I.23
Medieval Gypsum Mortars Used for Architectural Details in the Castle of the Teutonic Order in Toruń, Poland

Magdalena Jakubek¹, Frank Schlütter², Wioleta Oberta¹ and Jadwiga W. Łukaszewicz¹

¹ Nicolaus Copernicus University in Toruń, Institute for the Study, Restoration and Conservation of Cultural Heritage, Department for Conservation and Restoration of Architectonic Details and Elements, Poland, terrakotta@o2.pl
² Bremen Institute for Materials Testing, Dep. Analytical Microscopy of Building Materials, Germany, schluetter@mpa-bremen.de

Abstract This study is focused on Gothic architectonic gypsum mortar decoration from the Castle of the Teutonic Order in Toruń. The aim of the research was to complete a condition assessment of the architectonic details, determine the production techniques of these details and establish the composition of mortars.

1 Introduction

The fragments of architectonic decoration of the Teutonic Order castle in Toruń, were found during archaeological research in 1958-66 [1]. Relics surviving the demolition in 1454, represent a rich variety of technical solutions that were used to decorate the castle. The materials applied were stone, ceramics and gypsum mortars. The collection was secured, preliminarily classified and dated to the period around the 1250’s-1350’s by art historians [2, 3, 4, 5], and part of it was restored and presented at the exhibition in 1966 [6] – but was not the subject of scientific material research. It is currently under the care of The District Museum in Toruń.

The subjects of the research undertaken at the Department for Conservation of Architectonic Details are the exhibits from this collection, made of mortar (the so-called “artificial stone”). Mortars based on high-fired gypsum were a popular material for the production of architectonic elements in the State of Teutonic Order in Prussia and became regionally specific to this area of insufficient natural stone deposits [5, 7, 8, 9]. Many such details are preserved in churches and castles
(Chełmno, Malbork, Toruń, Gdańsk and others). There is a need for integrated research into this medieval gypsum material, as understanding is required both for conservation practice (to establish and develop suitable treatments), and for art-historical analysis (medieval sculpting and building workshops and dating) [10].

Fig. 1 Window tracery fragment, both sides; ca.:56x20x17,5cm; grey-coloured gypsum mortar, Muzeum Okręgowe w Toruniu, object No. MT/ZK-355

Fig. 2 Balustrade of the gallery, fragment, both sides; ca. 52,5x72,5x19cm; rose-coloured gypsum mortar, central part reconstructed in cement mortar in 1960’s, Muzeum Okręgowe w Toruniu, object No. MT/ZK-20

Fig. 3 Ceiling boss fragment, both sides; ca.:19x13x10cm; white-coloured gypsum mortar, originally polychromed; Muzeum Okręgowe w Toruniu, object No. MT/ZK-395
2 Material under investigation

An inventory undertaken in cooperation with the Archeological Department of The District Museum in Toruń showed that the collection of mortar fragments includes over 150 mortar pieces (7 to 58 cm length) which differ in appearance and condition. A visual assessment of these mortars allowed the collection to be divided into three groups – grey, rose and white:

- Grey mortars: with significant content of charcoal, form the largest group. Most of the identified fragments are window tracery parts (Fig.1), and consoles; some pieces could have originally been the ceiling bosses.
- Rose-coloured: addition of crushed ceramic. The defined fragments from this group are probably parts of two gallery balustrades and of vault ribs (Fig.2).
- White mortars: with slight presence of ceramic or charcoal particles (non-intentional). It is difficult to recognise by visual assessment only – because weathering and dirt allows it to be mistaken for grey mortar. However, it can be observed among sculpted pieces of ceiling bosses (Fig.3). Such white fine mortar was probably intended for indoor details with refined sculptural forms.

The definition of function is according to inventory books and articles from the 1960’s by Roman Domagała [2, 3]. It is not possible to identify the exact location of particular details as the castle was destroyed. So far, the research focused mostly on fragments with tracery decoration (that is, window tracery and balustrades) as the largest group of objects which are relatively easy to identify thanks to ornamental forms, and represent two significant types of mortars – grey- and rose-coloured [11]. The choice of samples for research by means of microscopy [12] was extended also to fragments of consoles and vault ribs, from these two mortar groups. The samples were taken from pieces ‘typical’ to both groups, and of those that differ in appearance. From fragments that consist of two layers of mortar, samples were taken to compare the composition of materials, to ascertain if it is a mark of medieval technique or rather modern reconstruction.

