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INFLUENCE OF SILICATE COMPOUNDS ON THE STRUCTURAL STRENGTHENING OF CERAMIC MASONRY ELEMENTS IN HISTORIC BUILDINGS

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Abstract

This study investigates the peel strength of bricks treated with silicate-based formulations designed to enhance durability. It examines the effects of seasoning time and the type of formulation—both undiluted and water-diluted—on the mechanical properties of the bricks. Particular attention was given to how dilution impacts the penetration of the material and its protective properties. The results indicate that peel strength is largely influenced by the bricks' physicochemical characteristics, including porosity, absorbability and micro-cracks. The findings confirm that silicate compounds with hydrophobic properties significantly improve brick durability by protecting against atmospheric agents such as moisture and environmental pollutants. Silicate impregnation not only enhances the structural integrity of bricks but also preserves their aesthetic value over time, improving resistance to erosion and degradation. These properties are especially critical for historically significant buildings, where maintaining material authenticity and stability is paramount. The study emphasizes the importance of selecting and applying strengthening preparations carefully to achieve optimal results. Undiluted formulations demonstrated superior efficacy in enhancing mechanical performance, particularly after prolonged seasoning periods. Nonetheless, in specific cases, diluted preparations offered advantages, highlighting the need for tailored, comprehensive pre-application studies. These results underscore the critical role of silicate compounds in brick conservation and pave the way for further research to optimize their use in preservation practices.

Keywords: *Brick; Pull-off strength; Silicone compound; Historic buildings; Durability*

Introduction

Strengthening the structure of materials in historic buildings is an important part of conservation and restoration, aiming to preserve the cultural and architectural values of monuments. The methods used are usually adapted to the type of material (e.g., stone, brick, wood, concrete, metal), as well as the specific damage and aging of the structure [1-3].

Strengthening the structure of brick materials in historic buildings is a process that aims to improve the load-bearing capacity, durability and stability of brick masonry. In the case of bricks, especially in older buildings, various problems may occur over time, such as weakening of joints, crumbling of bricks, or mechanical damage resulting from external forces (e.g., shocks, loads, changes in humidity). In order to prevent this and to strengthen the structure of brick masonry, various conservation and strengthening methods are used. One of these is the use of silicate compounds on bricks in historic buildings as one of the more advanced and specific conservation methods. The aim of this method of protecting brick structures is to improve the durability and weather resistance and also to preserve the properties of the building material in the long term. Silicate compounds have unique chemical and physical properties that make them ideal for applications in the conservation of historic structures, including bricks and brick masonry [4-7].

Among the tenets of using silicate compounds on historic brick structures are [8-20]:

- strengthening of the brick structure—calcium silicates, silicones, sodium silicates or potassium silicates penetrating into the pores of the brick chemically strengthen its structure by creating crystalline networks inside the pores, which helps to maintain the integrity of the material and improves its mechanical strength.
- improved moisture resistance—silicones and silicates form a hydrophobic barrier on the surface of the brick, which reduces its ability to absorb water while allowing internal moisture to evaporate.
- increase the durability of the material—the application of a layer of silicate compounds to the brick makes it less susceptible to erosion and other forms of degradation, thus maintaining its aesthetic and functional qualities.
- protection against salts and pollutants—silicate compounds effectively protect the brick against the penetration of chlorides, carbonates, or sulfates into the material from groundwater, rain, or contact of the object with brine and can also contribute to the neutralization and/or removal of salts that have already penetrated the material.
- protection against environmental pollution—in urban agglomerations, bricks can be degraded by air pollution from sulphuric acids, nitrogen oxides, or dust. Silicate compounds forming a coating on the surface of the brick limit the direct contact of the brick with contaminants and protect the brick from pollution.
- aesthetics and preservation of the authenticity of the material—silicate compounds due to their transparency or translucency does not change the color of a brick or its visual structure. In addition, they do not form greasy or glossy coatings on the surface of the brick, which is important in the case of historical buildings where the preservation of the authentic appearance of the material is crucial.
- aiding conservation processes—silicate compounds can be used as an auxiliary ingredient in work to stabilize joints between bricks and to strengthen weakened sections of brickwork or to prevent moisture migration (impregnation, component of conservation mortars).

