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Phenomenon of Moisture Expansion and Its Influence on Mechanical Properties of Brick Clay Products

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Abstract

The paper considers the moisture expansion phenomenon, as a specific form of corrosion process of brick clay products degradation [1]. The influence of the mineralogical composition of raw materials, firing temperature and environmental parameters on the magnitude of the moisture expansion phenomenon and mechanical properties of brick clay products have also been considered. The study of the moisture expansion phenomenon of brick products was done using two typical raw materials, one with a considerable and the other with a low content of earth-alkaline carbonates. All investigations were carried out at room temperature on the fired samples, on the fired samples after firing and after hydrothermal treatment and reheating of the samples at 550°C. It was found that brick moisture expansion depends on the presence or absence of earth-alkaline carbonates in raw materials, temperature of firing, appearance of amorphous phase as well as on the modulus of elasticity [2]. Brick raw materials with low content of earth alkaline carbonates in the fired state show a higher tendency to moisture expansion and fired brick products with high content of earth alkaline carbonates show a minor tendency to moisture expansion [3]. The experiments have confirmed the influence of the modulus of elasticity on moisture expansion magnitude. Moisture expansion caused the decrease of mechanical properties and small increase of the volume of brick clay products, ranging from 0,001 to 0,7 mm/m.

Keywords: Moisture expansion, Brick, Modulus of elasticity

ZJAWISKO ROZSZERZALNOŚCI WILGOCIOWEJ I JEJ WPŁYW NA WŁAŚCIWOŚCI MECHANICZNE PRODUKTÓW Z GLINY CEGLARSKIEJ

W artykule rozważane jest zjawisko rozszerzalności wilgociowej, jako szczególną postać procesu korozji podczas degradacji produktów z gliny ceglarskiej [1]. Rozważono również wpływ składu mineralogicznego surowców, temperatury wypalania i czynników środowiskowych na wielkość rozszerzalności wilgociowej i właściwości mechaniczne produktów z gliny ceglarskiej. Badanie zjawiska rozszerzalności wilgociowej produktów ceglarskich przeprowadzono przy użyciu dwóch typowych surowców, jednego ze znaczną i drugiego z małą zawartością węglanów ziem alkalicznych. Wszystkie badania przeprowadzono w temperaturze pokojowej na próbkach wypalonych, na próbkach wypalonych po wypaleniu i obróbce hydrotermalnej oraz po ponownym ogrzaniu próbek do 550°C. Stwierdzono, że rozszerzalność wilgociowa cegły zależy od obecności lub braku węglanów ziem alkalicznych w surowcach, temperatury wypalania, występowania fazy amorficznej, jak również od modułu sprężystości [2]. Surowce ceglarskie o małej zawartości węglanów ziem alkalicznych w stanie wypalonym pokazują wyższą skłonność do rozszerzalności wilgociowej, natomiast wypalone produkty ceglarskie o dużej zawartości węglanów ziem alkalicznych pokazują mniejszą skłonność do rozszerzalności wilgociowej [3]. Doświadczenia potwierdziły wpływ modułu sprężystości na wielkość rozszerzalności wilgociowej. Rozszerzalność wilgociowa spowodowała spadek właściwości mechanicznych oraz mały wzrost objętości produktów z gliny ceglarskiej mieszczący sie w przedziale 0,001 do 0,7 mm/m.

Słowa kluczowe: rozszerzalność wilgoci, cegła, moduł sprężystości

1. Introduction

In defining the concept of moisture expansion investigations we started from the assumption that all brick clays, regardless of their mineralogical composition and the presence or absence of earth alkaline carbonates, form in various ways a ceramic body in the firing process [4, 5]. Consequently, all the brick clays can be divided in to two groups:

– brick clays that form ceramic bodies by adequate reactions in the solid state and by sintering in the firing process, and
– brick clays that form ceramic bodies in the presence of a liquid phase in the firing process.

Since the presence of earth-alkaline carbonates supports the formation of crystalline silicate in the firing process, we

Table 1. Chemical composition of raw materials “A” and “B”.

Chemical composition	Raw material „A” [%]	Raw material „B” [%]
SiO_2	64.42	51.54
Al_2O_3	23.38	17.41
TiO_2	0.43	0.35
Fe_2O_3	1.78	5.61
CaO	0.57	7.36
MgO	0.82	3.43
Na_2O	0.20	0.97
K_2O	2.04	1.45
H_2O	2.02	2.91
L.ign.110°C	5.99	11.31

assumed that such products will show only a minor tendency to moisture expansion [6]. We, however, were of the opinion that fired clay products with low earth-alkaline carbonate content will have high tendency of moisture expansion. Considering the fact that the phenomenon of macroscopic moisture expansion was manifested in increasing volumes of fired brick products, it was logical to expect some changes of physical-mechanical characteristics in the case of non restrained expansion.

2. Experimental procedure

2.1. Properties of brick raw materials

Two characteristic brick raw materials which differ in their chemical composition, earth-alkaline carbonate content technological properties and moisture expansion value were used in the experiment. Table 1 gives the chemical composition of raw materials “A” and “B”. The “A” raw material is made up of illite, hydro-mica, kaolinite, quartz material with low montmorillonite and earth-alkaline carbonate content. The “B” raw material are illite, montmorillonite, quartz with high dolomite and limestone contents.

