RECYCLING HISTORIC PLASTERS FOR MORE EFFICIENT RENOVATION OF CULTURAL HERITAGE STRUCTURES

Mateja Golež¹, Tomaz Pazlar²

ABSTRACT

The Contemporary Theory of Conservation approaches the renovation of cultural heritage structures in terms of preserving the original substance as much as possible, or rather providing the compatibility of old and new materials, when original material is to be replaced with a new one during a renovation intervention. The authors of the article, hence, provide an innovative approach to the development of lime mortar mixture from recycled historic plaster, pursuant to the requirements of the standard regulating the use of mortar as a building product.

Pieces of plaster that have fallen off and were taken from a wooden cultural heritage structure were analysed in terms of establishing the composition of the original mortar and the preparation technology of the mortar mixture, and then crushed into an aggregate. The aggregate, lime binder and water were mixed in a lab into a new mortar mix and tested pursuant to the standards used for determining mechanical-physical and durability characteristics of mortars. The results of the research conducted on the mortar mix from recycled historic plaster reveal that the material is a suitable building product to be used for plaster application, complying with the requirements for the renovation of the mentioned wooden cultural heritage structure.

Keywords: Historic plaster, Recycling of plaster, Lime mortar, Renovation, Cultural heritage

1. INTRODUCTION

Secondary building raw materials, one of which is also aggregate from recycled plaster, today belong to those alternative sources of raw materials that can be reused, according to the European legislation, provided that products from recycled materials are tested pursuant to the applicable standards for construction products [1]. In line with the adopted European legislation, national legislation systems of Member States of the European Community are being amended in order to preserve the natural sources of mineral raw materials, reduce greenhouse gas emissions and the amounts of building waste at dumping areas, with the primary motive being the health and safety of people [2].

In case of a renovation of cultural monuments using mortar mixes made of recycled historic plasters, we speak of new mortar mixes that are prepared according to a carefully monitored process, from collecting the original plaster that has fallen off, precise analyses of its composition, crushing the plaster into an aggregate to selecting a quality lime binder and suitable additives [3]. Laboratory tests need to be performed pursuant to the adopted harmonised standards for lime mortar mixes and recommendations for the preparation of restoration mortars [4-7].

2. DEVELOPMENT OF A SUBSTITUTE MORTAR MIX FROM RECYCLED HISTORIC PLASTER

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2.1. Case study structure

A traditional rural massive timber house from the Kozjansko region, originated in the 19th century, was chosen as the case study structure (Fig. 1). An area of over 200 square kilometres in the south-east part of Slovenia is today protected as the largest regional park in Slovenia. The surroundings of the park indentified as biosphere areas also represent extensive areas of a different kind of ecosystem and landscape with original nature worthwhile preserving. The management of traditional build environment as part of historical heritage is therefore based on restoration rather than on renovation [8].

The chosen case study building is a small ground-floor one-family house with no basement. The timber wall structure made of 9 cm swallowtail jointed oak elements is set on sandstone foundation. All walls on the ground floor are made of timber, except a short stone wall section at the entrance door and in the kitchen. Timber wall elements are partly covered with plasters made of lime mortar. Without the plaster covering, the timber is directly exposed to the negative effects of wetting/drying process [9]. Spruce timber floor joists are on the ground floor side covered with ceiling boards and lime plaster which is reinforced with nailed split hazel rods. The top decking of floor elements is made of spruce boards. The same composition of inner walls and ceiling is also used in the attic room. Gables with windows and floors were covered with lime plaster installed on knitted hazel rods.

![Fig. 1 Traditional house in Kozjansko region](image1.jpg)

The degradation processes of historic plasters can be seen both on the exterior as well as on the interior of the structure, and are reflected as a separation (coming-off), scaling and falling-off of plasters from the ceiling and walls of the wooden structural frame and as the emergence of dark stains due to the settlement of mould in poorly aerated parts of the structure [10].

![Fig. 2 Historic plaster falling off the structure’s interior](image2.jpg)
The plaster that first came off the wooden walls on the structure’s interior due to degradation processes and then fell off was crushed into an aggregate and used for the development of a substitute mortar mix (Fig. 2).

