IOP Conf. Series: Materials Science and Engineering **365** (2018) 032051 doi:10.1088/1757-899X/365/3/032051

Monitoring the effect of external conditions on the properties of building materials

Monika Čáchová[1], Jaroslava Koťátková[2], Eva Vejmelková[3] and Robert Černý[4]

Czech Technical University in Prague, Czech Republic

E-mail: [1]monika.cachova@fsv.cvut.cz [2]jaroslava.kotatkova@fsv.cvut.cz
[3]eva.vejmelkova@fsv.cvut.cz [4]cernyr@fsv.cvut.cz

Abstract. Durability of building materials, as a vital parameter affecting the lifetime of structures, is related to their resistance to harmful effects of the external environment. This article is aimed at studying the changes in the properties of frequently used building materials after being exposed for four years to weathering in the conditions of Prague, Czech Republic. The selected materials were sandstone, normal strength concrete, fired clay brick and autoclaved aerated concrete. Their resistance to weathering was assessed using the measurement of basic physical properties, mechanical properties and water vapour diffusion parameters.

1. Introduction

There are various requirements on building materials depending on their application and main function. However, the common feature of all claims on building materials is their durability. As the lifetime of a building is given by the durability of the weakest element, it is desirable to prolong the durability of every single material used in the structure, which has a vital function and is not easily removable. This applies especially for materials with load-bearing function. The most common materials for load bearing structural members in the Czech Republic are concrete, bricks and - from the historical times - sandstone. Many research studies are concerned with the durability of these materials [1, 2, 3, 4, 5].

The durability of building materials is related to their resistance to external conditions. The harmful factors are air pollution, erosion and abrasion due to wind and rain, acid attack, freezing and thawing, carbonation, etc. This paper is aimed at studying the effects of external conditions on four selected building materials in the course of four years. The investigated materials are sandstone, normal strength concrete, fired clay brick and autoclaved aerated concrete.

2. Materials

Table 1 gives the list of studied materials with their labels. Sandstone marked S comes from Mšené-Lázně, Czech Republic, and was widely used in historical buildings on the Czech territory. C stands for concrete of class 15/20, which is commonly used for normal-strength elements. Fired clay brick as another representative of materials suitable for historical buildings is marked as FB. AC stands for autoclaved aerated concrete, which falls in the class P1.8, i.e., the minimal compressive strength of the blocks is supposed to be 1.8 MPa.

Table 1. The list of studied materials with their labels

Label	Material
S	Sandstone, Mšené-lázně
C	Normal strength concrete
FB	Fired clay brick
AC	Autoclaved aerated concrete P1.8 300

3. Experimental methods

3.1. Basic physical properties

Basic physical properties were characterized by bulk density ρ_v [kg m^{-3}], matrix density ρ_{mat} [kg m^{-3}] and total open porosity ψ_0 [%]. For the determination of these parameters water vacuum saturation method was used. The measurement was done on 50 x 50 x 50 mm samples. Each sample was dried in a drier to remove majority of the physically bound water. After that the samples were placed into a desiccator with deaired water. The specimen was then kept under water not less than 24 hours.

The water vacuum saturation method employs the Archimedes' principle for the determination of specimen volume. The difference between the weight of water saturated sample on the air, m_w, and the Archimedes weight, i.e., the weight of water saturated specimen fully immersed in water, m_a, is equal to the weight of water displaced by the whole volume of the specimen, V, which can then be determined from the equation

$$V = \frac{m_w - m_a}{\rho_l} \tag{1}$$

where ρ_l is the density of water. The open porosity, bulk density and matrix density are calculated according to the equations

$$\psi_0 = \frac{m_w - m_d}{V\rho_l} \tag{2}$$

$$\rho_v = \frac{m_d}{V} \tag{3}$$

$$\rho_{mat} = \frac{m_d}{(1-\psi_0)V} \tag{4}$$

3.2. Mechanical properties

Mechanical properties were characterized by compressive strength [MPa] and bending strength [MPa]. The compressive strength test was performed with the use of the testing device EU 40 and the procedure was done according to the EN standards [6-12].