Fig. 1 shows the results of X-ray diffraction of the raw materials used in the experiment.

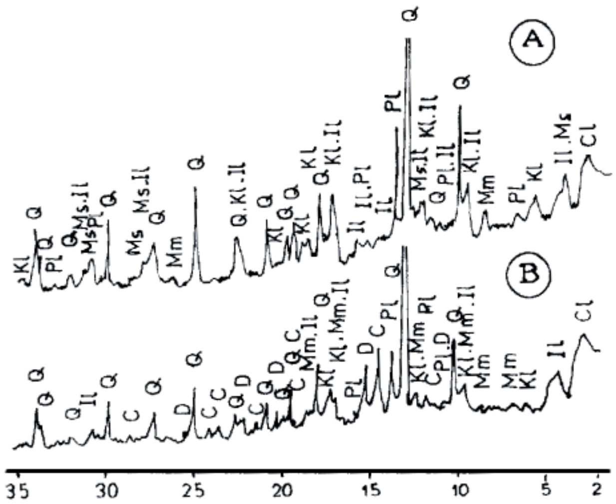

Fig. 1. X-ray diffraction analysis of raw materials “A” and “B”.

2.2. Preparation of samples

Laboratory samples of bricks were shaped in the laboratory vacuum press “Hendle” Type 4 in 0.08 MPa vacuum. The formed samples, (50x40x40) mm, (100x50x10) mm and (110x40x40) mm in size, were carefully dried and fired in a laboratory electric kiln at the temperatures of 900, 950, 1000 and 1050°C, that are common in brick production. The kiln heating temperature regime was identical in all the cases and the temperature rise was 2.5°C/min. Products were kept 60 minutes at each of the selected temperatures.

After firing, the kiln was switched off and samples were retained in the kiln to cool. When the temperature of 200°C was reached, samples were taken out of the kiln and transferred into desiccators in which they were left until cooled down to ambient temperature and stored till the test.

As the moisture expansion process in natural storage conditions is a slow one, the second half of the laboratory samples was subjected to accelerated moisture expansion by hydrothermal treatment in an autoclave. The samples were placed on a perforated metal plate. The autoclave was closed and heated until the pressure was raised up to 1.6 MPa and maintained for four hours. When this period of time expired, the pressure in autoclave was equalized with the atmospheric air pressure. After cooling, the samples were taken out of the autoclave and dried in an oven at the temperature of 105°C until their constant mass was achieved. Irreversible moisture expansion of hydrothermally treated brick samples was determined by a dilatometer method. Bars, (50x4x4) mm in size, were cut out of test samples and placed into a quartz dilatometer tube and the whole apparatus was brought into the indicator position. Heating proceeded at the rate of 5°C/min to the temperature of 550°C. When the required temperature was reached, it was maintained for another 30 minutes. The sample was left to cool in the dilatometer kiln down to ambient temperature. Changes of sample dimensions were constantly recorded. Difference in the level of the start point of the expansion curve and the end point of the cooling curve gave the sample moisture expansion magnitude. Compressive strength of parallelepiped samples (50x40x40) mm of size was determined according to EN 772-1 and bending strength of parallelepiped samples, (100x50x10) mm of size according to ISO 10545-4. High precision laboratory presses “Tonnindustrie”, digital display with accuracy rate ± 0.01 N were used. Dynamic modulus of elasticity ε_D of laboratory samples of bricks was determined by “Erudite” - CNLS Electronics LTD instrument. The dynamic modulus of elasticity was determined by a non-destructive method of resonance frequency at longitudinal oscillations. All these examinations were performed on the same laboratory brick samples of size (100x40x40) mm at room temperature immediately after firing, after hydrothermal treatment in the autoclave and after reheating at the temperature of 550°C.

3. Results of experimental studies

3.1. Compressive and bending strength of test samples

During experimental determination of compressive or bending strength of samples, test samples must break so that all the conclusions are to be made on the basis of the comparison of average values of the results of individual samples. Test results for the mechanical properties of laboratory samples produced from raw materials “A” and “B” were found to depend on firing temperatures and the hydrothermal treatment as shown in the graphic form in Figs. 2 and 3.

The analysis of the above listed results shows that both compressive and bending strength values decreased on all the samples subjected to a hydrothermal treatment. The compressive strength of brick test sample “A” decreased in the range of 4.7 % to 11.4 % and for brick test sample “B” in the range of 4.3 % to 7.7 %. The decrease of bending strength varied for the “A” test samples within the range from 6.6 % to 10.9 % and for the “B” test samples within the range from 3.4 % to 13.3 %, depending on firing temperature and the mineralogical composition of the initial raw materials.

