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Temperature influence on the physical and mechanical properties of a porous rock: San Julian's calcarenite

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ABSTRACT

This work discusses the results from tests which were performed in order to study the effect of high temperatures in the physical and mechanical properties of a calcarenite (San Julian's stone). Samples, previously heated at different temperatures (from 105 °C to 600 °C), were tested. Non-destructive tests (porosity and ultrasonic wave propagation) and destructive tests (uniaxial compressive strength and slake durability test) were performed over available samples. Furthermore, the tests were carried out under different conditions (i.e. air-cooled and water-cooled) in order to study the effect of the fire off method. The results show that uniaxial compressive strength and elastic parameters (i.e. elastic modulus and Poisson's ratio), decrease as the temperature increases for the tested range of temperatures. A reduction of the uniaxial compressive strength up to 35% and 50% is observed in air-cooled and water-cooled samples respectively when the samples are heated to 600 °C. Regarding the Young's modulus, a fall over 75% and 78% in air-cooled and water-cooled samples respectively is observed. Poisson's ratio also declines up to 44% and 68% with the temperature in air-cooled and water-cooled samples respectively. Slake durability index also exhibits a reduction with temperature. Other physical properties, closely related with the mechanical properties of the stone, are porosity, attenuation and propagation velocity of ultrasonic waves in the material. All exhibit considerable changes with temperature.

Contents

1. Introduction

Stone can be considered the most important building material throughout the history of architecture and civil works. Most historic buildings which form the cultural heritage of the cities are made of stone. However, although the stone is always perceived as an “eternal” material, it is well known that building stone undergoes many processes of deterioration. The San Julian's stone, studied in this paper, has been widely used in historic buildings from the city of Alicante (SE Spain). Recently, railway tunnels and cut-slopes have also been excavated in rock masses composed by San Julian's rock. Consequently, it is

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important to know the behaviour of this kind of rock against different aggressive agents. This study is focused on the effect of high temperatures (as achievable catastrophic fires) on some physical and mechanical properties of the San Julian's stone.

Fire produces physical and chemical changes, from certain temperatures, in the internal structure of the rocks. Rocks are composed of minerals, bounding matrix, cracks and pores. The geometry and density of the cracks and pores are the main controlling parameters for the physical properties of rocks (Yavuz et al., 2010). The temperature induces micro cracks in the material due to the different natures of the constituent minerals (intergranular) (Jansen et al., 1993) or within grains (intragranular). The intragranular microcracks can occur when any of the mineral undergoes a qualitative change or phase transition (such as the case of α/β phase transition in quartz) (Glover et al., 1995). The intergranular cracks are due to the different expansion coefficients of the component minerals, causing a differential expansion thereof with temperature, generating internal stresses resulting in the creation of cracks in the transition phase between components (Jansen et al., 1993). When temperature changes occur in a very short time, intergranular cracks occur by another different process than the previous ones: high temperature gradients in the material. These temperature gradients act by amplifying the differential dilation effects by different coefficients of expansion (Jansen et al., 1993). At 575 °C, α-quartz becomes β-modification, which causes volumetric increase, and thermal crack opening. Nevertheless this porosity increases, or decrease in strength, are of minor importance for quartz-rich sandstones (Hajpal, 2002). Due to the existence of open porosity and the presence of a calcitic matrix which undergoes a parallel calcining process, this micro-strain is absorbed by the matrix (Gomez-Heras et al., 2010). In contrast carbonate and clay containing sandstones show important changes in mineral composition and in physical properties even at lower temperatures (Hajpal, 2002). At temperatures above 250–300 °C, colour changes in sandstones correspond with the dehydration of iron compounds. Brown or buff coloured sandstone, changes colour to reddish brown but the change may not be apparent until the stone has been heated to temperatures above 400 °C (Chakrabarti et al., 1996).

The main aim of this paper is to study the influence of temperature and the cooling method on physical and mechanical properties of San Julian's stone, a porous calcarenite widely used locally as building material in the past, through laboratory tests. For this purpose uniaxial compressive strength, slake durability, porosity and ultrasonic wave propagation tests have been performed for 55 rock samples following standard procedures before and after heating at different temperatures and cooling under different conditions.