3.3. Water vapour transport properties

For the determination of water vapour transport properties, the wet and dry cup methods were used. The obtained parameter was the water vapour diffusion resistance factor μ [-]. The cup for the wet cup method was filled with water, for the dry cup method it was filled with silica gel [13]. The experiment took place in a climatic chamber with 50% relative humidity. Steady state values of mass gain or mass loss determined by the linear regression over the last five readings were used for the calculation of water vapour diffusion properties. As the primary parameter, the water vapour diffusion permeability δ [s] was calculated as

$$\delta = \frac{\Delta m \cdot d}{S \cdot \tau \cdot \Delta p_p} \tag{5}$$

where Δm the amount of water vapour diffused through the sample [kg], d the sample thickness [m], S the specimen surface [m^2], τ the period of time corresponding to the transport of mass of water vapour Δm [s], Δp_p the difference between partial water vapour pressure in the air under and above specific specimen surface [Pa]. In an analogous way, the water vapour diffusion coefficient D [m^{2}s^{-1}] was determined,

$$D = \frac{\Delta m \cdot d \cdot R \cdot T}{S \cdot \tau \cdot M \cdot \Delta p_p} \tag{6}$$

where R is the universal gas constant, M the molar mass of water, and T the absolute temperature [K]. On the basis of the diffusion coefficient D, the water vapour diffusion resistance factor μ [-], which is the diffusion parameter most often used in the building practice, was calculated,

$$\mu = \frac{D_a}{D} \tag{7}$$

where D_a is the diffusion coefficient of water vapour in the air.

4. Experimental results and discussion

4.1. Basic physical properties

Table 1 summarizes the values of basic physical properties of studied materials. The bulk density and matrix density increased in time for all studied materials. However, the change in the particular values was within 6% for bulk density and 4% for matrix density, with the exception of matrix density of autoclaved aerated concrete, which rose by 13%. The values of open porosity also grew up, only in the case of concrete the open porosity decreased, which could be the result of continuing hydration of the cement gel. The biggest increase in open porosity was found for fired clay bricks, which was 10%.

Table 2. Basic physical properties of studied materials

Material	ref			4 years		
	ρ_v [kg m^{-3}]	ρ_{mat} [kg m^{-3}]	ψ_0 [%]	ρ_v [kg m^{-3}]	ρ_{mat} [kg m^{-3}]	ψ_0 [%]
S	1868	2618	28.7	1879	2638	29.7
C	2207	2601	15.5	2327	2670	13.3
FC	1831	2581	27.9	1858	2682	31.0
AC	289	2200	86.9	304	2531	87.9

4.2. Mechanical properties

Figure 1 presents the results of the compressive strength test. The fired clay bricks showed a decrease in strength by 10%. An increase of compressive strength was found for autoclaved aerated concrete – by 24%. Rise in the compressive strength values for normal concrete was by 4%, for sandstone by 8%.

The values of bending strength are presented in Figure 2. Again, fired clay bricks showed a decrease – by 9%. The increase of bending strength for sandstone was 7%, for normal concrete 15%. The bending strength of autoclaved aerated concrete increased by 20%.

