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BURNING EFFECT ON SANDSTONES OF HISTORIC BUILDINGS AND THEIR PETROPHYSICAL AND MINERALOGICAL STUDIES

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Abstract

Historical monuments have always been in the centre of scientific interest. Natural disasters like fire can strongly damage or may even ruin these ancient buildings. Fire disaster related changes in the petrological and petrophysical properties of the building materials can often lead to stability problems.

Historical monuments built of sandstone were studied. The results of the petrological, petrophysical and thermal analyses often highlight the behaviour of the supporting structures exposed to fire. Sandstones with different cement types may show different fire resistance. The comparison of the results can provide useful information when replacing historical stone material, or when one has to choose the suitable restoring method for the damaged building part.

Keywords: historical monuments, fire-resistance, sandstone, burning effect, petrophysics.

1. Introduction

Natural stones have been used as a construction material since prehistoric time. The knowledge of mechanical properties of natural stones is fundamental for conservation and replacement of the building stones of the monuments. In addition, it serves as a basis for the development of conserving materials and for structural calculations.

Sandstones are one of the most widespread building stones albeit our knowledge is rather limited in terms of their mechanical behaviour in extreme conditions (e.g. in fire). Sandstones show a great variety in their particles (size and mineralogy) and cement type, which all influence their weather and heat resistance. The aim of this study is to examine the material properties and fire resistance of sandstones as building materials. The results can be directly implemented in the conservation work of monuments: stone replacement, static calculations of damaged structures, etc.

During historic times, many stone buildings were demolished by fire or sustained several lasting damages. The research of these damages is very problematic, especially in the case of historic buildings. A well-known example for that is the Frauenkirche (Church of our Lady) in Dresden, but many other monuments built of various stones could have been mentioned as well.

The Frauenkirche in Dresden was constructed from sandstone of the Elbe region and it belonged to the town picture as an architectural masterpiece and as a church for 200 years. In February, 1945 due to war bombardments the church was in flames for many hours, while on the 15th of February the dome collapsed (WENZEL, 1993). The reason of this damage was the approximate 1000 – 2000°C heat effect. Due to the flames and the high temperature inside the building, the sandstone has suffered peel-like separations causing damages of the supporting structure. The church itself will be now rebuilt. When rebuilding fire-damaged monuments it is possible to use also burnt stone blocks for sparing the quantity of the necessary stone material. In this care one should know the features of the burnt stone blocks and investigation of the whole structure depending on the circumstances of the rebuilding.

Another very important result of the examinations could be that the changes expected in a potential fire event should be reckoned with not only in the case of reconstruction of old, fire damaged buildings but also in the case of designing and measuring new stone buildings. So it is possible to calculate the risk incurred with stone buildings.

These studies form a part of the Ph. D. project 'Fire-resistance of sandstones', carried out at the Technical University of Budapest, Department of Engineering Geology, partly in co-operation with the University of Karlsruhe, Mineralogical Institute, Germany.

2. Sandstone Types

Sandstones with different cement types were chosen since they probably behave differently in fire. Due to the co-operation between the Technical University of Budapest and University of Karlsruhe 7 types of German sandstones were studied. Some of these sandstones were investigated also by GRIMM (1990).

- Cottaer Sandstone (pale grey, fine-grained, kaolinitic-illitic, Lower Turonian – Cretaceous)
- Donzdorfer Sandstone (yellowish grey, fine-grained, ferrigenous clayey, Middle Jurassic)
- Maulbronner Sandstone (reddish grey, fine-grained, clayey, Middle Keuper – Upper Triassic)
- Pfinztaler Sandstone (reddish, fine-grained, Triassic)
- Pliezhausener Sandstone (white, coarse-grained, dolomitic, Middle Keuper – Upper Triassic)
- Postaer Sandstone (whitish yellow, coarse-grained, siliceous-kaolinitic, Upper Turonian – Cretaceous)
- Rohrschacher Sandstone (grey, fine-grained, calcareous, Molasse)

Furthermore 3 Hungarian sandstones were analysed for comparison:

- Balatonrendes Sandstone (reddish, fine-grained, ferrigenous clayey, Permian)

– Ezüsthegy Sandstone (white, fine-grained, kaolinitic, Oligocene)

– Rezi Sandstone (greenish grey, medium-grained, Pannonian)

3. Test Conditions

From the sandstone blocks coming from quarries 40 mm diameter cylinder-shaped specimens were drilled. The specimens were burnt in an oven at 6 different temperatures (150, 300, 450, 600, 750, 900°C) for 6 hours. Under natural circumstances fire is a sudden, quick heat-effect, so warming up took 1 hour and after burning the specimens cooled down slowly in the oven.