3 Condition Assessment

The façade elements were exposed to weathering processes for over a century. Demolition of the castle by the citizens of Toruń in 1454 was the actual cause of damage. Broken gypsum elements with crushed masonry were covered with earth for next 500 years until the archaeological excavations. Today, it is neither possible to unequivocally identify the exact original location of particular objects in the destroyed building, nor to reconstruct the destruction processes that took place into rubble. It can only be assumed how many different factors these architectonic details have been exposed to during their almost 700-year-history. Taking this context into consideration, along with the solubility of gypsum (over
2g/l) and weakening of gypsum mortars under the influence of moisture [13], one must admit that the relics of medieval decoration of the castle are surprisingly well preserved.

![Figure 4](image)

**Fig. 4** Window tracery fragment MT/ZK-362. Left – principal view. Right – detail, weathered fracture surface: A – dense material layer of relief surface, B – dense material layer of old fracture surface, C – fresh fracture showing the actual colour of mortar

### 3.1 Condition of grey mortars – window tracery fragments

In most cases one profiled surface is preserved, while the other is strongly weathered. On some fragments the profiles are fully recognisable, while the opposite side (surface that was mounted into brickwork) shows deterioration. These changes could have been influenced by the original location of the tracery. Preserved relief and some fracture surfaces are coherent. On some fragments, a surface layer of approximately 1mm forms (Fig. 4-A), which itself is covered by dust and soil. The underlying material is slightly weakened, and is a probable cause of the partial loss of the original surface. Recrystallisation processes in these areas could cause this higher density of the surface. An assessment of fresher fractures shows that material in deeper parts is well preserved and hard (Fig. 4-c). Weathered areas are chalking, these are discolouring into white, and displaying loss of material (Fig. 4).

There are two examples from window tracery fragments that differ in appearance and condition. Piece numbered MT/ZK-359 is made of light grey mortar with a warm shade. The shape of relief is easily recognisable on one side, while on the other side it is washed out. However the mortar is hard and there is no evidence of chalking. The surface is rough, with remains of the original smooth surface observed in the cavities of the relief. This material is similar in appearance to five consoles from the collection. The other piece is made of mortar in a distinctly darker shade (MT/ZK-356). Some local sanding occurs, but the material is not strongly powdered as described above.
3.2 Condition of rose mortars

Tracery balustrades from the castle’s ambulatory are mechanically damaged, but the material is in relatively good condition. Powdering of surfaces occurs, especially on apparently weathered parts (like hand-modelled side of MT/ZK-20, see Figs. 2 and 6). However, the surfaces of the fractures are homogenous – the phenomena of a dense surface covering loose material, which was observed in the case of grey group, is not noticeable. A few pieces identified as vault rib fragments (and some unidentified parts) appear to be made from softer mortar, and loss of material occurred through powdering (MT/ZK-302).

4 Techniques of production of decorative details

4.1 Casting in moulds

Most of the elements were cast in gypsum mortar and their surface was, probably partially, sculpted (carved, smoothed) after setting. Pieces are monolithic, which indicates, that an exact amount of mortar was prepared for casting the elements. The consoles and bosses were cast as whole elements. Window tracery had to be made in pieces, to assure stability of large openwork and to allow mounting on site.

Traces of tools are recognizable on some elements. As the setting process allowed the removal of moulds and shuttering, the profiles were finished. Areas of further work were marked with lines, engraved by stylus (Fig. 5-A). To smooth surfaces or finish the edges, flat tools, such as knives or spatulas were used (Fig. 5-D). Some profiles were worked with stonemason’s chisels (Fig. 5-B), which indicates that the material after drying had levels of hardness comparable to natural stone.