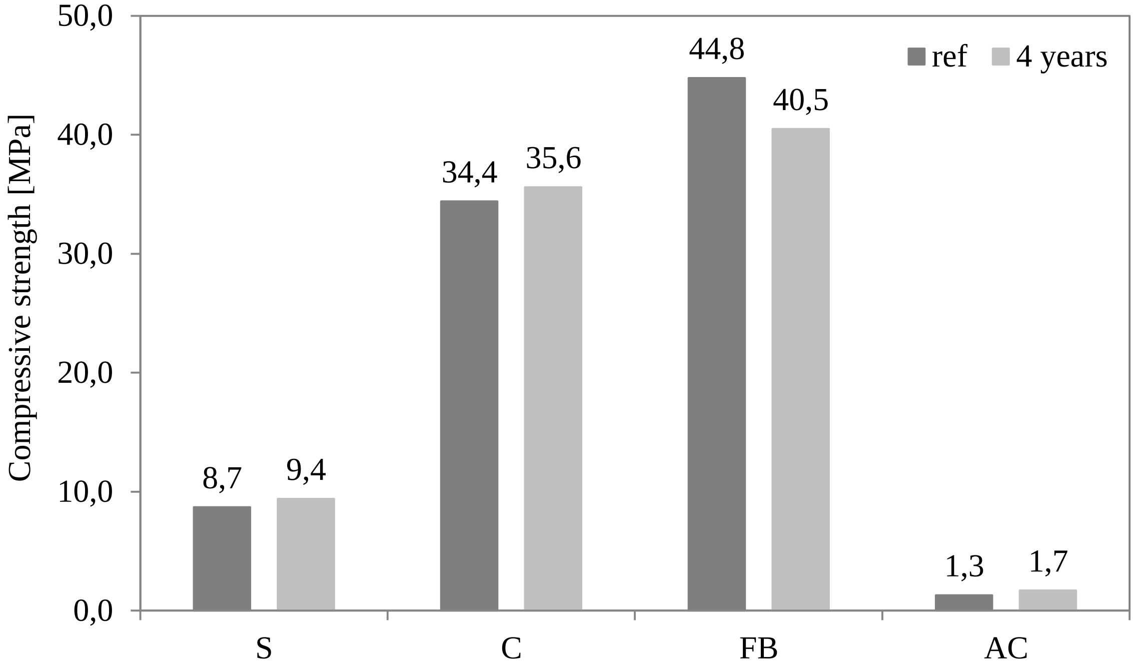

Figure 1. Compressive strength of studied materials

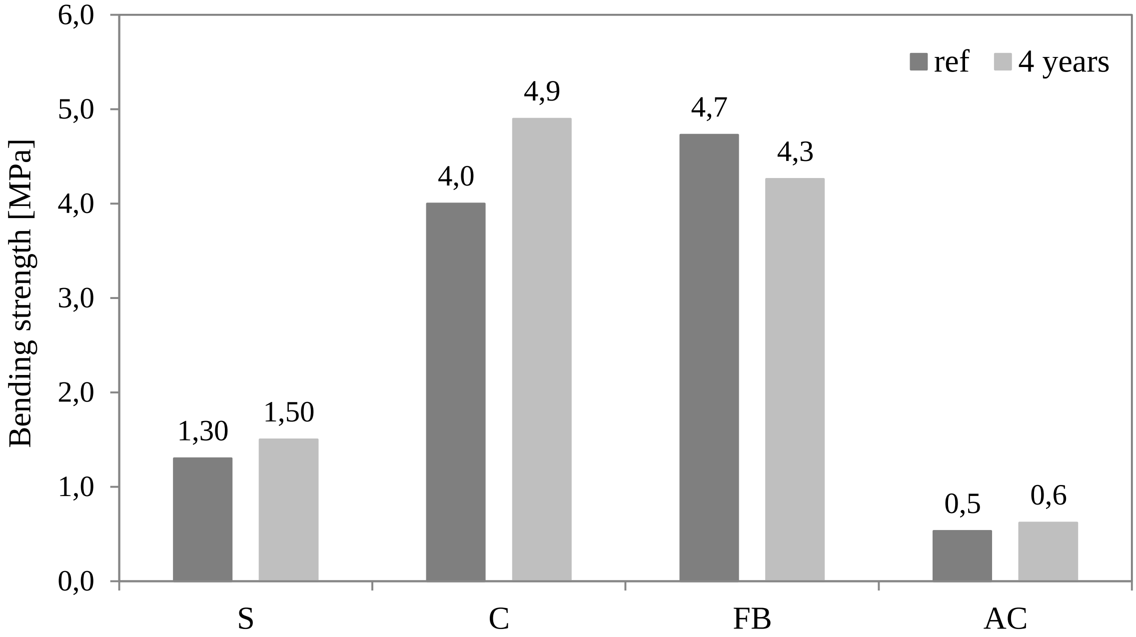

Figure 2. Bending strength of studied materials

IOP Conf. Series: Materials Science and Engineering **365** (2018) 032051 doi:10.1088/1757-899X/365/3/032051

