Staletá Praha 28, 2/2012, 137-148

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Research on mortars from Judith Bridge in Prague

ANNOTATION

This article briefly summarises the results of laboratory research on mortars samples from Judith Bridge, which were taken from its remains at Křižovnicke square, Prague 1 during rescue excavations in 2011. Considering the lack of comparative research on mortars from early medieval buildings in Prague, this research aimed to characterise and document the samples and their mutual comparison within different constructional elements of the bridge, i.e. the rubble masonry core, the bridge deck and the paving. Composition of the mortars is discussed; their macro and microscopic structure; mechanic characteristics and other basic properties. Specific attention is paid to the mortar binder as the most important factor of its quality. The results are compared with the published results of the mortar analysis from the core of Charles Bridge.

SUMMARY

The study concerns with laboratory research on mortars sampled from Judith Bridge during the rescue excavation in the area of Křižovnicke square in 2011 (Podliska/Semerád 2012). The samples were taken from the rubble masonry of the bridge core, from the masonry of separate construction of the bridge deck and from bridge paving. The samples were studied macroscopically and on prepared thin sections under polarised light using a binocular microscope. Selected samples were analysed under electron microscope as well. The carbonate percentage in the mortar was determined gravimetrically by dissolving part of the sample in a diluted hydrochloric acid, the insoluble residue was washed, dried and analysed by sieving. The analysis of the binder was provided by X-ray diffraction and thermal analysis of the particles of semi-fired limestone fragments. Mechanical characteristics were evaluated by measuring the compressive and bending strength on prepared non-standard specimens. Most of the analysed mortars from the paving and the deck are very firm; their matrix did not crumble even when being cut by a diamond disc, the matrix forms a compact material with the aggregate. Mortars from the paving compared to the deck mortars are more fine-grained and generally more homogenous, fragments of semifired limestone or clayey-calcareous silicite (opuka) are present up to a maximum of ca 3 mm. Carbonate proportion in them is usually around 21 %. Mortars of the deck represent a similar type as paving mortars, but they are significantly heterogenic in their composition as well as in their characteristics within the studied set. These mortars contain abundance of fired or semifired spalls of limestone or opuka with a size of up to several centimetres. Carbonate content varies from 19 to 40 %; and the mortar cohesion fluctuates significantly too. Porosity accessible by water reaches in paving mortars 30 % in average, in the deck mortar it ranges between 30 and 40 %. The mortar of the core is poor of lime binder, fragments of semi-fired limestone are not contained and the cohesion of core mortar is generally lower comparing to the others. The carbonate content was only 11 %; the low value corresponds with lower cohesion and darker tone of this mortar. The aggregate of all analysed samples is based on identical river sand which is characteristic with a high content of feldspar, mainly plagioclases. Quartz occurs in mono crystalline, less often poly crystalline grains usually of subangular or oval shape. Also grains of siltstone often with hematite or limonite edge are present and low quantities of degraded leaves of muscovite, along with probably accidentally introduced fragments of charcoal. The finest fraction of the insoluble residue of particles below 0,063 mm, which is formed mainly by dust particles of quartz, clay and other minerals, has light beige to light ochre hue and is represented by around 5 % of the aggregate weight in all mortars. The aggregate with particles up to 10 mm corresponds with river sand, probably taken from a local source. From the technological point of view the distribution of this sand can be estimated as very profitable as an important factor of mortar quality as well as factor minimizing the binder consumption. Apart from the components described above the stone aggregate of mortars is formed by fragments of opuka and to a lesser extent by tiny oval fragments of sandstone. Also particles of semifired limestone can be included in the aggregate, which were identified in high quantities mainly in the deck mortar. The thin sections of these mortars revealed how the grains of semi-fired limestone gradually changes to micritic matter of the mortar matrix. The coarsest fraction of the aggregate in the case of the rubble masonry of the core as well as of the deck comprises of rock fragments with sizes from several centimetres up to individual quarry stones. The coarsest particles captured within these samples are formed by sharp-edged fragments of grey to grey blue

Palaeozoic limestone, smaller fragments of Mesozoic opuka probably from Bila hora and rare ferrous sandstones of a ginger hue.

