Chapter 7.3

THE BEHAVIOUR OF NATURAL BUILDING STONES BY HEAT EFFECT

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Abstract: This paper deals with the effect that fire or high temperature has on natural stone. A lot of historic buildings have suffered fires, either accidentally or from warfare. This topic had not received much attention till the latest time. In case of fires all attention was focused on protection of human lives and the damage to historic buildings was only addressed subsequently. Studies like the present one try to convince authorities to solve the problem for the conservation of burnt built stone heritage.

Key words: fire; natural stone; high temperature; petrological and petrophysical changes.

1. INTRODUCTION

Fortunately in the recent time the topic of the historical monuments (preservation, reconstruction, etc.) came more and more in the focus of the scientific interest[1,2,3]. Also the every-day-people are much more interested in these questions. This is also due to the fact that more attention has been continuously paid in all possible sources in newspapers and TV-programs and so on. It is known that also in previous centuries a lot of fire occurred, which caused significant cultural loss of built heritage. A number of ancient buildings have suffered from the effects of fire – only during 1992 as follows:

- Odd Fellow Palace, Copenhagen
- Proveant Garden, Copenhagen
- Christianborg Palace Church, Copenhagen
- Windsor Castle, Berkshire, England
- Redoutensal, Hofburg Palace, Vienna

These and other major incidents are well known, since they were published in the world press. Of course some other samples could be mentioned, like:

S.K. Kourkoulis (ed.), Fracture and Failure of Natural Building Stones, 439–445.

- Hampton Court, England (1986)
- Theatre “La Fenice”, Venezia (1996)
- Cathedral of Torino “Sacra Sindone”, Torino (1997)
- St. Michael Church, Budapest (1998)
- Church “dell’Assunta”, Cavalese, Trento (2003)

The loss of historical monuments damaged by fire was the theme on some international conferences and other events (e.g. COST C17 Action, some intergovernmental bilateral project like Hungarian-Portuguese and Hungarian-Spanish).

The fire protection of the building of the built heritage hs not been worked out well enough. In many cases just the monument’s nature makes the installation of efficient fire-fighting equipment more difficult or even impossible. However, the prevention of fire must have much higher priority for both the building and the contents of the building (e.g. furniture) since they are, also, part of the cultural heritage. It is inevitable that the normal fire fighting is concentrated on life safety, but the historical monuments need a special treatment, as well. In case of a monument, besides the direct damage, the fire causes an extra harm because one cannot actually substitute the injured parts. Special fire-fighting methods for the monuments would have to be worked out because in many cases the traditional way of fire fighting may cause such damages as the fire itself.

The measure of damage caused by fire depends on many factors. Among these there are some such material properties, which are hardly known yet. Since determining these properties and their changes due to high temperature is a complex problem, reaching detailed results demands lot of work and time.

2. MATERIALS AND METHODS

Initially the area of the present research project was the investigation of the behaviour of natural stones by heat effect[1-4]. On this field only few results existed. That’s why at the beginning one dealt with sandstones due to their simple structure. For the time being the research is expanded for other stone types as well. In addition, coarse, freshwater and compact limestones, rhyolittuff are studied. Finally one should examine also marble and granite in the future. These are the stone types, which were the mostly used as building stones at historical monuments.

The signs of damage of former fires e.g. changes in colour, spalling, rounding off the corners, cracking, etc. were gathered, because they play a significant role in dating the stone elements or even the entire building. The injured stone material is exposed more intensively to the natural effects.

The effect of fire has been studied on cylinder-shaped specimens, which were drilled parallel and perpendicular to bedding. The specimens were heated in an oven at 6 different temperatures (150, 300, 450, 600, 750, 900 °C). The different test conditions were as follows: by room temperature (22 °C) air dry, water saturated and after 25 freezing cycle, burnt on different temperature air dry, water saturated and after 25 freezing cycle. The petrological (polarizing microscope, X-ray, SEM) and petrophysical (density, porosity, water adsorption, ultrasonic sound velocity, duroskop rebound, uniaxial compressive and indirect tensile strength, colour measurement) investigations have shown that heating changes the texture and mineral composition of various stone types. These changes influence the strength and durability of stone material.

