Budownictwo i Architektura 23(4) 2024, 83-90

DOI: 10.35784/bud-arch.6085
Received: 10.04.2024; Revised: 18.10.2024;
Accepted: 21.10.2024; Available online: 16.12.2024

Original Article

Evaluation of lime plaster on masonry walls in historical buildings prior to renovation

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Abstract: This study analysed a quantitative assessment of the adhesion of lime plasters to the substrate in a historic neo-Gothic building. The diagnostics of the plasters were conducted to preserve their large surface area due to their historical value. The use of modern non-destructive and destructive methods allowed for a significant reduction in the work required to remove the historic plaster. It was noted that only the correlation of non-destructive and destructive methods can enable an accurate determination of the necessary repair work on historic plasters. Challenges in diagnosing plasters in historic buildings are also discussed.

Keywords: lime plasters, historic buildings, renovation

1. Introduction

Historic buildings are often eagerly renovated to highlight their historical value. However, they are typically affected by structural and cladding damage due to poor technical condition or deterioration. In some cases, necessary renovation work requires interference with existing internal plasters, which hold significant historical and aesthetic value. As practice shows, determining the scope of necessary renovation work on plasters is particularly challenging [1-3]. This often leads to the removal of large areas of historical plaster, which is technically unjustified, followed by its reconstruction using modern materials, resulting in the loss of its historic value.

As Klimek [2] points out, restoration work in historic buildings is particularly difficult due to the need to ensure compatibility between historic and restoration materials, especially in lime-based materials. Banaszak and Halicka [4] described an example of comprehensive diagnostic tests on a historic building, where, through the use of various research techniques, it was possible to accurately determine the scope of renovation work and minimise the potential for damage to materials of significant historical value. Trochonowicz et al. [5] conducted comparative studies of moisture tests using various methods on historic materials, emphasising the importance of employing multiple diagnostic methods to optimally assess the condition of the tested materials. Skibiński [6] highlighted the significance of in-situ testing for lime plasters, which allowed for a considerable reduction in the renovation work initially proposed by the designer. Janicka-Świerguła [7] indicated that, in addition to in-situ tests conducted on lime plasters, it is crucial to establish the appropriate methodology for repair works and diagnostics to define the extent of the area requiring intervention. The researcher [7] particularly noted that the adhesion of lime plaster to the substrate may be compromised due to pores and cracks in the plaster, resulting from poor workmanship.

This paper addresses the issue of quantitative diagnostics of historic plasters in terms of their adhesion to the substrate, with the aim of estimating the necessary renovation works. The results of non-destructive and destructive tests are presented, which enabled a precise estimation of the required work while preserving as much of the historic plaster in its original form as possible.

2. Characterisation of buildings and plasters

The subject of the research is the existing internal lime wall plaster in the rooms of the above-ground storeys of a historic neo-Gothic building (constructed between 1895 and 1896). The load-bearing structure of the building consists of brick walls, and the ceilings are constructed as brick arched cross vaults. It is highly probable that part of the plasterwork is original, as the building was damaged during World War II. The building is listed on the Heritage Register. The focus of the study is the wall and ceiling plasterwork.

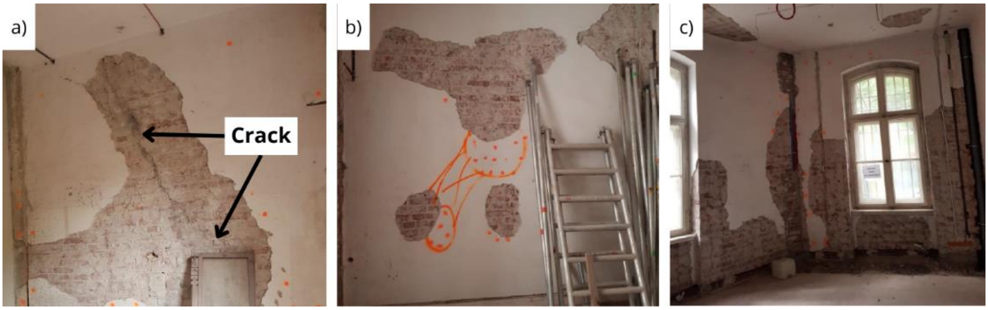

Fig. 1. Views of damage and defects in plasters: a) caused by a crack in the wall b, c) caused by delamination