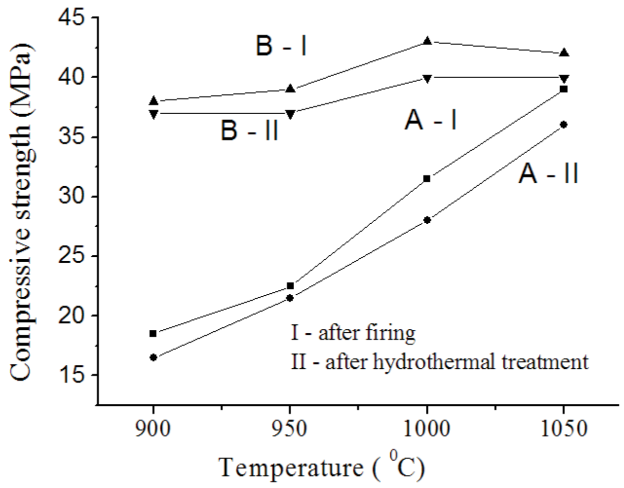

Fig. 2. Change in compressive strength of laboratory brick samples depending on firing temperature and hydrothermal treatment.

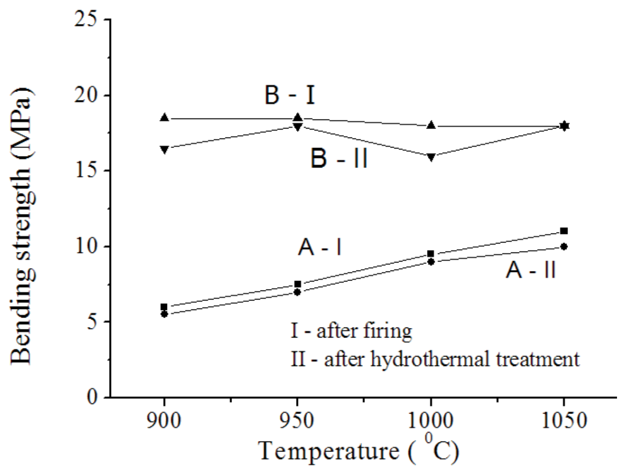

Fig. 3. Change in bending strength of laboratory tile samples depending on firing temperature and hydrothermal treatment.

Unfortunately, on the basis of the research carried out, it was not possible to establish a correlation between the reduction of the mechanical characteristics and moisture expansion. It is well known that degradation of brick clay products appeared as a result of the restrained expansion of bricks in walls but this research for the first time confirmed that a reduction of mechanical properties occurs in cases when the brick clay is alone.

3.2. Dynamic modulus of elasticity of test samples

Special emphasis is given to the study of deformation characteristics of brick products, and dynamic modulus of elasticity. This non-destructive testing allows a repeated testing on the same samples. Measurements of dynamic modulus of elasticity on test samples immediately after firing, hydrothermal treatment and reheating at the temperature of 550°C are shown in Table 2. The measurements pointed significant differences in the values of dynamic modulus of elasticity of test samples as a function of the mineralogical composition and firing. Differences in the values of e_D measured on samples produced from "A" raw material compared to samples produced from "B" raw material are significant regardless of firing temperature and these results indirectly point to a connection between the modulus of elasticity and moisture expansion magnitude. Therefore, it can be concluded that brick products having higher modulus of elasticity will show lower tendency to moisture expansion and vice versa. The above results stand for an experimental confirmation of Smith's hypothesis [7] on the impact of modulus of elasticity upon moisture expansion magnitude, which was established by this author in 1955, but which has not been proven until today. The conducted research on the same samples, immediately after firing, hydrothermal treatment and reheating, have undoubtedly shown the link between the reduction of the mechanical characteristics of product and the appearance of small increase of the volume of test samples. The change of dynamic modulus of elasticity was stated on all test samples as a consequence of elastic deformations of samples during hydrothermal treatment and these were macroscopically manifested as a volume increase of test samples. Brick test samples after reheating have shown permanent nonelastic deformation or the increase of the volume of samples.

Table 2. Mean values of the dynamic modulus of elasticity e_D of the laboratory test samples made of raw materials after firing, hydrothermal treatment and reheating temperature.

Firing temperature [°C]	e_D [MPa]; fired samples	
	Raw material A"	Raw material „B"
900	5570	18589
950	7715	18124
1000	10577	19644
1050	15760	22459
Firing temperature [°C]	e_D [MPa]; hydrothermally treated samples	
	Raw material A"	Raw material „B"
900	6613	21035
950	7970	19888
1000	11377	21232
1050	17396	23448
Firing temperature [°C]	e_D [MPa]; after reheating hydrothermally treated samples	
	Raw material A"	Raw material „B"
900	6416	19026
950	7870	18753
1000	10970	20182
1050	16206	23032

4. Conclusion

Moisture expansion magnitude of fired brick clay products depends mostly on mineralogical composition of input raw materials, temperature of firing and the fired product modulus of elasticity.

The experiments confirmed that the modulus of elasticity has an impact both on the moisture expansion magnitude and fired brick volume. The decrease of fired products mechanical properties in the case of non-restrained expansion being the result of permanent changes developed as a consequence of the occurrence of dislocations and movements of certain layers within brick material in relation to one another. The decrease of product mechanical properties is in direct correlation with irrecoverable increase of test samples volume determined after reheating at temperature of 550°C.

Acknowledgements

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