The most commonly used silicate compounds include:

- silicone impregnates, which form an effective barrier against moisture without altering the brick structure.
- calcium silicates—used in historic masonry where the lime mortar is too porous or has little resistance to weathering.
- potassium and sodium silicates used in severely degraded bricks where improvement of the brick structure is required, including restoration of joints and sealing of brick pores.

Materials and Methods

Laboratory tests were conducted in the Building Materials Laboratory of the Faculty of Civil Engineering at Wroclaw University of Science and Technology. The aim of the study was to ascertain the influence of a preparation based on silicate compounds with hydrophobic properties on the peel strength of bricks. Five preparations were tested by varying their concentrations (100% concentration and diluted with water in a 1:1 ratio was used). The bricks utilized in the study were contemporary, machine-made bricks with a water absorption of 14% and an open porosity of 25%. The samples were saturated by capillary action through the application of a layer of preparation, followed by a seasoning period of 3 and 14 days under laboratory conditions.

Quasi-destructive (QNDT) tests, whose testing and sampling process does not penetrate deeply into the material, were conducted to assess the influence of the agents employed. The utilization of quasi-destructive testing involves the minimal disruption of the material's near-surface layers, thereby preserving its structural integrity and functionality. This approach, situated at the intersection of non-destructive and destructive methods, positions quasi-destructive testing as a valuable instrument in technical diagnostics and quality control.

Pull-off tests are utilized to evaluate the adhesion of coatings to the substrate. The test involves measuring the force required to detach the coating from the substrate surface. The procedure is outlined as follows: sample and test surface preparation (Fig. 1), incision of the coating (Fig. 2), attachment of the mandrels (Fig. 3), fixing of the test device (Fig. 4) and test execution. Two incisions were made per brick, with one subjected to a peel strength test after 3 days and the other after 14 days of application. For one series of tests (one type of preparation), 12 bricks were utilized.

Fig. 1. Preparation of samples for testing

Fig. 2. Cutting the brick and seasoning under laboratory conditions

Fig. 3. Inserted pins into the tested bricks

Fig. 4. Conducting a pull-off strength test for bricks

The samples were labelled as follows: X_yy_zz_aa, where:

- x – type of substance used,
- yy – proportion of substance in the mixture (50 – 50/50 mixture with water; 100 – without water),
- zz – time from sample preparation to pull-off strength test (3 – after 3 days, 14 – after 14 days),
- aa – number of pull-off samples.

Table 1 presents a summary of the preparations used in the study (without specifying trade names), taking into account the type of active substance and the manufacturer's recommendations for their use. The trade names of the products are not shown; the identification of the preparations is based on the type of active substance used.