Fig. 5 Marks of technique of production of architectonic details: A – engraved line, B – chisel traces, C – air bubbles, D – traces of flat tool; window tracery fragments inv no. MT/ZK-357 (left) and MT/ZK-365 (right) [photo: J. Raczkowski and M.Jakubek]
4.2 **Casting of elements combined with free-hand modelling**

The fragments of rose-coloured pieces identified as fragments of balustrades were formed by a combination of techniques. First, the profiled pieces were cast. After setting, their reverse sides were worked out with a chisel, to obtain an adherent surface (Fig. 6-A). A layer of fresh mortar was then applied and modelled into shape to correspond with the cast profile (Fig. 6-B). This indicates that the mortar was capable of being used in free-hand modelling, at least in this application.

![Fig. 6 Detail of balustrade fragment inv. No. MT/ZK-20, reverse side (see Fig.2); cast part worked out with chisel (A) and a layer of mortar applied with free-hand (B)](image)

5 **Chemical composition and structure**

5.1 **Thermal differential analysis**

The samples were ground and dried at 60°C for 24 hours. Measurement conditions: oven temperatures 20 – 1000°C, sensitivity (TG) 200 mg, heating rate 10°C/min, atmosphere – air, ceramic crucible.

<table>
<thead>
<tr>
<th>object</th>
<th>description</th>
<th>CaSO₄.xH₂O</th>
<th>bound water</th>
<th>CaCO₃</th>
<th>residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT/ZK-355</td>
<td></td>
<td>73.87</td>
<td>1.01</td>
<td>6.11</td>
<td>19.01</td>
</tr>
<tr>
<td>MT/ZK-357</td>
<td>appearance “typical” for grey group, as described in 3.1.</td>
<td>61.28</td>
<td>0.67</td>
<td>8.44</td>
<td>29.61</td>
</tr>
<tr>
<td>MT/ZK-357</td>
<td></td>
<td>57.59</td>
<td>1.28</td>
<td>4.57</td>
<td>36.56</td>
</tr>
<tr>
<td>MT/ZK-362</td>
<td></td>
<td>70.46</td>
<td>1.12</td>
<td>6.09</td>
<td>22.33</td>
</tr>
<tr>
<td>MT/ZK-359</td>
<td>warmer colour, higher hardness</td>
<td>64.81</td>
<td>0.87</td>
<td>4.74</td>
<td>29.58</td>
</tr>
<tr>
<td>MT/ZK-351</td>
<td>darker colour, higher hardness</td>
<td>65.95</td>
<td>0.78</td>
<td>4.99</td>
<td>28.28</td>
</tr>
<tr>
<td>MT/ZK-356</td>
<td></td>
<td>66.29</td>
<td>0.59</td>
<td>6.04</td>
<td>27.08</td>
</tr>
</tbody>
</table>
All the analysed mortars are based on gypsum, and contain CaCO₃. In the grey group, the content of calcium carbonate differs from 4.57 to 8.44, but most often it is about 5-6%. In the rose-coloured group the content is 1.96 to 6.99, but the average rate is 3.5%.

Regarding the calcium carbonate content, two extreme results from the grey group are obtained from samples taken from two areas of the same window tracery (MT/ZK-357). Such inhomogenity could have originated during mixing or perhaps through weathering (dissolution and recrystallisation processes). The results should be considered as representative of two contrasting mortar groups.

5.2 Analysis of thin sections – in transmitted light and by SEM/EDX

To achieve information about the mortar’s composition the microfabrics have been analysed in detail by means of microscopy.

The grey mortars (Figs. 7, 8-left, 9) contain charcoal and quartz particles ≤ 0.5mm (sometimes with rests of ceramic matrix, small additions of crushed brick are possible). This group shows evidence of high firing of gypsum, namely: I. Thermally originated CaSO₄ (so-called thermal anhydrite) in dihydrate matrix, characterized by holes in anhydrite grains (Fig.7); II. Lime fired together with gypsum. Marl impurities can occur as inclusions in grains of the gypsum firing product (Fig. 9). Some limestone fragments are present, grain size and crystal shape indicate their origin as naturally occurring lime within a gypsum deposit (Fig. 9-left), no calcium hydroxide was added. The microfabric is dense, corresponding to the well preserved state of these mortars.

