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Deterioration of Different Sandstones Due to Freeze-Thaw Cycling

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Abstract: Present paper deals with experimental study of four types of sandstones of different quarries. Sandstone is a traditional building material in Czech Republic with respect to the base of local raw materials. Significance of sandstones in current building industry is getting down, but their application is necessary in case of renovation and reconstructions of number of historical monuments. Properties of sandstones essentially differ on the basis of their quarry what determinates their practical utilization. That is why the paper is focused on the study of mechanical and durability properties of selected sandstones of four different quarries. In performed experimental program basic physical and mechanical parameters were studied, but the main aim of present paper was to evaluate frost resistance which was accompanied by non-destructive measurement by using of ultrasonic pulse method.

Keywords: Freeze-Thaw Cycling; Sandstone; Non-Destructive Testing; Mechanical Properties.

1 Introduction

Utilization of various types of rocks has a long tradition in the history of civil engineering. Particular rocks were chosen according to their properties and predominantly empiric experiences for selected application. Nowadays we can meet several types of rocks in the structure of number of historical buildings and monuments. In connection with protection and renovation of such structures it is necessary to keep the historical character and apply original materials.

Essential sense of historical structure has an application of sandstone in Czech country because of their easy workability and wide availability. Unfortunately lot of sandstones exhibit low resistance to impact of environment what is often causing necessity of severe reconstruction works. Besides unsatisfactory mechanical properties there are increased transport properties which are influenced by different composition and condition of sedimentation. High open porosity and permeability increase risks of corrosion processes especially of action of frost in porous structure. Mentioned parameters are determined by the lithification process of given sandstone, what is the fundamental reason of wide variability of sandstones' properties.

Labus et al. [1] studied petrographic properties, including structure, texture and porosity, after cycle weathering loading performed by insolation, rain and frost. As the most important factor of rock deterioration was considered the rock texture, especially character of grain contacts, effective porosity in fact. Dominant mechanism of sandstone destruction was granular disintegration and weight loss.

Zhang in [2] investigated properties of various sandstones in different moisture condition. Final properties were influenced by sandstone composition especially in case of clay-cemented ones. Compressive strength of full saturated specimens was reduced to 40 % of natural condition, on the other side flexural strength is increasing what caused better frost resistance. Present mechanism is probably caused by softening of surface layers in state of full saturation and cycle frost cycling. Described mechanism was observed in case of other porous materials with investigated resistance to environment [3–5].

2 Experimental Program

Performed experimental program was focused on the evaluation of four different sandstones quarried in the most commonly used locations which is shown in Tab. 1. Besides a basic physical property – bulk density, were

Tab. 1: Description of studied sandstones.

Sign	SS1	SS2	SS3	SS4
Location	Božanov	Beroun	Hořice	Dvůr Králové nad Labem

investigated flexural and compressive strength and frost resistance. Changing of properties was documented by using non-destructive ultra-sonic pulse method.

Compressive strength f_c was determined by using cubic specimens of 50 × 50 × 50 mm^3 in term of CSN EN 1926. Measurement was performed on the set of six specimens by using loading machine EU40. Testing was controlled by speed of loading which was set up to 1 MPa per second up to the destruction. Compressive strength was calculated according Hook's law on the base of maximum reached load.

Flexural strength f_{tm} measurement was organized as a four point test with supports distant of 150 mm according CSN EN 12372 and was calculated by help of the maximum reached force. Couple of loads of distance 40 mm was centered on the axis of the prism 40 × 40 × 200 mm^3. For this testing was used universal loading machine MTS 100 allowing to control experiment by the deformation speed which was set up to 0.2 mm/min.

The Proceq PunditLab+ ultrasonic velocity test instrument has been used to determinate the ultrasound speed v_L by 54 kHz transducer. Ultrasonic direct transmission is the most frequently used because in this arrangement, pulse amplitude reaching the receiving transducer is the highest [6]. The Proceq Type L Silver-Schmidt rebound hammer was used to determine the compressive strength measured nondestructively. Tentative values of dynamic modulus of elasticity were calculated according (1).

Determination of frost resistance was realized according to CSN EN 12371 [7] by using prismatic specimen described above. Testing is consisting of cycle temperature loading of saturated samples. Load cycle starts with frosting phase down to -18 °C lasting for three hours and then continues by defrosting period up to 20 °C for another three hours. Defrosting is realized by flooding of climatic chamber by water of 20 °C. Before frosting is chamber automatically drained what ensures full saturation of the specimens. Non-destructive measurement as well as visual evaluation was performed after prescribed cycles. Frost resistance is often expressed by ratio of final and original investigated values.

$$E_{dyn} = v_1^2 \cdot \rho \cdot \frac{1}{k^2} \cdot 10^{-6}. \tag{1}$$

where E_{dyn} is the dynamic modulus of elasticity [GPa], v_l is the velocity of the impuls [m/s], k is the coefficient of sample sizing [-], and ρ is the bulk density [kg/m^3].

