PETROPHYSICAL AND MINERALOGICAL STUDIES OF BURNT SANDSTONES

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SUMMARY

Historical monuments have always been in the centre of scientific interest. Natural disasters like fire can strongly damage or even may 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 refer to 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 one have to choose the suitable restoring method for the damaged building part.

Keywords: historical monuments, fire-resistance, sandstone

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 exchange 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 the sense of mechanical behaviour in extreme conditions (e.g. in fire). Sandstones show great varieties in their particles (size and mineralogy) and cement type, which all influence their weathering- 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 exchange, static calculations of damaged structures, etc.

During historic times, many stone buildings were demolished by fire or sustained several permanent damages. The research of these damages is very problematic, especially in case of historic buildings. A well-known example for that is the Frauenkirche (Church of

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our Lady) in Dresden, but many other monuments built of various stones could have been mentioned as well.

The Faruenkirche in Dresden was constructed from Elbaer sandstone 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 expected changes in a potential fire event should be reckoned with not only in case of rebuilding old, fire damaged buildings but also in case of designing and measuring new stone buildings. So it is possible to calculate the risk undertaking in case of stone buildings.

These studies form a part of a Ph. D. project has been carried on "Fire-resistance of sandstones". The research at the Technical University of Budapest, Department of Engineering Geology and has been prepared partly in co-operation with the University of Karlsruhe, Mineralogical Institute, Germany.

2. ANALYTICAL METHODS OF SANDSTONES

2.1 Sandstone types

Sandstones with different cement types were chosen since they probably behave differently against fire. Due to the co-operation between TUB and University of Karlsruhe 7 types of German sandstones were studied (Grimm 1990):

- Cottaer Sandstone (fine-grained, kaolinitic-illitic, Lower Turonian-Cretaceous)
- Donzdorfer Sandstone (fine-grained, ferrigenous clayey, Middle Jurassic)
- Maulbronner Sandstone (fine-grained, clayey, Middle Keuper-Upper Triassic)
- Pfinztaler Sandstone (fine-grained, Triassic)
- Pliezhausener Sandstone (coarse-grained, dolomitic, Middle Keuper)
- Postaer Sandstone (coarse-fine-grained, siliceous-kaolinitic, Upper Turonian)
- Rohrschacher Sandstone (fine-grained, limy, 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)

2.2 Test conditions

From the sandstone blocks coming from quarries 40 mm diameter cylinder-shaped specimens were made. The specimens were burnt in an oven at 6 different temperatures (150, 300, 450, 600, 750, 900 °C) for 6 hours. In the nature 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 sandstone buildings suffered burn injuries 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 samples also after burning in a water saturated condition, 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 cycle
- burnt on different temperature, air dry (150, 300, 450, 600, 750, 900 °C)
- burnt on different temperature, then water saturated
- burnt on different temperature, then after 25 freezing cycle

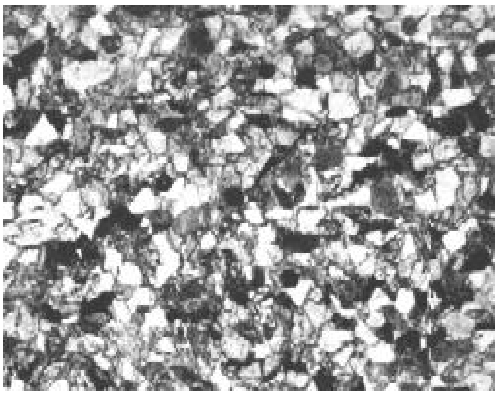
Smaller quantity of the Cottaer, Donzdorfer and Pliezhausener sandstones were available as a consequence no tests were carried out at 150 °C burning, after burning with water saturated and freezing. On account of the articles limited scale I show my results only at one kind of sandstone type in the next points.

2.3 Petrological analyses

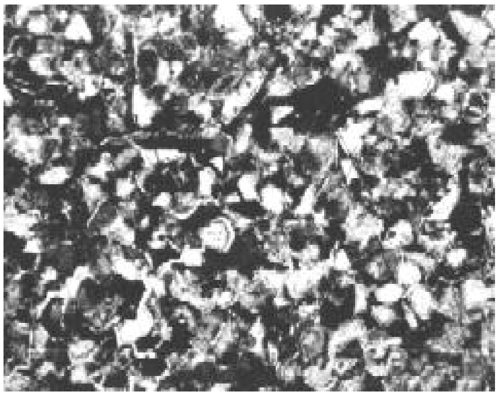
The petrological analyses of different sandstones in different thermal states (room temperature and burnt) involved the description of thin sections by polarising microscope, X-ray diffractometry test and few samples were studied by scanning electron microscope. These tests inform us about the changes of mineralogical composition and structure of the sandstones at various test stages.