Gypsum mortars from the rose coloured group (Fig. 8, right) contain crushed brick particles ≤ 0.7mm in size, and quartz particles that bear relicts of a ceramic matrix (Fig. 8-F). There was no addition of pure sand. There are single particles of limestone (from a gypsum rock) and charcoal present. No marl impurities, no intentional additions of lime and no primary anhydrite have been observed. Well preserved particles of limestone that occur in MT/ZK-20 (Fig. 8-G) indicate firing temperature below 800°C. In contrast, in sample MT/ZK-302 particles of the firing product contain anhydrite grains showing holes as described above that
indicate high firing. It can be recognized from the microfabrics that the weathering tendency of this object is not a result of binder dissolution, but that the higher porosity is rather an effect of the addition of more water during the production of mortar.

Fig. 7 BSE images of grey mortar sample (MT/ZK-93), marks of high firing. Left: anhydrite grains with holes (surrounded by dense dihydrate matrix). Right: lime structure originating from raw material

Fig. 8 Thin sections in transmitted light (+pol). Left – sample MT/ZK 353: A – preserved grain of firing product (dihydrate), B – calcareous marl, C – example of charcoal particle (the cause of grey colour), D – particle of limestone, green marking – the area of BSE-image, see Fig.9. Right – sample MT/ZK-20: E – large grain of crushed brick, smaller particles are spread in matrix (the cause of rose-colour), F – quartz grain with rests of ceramic matrix, G – limestone particles (no changes caused by firing)

Fig. 9 Sample of grey mortar, MT/ZK-353, the green marked area from Fig.8. Left - BSE image, showing particles of limestone (arrows) and areas of calcareous marl (circle). Right - EDX spectrum of calcareous marl (area marked by circle in the left image)
6 Conclusions

Research into fragments of mortar from the Teutonic Order Caste in Toruń revealed the material characteristics of two kinds of medieval gypsum mortars, which were used for the production of architectonic decorative details.

It is evident that mortar groups differ not only in their main aggregate addition, which defines the colour (charcoal – grey, crushed brick – pink). There are differences in function (grey – mostly window tracery, rose – gallery balustrades) and technique (hand-modelling on pieces from rose-coloured group). There are perceptible differences of character of both groups in their deterioration. However, it is very difficult to identify the destructive factors; this hinders the analysis of the relation between the composition and the durability of the mortars.

The research into the composition and structure showed that the grey group contains a larger amount of calcium carbonate, which originates from gypsum rock impurities. Also marl impurities are observed only in this group. These details suggest differences in raw materials, or in manufacturing processes of the binder. For further conclusions to be drawn, the research methods would need to be extended and material samples taken from other medieval objects as well as from gypsum deposits. To better understand the inhomogenities of the mortars, resulting from the production process and weathering would require more detailed analysis, with a sufficient number of samples to ensure a statistically significant sample to support general conclusions.

7 Acknowledgements

The research was possible thanks to The District Museum in Toruń, with support of director Dr. Marek Rubnikowicz and Mrs. Romualda Uziębło, head of the Archeology Department.

The scientific research was co-financed by the subsidies of the European Social Fund and the Government Budget within the framework of ZPORR-Integrated Operating Programme for Regional Development, Operation 2.6 “Regional Innovative Strategies and Transfer of Knowledge” the own project of Kujawsko-Pomorskie Voivodeship “Scholarships for Postgraduates 2008/2009 - ZPORR”.

235
8 References

2. Inventory books (manuscripts) in Archive of Department for Archaeology, The District Museum in Toruń: (1958-66) Inwentarz detali architektonicznych (Prace archeologiczno-konserwatorskie na terenie zamku krzyżackiego w Toruniu); (1970 – til nowadays) Księga inwentarzowa Muzeum Okręgowego w Toruniu, Oddział Zamek Krzyżacki (by Domagała R et al)
the Study, Restoration and Conservation of Cultural Heritage, Nicolaus Copernicus University in Toruń