3. INVESTIGATIONS AND RESULTS

The damage of natural stone building materials by heat effect was studied in terms of the physical phenomena involved. The heating produces not only colour changes at the stone materials but also influences their petrological and petro-physical properties, like inner texture, porosity, water adsorption, strength, hardness, weather resistance.

3.1 Petrological results

The mineralogical alteration stages[5] which could be associated to the heat analyses are the following: the minerals remain unaltered, formation of new mineral phases and disappearance of minerals.

Quartz and K-feldspar do not show significant alteration up to 900 °C, however the transformation of a-quartz to b-quartz associated with a volume increases. Another visible change in quartz and feldspar grains is the development of micro-cracks in grains and at grain boundaries above 600 °C.

Clay minerals and phyllosilicates are more sensitive to heat and show several transformations at elevated temperatures. The kaolinite structure collapses completely at around 550 °C. Illite-smectite mixed layer clay minerals are more stable than kaolinite. Illite can be still detected at 900 °C, although it looses the structural water (dehydroxylation) at 553 °C.

Besides mineralogical changes a colour change may also indicate the transformation of a clay mineral. For example glauconite will be orange (at 450 °C) and finally will become brownish red (at 900 °C). Another example is chlorite, which shows a colour change from green (at 22 °C) to yellow (at 900 °C) most probable due to the oxidation of iron (II) to iron (III).

In thin sections the first damages of calcite were detected at 450 °C, but major mineral transformation are only visible after heating at 600 °C. At 750 °C the collapse of the calcite structure is significant and easy to visualise under an optical microscope. At 900 °C the calcite and dolomite decompose to form CaO and MgO. Leaving the samples at room temperature induce the appearance of a new mineral phase, portlandite $Ca(OH)_2$, from the reaction that has been previously reported for limestones. The formation of portlandite is associated with volume increase and leads to the disintegration of heated cylindrical samples. In dolomite majority this kind of portlandite reaction was not observed, although the carbonate phase disappeared above 750 °C.

Goethite or jarosite (iron-bearing minerals) only show alteration at elevated temperatures. At 900 °C a new mineral phase, haematite, appears and both goethite and jarosite disappear. The heat resistant haematite is the final reaction product of any iron-bearing oxy-hydroxide at elevated temperatures.

3.2 Petrophysical results

Heat-related changes in mineralogy induce changes in physical properties of natural stones. In general, by increasing the temperature the bulk density decreases above 450 °C. Porosity has an opposite trend and the increasing will be remarkable also above 450 °C (Figure 1).

Figures 1-4 show the changes of some petrophysical properties as result of the heating. At heating on 450 °C and 600 °C some of the compact limestone samples are exploded and at elevated temperature (750, 900 °C) any samples decayed so it was impossible to use them. The coarse and freshwater limestone shows the portlandite reaction and also the disintegration of the limestone samples after higher heating temperature (600, 750, 900 °C) as well. The ultrasonic sound velocity is similar for all stone types: it decreases with increasing heating temperature (Figure 2).