The fire damaged sandstone buildings are standing in open air and mostly have lost their roofs as well. Therefore those are significantly effected by weathering. Since the injured stone material is exposed more intensively to the natural effects, it appeared to be practical to test the burnt samples under water saturated conditions, and after 25 freezing cycles. The test conditions were as follows:

– room temperature, air dry (22°C)

– room temperature, water saturated

– room temperature, after 25 freezing cycles

– burnt at different temperatures, air dry (150, 300, 450, 600, 750, 900°C)

– burnt at different temperatures, then water saturated

– burnt at different temperatures, then after 25 freezing cycles

As smaller quantities of the Cottaer, Donzdorfer and Pliezhausener sandstones were available, no tests were carried out on samples burnt at 150°C, after burning water saturated and frozen.

On account of the article's limited size I show my results only on an example of each sandstone type in the next points.

4. Petrological Analyses

The petrological analyses of different sandstones in different thermal states (room temperature and burnt) involved the description of thin sections by polarising microscope, X-ray diffractometry test, and few samples were studied by scanning electron mi

croscope. These tests inform us about the changes of mineralogical composition and structure of the sandstones under different test conditions.

4.1. Thin Sections Analyses

From the sandstones thin sections were made before and after burning. The changes of the internal structure and the minerals were analysed by polarising microscope, and the most characteristic textures were documented on photographs. By increasing heat in the internal structure we can observe increase of porosity of various size at the different sandstone types, at some places we can find cracks at minerals contacts or even inside of the minerals. Significant changes are generally shown in the cement material (*Fig. 1*).

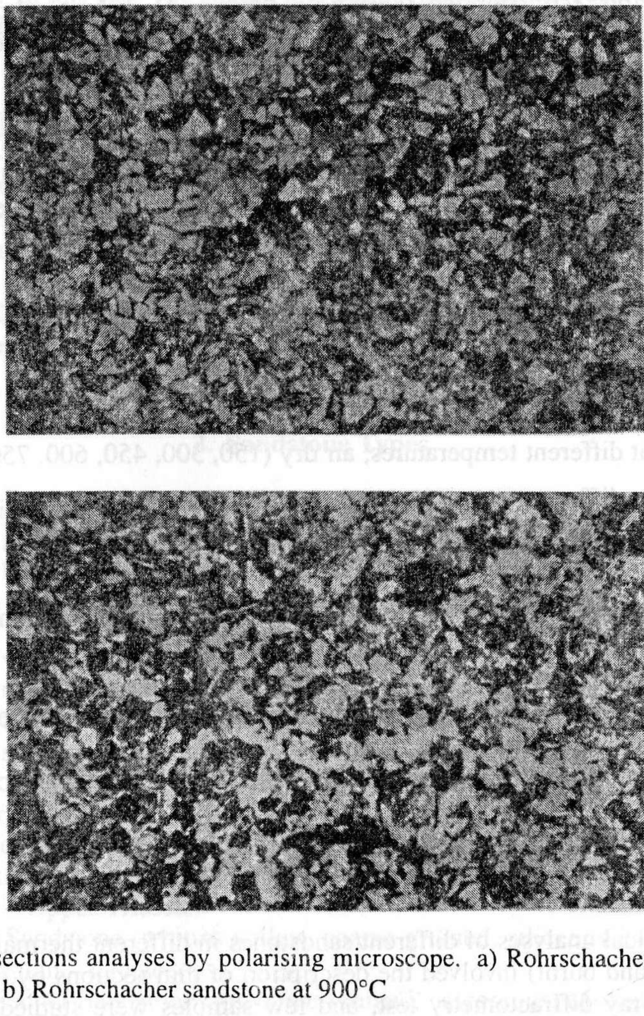

Fig. 1. Thin sections analyses by polarising microscope. a) Rohrschacher sandstone, at 22°C; b) Rohrschacher sandstone at 900°C

In the sandstones the following minerals are found: quartz, feldspars, clay minerals, micas. Among them quartz, feldspars and micas do not show any changes even at 900°C. In contrast clay minerals are increasingly destroyed above 450°C temperature.