Table 1. Hydrophilic preparations used in research

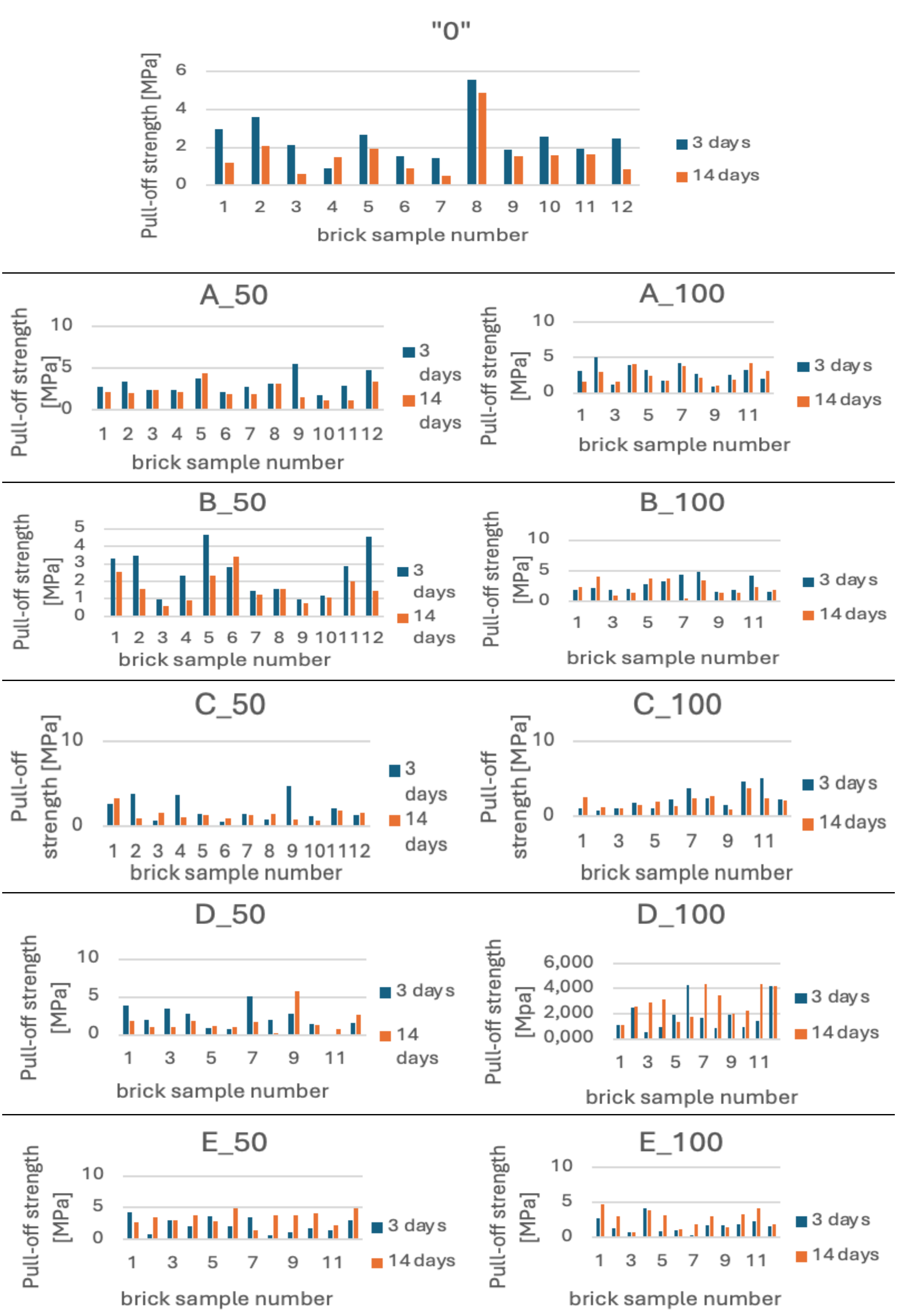
Used substance	Type of active substance (manufacturer's data)	Application
A	Solvent-free silica concentrate with reinforcing effect; alkali silicate 20-30%, potassium methyl silicate 2.5-3%.	Can be mixed with 1:1 water for priming.
B	Mineral primer with strong reinforcing effect; alkali silicate 30-40%	Without dilution
C	Water-based solution based on lithium silicate + additives to reduce surface water evaporation	Without dilution
D	Silane-siloxane impregnating product; ingredients: siloxane, silane, water, auxiliary substances	Without dilution
E	Silicifying product with deep penetrating, hydrophobic and penetrating and hydrophobic, reinforcing the surface	Use diluted with water 1:1

Results and Discussions

The results of the tests are presented in diagrams in the form of average results obtained for a batch of material, defined as a series of peel strength tests carried out on bricks impregnated with a given preparation (A, B, C, D or E) after a specified time from preparation of the samples for testing (3 or 14 days) (Fig. 5).

Fig. 5. Destruction protocol following testing for series "0"

Table 2. Summary of the results



In order to ascertain the influence of the aforementioned preparations, peel strength tests were conducted on bricks devoid of silicate compound layers, designated as '0'. The failure patterns of the tested samples were obtained in the majority of cases in the upper layer of the brick (normally described as a detachment between the substrate and the primer), as illustrated in Figure 5.

To eliminate the effect of firing variability on the analysis outcomes, two cuts were made per brick sample, with subsequent testing after 3 and 14 days. This approach ensures the reliability of the results and minimizes the influence of extraneous variables.

