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Research paper

Historical and aesthetic compatibility of earth-based mortars on the example of ancient stone structures in the Black Sea Basin

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Abstract: Material compatibility is a complex issue that is challenging to analyse, especially when it comes to historic structures undergoing revitalisation. The use of a solution that is incompatible with the existing structure may not only affect its durability, but also directly lead to the destruction of the historic material. One of the important aspects of compatibility assessment is historical and aesthetic compatibility, which is responsible for accurately conveying historical truth to future generations. In the case of earth-based reconstruction mortars, this compatibility primarily involves the analysis and proper selection of the colour and texture of the reconstruction solution, which, in addition to ensuring authenticity, will be resistant to changes under the influence of long-term environmental factors, i.e., radiation, weathering, and leaching. The selected solution should accurately reflect historical truth while ensuring that other requirements for reconstruction mortars, i.e., strength and durability, are met. The method of verifying the historical and aesthetic compatibility of earth-based mortars is presented on the example of ancient stone structures in the Black Sea Basin. The selected solution was subjected to a test application, which ultimately verified its suitability for use in the original structure. Key recommendations were formulated to ensure historical and aesthetic compatibility for earth-based mortars for reconstruction.

Keywords: ancient stone structures, earth-based mortars, historical and aesthetic compatibility

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1. Introduction

Material compatibility is a complex issue that is challenging to analyse, especially when it comes to historic structures undergoing revitalisation. Importantly, the use of a solution that is incompatible with the existing structure may not only affect its durability, but also directly lead to the destruction of the historic material. In general terms, a material compatible with historic material is one that will not cause chemical changes, will not initiate or intensify the deterioration of the historic structure, and will ensure uniform operating conditions and the possibility of restoring the state before the repair work (reversibility of the reconstruction process). The types of compatibility are presented in Fig. 1 [1, 2].

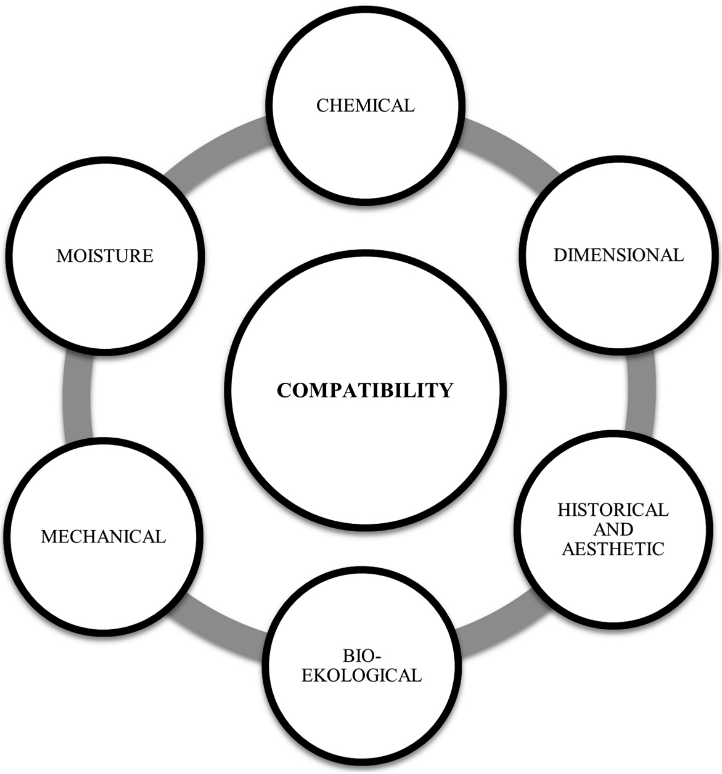

Fig. 1. Types of compatibility of reconstruction mortar (based on [1])

