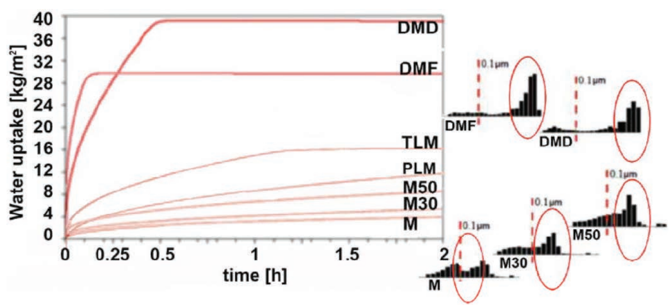

Fig. 8. Capillary water uptake in the tested materials with the pore size distribution (DMD-coarse limestone, DMF- fine limestone, M, PLM, TLM tested mortars).

8. ábra Kapilláris vízfelvétel a vizsgált anyagokban a pórusméret-eloszlással (DMD-durvaszemű durva mészkő, DMF- finomszemű durva mészkő, M, PLM, TLM habarcsok).

4. Conclusions

A close relationship between the pore structure, mechanical properties and water absorption of repair mortars were found. Previous experience has shown that increasing the aggregate content decreased the strength of the mortars and at the same time the porosity, water absorption and capillary suction are slightly increased [19, 21]. The lower water absorption of the repair mortars compared to natural stones is related to the very different pore size distribution. The oolitic limestone has exceptionally interconnected pore system with a wide range of pore radii, and high peaks in the pore size distribution histograms at macro-pores with diameter of around 10-100 μm. These macro-pores are missing from the pure mortars and from the mortars to which limestone aggregate is added. Among the tested repair mortars, only the mortars with trass cement binder have higher compatibility with the oolitic limestone, but the higher amount of aggregate decreased the strength and the workability of the mortar. It is important to highlight that the use of trass cement increased the capillary activity of the mortar and at the same time decreased the strength from the 28th day. Repair mortars with higher strength and different porosity than that of the limestone can cause damage (cracking and spalling in the original stone surface). Usually weak limestones have lower modulus of elasticity than mortars made by Portland cement.

To conclude, the test results have shown that the use of significant amount of porous limestone sand as aggregate for pre-mixed repair mortars does not guarantee the compatibility of the repair mortar with the porous limestone, however, it has an evidential positive effect in compatibility. Without long term laboratory experiments, newly designed repair mortars might have serious compatibility problems with limestone.

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References

[1] Griswold, J. – Uricheck, S.: (1998) Loss compensation methods for stone. Journal of the American Institute of Conservation 37:89–110

[2] Kriston L. (2000) A kő és vakolatrestaurálás alapismeretei. MKE, Budapest, 113–119 pp

[3] Pecchioni, E. – Malesani, P. – Bellucci, B. – Fratini, F: (2005) Artificial stones utilised in Florence historical palaces between the XIX and XX centuries Journal of Cultural Heritage 6:227–233 http://dx.doi.org/10.1016/j.culher.2005.06.001

[4] Isebaert, A. – Van Parys, L. – Cnudde, V: (2014) Composition and compatibility requirements of mineral repair mortars for stone – A review. Construction and Building Materials 59:39–50 http://dx.doi.org/10.1016/j.conbuildmat.2014.02.020

[5] Benachour, Y. – Davy, C. A. – Skoczylas, F. – Houari, H: (2008) Effect of a high calcite filler addition upon microstructural, mechanical, shrinkage and transport properties of a mortar. Cement and Concrete Research 38:727–736 http://dx.doi.org/10.1016/j.cemconres.2008.02.007

[6] Gosselin, C. – Verges-Belmin, V. – Royer, A. – Martinet, G.: (2009) Natural cement and monumental restoration. Materials and Structures 42:749–763 http://dx.doi.org/10.1617/s11527-008-9421-7

[7] Heikal, M. – El-Didamony, MH. – Morsy, MS: (2000) Limestone-filled pozzolanic cement. Cement and Concrete Research 30:1827–1834. http://dx.doi.org/10.1016/S0008-8846(00)00402-6

[8] Bülent. Y. – Asim, O.: (2007) Studies on cement and mortar containing low-calcium fly ash, limestone, and dolomitic limestone. Cement & Concrete Composites 30:194–201 http://dx.doi.org/10.1016/j.cemconcomp.2007.07.002

[9] Ghrici, M. – Kenai, S. – Said-Mansour, M.: (2007) Mechanical properties and durability of mortar and concrete containing natural pozzolana and limestone blended cements. Cement & Concrete Composites 29:542–549 http://dx.doi.org/10.1016/j.cemconcomp.2007.04.009

[10] Barsottelli, M. – Cellai, G. F. – Fratini, F. – Manganelli, F.: (2001) The Hygrometric behaviour of some artificial stone materials used as elements of masonry walls. Materials and Structures 34:211-216 http://dx.doi.org/10.1007/BF02480590

[11] Sinan, C.: (2003) Aggregate/mortar interface: influence of silica fume at the micro- and macro-level. Cement & Concrete Composites 25:557–564 http://dx.doi.org/10.1016/S0958-9465(02)00095-1

[12] Pavia, S. – Fitzgerald, B. – Treacy, E.: (2006) An assessment of lime mortars for masonry repair. Concrete Research in Ireland Colloquium, University College Dublin, 101–108.