### 2.2. Materials and research methods

There were approximately 10 kilograms of plaster that has fallen off taken from the treated structure, from which a sample was prepared for further research to determine the composition of the original plaster, while the remaining plaster sample was crushed into an aggregate. In order to characterise the original plaster, the method of electron microscopy with EDS analysis was applied, along with X-ray analysis.

![Fig. 3 A mixture of aggregate grains from the recycled historic plaster in a polished specimen](image)

Pursuant to the EN 933-1 standard, grain composition analysis was conducted on the sample of recycled aggregate from historic plaster. As substitute binder for the preparation of mortar mixes, lime paste from the Kozjansko park was selected and its chemical composition identified pursuant to the EN 459-2 standard. Using gas absorption measuring, the specific surface of hydroxide particles was determined as well.

Laboratory tests of fresh and carbonatised lime mortar mixes were carried out according to the procedures prescribed by a series of EN 1015 standards and the test results were evaluated according to the EN 998-1 and EN 12371 standards [11]. The monitoring of crack development and degradation effects of cycling on an applied mortar mix was carried using a 3D method of optical recording employed by ATOS I equipment, produced by Gom from Germany.

### 2.3. Characterisation of recycled aggregate

![Fig. 4 A composed aggregate grain with quartz and lime matrix (1), a composed aggregate grain with quartz, lime matrix and colour layers (2), quartz aggregate grain (3)](image)
In composition, the original plaster is a heterogeneous mixture of predominantly quartz aggregate grains and, in inferior amounts, grains of feldspars that are linked with calcitic binder into a cracked and porous matrix, in which dispersed elemental iron is found (Fig. 3). As a result, the recycled aggregate is identical in composition to the original plaster, meaning that aggregate grains are a mixture of quartz and feldspar aggregate grains and lime matrix (1), aggregate grains of quartz, lime matrix and colour layers (2) or individual aggregate grains of quartz (Fig. 4). The grain distribution curve is well graduated, continuous and somewhat irregular in the area of 0.125-0.5 mm particle size, which is attributed to an increased share of fine fraction that arises primarily from the crushed colour layers (Fig. 5).

2.4. Characterisation of lime paste

Lime binder that was selected for the development of a substitute mortar mix was prepared at the Slovenian National Building and Civil Engineering Institute in Ljubljana (ZAG) by slaking quicklime and was altered for six years before being used. Quicklime was brought from the Kozjansko park, where carbonate rocks (limestone, dolomite) are still burnt traditionally in limekilns, thereby producing quality lime.

Table 1 The results of the chemical analysis performed on lime paste from the Kozjansko park

<table>
<thead>
<tr>
<th>Component</th>
<th>Test procedure</th>
<th>Criterion EN 459-1</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free water (105°C)</td>
<td>EN 459-2, item 5.11</td>
<td>≥ 45 and ≤ 70</td>
<td>47.24</td>
</tr>
<tr>
<td>L.O.I. (1000°C)</td>
<td>EN 459-2, item 4.5</td>
<td>–</td>
<td>0.44</td>
</tr>
<tr>
<td>Bonded water (600°C)</td>
<td>JUS B.C8.040 [10]</td>
<td>–</td>
<td>26.92</td>
</tr>
<tr>
<td>SiO₂ + insoluble</td>
<td>JUS B.C8.040</td>
<td>–</td>
<td>0.56</td>
</tr>
<tr>
<td>R₂O₃</td>
<td>JUS B.C8.040</td>
<td>–</td>
<td>0.31</td>
</tr>
<tr>
<td>CaO</td>
<td>EN 459-2, item 4.2</td>
<td>–</td>
<td>46.58</td>
</tr>
<tr>
<td>MgO</td>
<td>EN 459-2, item 4.3</td>
<td>–</td>
<td>25.08</td>
</tr>
<tr>
<td>SO₃</td>
<td>EN 459-2, item 4.6</td>
<td>≤ 2</td>
<td>0.07</td>
</tr>
<tr>
<td>CO₂ *</td>
<td>EN 459-2, item 4.4</td>
<td>≤ 7</td>
<td>0.44</td>
</tr>
<tr>
<td>CaO + MgO**</td>
<td>EN 459-2, item 4.1.5</td>
<td>≥ 85</td>
<td>98.06</td>
</tr>
<tr>
<td>MgO*</td>
<td>EN 459-2, item 4.1.5</td>
<td>≥ 30</td>
<td>34.32</td>
</tr>
</tbody>
</table>