The plaster in question does not cover the entire walls in the rooms, as it has been removed in some areas by scraping (Fig. 1). The surfaces without plaster form irregular shapes, varying in size depending on the reason for their removal. However, the conservation and repair work required a comprehensive assessment of the plaster's condition (both qualitative and quantitative), and its historic value necessitated minimising the extent of removal.

3. Description of plaster defects

The condition of the building necessitated the removal of plaster in some areas to repair cracks in the masonry structure. Some plaster had detached from the base layer (wall), either falling off on its own or as a result of scraping. An organoleptic examination of the plaster revealed numerous areas where it had become detached from the substrate.

Cracks of varying widths, lengths, and shapes were observed on the plaster surface, along with numerous fissures and openings for structural repairs and installation work. It was noted that plaster had already been removed in some areas, where cracks of varying widths or multiple fine, multidirectional cracks were found.

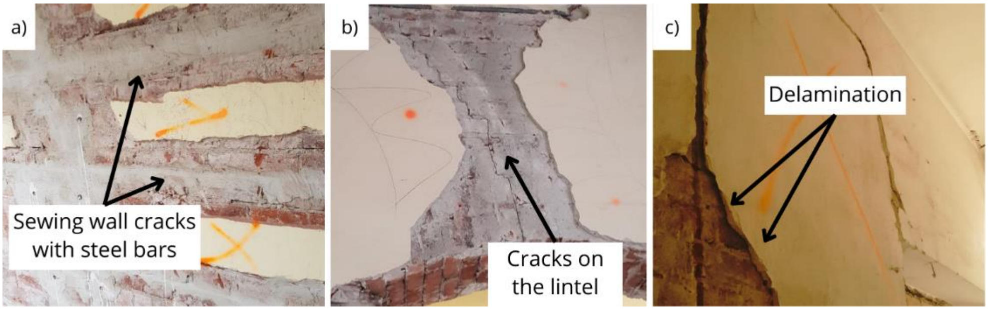

Fig. 2. Examples of defects in plasters: a) caused by the repair of a crack in the wall, b) caused by structural cracks, c) delamination

When repairing cracked walls (where the crack was more than 3 mm wide), a large area of plaster was removed to "stitch" the wall using steel rods placed in the horizontal joints of the masonry. Ensuring the proper anchorage length of these bars required removing significant lengths of narrow plaster strips to create a strip system (Fig. 2). It was also observed that, as a result of the repair work, the adhesion of some sections of plaster deteriorated, leading to a greater extent of plaster removal. The surface of the original plaster, significantly weakened by numerous irregular and random areas of chipping, was assessed by the supervisor overseeing the repair work as difficult to maintain. This led to an additional increase in the area to be chipped to ensure a permanent bond between the original and new plaster. There were also numerous instances of damage to the original plaster caused by the removal of old electrical and sanitary installation equipment. Additionally, many bruises and spot damage to the plaster were observed.

4. More important technical requirements for lime plasters

Table 1 presents selected key technical requirements for the analysed lime plasters.

Table 1. Technical requirements for lime plasters. *Source:* [8,9]

Low capillary water absorption	No visible signs of capillary rise in the plaster.
Adequate water vapour permeability	Ensuring moisture transport through the plaster structure, allowing proper release.
Ensuring the appropriate plaster structure	To allow for salt crystallisation or to prevent it, depending on the plaster's purpose.