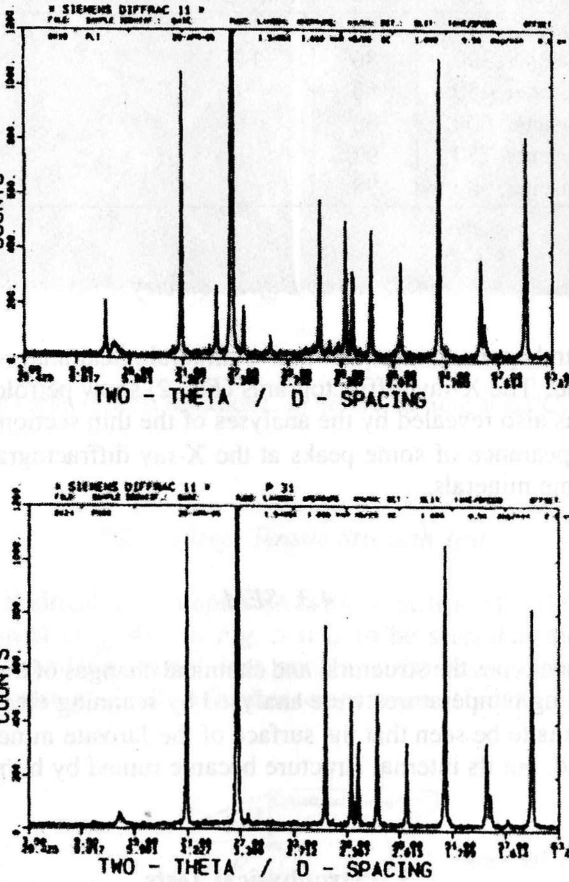

Fig. 2. X-ray diffractograms of Pliezhausener sandstone. a) before burning at 22°C; b) after burning at 900°C

Figure 1a shows the original internal structure of Rohrschacher sandstone with carbonate cement material coming from the region of Lake Boden. In *Fig. 1b* it is to be seen that cement material has discoloured and some cracks appear at the grain boundary. *Table 1* includes changes of the mineralogical composition of Pliezhausener sandstone by increasing burning heat. Quartz and feldspars do not suffer any damage, but kaolinite and dolomite gradually disappear at higher temperature.

Similar changes can be observed also at the other sandstone types.

Table 1. Mineralogical composition of Pliezhausener sandstone types (22 – 900°C)

Burning temperature	Minerals [%]			
[°C]	Quartz	Kaolinite	Plagioclases	Dolomite
Pliezhausener, 22	80	14	4	2
Pliezhausener, 300	86	11	2	2
Pliezhausener, 450	88	9	2	2
Pliezhausener, 600	98	~0	2	1
Pliezhausener, 750	97	–	3	–
Pliezhausener, 900	98	–	2	–

4.2. X-ray Diffractometry

For qualitative and approaching quantitative mineralogical analyses X-ray diffractometry was used. The X-ray diffractograms (*Fig. 2*) show petrological changes of the sandstones as also revealed by the analyses of the thin sections.

The disappearance of some peaks at the X-ray diffractograms points to the damaging of some minerals.

4.3. SEM

At some sandstone types the structural and chemical changes of the cement material at different burning temperatures were analysed by scanning electron microscope

In *Fig. 3* it is to be seen that the surface of the Jarosite mineral in the cement material survived, but its internal structure became ruined by burning effect.

5. Petrophysical Tests

Petrological and petrophysical analyses demonstrated how the cement material and the structure of the stone components changed due to heating and how it influenced strength and durability.

5.1. Mass Properties

At different testing stages specific and bulk density, porosity, water adsorption and ultrasonic sound velocity were measured.

