FIRE DAMAGE OF STONE STRUCTURES

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INTRODUCTION

Nowadays mostly the historic buildings are built of stone, they have also stone structural elements, the modern buildings contains only stone parts (embellishment, floor-plate). Natural stones were frequently used as building material in our historical monuments due to their advantageous properties.

Stone buildings were damaged by fire from ancient times until quite recently. In the stone material the fire causes irreversible changes, which influence the strength and static behaviour of the whole monument.

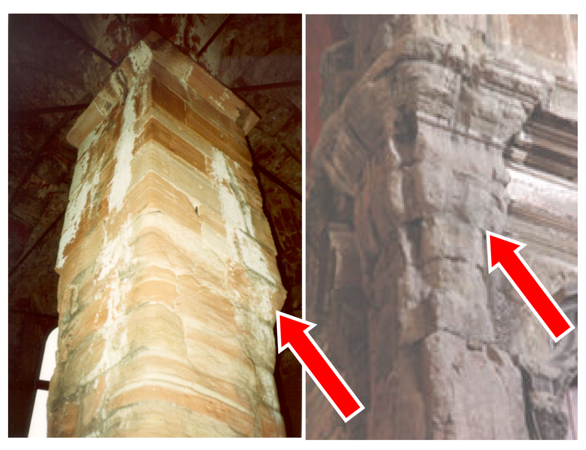
Some fires at the end of 20th century brought attention to the severe damage that fires can cause to historic buildings and their building stones:

- *York Minster (1984)*
- *Hampton Court Palace (1986)*
- *Chiado, Lisbon, Portugal (1988)*
- *Uppark House, England (1989)*
- *Katarina Church, Stockholm Sweden (1990)*
- *Windsor Castle, England (1992)*
- *Odd Fellow Palace, Copenhagen (1992)*
- *St. Michaels Church in Newquay (1993)*
- *Redoutensal, Hofburg Palace, Vienna, Austria (1992)*
- *Theatre "La Fenice", Venezia (1996)*
- *Cathedral of Torino "Sacra Sindone", Torino (1997)*
- *St. Michael Church, Budapest (1998)*

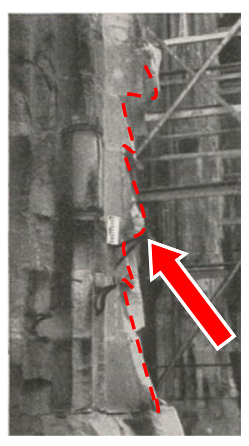
DECAYS, TRACE OF FORMER FIRES

The measure of damage caused by fire depends on many factors. The changes at the natural stones could be influenced by the burning circumstances, e.g. is the heating one-sided or more-sided, homogenous or heterogeneous, the size of the burned stone, velocity of heating, the maximum burning temperature, stone type and its characteristics.

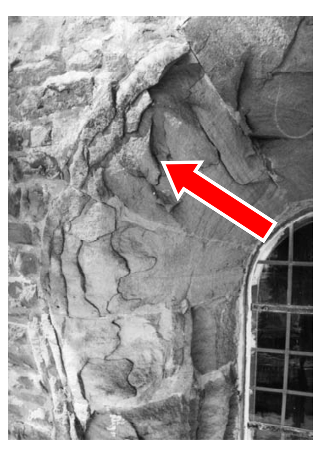
Colour changing



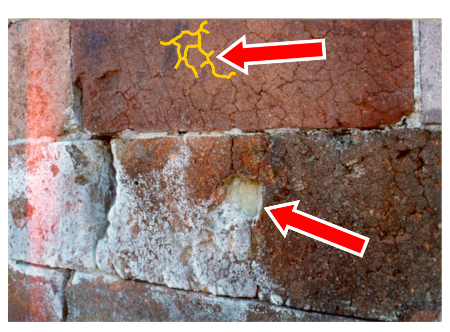
Rounding edges



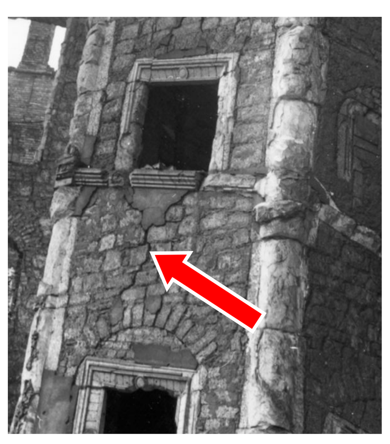
Breaking



Spalling



Incrusting, crazing



Cracking

The colour changes in natural stones almost corresponds to the dehydration of iron compounds. Heat causes the development of a pink or reddish-brown colouration in brown or buff-colour. The colour changes start at a temperature of 200-300°C in most rocks and it may not be apparent until a somewhat higher temperature. By big stoneblocks is a sharp boundary between the heated, red-coloured stone surface and the unaltered stone behind. This zone has a width about 2-3 cm or less. Some stones contain a small amount of organic substance, which occur that the grey colour covering the red one.