A chemical analysis was performed on the sample of lime paste that was prepared at the ZAG Institute in Ljubljana and the research results reveal that, in composition, the lime is dolomitic lime (Table 1). The presence of magnesium in the lime paste was also determined using EDS analysis of the carbonate crust crystallizing from the saturated solution of brucite, after quicklime slaking (Fig. 6). The measured average value of the specific surface of 6-year-old brucite particles (BET) amounts to 8.5801 g/m².
2.5. Mechanical-physical and durability characteristics of the fresh and hardened mortar mixes

A lime mortar mix was prepared from the recycled aggregate and dolomitic lime paste at 1-3 ratio (lime paste-aggregate) that was tested in terms of establishing the mechanical-physical and durability characteristics of the fresh and hardened mortar. The test results of mechanical-physical properties are provided in (Table 2) and indicate that the new mortar mix is suitable to be used for restoration mortars as an interior plaster.

Table 1 The results of mechanical-physical properties of fresh and hardened mortar

<table>
<thead>
<tr>
<th>Test procedure</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 1015-3:2001</td>
<td>169</td>
</tr>
<tr>
<td>EN 1015-6:1999</td>
<td>1765</td>
</tr>
<tr>
<td>EN 1015-7:1999</td>
<td>4.4</td>
</tr>
<tr>
<td>EN 1015</td>
<td>0.36</td>
</tr>
<tr>
<td>EN 1015</td>
<td>1.4</td>
</tr>
<tr>
<td>EN 1015-10:2001</td>
<td>1520</td>
</tr>
<tr>
<td>EN 1015-18:2004</td>
<td>1.4</td>
</tr>
<tr>
<td>EN 1015</td>
<td>11</td>
</tr>
</tbody>
</table>

Fig. 6 A SEM micro image of the crystals in dolomitic crust

Fig. 7 A brick module with the new mortar mix applied
The durability characteristics of the new mortar mix were established by applying mortars on brick modules and covering them with transparent foil for seven days in order to reduce the speed of drying. The monitoring of the drying process of applied mortar mixes revealed that the joint between mortar and brick groundwork is very good and that mortar cracking is very low (Fig. 7). The brick module with applied mortar mix was placed in a freezing chamber and the load tests were carried out pursuant to the standard regulating the freezing of natural stone. We decided to apply this standard, because there is no special standard for determining the durability characteristics of mortars for frost after their application. The brick module with the mortar mix was frozen at −10°C and heated at 20°C. After 28 cycles of freezing and thawing, the loss of mass during the weighing of test pieces before and after freezing amounted to 0.06 g. The monitoring of the condition of test pieces before and after loading that was carried out using the 3D recording method reveals that after 28 cycles of freezing and thawing the surfaces of applied mortars and their crack webs are completely comparable before and after freezing (Fig. 8).

![Fig. 8 A comparison of surfaces and the system of cracks of the mortar mix applied on a brick module prior to freezing (top) and after 28 cycles of freezing and thawing (bottom) using a 3D model](image)

3. CONCLUSIONS

The use of recycled aggregate for the preparation of restoration mortars that are used for renovations of cultural heritage structures is not an established conservation-restoration practice, principally due to the fact that new mortar mixes need to be tested in advance for each structure separately pursuant to the applicable standards for construction products, but also because we are often limited by the required amount of recycled aggregate sample for the needs of testing, because the historic plaster
sample can be contaminated with salts and thus inappropriate to be used for recycling or due to a lack of funding for preliminary research.

The research results of the suitability for historic plaster re-use to be built in the form of recycled aggregate in the described case showed that the new mortar mixture from recycled aggregate was an appropriate substitute material for the application of interior plasters, both in terms of providing the similarity of the new and old plaster by composition, as well as the comparability of preparation techniques of the new and old mortar mix.

The proposed methodology of mortar mixture preparation from recycled historic plaster is therefore a suitable basis, in terms of an approach method to the renovation of cultural heritage structures, when there is enough fallen-off historic plaster available.

REFERENCES