Chemical compatibility requires that the reconstruction mortar not introduce hazardous chemical compounds or substances that could react with those contained in masonry materials. Hazardous compounds include various types of salts that can decompose in the presence of moisture (e.g., soluble salts such as calcium sulphates and sodium salts, sometimes present in Portland cement, which can leach out over time and damage surrounding materials). Moisture compatibility ensures an even distribution of moisture in the masonry, and in particular, the absence of moisture concentration, especially in historic materials. There should also be no excessive capillary rise as a result of the use of reconstruction mortar. The moisture parameters and porosity of the repair material and stone should be comparable. Dimensional compatibility relates to several parameters: the modulus of elasticity, the creep coefficient, and the thermal expansion coefficient. They should be similar for both materials, as a significant difference can cause stress on the contact of the materials. Mechanical compatibility is related to both adhesion (which is influenced not only by the reconstruction mortar, but also by the properties of the substrate) and the compressive and flexural strength of both materials. The higher the adhesion, the better the interaction between the two materials and the performance of the composite system. From the point of view of compatibility, the compressive and flexural strength of the repair mortar and the masonry element should have similar values. Bioecological compatibility related to the idea of sustainable development is also an important aspect. The bioecological assessment of reconstruction mortar is related to the origin and manufacturing process of the raw materials used in its production, the life cycle of the mortar, its impact on people and the environment, as well as its durability, which affects the frequency of possible subsequent repair work. The use of ecological, sustainable materials that reduce energy consumption both in their extraction and in the production of the mortar itself is promoted. Historical and aesthetic compatibility is also an important aspect, which will be discussed subsequently in this article. Since reconstruction mortar is usually used for historic materials, it must ensure the authenticity of the heritage in the best possible way – the colour, texture, aesthetics, and materials used should create a harmonious whole that is similar to the original solution [3, 4].

The principle of material compatibility used in conservation and restoration work stems directly from the Conservation Charters. The Athens Charter already mentions anastylosis as the most appropriate method of restoration and conservation work [5]. It involves reassembling a ruined building or rebuilding part of it using preserved original fragments, building elements, and materials, as well as the original technology. In masonry structures, this applies to both masonry elements and mortar. Very often, it is difficult or even impossible to meet the condition of originality of materials due to the destruction of the wall and the inability to recreate the sources of materials (masonry elements and mortar). In such cases, it is necessary to use materials compatible with the original ones. The structure of a historic wall will only have value if the basic conservation value – authenticity and historical truth, which has been closely connected to the cultural aspect for centuries – is respected in the process of its conservation and restoration [6]. Colour and texture are not only important for aesthetic reasons but are also a very important factor indicating both the original, actual chemical composition of the mortar (it is, in a sense, a result of this) and the technical condition of the historic structure at a given moment (e.g. wet mortar has a different colour than dry mortar). Achieving the right colour of the mortar (without using additional pigments, of course) can also be an element verifying the correctness of the selected mortar composition.

All the above considerations make it important to create the guidelines for achieving historical and aesthetic compatibility of earth-based mortars for reconstruction, based on the example of historic masonry structures in the Black Sea Basin. It is part of a wider project aimed at selecting the optimal composition of reconstruction mortar for Black Sea Basin archaeological sites. The results of the first stage of the project, focused on the mechanical properties and durability of such mortars, are described in a separate publication [7].

2. Analysed historical structures

Archaeological activities in the Black Sea Basin were carried out by the Faculty of Civil Engineering at Warsaw University of Technology in cooperation with the National Museum in Warsaw (Conservation Mission in Tyritake in Crimea [8]) and the Institute of Archaeology at Warsaw University and the Centre for Research on Antiquity in Southern and Eastern Europe (Conservation Mission in Tanais near Rostov-on-Don) [9–11]. Over more than a decade of comprehensive research, it has been established that the predominant type of historical structures uncovered at both Tyritake and Tanais is irregular stone masonry. In the case of the historic walls in Kerch, we find a wide range of dates for the studied walls – from the 5th century BC to the 5th century AD. In the case of Tanais, it is between the 3rd BC and 3rd AD. These structures were built using ashlars and/or stones sourced from diverse limestone formations, typically unprocessed and unsorted, resulting in a range of structural characteristics, porosity, sedimentation levels, and absorbability – all factors that impact their moisture content (see Fig. 2 for Tanais and Fig. 3 for Tyritake). A common issue observed is the granular disintegration of the masonry stones and the poor properties of the earth-based mortar, which is composed of local soil and sand. Such walls exhibit low strength and internal coherence, leading to limited durability.

Fig. 2. View of a masonry wall on earth-based mortar, Tanis (Department of Fundamentals of Building WUT archives)

Fig. 3. View of a masonry wall on earth-based mortar, Tanis (Department of Fundamentals of Building WUT archives)

The studied walls have undergone significant degradation due to a combination of human activity and centuries of environmental exposure. Key factors include prolonged moisture contact, biological activity within the soil, and damage from rainfall. Once excavated, these structures become especially vulnerable to changing conditions and sub-zero temperatures, particularly due to the repeated freeze-thaw cycles that lead to water saturation in the masonry and mortar. Consequently, damp walls become more susceptible to deformation, losing their primary load-bearing capacity and compromising the physical properties of the materials. Additionally, water washes away the binder and loosely connected small masonry elements, resulting in rock erosion (ablation). Therefore, reconstruction is necessary, an important aspect of which is historical and aesthetic compatibility with the existing stone material.

