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CHARACTERISTICS OF BUILDING MATERIALS FROM THE ROOMS OF BARRACK NO. 41 AND THE GAS CHAMBER BUNKER OF THE MAJDANEK EXTERMINATION CAMP

Beata KLIMEK[1,*]

[1] Faculty of Civil Engineering and Architecture, Lublin University of Technology, Department of Conservation of Built Heritage, 20-618 Lublin, Poland

Abstract

The article presents the results of research carried out within the framework of the project to develop methods of conservation and preservation of historical materials from Barrack No. 41 and the gas chamber bunker located on the grounds of the former concentration camp at Majdanek. The scope of the research included tests of moisture content, determination of the content of harmful building salts. The physical and mechanical characteristics of the historic bricks were also determined as part of the research. Complementary analytical techniques were used to characterize the mortar samples: X-ray diffraction (XRD) and scanning electron microscopy (SEM-EDS). The results presented in the article are the only such studies conducted on the site and represent a step in an ongoing comprehensive study describing the actual technical condition and degree of degradation of the materials. The primary goal is to preserve the barracks serving as a museum facility open to the public. The studies and research carried out as part of the project aim to preserve for future generations the memorial site of the German Nazi concentration and prisoner of war camp at Majdanek in Lublin – a place that witnessed the tragic events of World War II.

Keywords: *Majdanek; barrack 41; gas chamber bunker; mortar and brick research*

Introduction

The Majdanek extermination camp was established in October 1941 in the southeastern district of Lublin, Poland. It was established by the Germans on the basis of a decision by SS and police chief of the Third Reich Heinrich Himmler. Soviet prisoners of war were the first to be sent here. In the winter of 1942, another expansion of the camp began, with plans to increase its area to 516 hectares. The camp was planned for 250,000 prisoners. The plan was partially carried out. In 1941-1944 the camp took up 95 hectares of land, on which barracks were built. Starting in the spring of 1942, the camp became a center for the extermination of Jews. In August 1942, construction began on the gas chambers at barracks No. 41, completed in October of the same year. There were 5 chambers operating using gas injected from cylinders or using Zyklon B pellets [1].

According to Tomasz Kranz, head of the Scientific Department of the State Museum at Majdanek, about 59,000 Jews and about 19,000 citizens of other nationalities, mainly Poles and Belarusians, perished in the camp [2].

* Corresponding author: b.klimek@pollub.pl

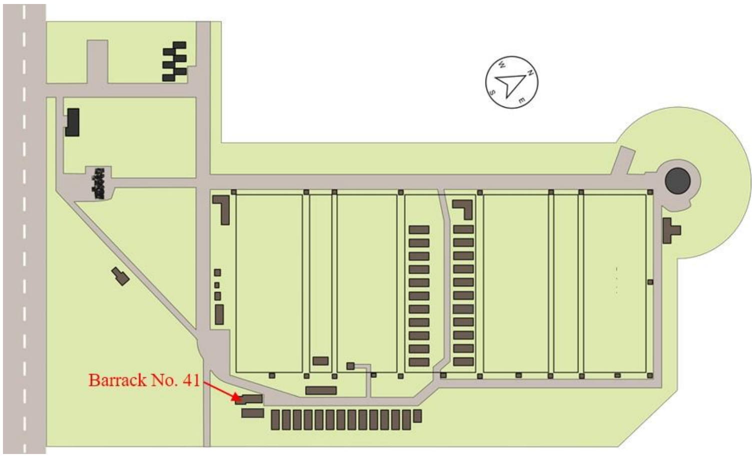

Fig. 1. Situation plan of the State Museum at Majdanek in Lublin: location of barrack No. 41 and chamber bunker [1]

In the course of data collection and analysis from archival documents, it was found that no research had been conducted into the characteristics of the building materials used in the construction of Barrack No. 41 and the gas chamber bunker. The progressive deterioration of the building made it necessary to develop the preservation of the building and therefore to assess the technical condition and conduct research. The results presented here are therefore the first information in this regard and methods of preserving and repairing the facility will be developed based on them.

Barrack No. 41 currently consists of two parts of a different structural nature. The main part of the building is a stable-type barrack with rooms with original functions placed in it: changing room, barber shop, bathhouse, dressing room and boiler room (Fig. 2).