Other significant kinds of decay of stones by burning are cracking, shattering, scaling, spalling, which completely destroy the richer carved forms of architecture and damages the smoother forms. They are often so badly spoiled that they have to be replaced by new ones.

The process of scaling and spalling is continued during the fire, therefore the strength of the stone is surpassed and a bursting of the hot outer part is forced and the rock peels like an onion.

Rounding off the edges can occur if there is an edge the heat can work from two sides. This form of decay is regularly seen on steps, pillars and window-heads.

Breaking is typical where single parts are jutting out of a plane. It heat up more quickly and burst off easier, since the stresses find the way out more quickly.

INVESTIGATED STONE TYPES

SANDSTONES

Balatonrendes (V) – reddish, fine grain, ferruginous-clayey, Permian
Ezüsthegy (E) – white, fine grain, kaolinitic, Oligocene
Rezi (R) – greenish, medium grain, jarositic, Pannonian
Cottaer (C) – greyish, fine grain, kaolinitic-illitic, Cretaceous
Donzdorfer (Dd) – ochre, fine grain, ferrigenous clayey, Jurassic
Maulbronner (M) – reddish grey, fine grain, clayey, Triassic
Pfinztaler (Pf) – greyish red, medium grain, chlorite, Triassic
Pliezhausener (Pli) – yellowish white, medium grain, dolomitic, Triassic
Postaer (Po) – off-white, medium grain, siliceous, Cretaceous
Rohrschacher (B) – grey, fine grain, calcareous, Miocene Molasse

LIMESTONES

Tardos compact (T) – red, pelagic, microbioclastic wackestone, Jurassic
Süttő travertine (F) – creamy, bioclastic wackestone to peloidal oncoidal packstone
Sóskút oolitic (D) – coarse grain, Miocene

RHYOLITE TUFF

Egertihamér (Rt) – grey white, Miocene

The selected stone types showed a wide range of their feature (colour, grain size, cement type, age, rock constituent minerals, porosity, strength). This compositional variation enables us to achieve a better understanding of how such properties influence the behaviour of natural stones under heat.

INVESTIGATION METHODS

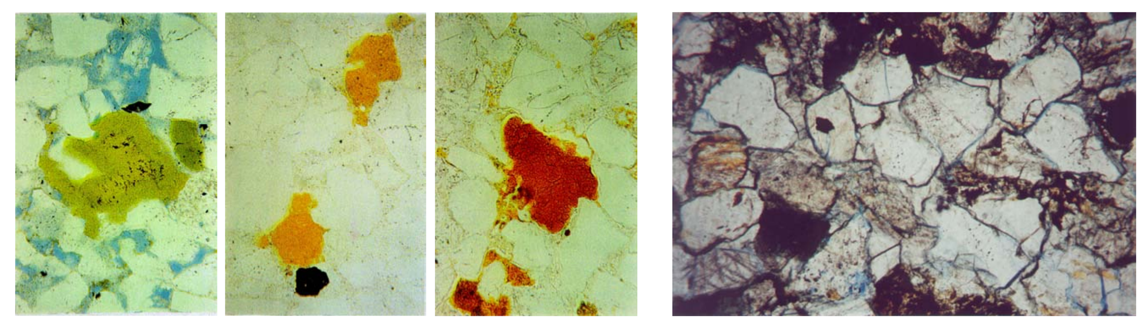
- Test conditions, heating in oven 6 hours 6 temperature (22, 150, 300, 450, 600, 750, 900°C)
- Makroscopical investigation
- Petrological analyses
  - Thin sections analyses with Polarising microscope
  - X-ray Powder Diffraktion (XRD)
  - Differential Thermal Analyses (DTA)
  - Scanning Electron Microscope (SEM)
- Petrophysical test
  - Mass properties (specific and bulk density, porosity, water adsorption)
  - Ultrasonic sound velocity, Duroskop
  - Uniaxial compressive strength test
  - Indirect tensile strength test
  - Colour measuring (CIELAB)

These curves were used in SAFIR to find the temperature evolutions on each of the exposed profiles, without fire protection. On the beams the fire was applied on three sides (the top being protected by the concrete slab). In the mechanical analysis, the collaboration between the steel beam and the concrete slab was not considered.