3. Methods for assessing the historical and aesthetic compatibility of earth-based mortars for reconstruction

Following guidelines [12, 13], to assess the historical and aesthetic compatibility of the reconstruction mortar with the existing historic material, the colour and texture of the new mortar should be assessed compared to the existing mortar. In addition, appearance should be durable and stable in various environmental conditions (ageing and weathering). The risk of efflorescence and staining due to the leaching of substances such as lime should be minimised. According to the guidelines, the texture, colour, and finish of the new mortar should match the existing mortar or comply with the requirements of historical authenticity and aesthetics. The colour is often matched to the unweathered colour of the existing mortar, although the colour after weathering should also be analysed. Since in the case of earth-based mortars, the colour and texture depend mainly on the binder and aggregate used, it is recommended to use materials similar to those of the original mortar.

Colour analysis may be performed using colourimeters or spectrophotometers [14, 15], but very often the analysis is also based on colour palettes. In the tests conducted, the assessment was made using the RAL K7 colour palette and supplemented with a PCE-XXM 30 colourimeter test. A colourimeter is a device that allows colours to be determined using numerical values in appropriate colour spaces, which eliminates the influence of the human eye on the result and the fact that the human eye is unable to notice slight differences in colours. In practice, there are several colour spaces available, but the most popular way to describe colour in various fields is the $L^*a^*b^*$ system, where L^* represents brightness and a^* and b^* are chromaticity coordinates ($+a^*$ corresponds to red, $-a^*$ to green, $+b^*$ to yellow and $-b^*$ to blue). The centre of the space is achromatic. In the $L^*a^*b^*$ colour space, the colour difference can be expressed as a single numerical value using Eq. (3.1) [11]:

$$\Delta E \cdot ab = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \tag{3.1}$$

where: ΔL^*, Δa^*, Δb^* are the differences between the values of L^*, a^*, and b^* for two measurements.

The differences between the individual values of L^*, a^*, and b^* also provide a lot of valuable information. An example of colour assessment with a colourimeter is shown in Fig. 4.

Fig. 4. Determining the colour of the reconstruction mortar using a colourimeter

When selecting mortar texture, the grain size of the mortar (appropriately matched fraction composition – as close as possible to the composition of the original mortar) and the shape of the grains are compared [16]. For other mortar properties, it is also important to determine the mineralogical and chemical composition, along with the particle size distribution [17, 18]. High-resolution photographs are also often used to compare the texture, as will be presented in this article. This is a difficult and time-consuming process that requires a lot of research, which in practice can be very expensive. However, it is the only way to reliably recreate the connection in the structure, which will reflect the historical truth for future generations. It should be noted that the method of finishing the mortar surface, e.g., with a trowel or a bristle brush, is also a very important aspect, which should also be taken into account when carrying out reconstruction work and selecting the finish of the reconstruction mortar.

4. Results of the historical and aesthetic compatibility assessment of reconstruction earth-based mortars

The mortar compositions adopted for the historical and aesthetic compatibility tests are shown in Table 1. The names of the samples represent: the volumetric amount of earth, sand, and additives (separated by the "–" symbol, C-cement, L-lime, N-adhesive promoter), for example, 4060-15C-N means 40% of earth, 60% of sand, 15% of cement with the addition of adhesive promoter. These are compositions selected after the preliminary design stage, which best meet the strength and durability criteria from among those proposed. Composition 4060 corresponds to the actual composition of mortar in stone walls in the Black Sea Basin.

Table 1. Mortar compositions for historical and aesthetic compatibility tests

Sample	Earth [%]	Sand [%]	Cement [%]	Lime [%]	Adhesive promoter
4060	40	60	–	–	–
4060-15C-N	40	60	15	–	+
3366-15C	33	66	15	–	–
3366-25C	33	66	25	–	–
2575-15C-10L	25	75	15	10	–

The colour analysis was carried out on both fresh mortar and mortar after a 28-day hardening period. For analysis, the mortar spread on the surface of the stone elements was used. The reference point will be earth-based mortar with a composition of 4060 – sample 1, as the mortar closest in composition, colour, and texture to the original mortar in stone walls in the Black Sea Basin. The stone elements together with the colour palette for fresh mortar are shown in Fig. 5, and for hardened mortar in Fig. 6.