2.3.1 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. In the internal structure by increasing heat 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.). 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 900 °C. In the contrary clay minerals are increasingly destroyed above 450 °C temperature.



a) Rohrschacher sandstone, at 22 °C



b) Rohrschacher sandstone at 900 °C

Fig.1 Thin sections analyses by polarising microscope

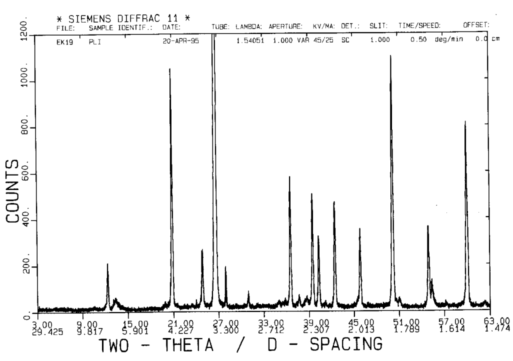
Fig.1. show how internal structure of Rohrschacher sandstone of limy cement material coming from the country Lake Boden changed. In the b) picture it is to be seen that cement material has discoloured and some cracks appear at the grain boundary. Tab.1. includes changes of the mineralogical composition 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 like with the examples shown formerly.

Burning temperature [°C]	**Minerals [%]**			
	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	-

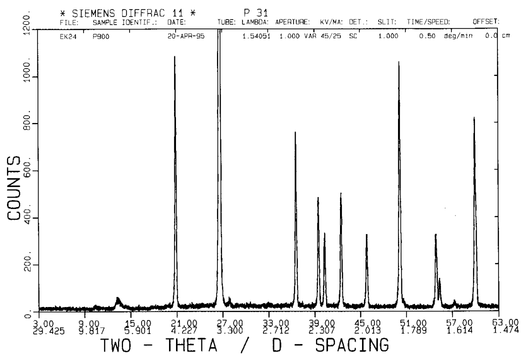
Tab. 1 Mineralogical composition of Pliezhausener sandstone types (22-900 °C)

2.3.2 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 it was also revealed by the analyses of the thin sections.



a) before burning at 22 °C



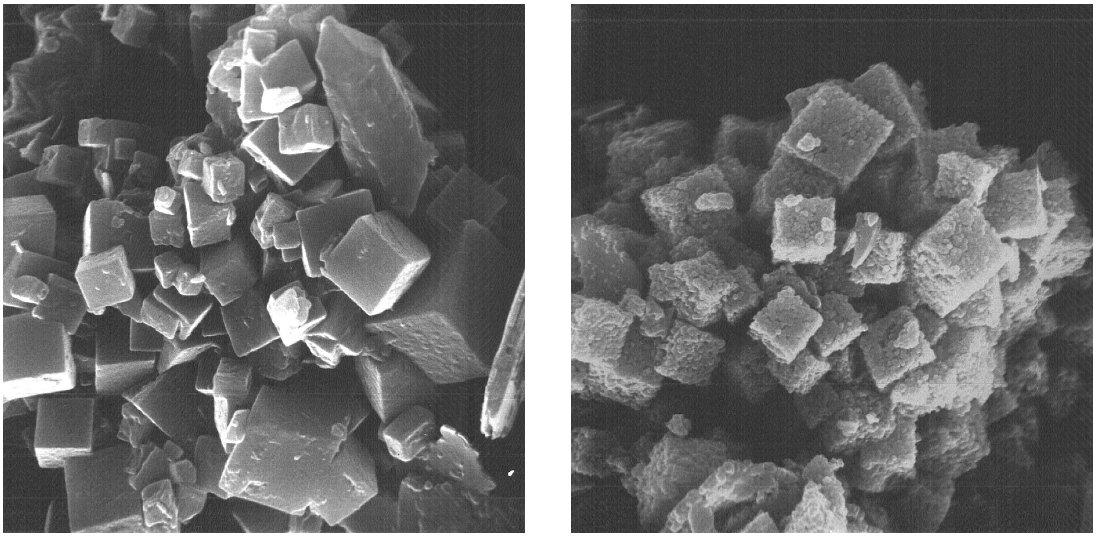
b) after burning on 900 °C

Fig.2 Diffractogram of Pliezhausener sandstone

The disappearance of some peaks at the X-ray diffractograms point to the demaging of some minerals.

2. 3. 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



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

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

2.4 Petrophysical tests

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

2.4.1 Mass properties

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

2.4.2 Indirect tensile strength test

For the tests cylindrical 1:1 samples of 40 mm in diameter were used (Alfes-Schiessl 1994.). In Fig.4. 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 start to decrease gradually at higher temperature.