The analysis of the test results, as presented in Table 2, was conducted on the basis of the varying concentrations of the formulations and their respective seasoning times. It was observed that within the comparative series, the outcomes exhibited variation according to the seasoning time (3 and 14 days) for the 12 brick samples examined. This phenomenon signifies that the internal structure of the bricks underwent alteration due to the technological processes employed during their production. The heterogeneity of the brick structure is influenced by variation in porosity (different areas of the brick may have different porosity) and micro-cracks and internal defects (material defects, such as micro-cracks or inclusions, may alter local mechanical properties).

The mean values of the results for each series of measurements are summarized. in Figures 6 and 7, thus facilitating clear interpretation.

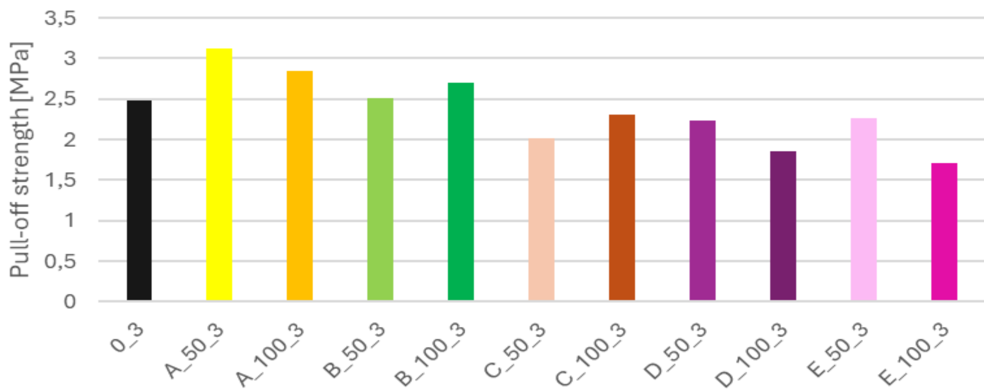


Fig. 6. Brick pull-off strength was measured after a three-day seasoning period following the application of the products (silicates)

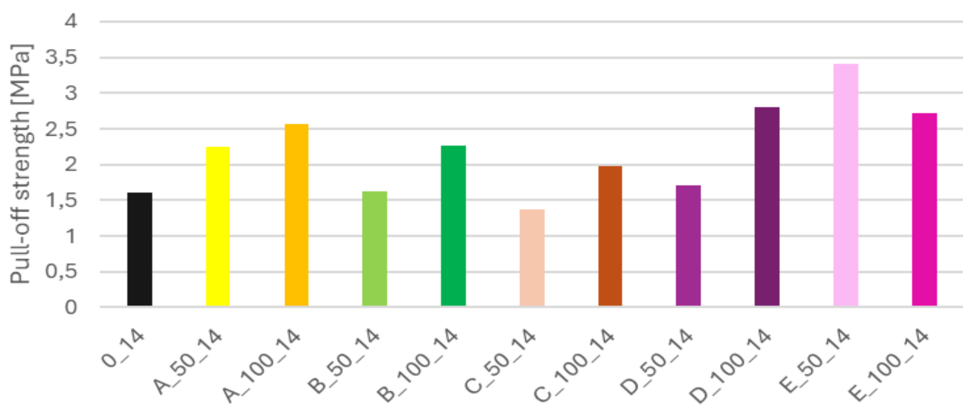


Fig. 7. Brick pull-off strength is measured after 14 days of curing following the application of the products (silicates)

The question of whether it is advisable to dilute hydrophobic products is difficult to resolve unequivocally, as it depends on the specifics of the individual products and their conditions of use. For products A, B, C and D, it was observed that extending the seasoning time had a positive effect on adhesion, provided that the products were applied undiluted, as recommended by the manufacturers. Conversely, product E exhibited an enhanced peel strength with water dilution, irrespective of the elapsed time between application and measurement.