Fig. 3. Cement material of Rezi sandstone. a) before burning at 22°C; b) after burning at 900°C

5.2. Indirect Tensile Strength Test

For the tests cylindrical 1:1 samples (ALFES – SCHIESSL, 1994) of 40 mm in diameter were used (*Fig. 4*). In *Fig. 5* it is to be seen that the indirect tensile strength of the 4 sandstone types does not show significant changes up to 450°C and starts to decrease gradually at higher temperature (HAJPÁL, 1995).

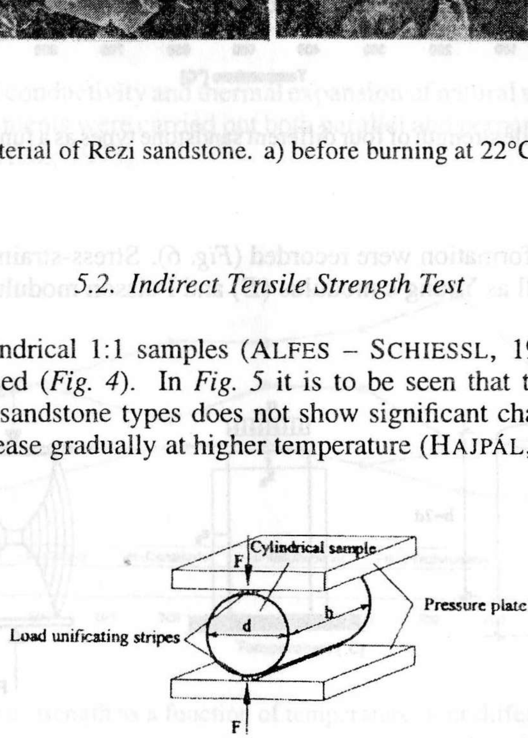

Fig. 4. Test configuration of indirect tensile strength measurements (ALFES – SCHIESSL, 1994)

5.3. Uniaxial Compressive Strength Test

For the compressive strength tests cylindrical 2:1 samples of 40 mm in diameter were drilled parallel and perpendicular to bedding. Besides the load, the longitudinal

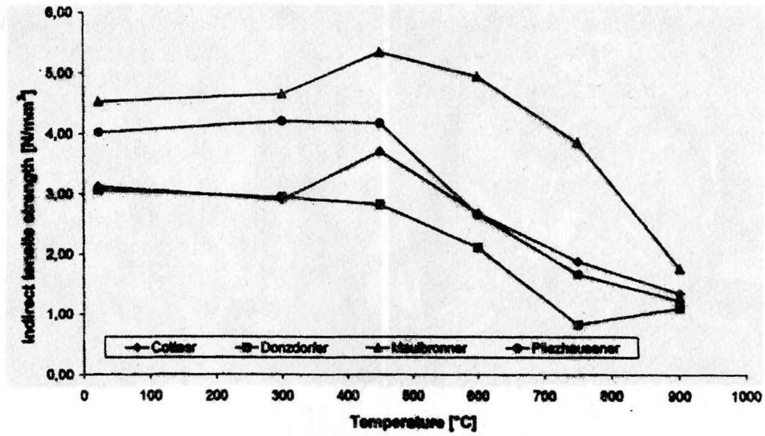

Fig. 5. Indirect tensile strength of four different sandstone types as a function of temperature

and transversal deformation were recorded (*Fig. 6*). Stress-strain ($\sigma - \varepsilon$) diagrams were drawn as well as Young's modulus (E) and Poisson modulus were calculated (HAJPÁL, 1995).