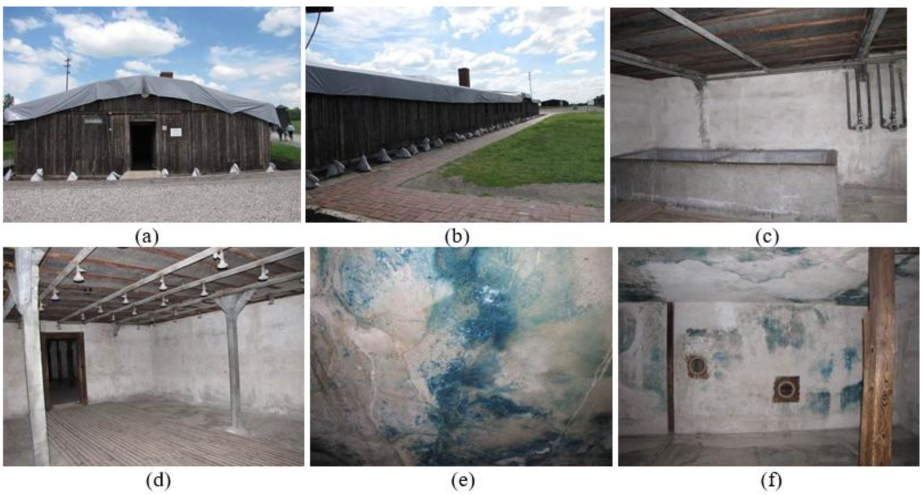

Fig. 2. Barrack No. 41 on the grounds of the former extermination camp at Majdanek a) entrance, front façade; b) the main part of the building is a barrack of the stable type; c) walls and floors of the barrack; d) the ceiling of the bathhouse covered with bituminous paper; e) Prussian blue efflorescence on the wall of the dressing room; f) in the disinfection rooms, the walls and ceilings are plastered and whitened

The second part of the camp is the gas chamber bunker. Unlike the wooden part, the bunker is a solid brick building. It is covered with a reinforced concrete ceiling. The facility is divided into three rooms by masonry walls, with a concrete floor laid in each room. The interiors of the rooms are plastered. An extension also made of brick is adjacent to the bunker on the south side. Currently, the two structures are connected by a wooden connector with windows and doors (Fig. 3).

Fig. 3. Gas chamber bunker, on the grounds of the former extermination camp at Majdanek: a) view from the north; b) wooden extension to the furnace with a blower on the west side; c) main room of the gas chamber; d) Prussian blue efflorescence on the plaster in the chamber; e) damage to the bricks and joint of the bunker walls; f) Prussian blue efflorescence on the bricks and joint on the exterior side

The goal of the conducted research was to develop a preservation program designed to preserve the natural character of the materials and to maintain the finer details of the surroundings. These requirements reflect the preservation doctrine enshrined in the Venice Charter [3]. The preservation program requires, in addition to history, architectural documentation, photographic documentation and the collection of information about building materials and the causes of their deterioration.

Experimental part

Materials and methods

The study characterized the building materials from Barrack No. 41 and the gas chamber bunker. This is the first step to gain sufficient knowledge of their construction and state of preservation to propose an appropriate preservation plan. The assessment of the technical condition of the partitions included determining the moisture content of the masonry and determining the concentration of harmful building salts.

Representative samples were taken from historic bricks and mortar. Sampling was carried out under the supervision of the responsible conservators. The size of each sample was determined in order to complete all analyses and reserve a portion of the material for future research.

In order to perform characterization of historic materials, it was necessary to conduct *in situ* and laboratory tests. Laboratory tests for the strength of historic bricks and masonry [4, 5].

For historic bricks, physical properties (saturation, specific gravity, porosity) and mechanical properties were determined experimentally by performing a uniaxial compression test [6, 7]. Samples of historic mortars were tested using a standard mortar analysis procedure [8].

Research methods

Moisture testing of the masonry

Samples were taken from the bunker rooms of the chamber, the dressing room and the bathhouse to determine moisture content, in which building salt loading tests were then conducted for comparison. A total of 10 boreholes were drilled—six in the bunker walls, two in the bathhouse and two in the dressing room. The method for determining moisture content is specified in EN ISO 12570 [9].