Necessary compressive strength	0.5 – 1.5 MPa, but lower than the masonry mortar.
Minimum thickness:	12 mm (for masonry plasters) +5/-7 mm.
Ensuring appropriate deformability	To prevent cracks caused by permissible deformations of the structure.
Minimal adhesion of the plaster to the substrate	Minimum 0.005 MPa.
Surface evenness	Only local irregularities related to manual trowelling of plaster, up to 3 mm deep and 5 cm long, are allowed, with a maximum of 3 per 10 m^2.
Cracks	Unacceptable, except for hairline shrinkage cracks in plasters left raw for further processing.
Efflorescence on the plaster surface (salt, fungi, mould, etc.)	Not allowed.
Providing aesthetic value	Uniform structure, colour, flatness, and light reflection.

The requirements presented (Table 1) are essential for lime plaster to fulfil its function. In historic buildings, it is particularly important to ensure the required durability by providing the necessary resistance to water migration within the plaster structure and selecting the appropriate plaster composition to ensure the correct structure and properties. Attention should also be given to the proper application of the plaster, especially the thickness of the layer and ensuring adhesion across its entire surface. These factors will ensure that the minimum adhesion between the plaster and the substrate is achieved, along with the required compressive strength. Proper surface finishing results in an even plaster surface, while appropriate techniques prevent air voids or unevenness, helping to avoid cracks.

5. Research conducted and results

To determine the minimum extent of historic lime plaster that needed to be removed due to failure to meet technical requirements, qualitative and quantitative tests were carried out on the plaster, using both destructive and non-destructive methods.

5.1. Performed research

As a first step, non-destructive testing was conducted to identify potential areas where there was a lack of adhesion between the plaster and the substrate. Subsequently, destructive tests were performed at selected locations. The research included the following:

1. non-destructive testing:
- organoleptic evaluation of the adhesion of the plaster to the substrate,
2. destructive testing:
- plaster thickness tests conducted by open-cutting at 4 locations (5 test points at each location),
- Pull-off tests to assess the adhesion of the plaster at 4 locations (5 test points at each location). To perform the test, a 50 mm diameter drill hole was made in the plaster, drilling 5 mm into the substrate. The plaster surfaces were then cleaned and degreased. Steel discs were glued to the drill hole, and after the adhesive set, a tearing force was applied using a measuring device, increasing at a speed of 0.005 kN/s until

the disc was torn off. The detachment should occur within the plaster, at the plaster-substrate interface, or in the substrate itself, but not in the adhesive layer.

5.2. Research results

A summary of the test results is presented in Table 2.

Table 2. Results of the destructive tests

Test site number/ location	Sample number	Thickness of plaster [mm]	Fulfilment of condition PN-58/B-10100	Adhesion of plaster to substrate [MPa]	Location of destruction	Fulfilment of condition PN-58/B-10100
1	2	3	4	5	6	7
1/wall	1	12	Yes	0.08	plaster	Yes
	2	12		~~0.07~~		
	3	14		0.08		
	4	13		~~0.16~~	plaster-brick joint	
	5	15		0.10	plaster	
Av.:		**13.2**		**0.09**	-	
2/wall	1	20	Yes	0.12	plaster	Yes
	2	22		0.10		
	3	21		~~0.23~~		
	4	18		0.11		
	5	20		~~0.07~~		
Av.:		**20.2**		**0.11**		
3/wall	1	14	Yes	0.01	plaster	Yes
	2	12		0.13		
	3	14		0.07		
	4	11		0.09		
	5	12		0.10		
Av.:		**12.8**		**0.09**		
4/wall	1	11	Yes	0.02	plaster	Yes
	2	12		0.02		
	3	10		0.07		
	4	11		0.08		
	5	11		0.03		
Av.:		**11**		**0.04**		

* - crossed-out values were rejected as they did not meet the conditions for statistical analysis.