2. Previous works

Most studies on the effects of fire or heating in sandstones refer to chemical changes, such as changes in colour and mineralogical composition (Chakrabarti et al., 1996; Hajpal, 2002; Hajpal and Torok, 2004; Gomez-Heras et al., 2008, 2010). In connection with physical changes, porosity, bulk density and propagation velocity of the ultrasonic waves are also frequently analysed (Yavuz et al., 2010). Hong et al. (2012) performed an interesting compilation of physical changes produced by temperature on sandstones from other scientific works, stating next general conclusions: density does not vary substantially below 500 °C, porosity increases with temperature especially from 300 °C and P-wave velocity decreases linearly with temperature, from 200 °C.

A key feature for the use of stone as a building material is the uniaxial compressive strength. The variation of this parameter has been systematically studied for engineering applications such as geothermal energy systems or nuclear waste disposal. However, for these cases of study, the tests were performed at the target temperature (without cooling) rather than after a cooling process. The works carried out to consider the temperature influence on non-crystalline sedimentary rocks show quite different results depending on the type of studied rock. Wu et al. (2005) studied various types of sandstones, detecting minimum strength decreases until 400 °C, and a sharp drop between this temperature and 600 °C, where strength was just under 60% of the initial value. Rao et al. (2007) tested eight sandstone samples and observed a strong initial increase of resistance to 250 °C, and then a decline to 300 °C, however at this temperature, resistance is 138% higher than the initial. Zhang et al. (1993, 2009) found that, for their studied sandstones, the strength quickly decreases with temperature, to reach 60% of the initial at 200 °C, then rises until it reaches 120% of the initial strength at 500 °C, it keeps at 600 °C, and then decreases close to 70% to the maximum tested temperature of 800 °C. Ranjith et al. (2012) tested sandstones until 950 °C obtaining different results than in other works, highlighting the significant increase in strength with temperature, reaching 180% of the initial strength at 600 °C, then lowering until the maximum test temperature is reached, remaining above the initial strength. Koca et al. (2006) studied nine samples of intact marble, under different temperatures observing important descents of the rock strength. These authors also tested five rock samples obtained from building elements previously exposed to fire (subjected to an estimated temperature of 500 °C) using temperatures from room temperature to 300 °C which caused a very high elastic modulus decrease beyond 200 °C. A noteworthy aspect in the work from Koca et al. (2006) is that the uniaxial compressive strength of the material exposed to 500 °C and then cooled to room temperature exhibits very similar uniaxial compressive strength values than the intact material tested at 500 °C. Ferrero and Marini (2001) tested 15 samples of two types of marble which were previously heated to temperatures up to 600 °C and later cooled applying a very low gradient of temperature. These authors noted that the compressive strength was not affected after a single heating cycle, whilst the modulus of elasticity decreased sharply up to 50% of the original value in the first type of rock and up to 35% in the second one. Fig. 1 graphically summarizes the previously described results.

San Julian's stone exhibits a clear decrease of the elastic modulus in agreement to Wu et al. results (2005). However, other authors detected some initial hardening at different temperatures. Rao et al. (2007) registered a slight hardening, until 250 °C and a decline at 300 °C. Zhang et al. (1993, 2009) noticed that the modulus remains almost constant until 600 °C, then falling to 65% at 800 °C. Ranjith et al. (2012) recognized a tightening until 400 °C reaching almost 40%, subsequently continuously decreasing up to 35% at 950 °C. Fig. 2 summarizes the variation of elastic modulus against temperature of the above mentioned works.

In most of the previously mentioned works (Koca et al., 2006; Rao et al., 2007; Zhang et al., 2009; Ranjith et al., 2012) the tests were performed at a target temperature (without cooling). Wu et al. (2005) performed the tests under and after high temperature, noting that the peak-value strength, elastic modulus and deformation modulus at high temperatures and after high temperatures gradually decreased exhibiting a general similar variation trend (cooling method is not specified). Ferrero and Marini (2001) used a very slow cooling process with a negative gradient of 0.23 °C/min. Koca et al. (2006) also tested at room temperature a sample previously exposed to fire at 500 °C.

3. Samples and heating process

3.1. Rock description and samples preparation

Block samples were taken from the Serra Grossa hill, located at the NE of the urban area of Alicante (SE of Spain). The specimens studied in this paper were obtained from rock blocks collected from the dump of a railway tunnel under construction. The rock blocks were picked up just after the excavation and transported to the laboratory, where the samples were extracted by means of a drill. The orientation of stratification planes in the blocks was taken into account when drilling