The test apparatus included a dryer capable of maintaining a drying temperature of at least 105°C with an accuracy of ±2°C and a relative humidity of less than 10%; in the case of hot and humid air or low drying temperatures, it may be necessary to provide drying air to ensure adequate relative humidity. A balance capable of weighing the test samples with an uncertainty of no more than 0.1% of their weight. The first stage of the study consisted of collecting samples and then weighing them to the nearest 0.01 g using an Adventure Pro Type AV264CM. The next step was to dry the samples for 48h at 105°C to constant weight and then weigh the dried samples. The final step was to weigh the measuring vessel itself for correct calculations.

Salt content testing

The scope of the chemical analysis also included determining the pH value and the content of sulfates, chlorides and nitrates in ceramic bricks, mortar and plaster. The chemical properties were tested on the samples taken from the site materials, which were then ground and mixed with water in a ratio of 1:5 (powdered material/distilled water). Chemical analysis was carried out using certified tests. Sulfate, chloride and nitrate contents were expressed as a percentage relative to the weight of the whole sample. The pH value of water extraction was measured with a digital pH meter equipped with a combination electrode [10].

Mortar tests

For mortar and plaster testing, 6 samples were taken from the bunker chamber rooms. The following methods were used: X-ray diffraction (XRD) [11, 12] and scanning electron microscopy with energy dispersive X-ray analysis (SEM-EDX) [13-15].

Diffraction patterns were collected using a Bruker AXS D8 Advance powder diffractometer (CuKα radiation) equipped with a Lynxeye superfast detector system.

Results and discussion

The results of the partition moisture tests determine the mass moisture content of various elements. These values were referred to data from the literature, in which moisture levels were quantified from dry to wet conditions, as shown in Table 1.

Table 1. Permissible values of masonry moisture [16]

Degree of moisture	Results [%]	Degree of masonry moisture
I degree	0-3 %	Masonry with acceptable moisture content
II degree	3-5 %	Masonry with increased moisture content
III degree	5-8 %	Masonry with moderate moisture content
IV degree	8-12 %	Masonry with high moisture content
V degree	<12 %	Wet masonry

Table 2 shows the moisture results of the walls of the bunker chamber, bathhouse and dressing room.

Table 2. Moisture content of the walls of the bunker chamber, bathhouse and dressing room

Measurement	Location	Results [%]	Degree of masonry moisture
KDW/1	bunker chamber	2.39 %	I degree – Masonry with acceptable moisture content
KDW/2	bunker chamber	1.55 %	I degree – Masonry with acceptable moisture content
KDW/3	bunker chamber	3.86 %	II degree – Masonry with increased moisture content
KDZ/1	bunker chamber	4.70 %	II degree – Masonry with increased moisture content
KDZ/2	bunker chamber	5.24 %	III degree – Masonry with moderate moisture content
KDZ/3	bunker chamber	4.34 %	II degree – Masonry with increased moisture content
UB/1	dressing room	3.29 %	II degree – Masonry with increased moisture content
UB/2	dressing room	3.16 %	II degree – Masonry with increased moisture content
LAZ/1	bathhouse	3.67 %	II degree – Masonry with increased moisture content
LAZ/2	bathhouse	3.36 %	II degree – Masonry with increased moisture content

Eight of the ten measurement points in the bunker chamber, the dressing room and the bathhouse were found to exceed the moisture level. Increased moisture, which persists for a long time, is the cause of significant corrosion of masonry materials—bricks and joints are severely degraded. Locally, the damage does not only affect the surface of the walls and plaster, but the degradation causes damage to the deeper structures of the bricks (Fig. 3e).

The presence of moisture in the near-surface layers intensifies the crystallization of blue; however, currently, the crystallization is less due to the presence of an interlocking layer on the plaster. XRD studies did not reveal to a certain degree the composition of this layer; however, indications from the recommendations of the 1961 post-research documentation suggest that it may be a water glass layer [17]. The use of a blocker, postulated in the aforementioned documentation, was intended to stop the dampening of the walls of the rooms, but the results of the current study show a low degree of blocking the penetration of plaster layers by condensation moisture. However, it seems that the blocker used stabilizes the position of Prussian blue efflorescence. A negative effect of the used blocker was observed in the zone near the floor. With high humidity of the floor, there is a passage of salt solutions into the plaster of the walls. The blocker present on the plasters inhibits the crystallization of salts on the plasters and their surface layers, which occurs in the deeper layers, causing their degradation. In batches of plaster near the floor, peeling of the layers occurs.

The moisture content results shown in Table 2 are for the samples taken in summer. Previously, similar tests were performed in winter, in which the walls had a significantly higher moisture content. The moisture content of the material samples taken in winter was noticeably higher—from a few to as much as a dozen percent. In parts of the masonry where the moisture content is not too high, corrosion caused by building salts is visible.