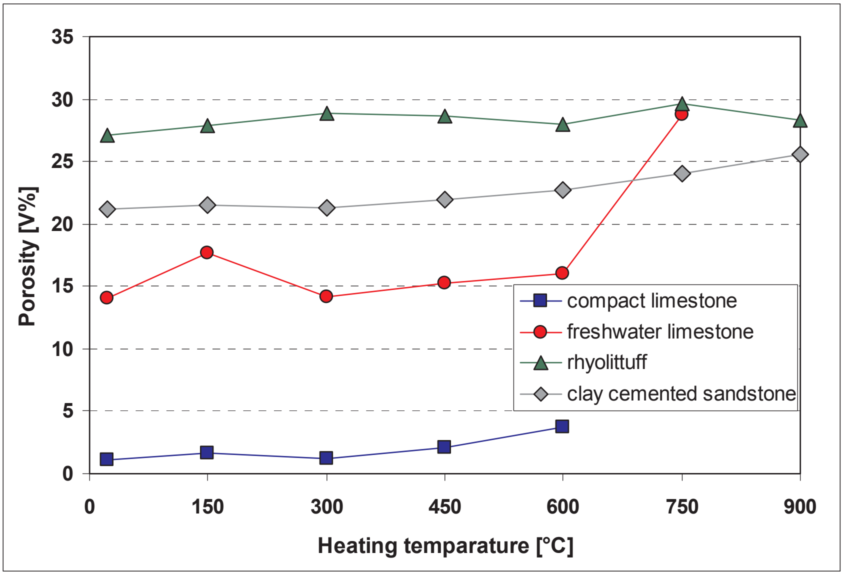

Figure 1. Porosity of different natural stone types as a function of heating temperature.

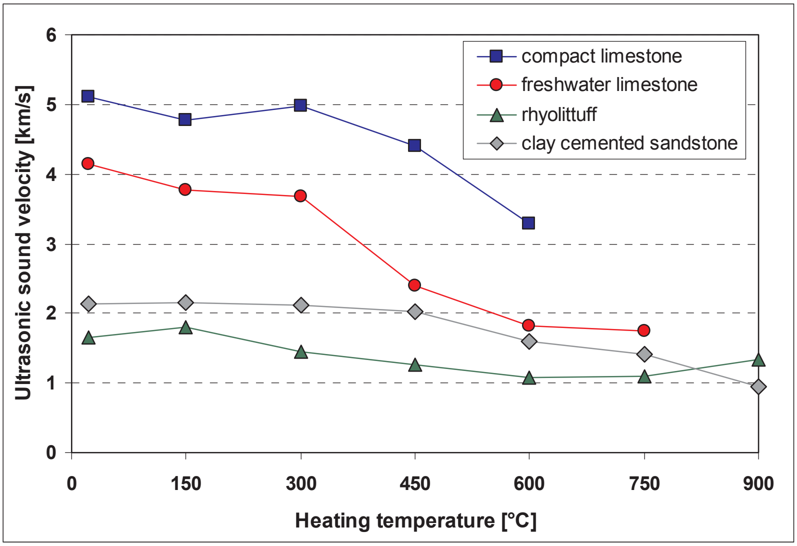

Figure 2. Ultrasound velocities for different natural stone types as a function of heating temperature.

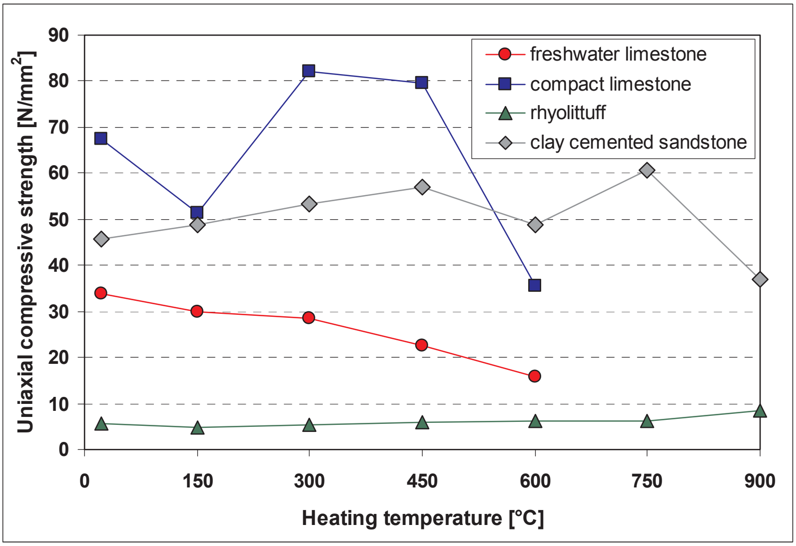

Figure 3. Uniaxial compressive strength of different natural stone types as a function of heating temperature.