4.3. Water vapour transport properties

Results of the measurement of water vapour transport properties are given in Figures 3 and 4. The ability of water vapour diffusion through all studied materials except for normal concrete rose in time, or in other words their resistance to water vapour transport decreased. The most significant drop in values of water vapour diffusion resistance factor (Figure 4) was recorded for brick, being by 50% (dry cup), followed by autoclaved aerated concrete and sandstone – by 25% (wet cup). For normal concrete the increase in water vapour diffusion resistance factor was up to 8% which was related, similarly to the open porosity and mechanical parameters, to the continuation of the hydration process.

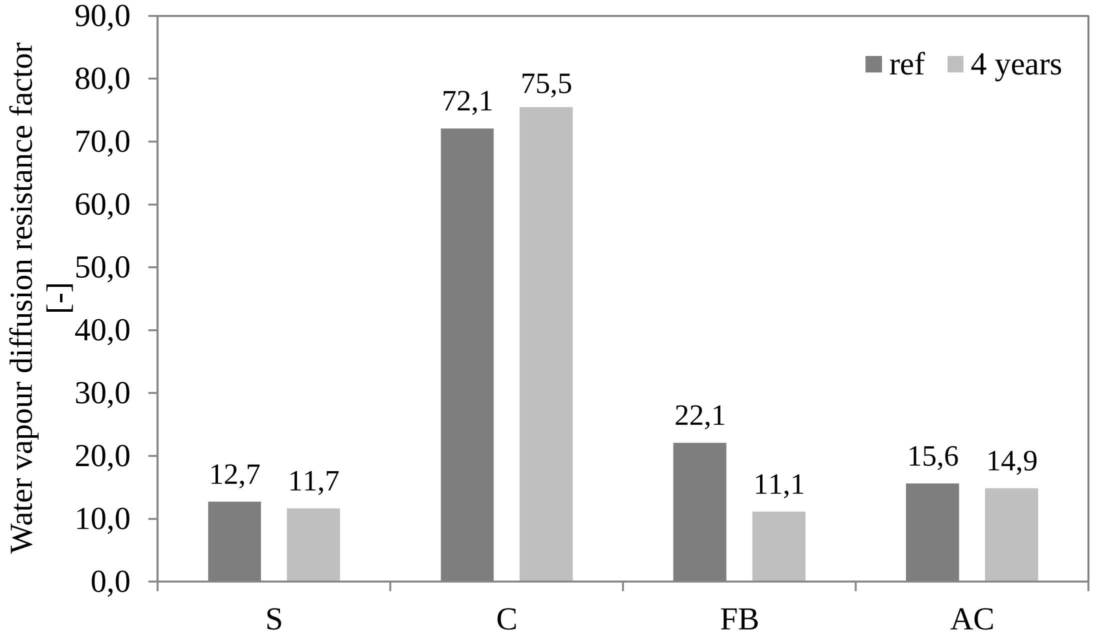

Figure 3. Water vapour diffusion resistance factor obtained by dry cup method

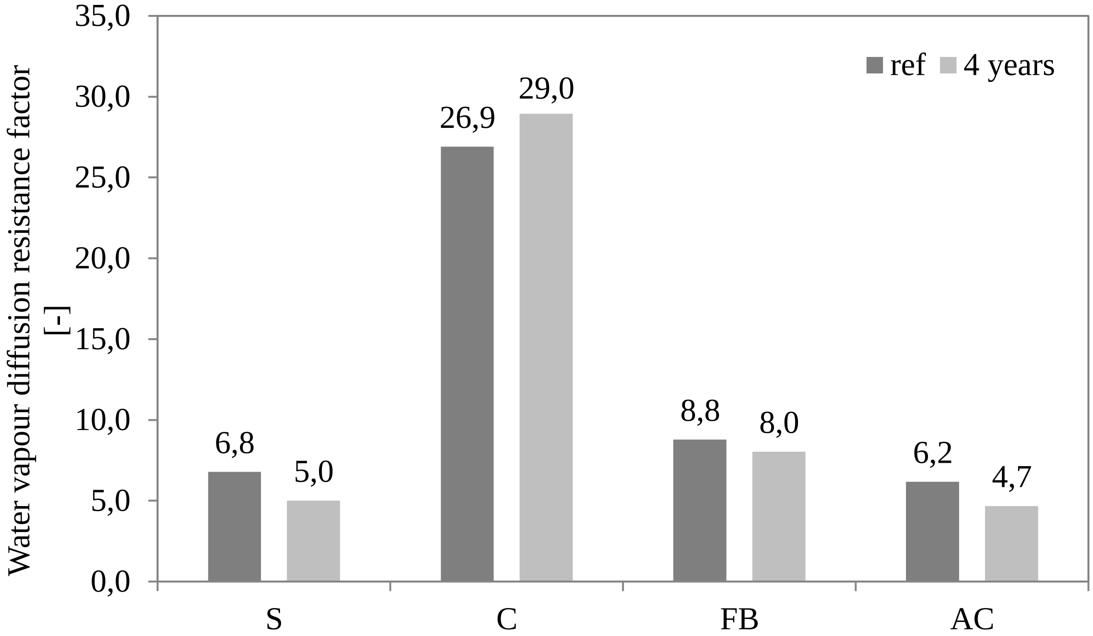

Figure 4. Water vapour diffusion resistance factor obtained by wet cup method

5. Conclusions

Durability of building materials is the essential parameter controlling the lifetime of all structures. The harmful effects of the external conditions cannot be avoided and therefore it is necessary for the building materials to withstand as much as possible. Four commonly used building materials were selected and left for four years on the outside environment in Prague, Czech Republic to suffer from weathering. The selected materials were sandstone, normal strength concrete, fired clay bricks and autoclaved aerated concrete. These were tested in terms of basic physical properties, mechanical properties and water vapour transport parameters. Experimental results showed increase in strength for all materials except from fired bricks, which values decrease was within 10%. The ability of water vapour diffusion rose in time for all materials except for normal strength concrete. The overall higher resistance of normal strength concrete to weathering, as compared to the other studied materials, was caused by the continuing hydration process in the cement gel.