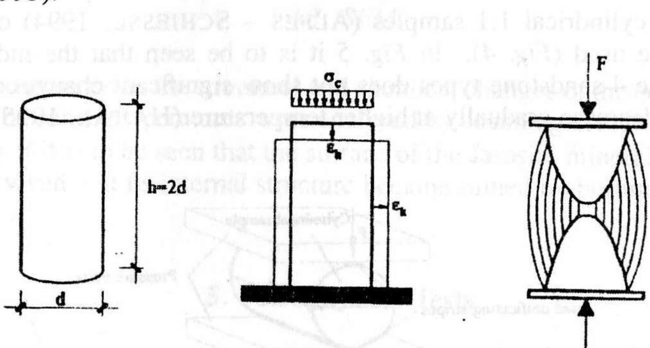

Fig. 6. Longitudinal and transversal deformations and the compressive strength test (EGERER – KERTÉSZ, 1993)

Unlike the tensile strength, no significant general changes were observed as a function of temperature (*Fig. 7*). The situation is not so unambiguous as in the indirect tensile strength test. The effect of the burning and the following strength decrease cannot be recorded. Even more, at the Maulbronner sandstone with the clayey cement the strength increased at 750°C once and a half the starting compressive strength, and even at 900° C had the same value as the non burnt samples (HAJPÁL, 1996).

6. Thermal Analyses

According to the Hungarian (MSz 595/2) and German Standards, natural stones are classified as 'non combustible' materials. However, it does not mean that their inner structure would not change with an increase of temperature. Three major parameters can be used for the description of these changes:

- specific heat
- thermal conductivity
- thermal expansion

The thermal conductivity and thermal expansion of natural stones are anisotropic, therefore measurements were carried out both parallel and perpendicular to bedding (EGERER – KERTÉSZ, 1993).

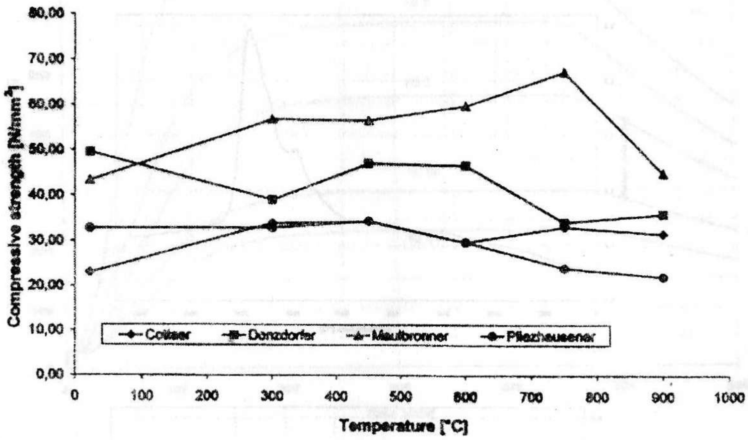

Fig. 7. Compressive strength as a function of temperature, four different sandstone types

6.1. Specific Heat

For the measurement of specific heat a calorimeter is used. A rock sample is placed into the calorimeter and the temperature of the calorimeter is measured as a function of time.

It can be observed in *Fig. 8* that specific heat can be rather different for the various sandstone types.

6.2. *Thermal Conductivity*

The inner side of the isolated rock sample is heated which creates a thermal gradient between the inner and outer side of the sample (*Fig. 9*).

Figure 10 shows the measured temperatures at the thermoelements during an experiment.

7. Finite Element Modelling

Up to the present, fire resistance was analysed only on small samples, but it i3s necessary to evaluate the load bearing capacity of larger stone structures such as walls, pillars, etc. Therefore the effect of fire on structures is planned to be studied. To obtain better results, a sandstone wall structure will be examined with the aid of a FEM software.

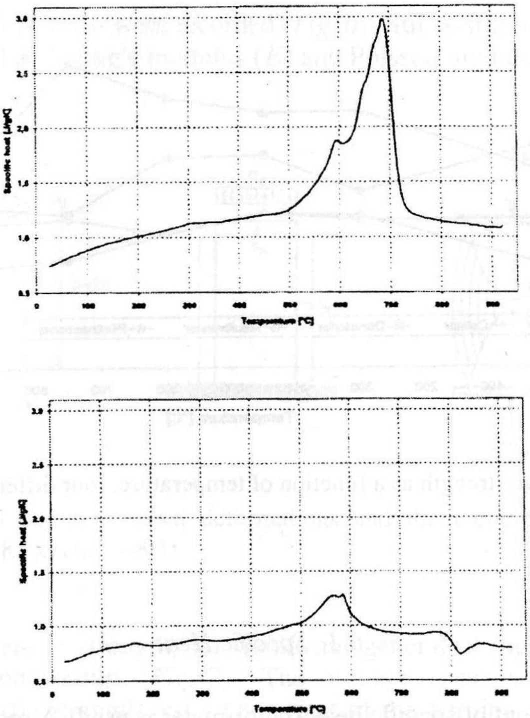

Fig. 8. Specific heat of Balatonrendes sandstone as a function of the temperature. a) Balatonrendes sandstone; b) Maulbronner sandstone