[13] Pavia, S. – Toomey, B.: (2008) Influence of the aggregate quality on the physical properties of natural feebly-hydraulic lime mortars. Materials and Structures 41: 559–569 http://dx.doi.org/10.1617/s11527-007-9267-4

[14] Bultrini, G. – Fragala, I. – Ingo, GM. – Lanza, G.: (2006) Minero-petrographic, thermal and microchemical investigation of historical mortars used in Catania (Sicily) during the XVII century A.D. Applied Physics. 83:529–536 http://dx.doi.org/10.1007/s00339-006-3551-y

[15] Tunçoku, SS. – Caner-Saltık, EN.: (2006) Opal-A rich additives used in ancient lime mortars. Cement and Concrete Research 36:1886–1893 http://dx.doi.org/10.1016/j.cemconres.2006.06.012

[16] Budak, M. – Maravelaki-Kalaitzaki, P. – Kallithrakas-Kontos, N.: (2008) Chemical characterization of Cretan clays for the design of restoration mortars. Microchim Acta 162:325–331 http://dx.doi.org/10.1007/s00604-007-0927-4

[17] Szemerey-Kiss, B. – Török, Á.: (2011) Time-dependent changes in the strength of repair mortar used in loss compensation of stone. Environmental Earth Sciences, 63:1613-1621 http://dx.doi.org/10.1007/s12665-011-0917-z

[18] Szemerey-Kiss, B. – Török, Á.: (2012) Porosity and compatibility of repair mortars and Hungarian porous limestones. Central European Geology, 52:123-133. http://dx.doi.org/10.1556/CEuGeol.55.2012.2.1

[19] Szemerey-Kiss, B.: (2012) The application of adhesion strength test in the assesment of compatibility of repair mortars and porous limestones. Conference of Junior Researchers in Civil Engineering, 2012.06.19-2012.06.20. Budapest, BME, ISBN 978-963-313-061-2

[20] Szemerey-Kiss, B. – Török, Á. – Siegesmund, S.: (2013) The influence of binder/aggregate ratio on the properties and strength of repair mortars. Environmental Earth Sciences, 69:1439-1449 http://dx.doi.org/10.1007/s12665-013-2413-0

[21] Lanas, J. – Sirera, R. – Alvarez, JI.: (2006) Study of the mechanical behavior of masonry repair lime-based mortars cured and exposed under different conditions. Cement and Concrete Research 36:961–970 http://dx.doi.org/10.1016/j.cemconres.2005.12.003

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Magyarországi porózus mészkövekhez alkalmazható kőkiegészítő anyagok

A kutatás során olyan kőkiegészítő habarcsok tulajdonságát elemeztük és hasonlítottuk össze a miocén korú durva mészkő két típusának azonos tulajdonságaival (durvaszemű – DMD, és finomszemű – DMF), amelyeket hazai kereskedelmi forgalomban lehet beszerezni. A vizsgálatokat kiterjesztettük továbbá olyan általunk összeállított habarcsokra, amelyek kötőanyagának és töltőanyagának minőségét és mennyiségét mi határoztuk meg. Az így készített habarcsok közül a portlandcement és mészhidrát kötőanyaggal készített habarcsok szilárdsága jelentősen nagyobb volt, mint a vizsgált mészköveké, de porozitásuk, ezáltal hidrotechnikai tulajdonságaik is nagymértékben eltértek a mészkövekétől. Összetételük változtatásával (+30 m%, de elsősorban a +50 m% mészkő zúzalékkal) a kőzetekhez nagyobb hasonlóságot érünk el, de egyes típusoknál ez a beavatkozás nem alkalmazható egyes anyagjellemzők drasztikus változása miatt. A traszcement tartalmú habarcsok vizsgálata során megállapítottuk, hogy a portlandcement kötőanyagú habarcsokhoz képest nagyobb hasonlóságot mutatnak a kiválasztott mészkövek több tulajdonságával is – szilárdság, vízfelvétel, porozitás.
Kulcsszavak: javítóhabarcs, mészkő, kötőanyag/adalékanyag arány, nyomószilárdság, kompatibilitás