Acknowledgments

This research has been supported partially by the Czech Science Foundation, under project No P105/12/G059, and partially by the Czech Technical University in Prague, under project No SGS16/199/OHK1/3T/11.

References

[1] Jerman M, Keppert M, Vyborny J and Cerny R 2013 *Constr Build.Mater* **41** 352–59
[2] Molina E, Benavente D, Sebastian E and Cultrone G 2015 *Eng Geol* **197** 67–81
[3] Mulvin L and Lewis J O 1994 *Build Environ* **29** 113–38
[4] Stefanidou M and Karozou A 2016 *Constr Build Mater* **111** 482–87
[5] Tang S W, Yao Y, Andrade C, and Li Z J 2015 *Cement Concrete Res* **78** 143–54
[6] ČSN EN 1926: 2007 *Natural stone test methods - Determination of uniaxial compressive strength* (Prague: Czech Standardization Institute)
[7] ČSN EN 12390-3: 2002 *Testing of hardened concrete – Part 3: Compressive strength* (Prague: Czech Standardization Institute)
[8] ČSN EN 1290-5: 2009 *Testing hardened concrete - Part 5: Flexural strength of test specimens* (Prague: Czech Standardization Institute)
[9] ČSN EN 772-1+A1: 2016 *Methods of test for masonry units – Part 1: Determination of compressive strength* (Prague: Czech Standardization Institute)
[10] ČSN 72 2605: 1979 *Testing of brick products. Determination of mechanical properties* (Prague: Czech Standardization Institute)
[11] ČSN EN 679: 2006 *Determination of the compressive strength of autoclaved aerated concrete* (Prague: Czech Standardization Institute)
[12] ČSN EN 1351: 1998 *Determination of flexural strength of autoclaved aerated concrete* (Prague: Czech Standardization Institute)
[13] EN ISO 12572: 2001 *Hygrothermal performance of building materials and products. Determination of water vapour transmission properties* (Prague: Czech Standardization Institute)