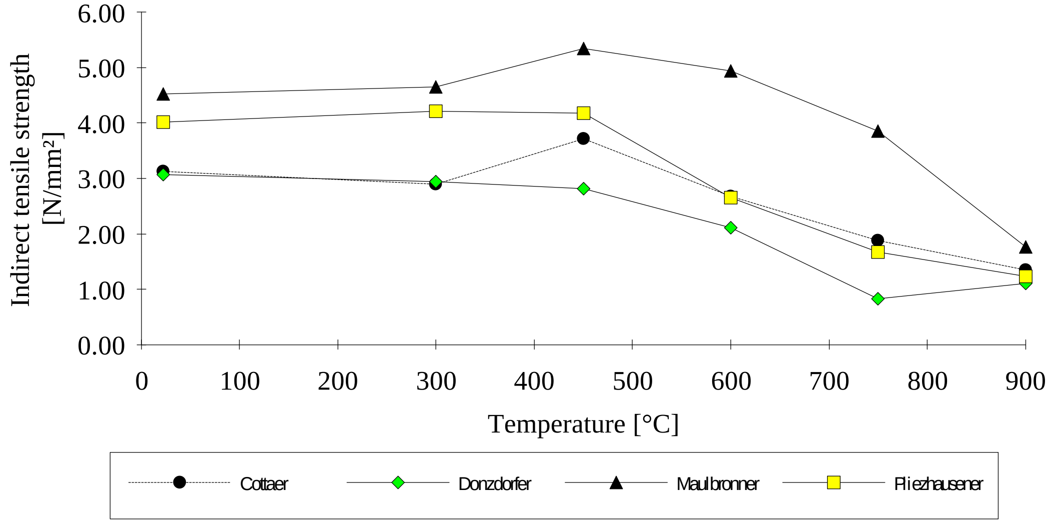


Fig. 4 Indirect tensile strength as a function of temperature by four different sandstone types

2.4.3 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 and transversal deformation were recorded. Stress-strain (σ–ε) diagrams were drawn as well as Young's modulus (E) and Poisson modulus were calculated (Hajpál 1995).

Contrary to the tensile strength, no significant general changes were observed as a function of temperature (Fig. 5.). The situation is not so unambigous than by indirect tensile strength test. The effect of the burning and the following strength decrease can not be recorded. What is more, at the Maulbronner sandstone with the clayey cement the strength is increased at 750 °C and half as much at 900 °C having the same value as the non burnt samples.

2.5 Thermal analyses

According to the Hungarian (MSz 595/2) and German Standards, the natural stones are ranged as "non combustible" materials. However it does not mean that their inner structure would not change by 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.)

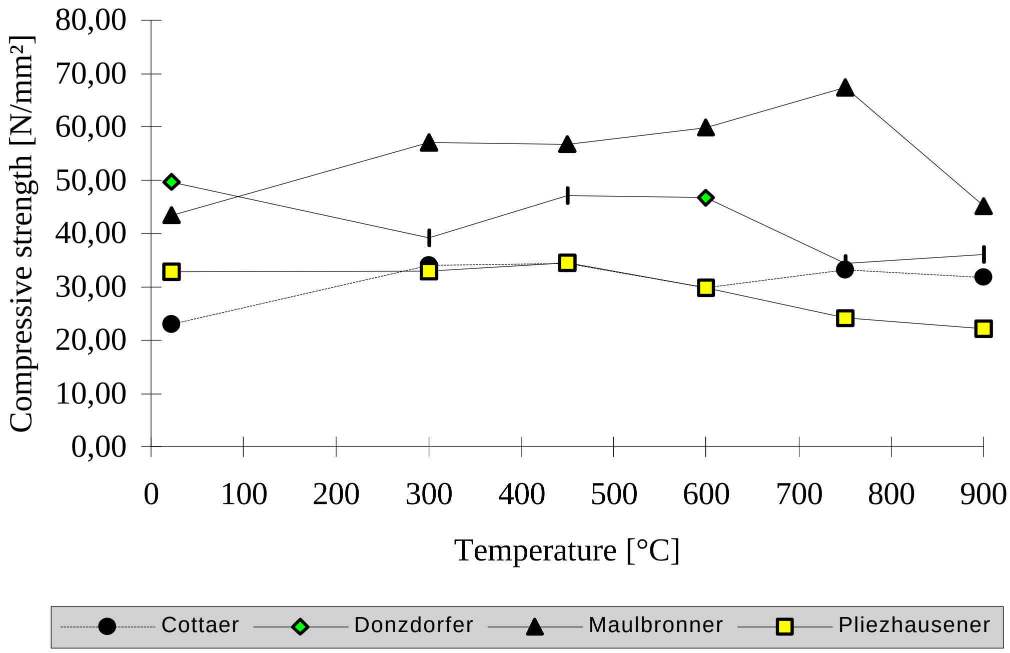
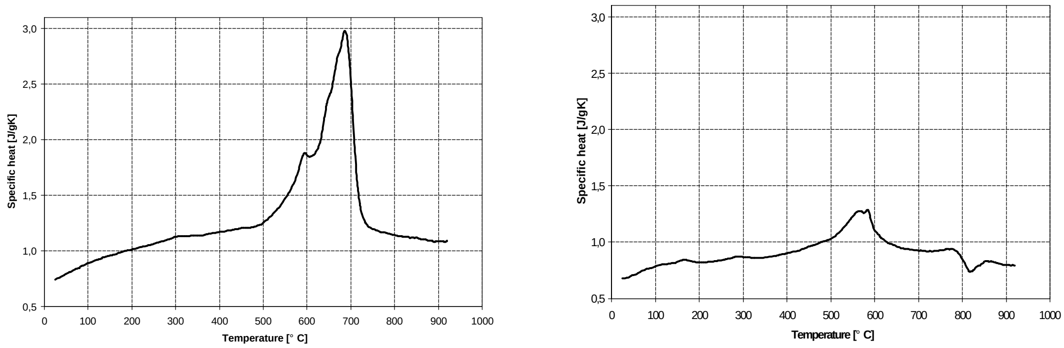