Results of building salt content

Table 3 shows the results of the sulfate, chloride and nitrate salt contents and pH values. They are presented as ranges of values for individual salts obtained in tests performed on 6 samples for the chamber bunker and 4 for the dressing room and bathhouse.

High levels of sulfate salts and high and medium concentrations of nitrate ions in the bunker and dressing room, as well as high concentrations of chloride ions, were recorded. Taking into account the results of the chemical analysis of all ions and the permissible degrees of salt content in the walls shown in Table 3, it was concluded that the walls show a high degree of salinity (Table 4) [10].

Table 3. The pH value and content of building salts in the walls of the bunker chamber, dressing room and bathhouse

Measurement	Location	Sulfates [%]	Nitrates [%]	Chlorides [%]	pH
KDW/1	bunker chamber	1.73%	0.24%	0.67%	6.0
KDW/2	bunker chamber	1.67%	0.48%	0.38%	5.0
KDW/3	bunker chamber	1.62%	0.24%	0.52%	5.0
KDZ/1	bunker chamber	1.21%	0.12%	0.77%	5.0
KDZ/2	bunker chamber	1.75%	0.12%	0.59%	6.0
KDZ/3	bunker chamber	1.80%	0.50%	0.29%	6.0
UB/1	dressing room	1.75%	0.12%	1.02%	6.0
UB/2	dressing room	0.53%	0.24%	0.34%	6.0
LAZ/1	bathhouse	0.51%	0.00%	0.27%	6.0
LAZ/2	bathhouse	0.68%	0.10%	0.15%	6.0

Table 4. Acceptable pH and building salt contents in masonry [10]

Salt	Degree of salt content		
	Low	Medium	High
Chlorides	< 0.2%	0.2 – 0.5%	> 0.5%
Nitrates	< 0.1%	0.1 – 0.3%	> 0.3%
Sulfates	< 0.5%	0.5 – 1.5%	> 1.5%
pH:	**Acidic**	**Neutral**	**Alkaline**
	0-6.5	6.5-7.5	7.6-14

Mortar and plaster tests

The walls of the gas chamber bunker are made of brick and plastered on the inside of the bunker. XRD analysis showed that the masonry mortars were lime-sand mortars (M/1A), (M/2A) and (M/3A).

On the other hand, from the results of plaster samples taken from the interior surfaces of the chamber bunker walls, we have two types of plaster. XRD results are shown in Table 5 and figure 4.

Table 5. Mineralogical composition of plaster and mortar samples

Sample	Mineral Name	Chemical Formula	Semi-Quant [%]
M/1A	Calcite	$Ca\ (CO_3)$	20
	Quartz	SiO_2	77
	Albite	$Na\ Al\ Si_3O_8$	2
	Halite	$Na\ Cl$	1
M/2A	Calcite	$Ca\ (CO_3)$	22
	Quartz	SiO_2	74
	Albite	$Na\ Al\ Si_3O_8$	2
	Halite	$Na\ Cl$	1
M/3A	Calcite	$Ca\ (CO_3)$	29
	Quartz	SiO_2	64
	Albite	$Na\ Al\ Si_3O_8$	5
	Halite	$Na\ Cl$	2
P/LG	Calcite	$Ca\ (CO_3)$	28
	Gypsym	$Ca\ SO_4\ 2H_2O$	10
	Quartz	SiO_2	60
	Halite	$NaCl$	2
P/L	Calcite	$Ca\ (CO_3)$	31
	Quartz	SiO_2	63
	Albite	$Na\ Al\ Si_3O_8$	4
	Halite	$Na\ Cl$	2

