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Investigation of some property changes of natural building stones exposed to fire and high heat

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HIGHLIGHTS

- ▶ The color of natural stones becomes lighter in appearance with increasing temperature.
- ▶ It is possible to polish all natural building stone samples up to 600 °C.
- ▶ While some samples can hold polish at 800 °C, all samples fall apart at 1000 °C.
- ▶ Depending on the composition and temperature exposure, color and lightness of samples change.
- ▶ Structure of natural building stone becomes damaged and/or changes when heated above 800 °C.

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ABSTRACT

Under the influence of fire and other high heat sources, a number of changes occur in natural stones. These changes vary according to the values of the temperature exposure. Therefore, this study aims to understand the effect of heat in a fire and high temperatures on some properties of limestone and marble, as they are widely used natural building stones. For this purpose, eight natural stones (four limestone and four marble) of different origins and textural characteristics were exposed to 200, 400, 600, 800 and 1000 °C temperature in the oven. After each exposure, the rock properties were determined and compared with the properties at room temperature. Discoloration and whiteness, polish reception, daily physical change, variation of pH and temperature of the cooling solution were taken into account in the comparison. As a result of this study, the positive and negative aspects of the property changes that occur in natural stones which are exposed to different temperatures are discussed.

1. Introduction

Buildings such as houses, schools, factories and offices and structures such as tunnels, bridges and oil platforms can be influenced by high temperatures due to their functions or due to fire. As a result of the effect of temperature, a number of decompositions occur in the elements forming them. There are several significant studies about the decomposition of the elements that form the structure, such as the effect of high temperature and fire on concrete [1–6], high performance concrete [7–12], lightweight concrete [13–17], mortars [18–20], beams and slabs [21–23], panels and bars [24,25], steels [26,27], wall lining minerals [28], clay bricks [29] and engineered stones [30] but there are only a few studies on natural building stones. Studies on the effect of temperature on natural stones are usually based on sandstone [31–34]. These studies have shown that the length of time over which extreme heat is maintained and the speed with which high temperatures are reached are key factors in determining stone response [35]. Extreme high temperatures have the potential to cause catastrophic damage to stone because thermal surface/substrate stresses are set up within the stone relatively rapidly, giving the stone no time to physically absorb the change (thermal shock). Physically, quartz sandstones can be especially susceptible to extreme heat [35], with temperatures in excess of 573 °C usually resulting in the internal fracturing of quartz grains [36]. Chemically, the extreme heat produced by fires can bring about changes in the mineral matrix or cement of a sandstone, creating lines of weakness for subsequent exploitation by physical processes including salt weathering and environmental heating and cooling, leading to

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Table 1
Types and names of samples.

Sample code	Commercial name	Stone type	Rock type
HP	Hazar pink	Limestone	Sedimentary
DB	Daisy beige	Limestone	Sedimentary
SB	Sivrihisar beige	Limestone	Sedimentary
BB	Burdur beige	Limestone	Sedimentary
AW	Afyon white	Marble	Metamorphic
AG	Afyon gray	Marble	Metamorphic
AT	Afyon tigerskin	Marble	Metamorphic
MM	Mugla milas	Marble	Metamorphic

the establishment of near-surface thermal gradients that could result in the formation and development of microfractures [37].

Reviewed literature does not seem to include any significant work on the effects of high temperatures on natural stones. In these studies, the effects of low temperatures on limestone and marble have been investigated [30,37,38]. In the studies in which the provided temperature values do not exceed 400–500 °C, these do not resemble the actual temperature a stone might be exposed to in a real case of fire. Therefore, this study aimed to understand the effect of high temperatures and heat in a fire on natural building stones such as limestone and marble, which are widely used in buildings. The effects of different degrees of temperature from room temperature up to 1000 °C (room temperature, 200, 400, 600, 800, 1000 °C) on marble and limestone were investigated by the aspects of change in color and whiteness, polish reception, daily physical change, pH and temperature variations of the cooling solution which was prepared from the cooked samples at 800 °C and 1000 °C.

2. Materials and methods

This study aims to determine the variations in the properties of some natural stones which have different structural and textural properties, and are widely available and commercially produced in Turkey. For this purpose, eight different samples (four limestone and four marble samples) were analyzed. The commercial names, stone types and rock types of these samples are given in Table 1.

First, some physical and mechanical properties of the samples used in the study were determined. The experiments were made under the conditions stated in the standards with all samples given in Table 1. Results of the experiments are given in Table 2.

Thin sections of the natural stone samples were prepared and then they were examined under a polarized microscope to determine the textural features of each sample. The petrographic descriptions and microphotographs of the samples were determined from these thin-sections and are given in Table 3.

