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Fire damage of natural building stones

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Introduction

Almost every representative ancient building suffered from a fire within its history. Most prominent examples are the "Frauenkirche" in Dresden (Germany), the Windsor castle in London (England) and the cathedral in Lisbon (Portugal). The damage of natural building stones due to fire deserves systematic studies. The question is, which damage processes occur and how high the damage potential is associated to each process.

Materials and methods

Therefore, a number of different sedimentary, magmatic and metamorphic rock types were investigated. The group of sedimentary rocks comprises limestones (Eibelstadt, Thüste, Bad Langensalza, Germany), sandstones (Obernkirchen, red and grey Wesersandstone, Germany) and a gypsum (Uehrde, Germany). As magmatic rocks a granite (Kösseine, Germany), a tuff (Weibern, Germany) and an ignimbrite (Rochlitz, Germany) are included. Metamorphic rocks are represented by an orthogneiss from Switzerland (Verde Andeer) and two marbles from the Carrara area (Italy). Investigations include thermal expansion measurements up to a temperature of 1000°C, characterizations of fire induced changes of the pore space, of fabric changes and associated mineral reactions. The latter are quantified by means of differential thermal analysis (DTA) and differential thermogravimetry (DTG). Changes in the modal composition due to fire damage are characterized by X-Ray diffraction measurements (XRD).

Results

Thermal expansion measurements up to 1000°C reveal that the expansion of different rock types is quite different. Variations are caused by the single crystal thermal expansion properties of the rock forming minerals and by different damage processes. In silicate rocks intragranular fracturing is the predominant damage phenomenon. Carbonate rocks show at low temperatures a behavior mainly controlled by the anisotropic thermal expansion coefficient of calcite. At higher temperatures, specific mineral reactions, such as decarbonatization, are directly evidenced by sudden jumps in thermal expansion curves. If water is present, a second stage of deterioration follows fire damage. The huge volume increase due to portlandite formation from decarbonized CaO causes severe scaling at the outermost surface of limestones if the surface is exposed to the environment. Small amounts of silicates in carbonate rocks may improve stability of those rocks due to dicalciumsilicate formation. At high temperatures an increase in the expansion coefficient may be explained by partial melting for some rock types. Phase changes (e.g. in quartz) are monitored by sudden increase in the expansion coefficient. Investigations on gypsum reveal that dehydration reactions reduce fire temperatures in the vicinity of gypsum rocks significantly. All thermal expansion measurements reveal that the samples are severely damaged after firing. In every case a large residual strain is observed in thermal expansion measurements. Laboratory simulations of real fires in small scale fire tests following the international standard fire curve adopted by ISO 834 show that the penetration depth of heat and associated damage types vary as a function of lithology. While for granites cracks predominately in feldspars predominate, the firing in limestone causes a scaling of the outermost layer. The investigations may lead to an improved assessment of natural building stones which have been damaged by fire. Implications can also been drawn for the recent use of facade panels made of natural building stones in case of a fire.

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