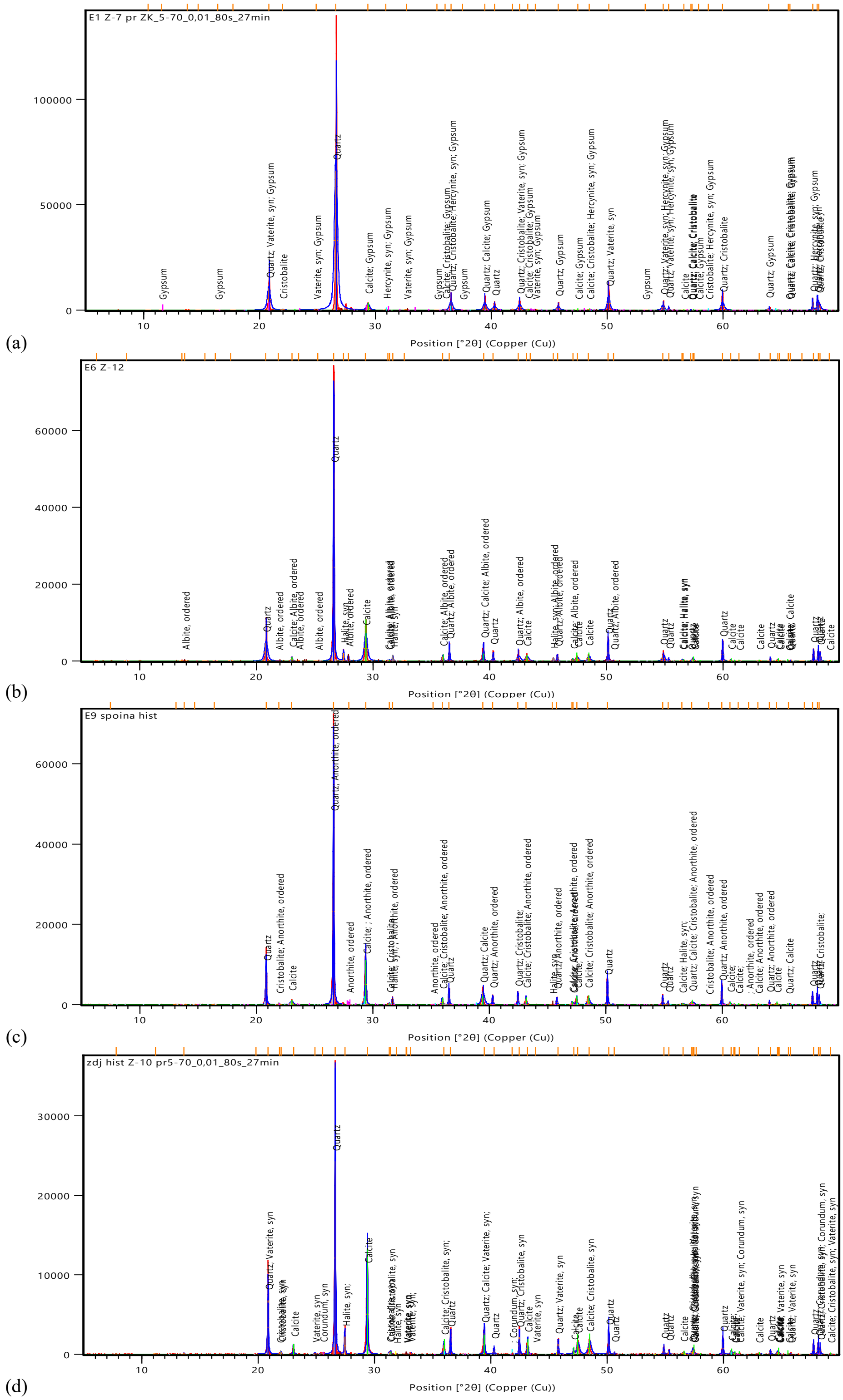

Fig. 4. XRD spectra: a) historical lime-sand plaster with gypsum (P/LG); b) secondary lime-sand plaster (P/L); c-d) lime-sand mortar (M/1A) (M/2A)

The first type of plaster (P/L) is a lime plaster with sand with a calcite content of up to 31% and quartz content of up to 63%. This plaster should be considered secondary plaster in light of the survey. It is likely that this condition is the result of the renovation of the building carried out according to the recommendations of the 1961 post-study documentation [17]. This documentation called for the corroded original plaster to be scraped off and replaced with lime sand plaster.

The second type of plaster (P/LG) is also lime plaster with a calcite content of up to 28% with sand; however, XRD analysis also showed the presence of gypsum up to 10% in the plaster mass. This type of plaster is definitely stronger, with a lower proportion of fillers up to 60%. It is presumed that the addition of gypsum was intended to reduce the porosity and absorbency of the layer by tightening it. In light of the analyses carried out, this layer of plaster was considered a proper layer. For samples of this composition, the presence of titanium white (TiO_2) was additionally recorded.

The mortars consisted of lime represented by calcite of 20% and 22% mixed with sand represented in quartz of 77% and 74%.