Fig. 5. Colour analysis of fresh mortars: 1 – 4060, 2 –4060-15C-N, 3 – composition 3366-15C, 4 – composition 2575-15C-10L, 5 – composition 3366-25C

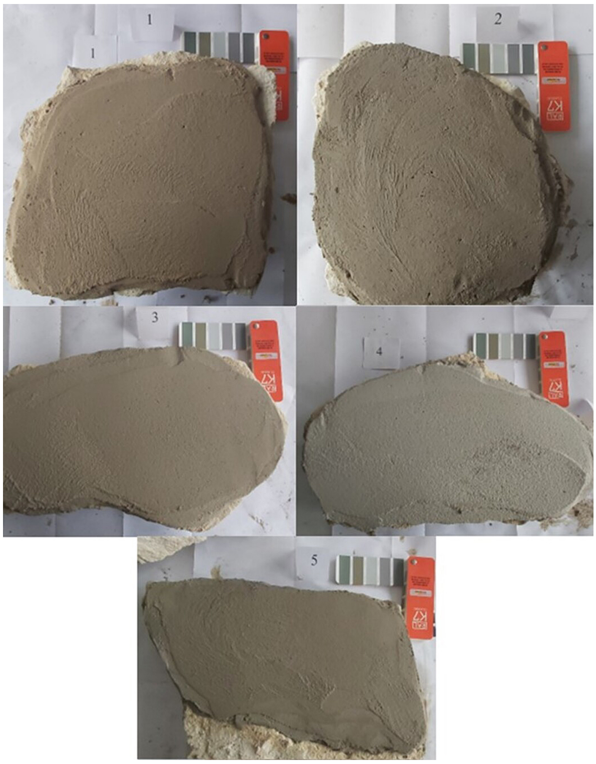

Fig. 6. Colour analysis of hardened mortars: 1 – 4060, 2 – composition 4060-15C-N, 3 – composition 3366-15C, 4 – composition 2575-15C-10L, 5 – composition 3366-25C

Analysing the results obtained, it can be seen that fresh earth-based mortar and earth-based mortar with lime and cement additives do not show significant colour differences. The colour of earth-based mortar with composition 4060 – sample 1, was determined as RAL 7008 (khaki grey), the colour of compositions 16 (3366-15C) – sample 3, 22 (2575-15C-10L) – sample 4, and 200 (3366-25C) – sample 5, as RAL 7006 (beige grey). A visible difference can be seen in the case of mortar with composition 4060-15C-N, where the colour was assessed as RAL 7005 (mouse grey). In the case of hardened mortar, the colours undergo visible changes. The colour of the earth-based mortar can still be described as RAL 7008, while the colour of the mortars with cement added (16-3366-15C and 3366-25C) deviates slightly towards grey tones – it has been described as RAL 7034 (grey yellow). In the authors' opinion, the slight grey colouration in this case remains at an acceptable level of colour difference. In the case of mortar with a composition of 22 – sample 6, the colour of the sample deviates much more towards the grey colour scale (defined as RAL 7035 – light grey). In this case, it can be concluded that the addition of lime contributes to the grey colour of the sample to a much greater extent than the addition of cement alone. In the case of sample 10 (4060-15C-N), the colour returned to brown after drying, slightly darker than the mortar with composition 1. Based on the above considerations, it can be concluded that among the selected compositions, the mortars with the addition of cement alone are closest to the original colour of the mortar – composition 16 (3366-15C) – sample 3 and composition 3366-25C – sample 5. The colour of the mortar with composition 4060N-15C-N is also acceptable in its final form, but the initial colour may cause concern during reconstruction work. In the authors' opinion, the mortar with composition 2575-15C-10L deviates too much from the base mortar (towards a grey colour).

The analysis based on the RAL K7 palette and subjective colour assessment was supplemented with a colourimeter test for hardened mortar samples. The measurements were taken in the $L^*a^*b^*$ colour system, and then the colour differences between the base sample 4060 and the other compositions were calculated. The results are presented in Table 2.