The changes in indirect tensile strength and uniaxial compressive strength are not so uniform. The clay cemented sandstone and the rhyolittuff show an increase in uniaxial compressive strength with increasing the heating temperature. Limestones respond in a more sensitive manner to heat effect: they are characterised by a decrease in strength with increasing temperature (Figures 3, 4).

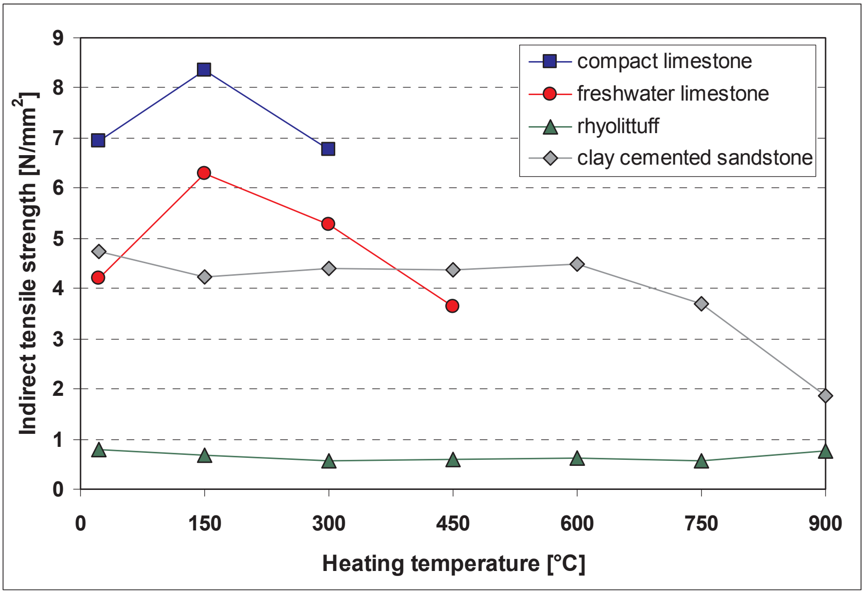

Figure 4. Indirect tensile strength of different natural stone types as a function of heating temperature.

After a fire, structures are exposed and thus weathering begins. In this study, some heat exposed specimens were water saturated before tested and also subjected to 25 freeze-thaw cycles.

All stone types show more or less colour changing due to the heating. For most of them the measured colour values show a positive shift from green towards red with increasing temperature, e.g. sandstones become more reddish after heating. This colour change is mostly attributed to the iron-bearing minerals.

4. CONCLUSIONS

The mineralogical composition and texture of natural stones significantly influence their resistance to fire and thermal changes. The heat resistance of different stone types depends on the type and amount of cementing material (grain/cement ratio), the grain size (fine, medium, coarse) and the grain to grain or matrix to grain contacts.

The investigated natural stone specimens showed textural and mineralogical changes during the laboratory heating tests carried out. The changes were mainly observed at elevated temperature. Some mineral transformations result to a volumetric increase, which generates thermal expansions cracks in stone. This effect can be responsible for the increase in porosity and the decrease in strength.

The clay containing stones are more resistant to heat as the calcareous types. The best properties are showed by the fine-grained matrix-rich sandstone and the rhyolittuff.

It is very important to continue this research, because the results could be applied in many fields. For example it was observed that the use of cold extinguishing water at the fire fighting is very harmful for the stone parts of the historical monuments and it can cause damages in the stone structure, which can lead to stability problems. The observations and the results of the present research contribute to the better knowledge of the mechanical properties of natural stones, something which is fundamental for conservation and restoration of the building stones. In addition, it can serve as a basis for the development of conserving materials as well as for structural calculations.

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