Halite (NaCl) salts appear in mortar and plaster analyses (Table 5 and Fig. 4).

The salt appeared in the mortars as a result of groundwater entering the masonry walls through capillary rise. The differences in salt content can be attributed to lower porosity and water absorption for the different sampling sites.SEM examination of the lime mortar samples showed high porosity and lack of cohesion between the components (Fig. 5a and Fig. 5b). This was due to the deterioration of the mortars caused by the action of moisture and crystallization of salts.

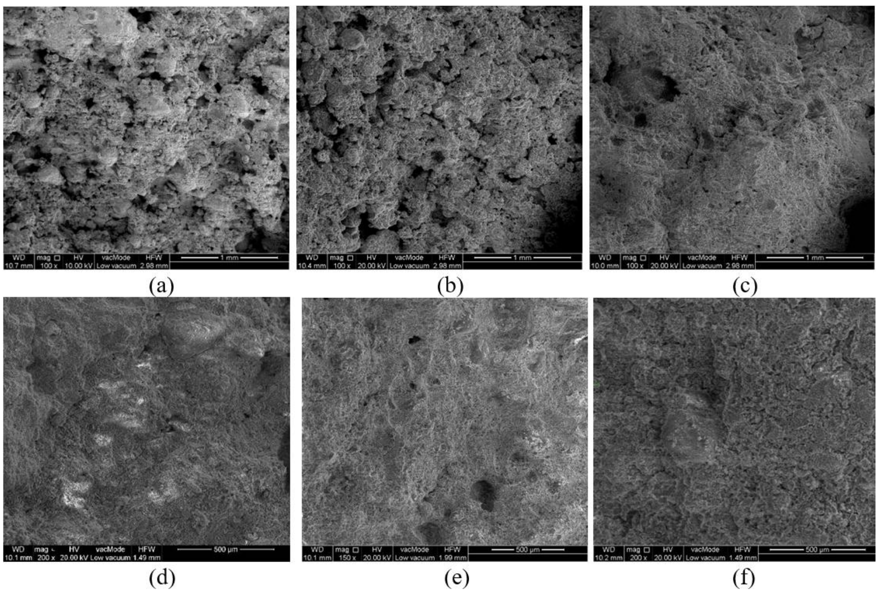

Fig. 5. SEM images: a) lime-sand mortar (M/3A); b) lime mortar sample (M/4A); c) lime-sand mortar (M/1A); d) lime-sand mortar (M/2A); e) lime-sand plaster with gypsum (P/LG); f) lime-sand plaster (P/L)

The main constituent elements of the lime mortars were Ca, C, Si and N, according to the EDS test (Table 6 and Fig. 6). The weight percentage containing the individual oxides CaO, C_2O, SiO_2 and N_2O_5 ranged from 26.49 to 35.30, 11.54-15.77, 22.60 to 29.76 and 13.53 to 17.84, respectively, in the four mortar samples tested (M/1A, M/2A, M/3A and M/4A). The remaining oxides Na_2O (1.13-2.56), Cl_2O (1.73-3.18), SO_3 (0.25-1.50) and K_2O (0.98-1.45) contributed to the existence of salts.

Table 6. Chemical composition of plaster and mortar samples

Sample	C_2O	N_2O_5	Na_2O	MgO	Al_2O_5	SiO_2	P_2O_5	SO_3	Cl_2O	K_2O	CaO	TiO_2	Fe_2O_3
M/1A	15.77	13.53	2.56	0.87	2.28	29.76	0.20	1.50	2.68	1.14	29.90	-	0.78
M/2A	15.54	17.84	2.47	0.93	2.31	27.73	0.32	0.25	3.18	0.98	26.49	-	1.95
M/3A	11.54	17.72	1.31	1.17	3.86	22.60	0.28	0.95	2.31	1.45	34.59	0.07	2.15
M/4A	13.27	15.94	1.13	1.06	3.58	22.95	0.35	1.13	1.73	1.38	35.30	0.05	2.14
P/LG	12.43	13.23	4.31	1.17	2.49	23.16	0.27	6.43	3.82	1.45	29.72	0.38	1.00
P/L	8.75	15.53	1.18	1.06	6.38	22.59	0.41	4.24	1.42	1.16	28.76	0.06	0.43