Fig. 5 Compressive strength as a function of temperature, four different sandstone types

2.5.1 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 the Fig.6. how different specific heat can be at different sandstone types.



a) by Balatonrendes sandstone *b) by Maulbronner sandstone*

Fig. 6 Specific heat as a function the temperature by Balatonrendes sandstone

2.5.2 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. 7.). Fig.8. shows the measured temperatures at the thermoelements during an experiment.

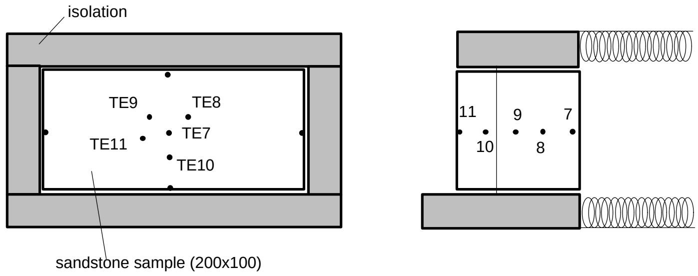


Fig. 7 Test apparatus for measuring the thermal conductivity of rocks

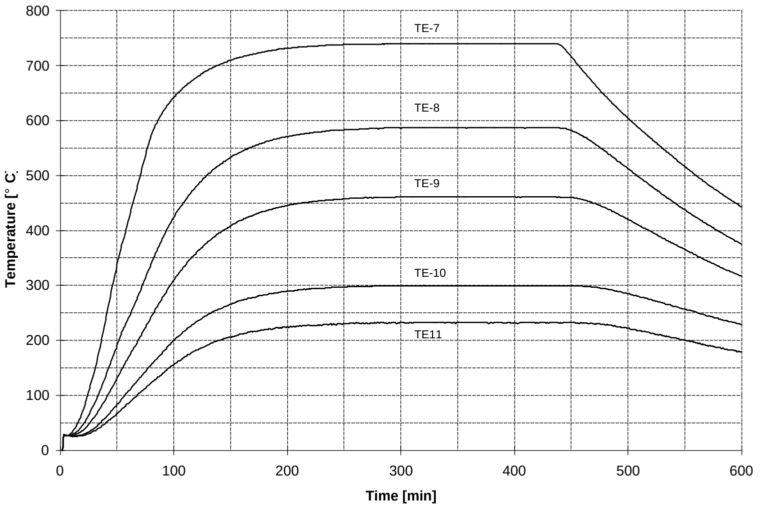


Fig. 8 Temperature distribution by the different thermoelements in the Postaer sandstone

2.6 Finite element modelling

Up to the present, the fire resistance was analysed only on small samples, but it is 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 structures will be examined with the aid of a FEM software.

3. CONCLUSIONS

Damages of natural stone historical monuments can have different reasons produced e.g. 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. By burning effect arising petrophysical changing often decrease the carrying capacity of structure. There are a lot of example for the catastrophic aftermathes e.g. Frauenkirche in Dresden, Castle of Hohenrechberg, Monastery of Lobenfeld, Castle of Heidelberg, Stephanskirche in Karlsruhe, etc. The knowledge on physical-mechanical properties of natural stones is needed fundamentally at planning, restoring, preservation and stone exchange. The petrological and petrophysical analysis have shown that the internal structure and mineralogical composition of sandstones will be changed by burning effect. These changes influence the 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 temperature. It can also be observed that sandstones of different cement types show various features to fire. The static calculation made by the help of experimental results make it possible to determine approximately carrying capacity and stability of burnt sandstone structures.

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