The results obtained using a colourimeter confirmed the analysis carried out using the colour palette. The sample that differs the least in terms of colour is sample 3366-15C, with a difference of 2.9. Its colour shows differences in the a^* and b^* values, with a deviation towards blue and green, while the L^* values (brightness) remain similar. The second place was assigned to sample 3366-25C – difference 6.26. Similar to sample 3366-15C, it shows a deviation in the a^* and b^* parameters, and additionally, a higher L^* parameter value. Sample 4060-15C-N shows the most evident deviation of all the samples tested in terms of the L^* parameter from the value for the base sample. This means that its colour has a lower brightness. Sample 2575-15C-10L shows the greatest colour difference ΔE and, in addition, a significant deviation in the L^* (brightness) and b^* (towards blue tones) parameters. This confirms the order of the samples in terms of the best colour match obtained from the primary analysis. For research purposes, photographs were taken with a Keyence Vhx 7000 digital microscope to assess the texture of mortar composition 3366-25C (a composition that meets all the strength and durability requirements analysed in earlier stages of the project [7]) and for the mortar closest in composition and texture to the original mortar used in stone structures in Black Sea Basin (to compare their texture) (Fig. 7 – mortar 3366-25C and Fig. 8 – mortar 4060). The composition 3366-25C, due to the addition of cement, has a slightly more compact structure. In contrast, composition 4060 has more loose particles (this is also a result of the preparation of the sample for testing – cutting the beam samples into 2 cm thick slices). However, it can be considered that the compatibility of the selected composition in terms of texture will be sufficient for reconstruction purposes.

Table 2. Analysis of the colour difference between the tested compositions in the $L^*a^*b^*$ system

Sample	L^*	a^*	b^*	ΔE
4060	55	4.5	18	–
4060-15C-N	47.6	3.4	16.1	7.85
3366-15C	55.5	3.1	15.5	2.90
3366-25C	58.7	2.2	13.5	6.26
2575-15C-10L	64.2	2.6	10.8	11.0

Fig. 7. Photo of a sample with a composition 3366-25C taken with a Keyence Vhx 7000 digital microscope

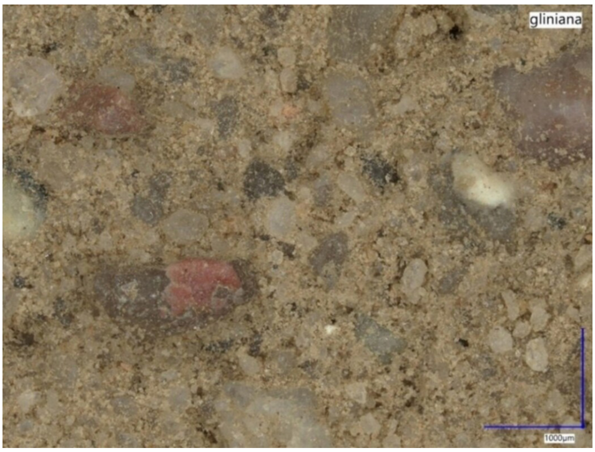

Fig. 8. Photo of a sample with a composition 4060 taken with a Keyence Vhx 7000 digital microscope

5. Results of the test application

As part of semi-technical research, test walls were built using Tertiary limestone available in Poland (Pińczów limestone) on selected earth-based mortar compositions in the autumn (September 2022). The first composition was earth-based mortar without additives –4060 (Fig. 9). The second application was selected mortar 3366-25C (Fig. 10). The main objectives of the test research in the context of historical and aesthetic assessment are analysis of possible changes in the colour and texture of the mortar over time due to leaching, sun exposure, wind impact, the appearance of salt efflorescence, etc. The first verification of the mortar used was carried out 6 months after the construction of the described structures (beginning of March 2023) and then every six months until July 2025. No changes in the colour and texture of the solution used were noted for any of the analysed walls during this period. The mortar did not change colour, nor were there any visible changes in the texture or efflorescence on its surface. It can therefore be concluded that the analysis of historical and aesthetic compatibility was carried out correctly.

Fig. 9. Stone wall built with earth-based mortar without additives – composition 4060

Fig. 10. Stone wall on mortar 3366-25C

6. Conclusions

Based on the analyses carried out, the following recommendations for earth-based reconstruction mortars in terms of historical and aesthetic compatibility can be stated:

– The most important features in terms of the historical and aesthetic compatibility of earth-based reconstruction mortars are their appropriate colour and texture.

– These properties should always be integrated with other parameters necessary for reconstruction mortars, i.e. mechanical and durability properties and the compatibility of the solution used with the stone material.
– In addition to visual assessment, it is advisable to confirm the correct choice of colour using appropriate measurements, e.g. with a colourimeter, to find the solution that best reflects historical truth.
– In the case of the correct selection of the texture of the earth-based mortar, its appropriate fractional distribution is crucial, which should always be as close as possible to the historical solution.
– To determine the appropriate texture of reconstruction solution, photographs with a digital microscope at high magnification may be a necessary tool.
– The analysis of historical and aesthetic compatibility should be carried out under various operating conditions of the structure, i.e. considering the possible effects of the environment.
– Before any reconstruction, it is recommended to carry out a trial application and analyse it for at least one year to verify the changes taking place in the mortar.