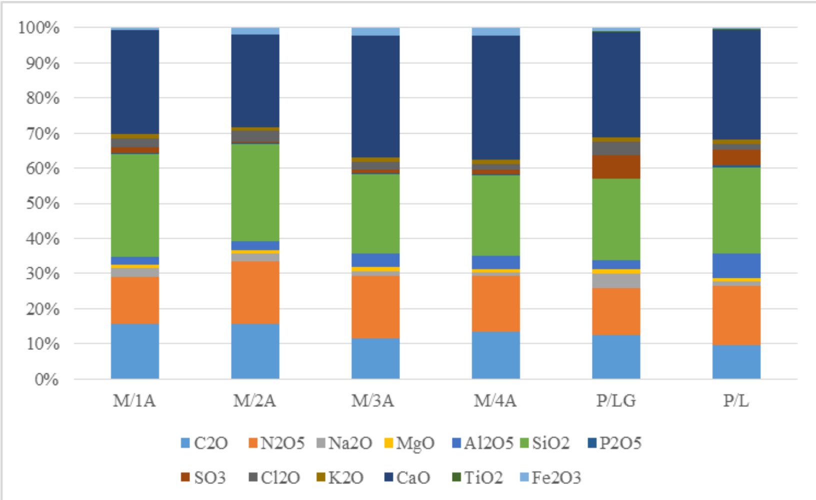

Fig. 6. Weight percentage (Wt%) found for oxides in each sample: (M/1A) – lime-sand mortar; (M/2A) – lime-sand mortar; (M/3A) – lime-sand mortar (M/4A); (P/LG) – lime-sand plaster with gypsum; (P/L) – lime-sand plaster

SEM images of the plasters show a compact microstructure. EDX analysis confirmed the XRD results that the lime plaster with gypsum (Fig. 5e) contained an increased content of SO_3, up to 6.43%; CaO, up to 29.72%; C_2O, up to 12.43%; SiO_2, up to 23.16%; and N_2O_5, up to 13.23%.

The lime plaster samples contained a high percentage of CaO (up to 28.76%), C_2O (up to 8.75%), SiO_2 (up to 22.95%) and N_2O_5 (up to 15.53%), reflecting the nature of the mortar as a lime mortar (Fig. 5f). Salt testing showed that it was halite (NaCl) with cubic crystals. EDX analysis showed weight percentages of Na_2O (up to 4.31) and Cl_2O (up to 3.82).

All mortar and plaster samples showed very high N_2O_5 contents of more than 17.84% bound by nitrates, which are a direct result of biological metabolism. They are formed as a product of processing feces and other residues produced by microorganisms.

Nitrifying bacteria oxidize ammonia to nitrous acid, which is then oxidized with nitrosative bacteria to nitric acid. Nitric acid reacts with carbonate minerals in the mortars to form nitrate salts.

Prussian blue was found on the plaster in the gas chambers (Fig. 2e and Fig. 2f). This is a result of the use of Zyklon B in these rooms. Zyklon B, containing the so-called Prussian acid, together with iron compounds contained in the plastering compounds, is transformed into a dye with a characteristic blue color when exposed to a reducing atmosphere of carbon monoxide. Due to the reactivity of Prussian blue to water, blue efflorescence is also present on lime plaster (repairs according to the recommendations of the 1961 post-study documentation) [17]. In quantitative studies of ferrocyanide, it was found that the reapplied plasters contain a higher amount of it than the original plasters. The reason for this condition may be twofold. The first reason for the quantitative difference in ferrocyanide is the presence of gypsum in original plasters. Gypsum, through absorption of water particles, hydrates by increasing its volume, while drying the structure inhibits the hydration of blue and its migration. The lack of a crystalline form of gypsum results in greater packing of the mortar so that the crystallization of Prussian blue occurs to a lesser extent. In the case of reapplied plasters, used in the places where the original plasters degraded, the freshness of the mortar and the presence of the mortar water, as well as the greater porosity of the structure, caused the blue to migrate out and spread easily and crystallize.

Brick tests

Brick tests were carried out in accordance with PN-EN 771-1:2003 [6]. Table 7 summarizes the results obtained.