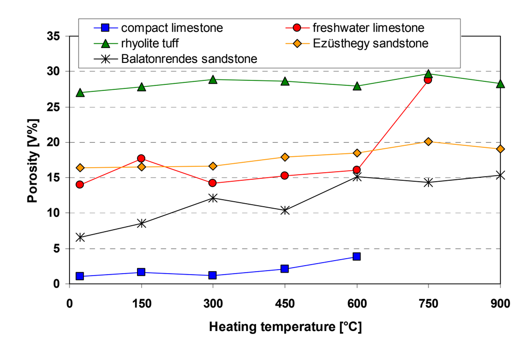
The analysis procedure for damaged structures is shown in figure 8b for the damaged Frame B – Banat under ISO fire. The structure subjected to vertical loads corresponding to the fire load combination is loaded with the lateral forces (push-over by

MINERALOGICAL CHANGES

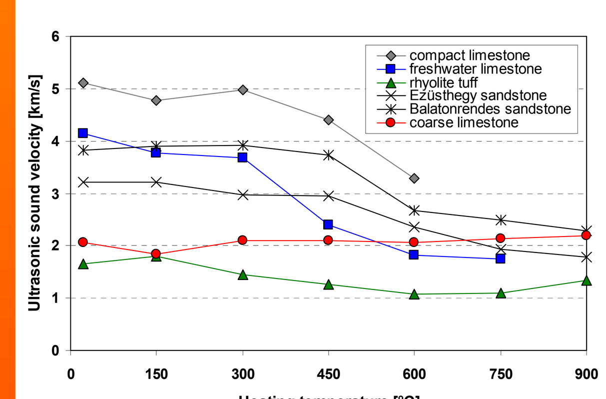
As result of the mineralogical analyses the changes of the texture and inner structure and hereby the increasing in porosity, the disappearance of minerals or formation of new mineral phases and the colour change are observable. On effect of heating the quartz and K-feldspar do not show significant alteration up to 900°C. As major effects the transformation of α-quartz to β-quartz (580-595°C) and the formation of micro-cracks at quartz and feldspar grain boundaries above the 600°C heating temperature were detectable. Micro-cracks develop also within the crystals but only at higher temperatures (above 750°C). Clay minerals and phyllosilicates show several transformations on heat effect. Kaolinite and chlorite first coloured by increasing the temperature then ruined additionally in the inner structure and in quartz grains cracks occurred. Due to calcination processes at limestones in the carbonate minerals the major changes took place at 450°C and above. At 750°C the structure of calcite collapsed and at 900°C calcite and dolomite was not possible to detect; however after leaving the samples at room temperature for two hours at about 45% relative humidity a new mineral phase, portlandite was detected. This is a reaction product of air humidity (water) and CaO and associated with a volume increase of 20% in average and leads to the disintegration of cylindrical specimens.

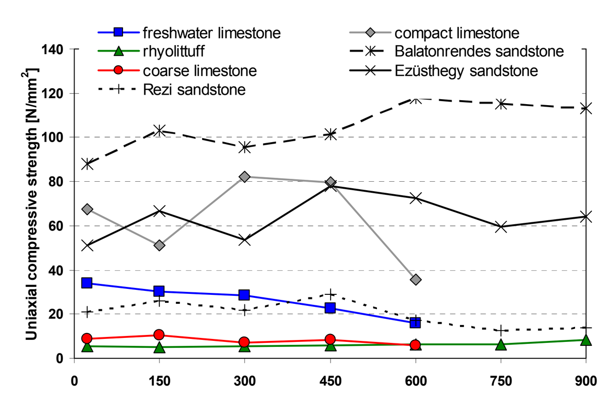


PETROPHYSICAL CHANGES



The limestone samples were sensitive at the heating. On the compact limestones specimens small hairline cracks arised already after at heating on 450°C and over the 600°C heating temperature the samples exploded. These specimens faded at the elevated temperature (750°C). The travertine samples grown dark till 450°C and smelt foul due to organic matter content, but after this there also paled. These specimens survived the heating, but some hours after the test the CaO had reaction with the air moisture and due to nascent portlandite and the volume increment the samples crumbled. The coarse limestone samples also stand out the effect of heat at 750°C and 900°C, but they have falled into dust soon. The heating did not result similar problems at the sandstones and the rhyolite tuff samples.





At the effect of heat changes take place in the inner structure and mineral composition of the natural stones, which influences the petrophysical parameters. This changing is not always adverse, but we have to take it to account for instance at the restoration of a fire damaged stone building. The heat resistance of different quartz sandstone depends on the type of the cementing mineral, the amount of cement (grain/cement ratio), the grain size (fine, medium, coarse) and the grain to grain or matrix to grain contacts. The initial porosity, compactness influences the behaviour of limestone and rhyolite tuff at heat effect. The compact stones show more dramatic change in porosity at elevated temperatures than the less cemented ones and they are more rigid. At a porous and cement rich stone is more adaptable, these can adopt the addition strength caused by thermal expansion. The mineral composition is also determinant factor. The silica cemented, ferruginous or clayey stones are less sensitive than the carbonatic ones, which disintegrate at higher temperature.