In the future, further inspections of the test walls (semi-technical research described in Chapter 5) are planned to confirm the long-term preservation of the assumed colour aspects and texture (aesthetic compatibility). The studies are also a part of a wider project aimed at selecting the optimal composition of reconstruction mortar for Black Sea Basin archaeological sites, which results will be presented in the future. There are also some future studies planned to check out the historical and aesthetic compatibility of earth-based mortar for other historic buildings, such as the oldest preserved mosque in Dongola (Sudan), made of sun-dried earth blocks on earth-based mortar [19].

Historical and aesthetic compatibility is crucial for preserving historical truth for future generations. We should take care to ensure their proper restoration, as described in this article, in the case of earth-based mortars.

References

[1] M. Apostolopoulou, E. Aggelakopoulou, A. Bakolas, and A. Moropoulou, "Compatible mortars for the sustainable conservation of stone in masonries", in *Advanced Materials for the Conservation of Stone*, Springer International Publishing, 2018, pp. 97–123, doi: 10.1007/978-3-319-72260-3_5.

[2] J. D. Rodrigues and A. Grossi, "Indicators and ratings for the compatibility assessment of conservation actions", *Journal of Cultural Heritage*, vol. 8, no. 1, pp. 32–43, 2007, doi: 10.1016/j.culher.2006.04.007.

[3] *Nara Document of Authenticity*. Nara, 1994.

[4] Council of Europe, "European Convention on the Protection of the Archaeological Heritage (Revised)", *European Treaty Series*, 1992, no. 143, pp. 1–8. Available: https://rm.coe.int/168007bd25.

[5] "Karta Ateńska," 1931.

[6] J. Tajchman, "Konserwacja zabytków architektury – uwagi o metodzie", *Ochrona zabytków*, vol. 48, no. 2 (189), pp. 150–159, 1995.

[7] E. Sobczyńska and A. Garbacz, "The influence of additives on the characteristics of earth-based mortar on the example of ancient stone structures in the Black Sea Basin", in *Proceedings of SUBLimeConference 2024 – Towards the Next Generation of Sustainable Masonry Systems: Mortars, Renders, Plasters and Other Challenges*, 2024, doi: 10.1051/matecconf/202440302014.

[8] W. Terlikowski and K. Wasilewski, “Technical issues of ancient Masonry maintenance for future open-air exposition, for example, the Tyritake excavation in Kerch,” in *Proceedings of the 2nd International Conference on Protection of historical constructions PROHITECH’14*, 2014, pp. 759–766.

[9] W. Terlikowski, K. Wasilewski, E. Sobczyńska, and M. Gregoriou-Szczepaniak, “Approach to conservation of irregular stone masonry based on archaeological excavations in the Black Sea basin”, in *E3S Web of Conferences*, vol. 49, 2018, doi: 10.1051/e3sconf/20184900117.

[10] W. Terlikowski, M. Matera, K. Wasilewski, M. Gregoriou-Szczepaniak, and E. Sobczyńska, “Conservation of irregular stone masonry in Tanais in Russia”, in *MATEC Web of Conferences*, vol. 196, pp. 1–7, 2018, doi: 10.1051/matecconf/201819602041.

[11] E. Sobczyńska, W. Terlikowski, and M. Gregoriou-Szczepaniak, “Stability of treatment from earth-based mortar in conservation of stone structures in Tanais, Russia”, *Sustainability*, vol. 13, no. 4, pp. 1–20, 2021, doi: 10.3390/su13042220.

[12] *ASTM C1713-17 Standard Specification for Mortars for the Repair of Historic Masonry,2023.*

[13] P. Maurenbrecher and C.Groot, *Repair mortars for historic masonry. State-of-the-art report RILEM TC 203-RHM*. RILEM Publications S.A.R.L., 2016. Available: https://www.rilem.net/publication/publication/453

[14] Y. Govaerts, W. Meulebroeck, A. Verdonck, and M. de Bouw, “Measuring the colour of rendering mortars”, in *Proceedings of SPIE – The International Society for Optical Engineering*, 2014, doi: 10.1117/12.2052309.

[15] Y. Zhang and D. Kruger, “Repair mortar colour matching by colourimetric method,” in *Proceedings of 9th International Conference on Inspection, Appraisal, Repairs and Maintenance of Structures*, 2006.