Table 7. Bulk specific gravity, water absorption and porosity of historical bricks

Sample Code / cube	Bulk Specific Gravity (N/m³)	Water Absorption (%)	Porosity (%)
B/4	3.88	18.0	16.47
	3.51	16.30	14.92
	3.47	16.10	14.73
	4.05	18.8	17.21
	2.95	13.7	12.54
	3.27	15.2	13.91
Average	**3.52**	**16.35**	**14.96**
Standard Deviation	**0.36**	**1.68**	**1.54**
B/1	2.63	12.2	11.16
	3.32	15.4	14.09
	3.55	16.5	15.10
	2.82	13.1	11.99
	3.27	15.2	13.91
	3.29	15.3	14.19
Average	**3.14**	**14.62**	**13.40**
Standard Deviation	**0.31**	**1.48**	**1.36**
B/6	2.58	12.0	10.98
	3.49	16.2	14.83
	2.78	12.9	11.80
	3.49	16.2	14.83
	3.68	17.1	15.65
	3.83	17.8	16.29
Average	**3.30**	**15.37**	**14.06**
Standard Deviation	**0.46**	**2.15**	**1.96**

For the physical properties of the bricks tested, similar values were obtained. Bulk specific gravity averaged 3.14-3.53 N/m³, with a standard deviation of 0.31-0.46. Water absorption was 14.62-16.35% with a standard deviation of 1.48-2.15. Porosity was 13.40-14.96% with a standard deviation of 1.36-1.96.

Brick compression tests were carried out in accordance with PN-EN 772-1:2001 [7]. Table 8 summarizes the results obtained.

Table 8. Compressive strength results

Sample Code / cube	Strength (MPa)	Sample Code / cube	Strength (MPa)	Sample Code / cube	Strength (MPa)
B/4	16.5	B/1	23.2	B/6	15.2
	17.0		13.0		15.3
	9.6		7.3		18.0
	8.9		16.5		18.0
	11.3		7.4		9.7
	9.3		7.7		12.5
Average	**12.1**	**Average**	**14.78**	**Average**	**12.51**
Standard Deviation	**3.37**	**Standard Deviation**	**2.94**	**Standard Deviation**	**5.87**

The average compressive strength of the historic bricks ranged from 12.1 to 14.78 MPa, while the coefficient of variation was 3.37-5.87. Given that the bricks for testing were taken from different walls of the chamber bunker, the variation of strength should be considered relatively small. The overall evaluation of the masonry should take into account the specific characteristics of the historic masonry and its structure, e.g., the thickness and degree of mortar filling of joints, geometric deviations of bricks and joints and material heterogeneity of components. The impact of long-term moisture loading and salt and biological corrosion.

Conclusions

The article presented the results of research carried out within the framework of the project to develop methods of conservation and preservation of historical materials from Barrack No. 41 and the gas chamber bunker located on the grounds of the former concentration camp at Majdanek. The objects are heavily degraded and require urgent repair work.

The moisture content of the tested materials varied and was clearly dependent on the season in which the samples were collected. It can be concluded that the constant changes in the degree of moisture in the walls influenced to some extent the intensification of the resulting masonry degradation processes from salt crystallization in the subsurface zones and on the wall surface.

The aggressive salt content of the partitions was determined to be high. As it was mentioned, salt corrosion is present in the parts of the walls near the floor; however, in the higher parts of the walls, despite the increased humidity, the state of salinity is medium, with no visible changes in the structure of the plaster.

The catalyst of salinity probably corresponds to microorganisms, so there is a synergistic effect because the presence of a biofilm accelerates the physical and chemical deterioration of the material. The combination of several corrosive factors accelerates the destructive processes.

In its current state, the lime mortar used to repair the plaster, as well as lime plaster with gypsum, is covered with Prussian blue efflorescence. Prussian blue is reactive to water, so it migrated when it came into contact with fresh mortar. The migration was favored also by the structure of the plaster itself in the repair area, as it was more porous than the plaster considered original. Crystallization of blue occurs in the free spaces of the texture of the plaster mass, through which it has no direct effect on weakening the technical parameters of the material. The presence of moisture in the near-surface layers intensifies the crystallization of blue.

According to the results of tests on the strength and physical properties of bricks, the heterogeneity of the materials used to erect the walls of the facility was found. Demolition material from different types of buildings was probably used to construct the object. The varied technical condition of the walls was influenced by corrosive factors from the external environment lasting for more than 80 years.

The study of the original materials of the rooms of barrack No. 41 and the gas chamber bunker of the former extermination camp at Majdanek constitutes documentation as well as an important element of the technical analysis and concept of conservation and repair of the camp buildings. Ultimately, these results make it possible to select appropriate materials for repairing plaster and masonry materials.

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