Altogether good or excellent mechanical characteristics of the analysed mortars (flexural strength was measured in some cases up to 1,5 MPa, compressive strength up to 6,2 MPa) together with relatively low carbonate content indicate the outstanding quality of the lime binder. In order to determine the character of the lime, samples of fired limestone were separated from the mortar of the deck. Composition of the lime lumps was evaluated on the base of X-ray diffraction analysis and thermogravimetry according to methodology already published (Moropolou 1995, 2004). Hydraulic phases in the matrix were not directly confirmed by diffraction analysis. The thermically determined character of the lime corresponded in one case with common air lime, in other cases lime with a pozzolan admixture and marginally also hydraulic lime. This confirms that it was possible to produce low hydraulic lime by firing the limestone identified in these mortars. Further development of hydraulic phases can be considered in a relatively long time horizon after the building was finished. It can be related to the gradual reaction of the calcium hydroxide with the amorphous quartz contained in the clayey-calcareous silicite fragments (Přikryl 2009, Přikryl/Šťastná 2010), which were identified in the mortars to a limited extend. The hydraulic character of the lime was indicated also by element analysis of the matrix and the lime lumps. Observation of the mortar matrix on the thin section under a polarised light showed significantly different character of the binder of the paving mortar. Lime binder, which composes similarly to other mortars primary of micrite, was partly permeated, in other places completely substituted by amorphous whitish isotropic material. Element analysis pursued within the electron microscopy identified mainly calcium and silicon in this material. A rising concentration of silicon approximately follows the representation of the different binder and the content of silicon compared to calcium rises up to the ratio ca 2 : 1. This effect is more probably caused by a specific position of the mortar deposit rather than by use of different binder or preparation technology of the paving mortar. The way how the isotropic substance penetrates the micrite and in places preferentially fills the microcracks in the matrix indicates a long term secondary process. This could correspond with the exposition of these mortars to weathering. The simplest explanation, which can be found with the current knowledge, presumes gradual precipitation of the siliceous gel in the porous system of the mortar matrix. The source of the SiO_2 could be the already mentioned activated siliceous components of the mortar from the fully fired clayey-calcareous silicite fragments. Finally the physical and chemical characteristics of the studied mortars from Judith Bridge are compared with published results of mortar characteristics from analogous constructions – Charles Bridge and a gothic bridge in Roudnice nad Labem.

Fig. 1. Prague 1-Stare Město, Křižovnicke square Plot No. 72. Detail of the diabase paving of the Judith Bridge in mortar bedding in the trench S01. Position of the mortar samples: **1** – paving, **2** – bridge deck.

Fig. 2. Prague 1-Stare Město, Křižovnicke square Plot No. 72. Structure of the bridge deck in the trench S01. Position of the mortar samples **2** – bridge deck, **3** – bridge core.

Fig. 3. Prague 1-Stare Město, Křižovnicke square Plot No. 72. A section of the mortar from the bridge deck, the mortar contains big fragments of gray limestone, light ochre fragments of opuka (clayey-calcareous silicite), noticeable fragment of charcoal and abundant tiny lumps of lime. The sample was slightly dampened with water in order to highlight the contrast of its composition.

Fig. 4. Prague 1-Stare Město, Křižovnicke square Plot No. 72. A sample of mortar from the bridge core, oval particle of ginger sandstone is on the left, two small light coloured fragments of opuka and an oval lump of lime on the right. The sample was slightly dampened with water in order to highlight the contrast of its composition.

Fig. 5, 6 and **7**. Prague 1-Stare Město, Křižovnicke square Plot No. 72. Thin section of the mortar from the bridge core, polarised light transmission, crossed nicols (**top**), parallel nicols (**centre**) and reflected skew light (**bottom**). An oval lime lump apparent almost in the centre. Scale 500 μm.

Fig. 8. Prague 1-Stare Město, Křižovnicke square Plot No. 72. Granulometry of the aggregate from the researched mortars, fraction component sizes between 0–16 mm Fig. 9, 10 and 11. Prague 1-Stare Město, Křižovnicke square Plot No. 72. A thin section of the mortar from the bridge deck, polarised light transmission, crossed nicols (**top**), parallel nicols (**centre**) and reflected skew light (**bottom**). A fragment of fired limestone with a cracked edge fading into micrite matrix. Scale 500 μm.

Fig. 12. Prague 1-Stare Město, Křižovnicke square Plot No. 72. Results of the thermic analysis of the lime lump sampled from the bridge deck mortar, ratio of CO_2/H_2O 6,1 and the content of $CaCO_3$ 63 % correspond with hydraulic lime.

Fig. 13. Prague 1-Stare Město, Křižovnicke square Plot No. 72. A thin section of the mortar from the bridge deck, secondary (**left**) and back scattered electrons with spots of element analysis (right), particle of opuka in the centre.

The reaction edge enriched by calcium is well apparent in the contact edge of opuka with lime. Results of the element analysis are in the Table 1.

Fig. 14, 15 and **16**. Prague 1-Stare Město, Křižovnicke square Plot No. 72. A thin section of the mortar from the bridge paving, polarised light transmission, crossed nicols (**top**), parallel nicols (**centre**) and reflected skew light (**bottom**). The photographs document different character of the paving mortar matrix containing abundance of white isotropic matter. Scale 500 μm.

Fig. 17. Prague 1-Stare Město, Křižovnicke square Plot No. 72. A thin section of the paving mortar, SEM. Spot element analysis of the transformed mortar matrix. Measurement results are in the Table **2**.

Tab. 1. Prague 1-Stare Město, Křižovnicke square Plot No. 72. Results of the spot element analysis pursued on a thin section of the deck mortar (see Fig. **13**).

Tab. 2. Prague 1-Stare Město, Křižovnicke square Plot No. 72. Results of the spot element analysis pursued on a thin section of the paving mortar (see Fig. **17**).

Tab. 3. Overview of the material characteristics of the researched mortars.

Tab. 4. Overview of the chemical and mineralogical characteristics of the researched mortars.

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