[16] L. Rampazzi, A. Pozzi, A. Sansonetti, L. Toniolo, and B. Giussani, “A chemometric approach to the characterisation of historical mortars,” *Cement and Concrete Research,* vol. 36, no. 6, pp. 1108–1114, 2006, doi: 10.1016/j.cemconres.2006.02.002.

[17] B. Punmia and A. Jain, *Soil Mechanics and Foundations*. New Delhi, India: Laxmi Publications, 2005.

[18] B. Karpiński and M. Szkodo, “Clay Minerals – Mineralogy and Phenomenon of Clay Swelling in Oil & Gas Industry”, *Advances in Materials Science*, vol. 15, no. 1, pp. 37–55, 2015, doi: 10.1515/adms-2015-0006.

[19] W. Terlikowski, M. Gregoriou-Szczepaniak, E. Sobczyńska, and K. Wasilewski, “Structural Assessment of Mosque Building in Old Dongola.” In *Proceedings of Nile’s Earth 2023 International Conference: Study and Conservation of Earthen Archaeological Sites in Ancient Egypt and Sudan*, 2023.

Kompatybilność historyczno-estetyczna zapraw glinianych na przykładzie starożytnych konstrukcji kamiennych w basenie Morza Czarnego

Słowa kluczowe: starożytne konstrukcje kamienne, zaprawy gliniane, zgodność historyczno-estetyczna

Streszczenie:

Kompatybilność materiałów jest zagadnieniem złożonym i trudnym do analizy, zwłaszcza jeśli mówmy o konstrukcjach zabytkowych, poddawanych rewitalizacji. Parametrów decydujących o jej osiągnięciu jest wiele i są one wzajemnie od siebie zależne. Co istotne – zastosowanie rozwiązania niekompatybilnego z istniejącą strukturą może nie tylko wpłynąć negatywnie na jego trwałość, ale także bezpośrednio doprowadzić do zniszczenia zabytkowego materiału. W ogólnej definicji materiał kompatybilny z materiałem zabytkowym to taki, który nie doprowadzi w nim do zmian chemicznych, nie zainicjuje ani nie nasili zjawisk niszczenia konstrukcji zabytkowej oraz zapewni jej jednorodne warunki pracy oraz możliwość powrotu do stanu sprzed działań naprawczych (odwracalność procesu rekonstrukcji). Można sklasyfikować kilka rodzajów kompatybilność np. wymiarowa, mechaniczna, bioekologiczna. Wyróżniająca się jest natomiast kompatybilność historyczno-estetyczna. Ponieważ zaprawa rekonstrukcyjna jest zwykle używana do zabytkowej materii, musi w możliwie najlepszy sposób