Product A, as per the manufacturer's recommendations, can be applied in a diluted form (1:1) during priming. Tests have demonstrated that this concentration is advantageous during the initial days after application; however, over a prolonged period (14 days), higher strength parameters were obtained with the undiluted preparation. An analogous trend was observed for product D. For product B, the highest adhesion parameters were obtained with the undiluted product, which is in line with the manufacturer's recommendations.

Product C, when used in diluted form, showed lower performance compared to the reference sample, indicating an adverse effect of diluting lithium silicate-based formulations on the mechanical properties of the tested bricks. However, application of the product according to the manufacturer's recommendations revealed an increase in peel strength with an increase in seasoning time from 3 to 14 days.

The manufacturer of product E recommends the application of the product in a diluted form at a ratio of 1:1, which, as the test results showed, is also justified for its application on bricks. However, due to the lack of detailed information on the chemical composition of the product, it is not possible to carry out a more precise analysis of the results obtained. It is therefore advisable to use the product in accordance with the manufacturer's instructions.

Silicate compounds play a pivotal role in the preservation of bricks as historic materials, thanks to their distinctive chemical and physical characteristics. These compounds enhance brick strength, boost resistance to moisture and curtail degradation processes while preserving the material's original appearance. The formulations in question offer long-term protection for historic buildings by shielding them from weather, salt, pollution and moisture. This is of particular significance for historically significant structures, where preserving both aesthetics and structural integrity is paramount.

Research has highlighted the significant benefits of silicate compounds, such as potassium silicates, sodium silicates and siloxane formulations, in improving the durability and strength of bricks, especially over the long term. However, the selection of a specific preparation must be preceded by thorough testing to assess its effectiveness and eliminate potential adverse effects, such as excessive hydrophobicity, which could impair the brick's breathability.

Conclusions

Silicate compounds play a key role in contemporary heritage conservation. Their appropriate application not only makes it possible to preserve the value of historic buildings but also supports sustainability measures by reducing the costs of maintenance and conservation of monuments. A well-planned conservation process allows for effective protection both structurally and aesthetically, guaranteeing the durability and authenticity of objects for many decades. Based on the results of the study, the following conclusions were drawn regarding the effective use of silicate compounds in the conservation of historic bricks:

- Laboratory tests are necessary before applying silicate compounds. These allow the effect of the products on the structure and strength of the bricks is to be assessed, taking into account the specific nature of the material and the local environmental conditions. This is the only way to ensure maximum effectiveness of the products.
- Products should be applied in accordance with the manufacturer's recommendations, particularly with regard to dilution. Dilution should not be used unless specifically

recommended, as this may adversely affect the protective and mechanical properties of the products. Excessive hydrophobicity of the brick, resulting from inappropriate use of products, can reduce the natural porosity and moisture wicking capacity of the brick, which in the long term can lead to structural damage.

- Strengthening products based on alkali silicates and lithium silicate are effective in increasing peel strength, meeting expectations for their effectiveness. Siloxane- and silane-containing impregnations also show high effectiveness, improving the mechanical properties of the materials tested and increasing their resistance to external agents.
- Regular application of silicate compounds reduces the degradation processes of the bricks, reducing the need for costly repairs. When properly carried out, conservation preserves the authentic character of historic buildings and prolongs the life of their materials.
- The process of strengthening brick materials in historic buildings requires a multi-stage and precise approach. It is crucial to take into account the specifics of the building, the type of brick, the nature of the damage and the intended conservation objectives. Only through a tailored approach can optimum results be achieved that will ensure the stability, aesthetics and durability of historic buildings for many years to come.

These findings underline that appropriately selected and applied silicate compounds are a key element in the effective conservation of bricks in historic buildings while supporting sustainability measures.

Future research directions

Developments in technology and the growing need to protect cultural heritage point to the need for further improvements in conservation methods. Future research should focus on:

- Testing new generations of products with optimized chemical properties.
- Analyzing the effects of products on bricks under real conditions, taking into account climatic and environmental diversity.
- The use of advanced diagnostic tools, such as 3D imaging techniques and microstructural analyses, to more accurately assess the effects of conservation.

Such efforts will contribute to more effective, sustainable and tailored conservation practices, ensuring the preservation of cultural heritage for future generations.

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