After the samples were taken from natural stone quarries to expose the effect of fire and high temperatures on natural stones, they were cut to a 50 mm diameter core with a drilling core machine in the laboratory and then 25–30 mm thick plates were formed with smooth surfaces. This thickness was chosen considering the thickness of natural stones used in coating, steps, benches, etc. and the thickness of the natural stone which will mostly be exposed to temperature. To determine the effect of the temperature, samples in the room conditions were separated and all the variations which occurred in the structural properties of the samples at different temperatures were compared with them. Different temperature degrees were selected to present the effects of the temperature on the samples. The highest temperature was determined as 1000 °C, by considering the highest temperatures that could occur in fire and the temperatures that are expected to decompose natural stone. Samples were exposed individually to the temperatures starting with 200 °C, then sequentially 400, 600, 800 and 1000 °C. An example of placing the samples in the oven is given in Fig. 1.

To present the effect of heat in a fire and other heat sources on natural stones, a Protherm PLF 130/25 brand oven was used while the samples were heated at the specified temperatures. The samples were heated at a heating rate of 5 °C per minute. After reaching the desired temperature in the oven, the natural stones were exposed to temperature for a period of 1 h. To avoid the thermal shock of the temperature exposed natural stones, the samples were cooled to room temperature inside the oven. For the purpose of the study, to present the changes in the temperature exposed samples, physical tests were performed in conjunction with observational investigations. The main purpose of this study is to determine which processes such as restoration, and renovation, would be needed on samples exposed to different temperatures. Therefore, color changes, and decomposition-breaking, changes and polish reception changes in samples exposed to 800 and 1000 °C were kept at room conditions for 30 days and changes in those samples were investigated. 800 and 1000 °C were the specially chosen temperatures since they are the highest temperatures of fire and they are expected to show the structural collapse. The method followed in the study is given in Fig 2.

3. Results and discussion

In the study, color change and whiteness, polish reception, daily physical change, change of pH and temperature of the cooling solution are taken into account to investigate the effect of high temperature and heat in a fire on natural stones.

3.1. Color change and whiteness

The study shows that there is a color change in the natural stones when they are exposed to different temperatures. The views of the samples exposed to different temperatures are given in Fig. 3. Generally, decolorization is observed while the temperature rises. However, after 800 °C, samples were dominated by the white color. The reason is that a white coat occurs on the surface at 1000 °C, while a small quantity of white coat also appears at 800 °C.

Another notable case on the effect of the temperature on natural stone temperature is that at 400–600 °C temperature, samples AT and AG's colors get quite bright, which is highly attractive in commercial terms. Thus, it is obtained that when the natural stones of different colors are exposed to high temperatures, they become the commercially attractive white colors of natural stones. However, the important point here is that the natural stones which

Table 2
Some physical and mechanical properties of the samples used in the study.

Tests	Units	HP	DB	SB	BB	AW	AG	AT	MM	Used standard
SG	g/cm^3	2.74	2.72	2.72	2.75	2.72	2.72	2.73	2.73	ASTM D5550-06:2006
UW	g/cm^3	2.64	2.66	2.70	2.68	2.71	2.71	2.71	2.71	TS 699:1987
RF	%	96.3	97.8	99.0	97.6	99.8	99.8	99.3	99.3	TS 699:1987
P	%	3.7	2.2	1.0	2.4	0.2	0.2	0.7	0.7	TS 699:1987
AP	%	2.4	1.7	0.6	2.0	0.2	0.2	0.3	0.4	TS 699:1987
H	Mohs	4.0	4.0	3.5	4.0	3.0	3.0	3.0	3.0	TS 6809:1989
WA	%	0.9	0.6	0.2	0.7	0.1	0.1	0.1	0.1	TS EN 13755:2009
WACC	$g/m^2\,s^{0.5}$	1.575	0.985	0.400	0.888	0.187	0.151	0.142	0.232	TS EN 1925:2000
UCS	MPa	149.2	187.4	137.2	139.3	83.3	80.4	70.3	61.2	EN 1926:2006
TS	MPa	8.52	10.35	10.22	9.16	7.86	9.60	6.89	5.04	TS 7654:1989
AR	$cm^3/50cm^2$	11.7	10.3	13.7	12.3	23.6	24.6	23.6	23.0	EN 14157:2004
FL	%	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	TS 699:2009
FTR	MPa	122.7	191.1	134.7	183.8	85.1	92.0	74.2	77.5	TS 699:2009

SG: Specific Gravity, UW: Unit Weight, RF: Ratio of Fullness, P: Porosity, AP: Apparent Porosity, H: Moh's Hardness, WA: Water Absorption at Atmospheric Pressure, WACC: Water Absorption Coefficient by Capillarity, UCS: Uniaxial Compressive Strength, TS: Tensile Strength, AR: Abrasion Resistance, FL: Freeze Loss, FTR: Freze–thaw Resistance.