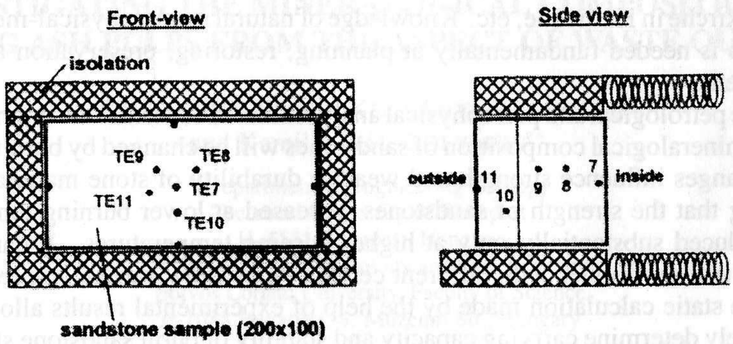

Fig. 9. Test apparatus for measuring the thermal conductivity of rocks

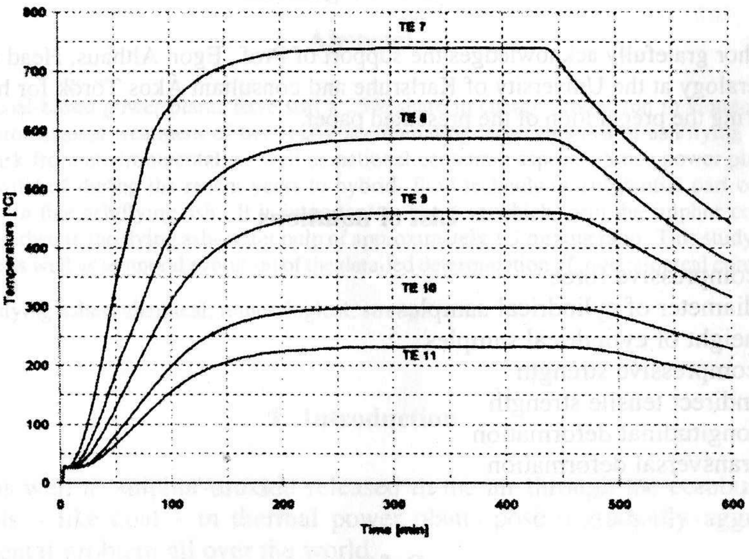

Fig. 10. Temperature distribution by the different thermoelements in the Postaer sandstone

8. Conclusions

Damages of natural stone historical monuments can have different reasons produced, e.g. by crumbling, environment pollution, faulty building care, natural disaster and war effect. A historical monument can be damaged by a big fire so much that their stability can be endangered. Petrophysical changes due to burning effect often decrease the carrying capacity of structure.

There are a lot of examples for the catastrophic aftermath, e.g. Frauenkirche in Dresden, Castle of Hohenrechberg, Monastery of Lobenfeld, Castle of Heidelberg, Stephanskirche in Karlsruhe, etc. Knowledge of natural stones physical-mechanical properties is needed fundamentally at planning, restoring, preservation and stone replacement.

The petrological and petrophysical analyses have shown that the internal structure and mineralogical composition of sandstones will be changed by burning effect. These changes influence strength and weather durability of stone material. It was surprising that the strength of sandstones increased at lower burning temperature and it reduced substantially only at higher burning temperatures. It can be also observed that sandstones with different cement types show various fire resistace.

The static calculation made by the help of experimental results allows to approximately determine carrying capacity and stability of burnt sandstone structures.

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List of notations

F compressive force
d diameter of cylindrical samples
h height of cylindrical samples
σ_c compressive strength
σ_t indirect tensile strength
ε_h longitudinal deformation
ε_k transversal deformation

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