Analysing these results, it can be observed that the plaster at the test sites exhibited varying properties. The average thickness of the plaster ranged from 11 to 20.2 mm, while the average pull-off strength ranged from 0.04 to 0.11 MPa. All the tested plasters met the requirements of the PN-58/B-10100 standard [8]. Figure 3 presents example images from the pull-off strength tests. The causes of reduced plaster adhesion are typically linked to poor workmanship, external factors (e.g. war damage, partial destruction of the building, settling of the structure), or weather conditions [1-5]. Nevertheless, plasters generally show relatively good adhesion to the substrate, though the main issue tends to be aesthetic defects (cracks, scratches), which often lead to the decision to repair them [6-7].

Fig. 3. Examples of photos from pull-off testing of plasters

6. Recommendations for plaster repair

A convoluted design situation and an inaccurate diagnosis of the historic lime plaster led to the identification of an excessively large area for removal. Considering the historic value of the tested plasters, by re-verifying their condition using both non-destructive and destructive methods, it was possible to significantly reduce the extent of the plaster to be removed. It was recommended to replenish local plaster defects and carry out local repairs. A combination of several diagnostic methods was advised to thoroughly assess the condition of the plasterwork, as using the rinsing method alone does not provide sufficient information to determine whether or not to remove historic plaster. Due to the aesthetic and historical value of lime plaster in historic buildings, a combination of the qualitative rinsing method with the quantitative pull-off method is considered the most appropriate approach. This combination allows the identification of areas requiring further plaster diagnostics through rinsing in the first step, without performing semi-destructive tests such as pull-off testing. In areas where troweling indicates questionable quality, a quantitative pull-off test should be conducted to assess the plaster's adhesion to the substrate and compare it with standard requirements. It is also recommended that, in the case of historic plaster, the number of test samples should be increased (compared to standard requirements), due to the significant variation in the plaster's properties. While the location of the measuring device did not appear to affect the test results, it should be noted that ceiling plaster adhesion is generally lower than that of wall plaster. It is advised to limit the extent of plaster to be repaired based on diagnostic results, particularly using non-destructive methods.

7. Challenges in plaster diagnostics in historic buildings

The diagnosis of historic plaster is a complex process that should not be limited to simply testing the condition of the material. To fully preserve the historic value of the plasterwork, a collaborative effort from multiple specialists is required to guide the repair work in a way that preserves as much of the original plaster as possible. Figure 4 presents a summary of the challenges in diagnosing historic plasters, based on literature [4,5,10].