3 Results and Discussion

Aim of performed program was to evaluate the frost resistance of different quarried sandstones. During described testing studied materials did not exhibit extensive destructive changes by used pulse method which successful application was confirmed in several research works [6, 8]. Essential influence of bulk density was confirmed what well documents evolution of modulus of elasticity during freeze-thaw cycling in Fig. 1. as well as original properties in Tab. 2. Sandstones of extreme values of bulk density (SS2 and SS3) exhibited also the most decreasing of modulus of elasticity which was on the level of 20-30 % what means coefficient of frost resistance below 0.8. Minimal limit of 0.8 is commonly used criterion for most of building materials in case of expression of durability [9]. It is very interesting that the major reduction was performed at the beginning of freeze-thaw cycling, another temperature cyclic loading did not effected the final values significantly. Although SS2 and SS3 reached the lowest level of resistance, there was not observed any visual exhibition of destruction.

Sandstones of common properties (SS1 and SS4) proved very encouraging results, coefficient of frost resistance 0.95 – 0.8 what passes generally established level. Deterioration of the above mentioned sandstones sets progressed gradually during course of testing. Behaviour of SS1 and SS4 is very similar because of similarity of their physical and mechanical properties. Action of frost is a specific way of degradation. Suitable durability properties of porous materials usually correspond with good mechanical properties, but lot of research works demonstrate quite opposite dependence in case of frost resistance [10].

Tab. 2: Properties of studied sandstones.

Sign	SS1	SS2	SS3	SS4
Bulk density [kg/m^3]	2170	2610	1970	2210
Compressive strength [MPa]	22.6	103.8	14.6	35.5
Flexural strength [MPa]	3.1	21.6	3.3	5.9
Dynamic modulus of elasticity [GPa]	20.2	80.3	22.6	19.3

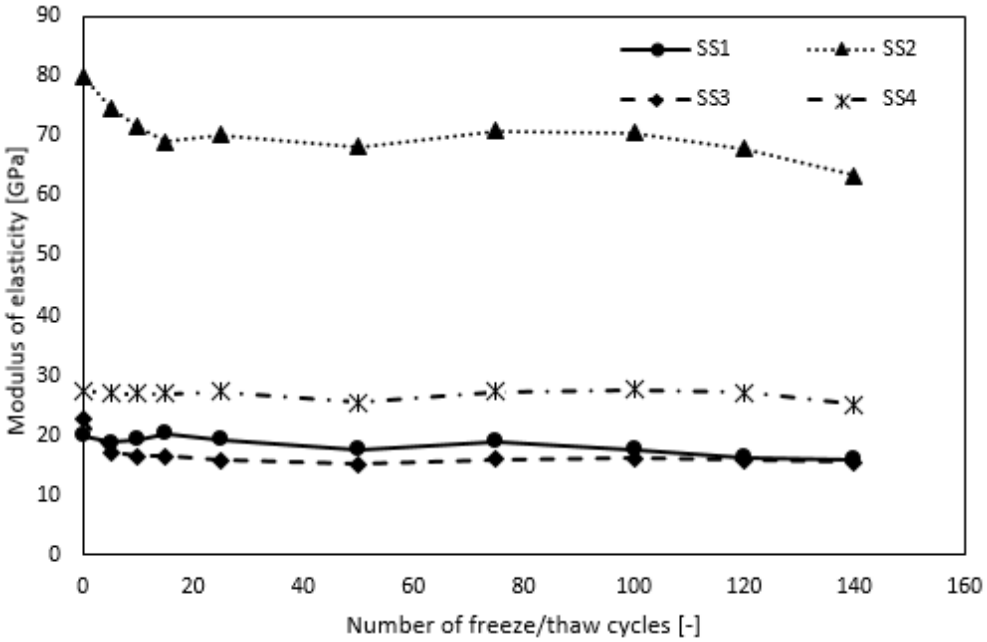

Fig. 1: Evolution of modulus of elasticity during freeze-thaw cycling.

4 Conclusion

In performed experimental program were evaluated four types of sandstones quarried in different locations. Scope of present research was to investigate frost resistance of studied sandstones what is important durability property of porous materials attacked by external environment. Motivation was to consider this crucial parameter in relation to protection and preservation of historical structures and monuments often made of various types of sandstones.

In real condition structural sandstone is often attacked by other types of degradation processes, especially caused by recrystallization of salts [11]. Unlike of salt action deterioration caused by frost is not realized on the surface but pervade through entire element. It could be reason of sudden collapse of sandstone structure. That is why non-destructive measurement of modulus of elasticity was ranked into the experimental program. Studied rocks are considered as homogenous materials but they properties are often affected by layered structure determined by its origin. Ultrasound pulse method is commonly applied to investigating of soft structural changes in materials and it is suitable for such focused experimental program. Also it is often applied for consideration of actual state of building structures. Course of NDT measurement during freeze-thaw cycling exhibited different impact on the way of destruction with respect to original properties of studied sandstones. Paradoxical sandstone of the highest mechanical parameters evinced the highest rate of deterioration due to weathering. Total decrease of dynamic modulus of elasticity reach the rate of 78 % after 140 load cycles, continuing reduction of observed parameter is expectable. Other sandstone samples did not reach so extensive decrease, after just about 15 load cycles are values of dynamic modulus of elasticity stabilized.

Present noticeable differences in final properties of studied sandstones were caused predominantly by diverse internal structure of individual sandstone. It is very important to evaluate parameters of commonly used building materials with regard to durability. Progressive deterioration of sandstone reduces life-time of the structure as well as its visual quality.

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