zapewniać autentyczność dziedzictwa – kolor, faktura, estetyka i zastosowane materiały muszą tworzyć całość zbliżoną do oryginału (co wynika z zapisów doktryn konserwatorskich). Jest to zagadnienie wymagające dużej staranności i dbałości o detale i w przypadku rekonstrukcyjnych zapraw glinianych wykonane w ściśle określony sposób, biorąc jednocześnie pod uwagę pozostałe parametry wytrzymałościowe i trwałościowe zapraw. W niniejszym artykule opisany został przykład oraz wytyczne do spełnienia kompatybilności historyczno-estetycznej zapraw glinianych na przykładzie zabytkowych konstrukcji murowych w Basenie Morza Czarnego. W ciągu ponad dziesięciu lat kompleksowych badań ustalono, że dominującym typem historycznych konstrukcji odkrytych w Basenie Morza Czarnego są nieregularne mury kamienne na zaprawie glinianej. W przypadku historycznych murów w Kerczu daty powstania badanych murów są bardzo zróżnicowane – od V wieku p.n.e. do V wieku n.e. W przypadku Tanais jest to okres od III wieku p.n.e. do III wieku n.e. Budowle te zostały wzniesione przy użyciu ciosów kamiennych i/lub kamieni pochodzących z różnych formacji wapiennych. Charakteryzują się niską wytrzymałością i spójnością wewnętrzną, co prowadzi do ograniczonej trwałości oraz konieczności przeprowadzenia działań rekonstrukcyjnych. Zgodnie z wytycznymi do dokonania oceny kompatybilności historyczno-estetycznej zaprawy rekonstrukcyjnej z istniejącym materiałem zabytkowym należy dokonać oceny koloru i tekstury nowej zaprawy w odniesieniu do zaprawy istniejącej. Ponadto wygląd powinien być trwały i stabilny w różnych warunkach środowiskowych (starzenie i wietrzenie). W przypadku analizy koloru w badaniach stosowane są kolorymetry lub spektrofotometry, ale również bardzo często analizę wykonuje się bazując na próbnikach kolorystycznych. W przeprowadzanych badaniach ocena została dokonana przy pomocy próbnika kolorów RAL K7 i uzupełniona o badanie kolorymetrem PCE-XXM 30 przy zastosowaniu przestrzeni barw $L^*a^*b^*$.W przypadku doboru tekstury zaprawy porównuje się uziarnienie zaprawy (odpowiednio dopasowany skład frakcyjny – jak najbardziej zbliżony do składu oryginalnej zaprawy) oraz kształt ziaren. Często używa się także zdjęć o dużej dokładności – w tym przypadku wykorzystano zdjęcia robione mikroskopem Keyence Vhx 7000, w celu porównania tekstury zaprawy rekonstrukcyjnej do zaprawy bazowej. Do analizy kolorystycznej wykorzystano 5 zaproponowanych składów zapraw, będących wyniki pierwszego etapu badań wytrzymałościowych i trwałościowych opisanych w osobnej publikacji. Analizę kolorystyczną przeprowadzono zarówno na świeżej zaprawie, jak i na zaprawie po 28 dniowym okresie twardnienia. Do analizy wykorzystano zaprawy rozprowadzone na powierzchni elementów kamiennych. Analiza przy pomocy kolorymetru PCE-XXM 30 potwierdziła wnioski z oceny dokonanej przy pomocy próbnika RAL K7 o najlepszym dopasowaniu kolorystycznym zapraw 3366-15C i 3366-25C. W celach badawczych do oceny tekstury wykonano zdjęcia mikroskopem cyfrowym Keyence Vhx 7000 dla składu zaprawy 3366-25C (skład spełniający wszystkie założenia wytrzymałościowe i trwałościowe analizowane we wcześniejszych etapach projektu) oraz dla zaprawy najbliższej składem i teksturą oryginalnej zaprawie stosowanej w konstrukcjach kamiennych w Basenie Morza Czarnego – skład 4060 Na tej podstawie można uznać, że zgodność wybranego składu pod względem tekstury będzie wystarczająca do celów rekonstrukcyjnych. W ramach badań w skali półtechnicznej wykonano dodatkowo murki z kamienia wapiennego trzeciorzędowego dostępnego w Polsce (wapień pińczowski) na wybranych składach zaprawy glinianej w okresie jesiennym (wrzesień 2022). Do lipca 2025 nie odnotowano zmian w kolorze zaprawy, nie zaobserwowano również żadnych widocznych zmian tekstury ani wykwitów na jej powierzchni. Można zatem stwierdzić, że analiza kompatybilności historyczno-estetycznej została przeprowadzona prawidłowo. Na podstawie przeprowadzonych analiz sformułowano następujące zalecenia dotyczące rekonstrukcyjnych zapraw glinianych pod kątem zgodności historyczno-estetycznej: Najważniejszymi cechami zapraw do renowacji na bazie gliny pod kątem zgodności historycznej i estetycznej są odpowiedni kolor i faktura; – właściwości te powinny być zawsze połączone z innymi parametrami niezbędnymi dla zapraw renowacyjnych, tj. właściwościami mechanicznymi i trwałością oraz zgodnością zastosowanego rozwiązania z materiałem kamiennym; – oprócz oceny wizualnej wskazane jest potwierdzenie prawidłowego doboru koloru za pomocą odpowiednich pomiarów, np. kolorymetrem, w celu znalezienia rozwiązania, które najlepiej odzwierciedla prawdę historyczną; – w przypadku prawidłowego doboru tekstury zaprawy ziemnej kluczowe znaczenie ma jej odpowiedni rozkład frakcyjny, który powinien być zawsze jak najbardziej zbliżony do rozwiązania historycznego; – aby określić odpowiednią teksturę rozwiązania rekonstrukcyjnego, niezbędnym narzędziem mogą być zdjęcia wykonane za pomocą mikroskopu cyfrowego przy dużym powiększeniu; – analiza zgodności historycznej i estetycznej powinna być przeprowadzona w różnych warunkach eksploatacyjnych konstrukcji, tj. z uwzględnieniem możliwego wpływu środowiska; – przed przystąpieniem do jakiejkolwiek rekonstrukcji zaleca się przeprowadzenie próbnego zastosowania i analizowanie go przez co najmniej rok w celu zweryfikowania zmian zachodzących w zaprawie.

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