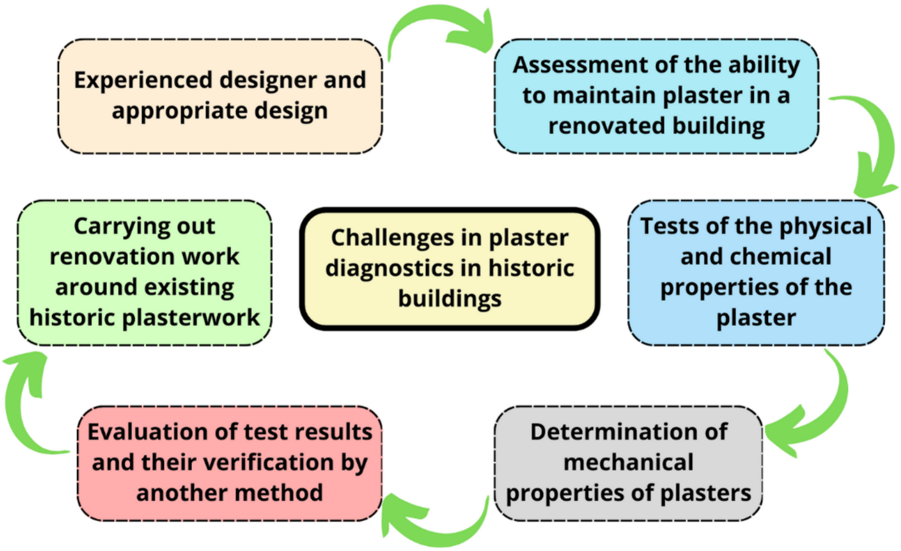

Fig. 4. Description of challenges in diagnosing historic plasters

The process of restoring historic buildings requires extensive knowledge from the designer, along with careful attention to the valuable cladding details present in the building (Figure 4). Proper planning of renovation work involves assessing the quality and condition of the plaster that will be affected. For this, it is recommended to conduct tests to evaluate the technical condition of the plaster, including its physical properties, adhesion, durability, and aesthetic value. Based on these assessments, the designer should choose the appropriate methodology for the repair work and ensure measures are in place to protect the historic plaster during the process. It is also important to consider established plaster repair methods while limiting their use to preserve the characteristics of historic lime plaster.

8. Summary

The study analysed an attempt to preserve lime plaster in a neo-Gothic building. It included a description of the condition of the existing cladding, followed by an account of the destructive and non-destructive tests conducted. The results of non-destructive testing provided an estimate of the plaster areas with potentially weakened adhesion to the substrate, while destructive testing enabled a proper assessment of the plaster's actual condition. By correlating the results of different testing methods, it was possible to reduce the removal of historic lime plasters to only those areas necessary due to low adhesion or structural cracks. This article highlights the importance of using a synergy of diagnostic methods to thoroughly analyse damage in lime plasters and maintain them during renovation. The study also identifies significant challenges in assessing the condition of plasters in historic buildings, stressing the importance of collaboration among specialists at every stage of the construction process.

Funding

This work was not supported by any external funding.

References

[1] Konca P. et al., "Możliwość stosowania tynków lekkich jako tynków renowacyjnych", *Materiały Budowlane*, vol. 1, no. 9, (Sep. 2016), pp. 18-20. https://doi.org/10.15199/33.2016.09.06

[2] Klimek B., "Research on historical mortars from the Gothic Tower in Lublin", *Teka Komisji Architektury, Urbanistyki i Studiów Krajobrazowych*, vol. 18, no. 3, (Dec. 2022), pp. 18-29. https://doi.org/10.35784/TEKA.3364

[3] Kamiński K., "Tynki osuszające skuteczną technologią renowacji ścian gotyckiego kościoła", *Materiały Budowlane*, vol. 1, no. nr 3, (Mar. 2015), pp. 24-26. https://doi.org/10.15199/33.2015.03.07

[4] Banaszak J. and Halicka A., "Kompleksowa ocena techniczna budynku zabytkowego na przykładzie plebanii w Wojsławicach", *Budownictwo i Architektura*, vol. 9, no. 2, (2011), pp. 51-68. https://doi.org/10.35784/bud-arch.2243

[5] Trochonowicz M. et al., "Analiza porównawcza badań wilgotnościowych metodą chemiczną w stosunku do badań grawimetrycznych wybranych materiałów budowlanych", *Budownictwo i Architektura*, vol. 15, no. 4, (2016), pp. 163-171. https://doi.org/10.24358/Bud-Arch_16_154_16

[6] Skibiński S., "Przyczyny zniszczeń elewacji Starego Ratusza w Poznaniu." Ochrona zabytków 2 (1998): 116-132.

[7] Janicka-Świerguła K., "Rekonstrukcja sufitu w sali teatralno-kinowej kasyna oficerskiego w Twierdzy Modlin", *Builder*, vol. 303(10), (2022), pp. 56-60. https://doi.org/10.5604/01.3001.0015.9802

[8] *PN-58/B-10100 "Plastering work. Standard plasters. Requirements and inspection tests".*

[9] Nogueira R. et al., "Design and behavior of traditional lime-based plasters and renders. Review and critical appraisal of strengths and weaknesses", *Cement and Concrete Composites*, vol. 89, (May 2018), pp. 192-204. https://doi.org/10.1016/J.CEMCONCOMP.2018.03.005

[10] Niedostatkiewicz M. and Majewski T., "Badania doświadczalne tynków wewnętrznych", *Izolacje*, vol. R. 24, no.4, (2019), pp. 82-87.