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Possibility of using Kütahya Volcanic Tuff as building stone: Microstructural evaluation and strength enhancement through heat treatment

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HIGHLIGHTS

- Heat treatment of low strength tuffs for using it as building stone was evaluated.
- Corundum and leucite were formed at 1200 °C.
- Homogeneous distribution of micro crystalline structures enhanced the strength.
- Heat treatment enhanced the uniaxial compressive strength of tuff from 7 to 47 MPa.
- Estimated costs for heat treatment of tuffs (5–8 $\$/m^3$) were found feasible.

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ABSTRACT

Tuffs undergo physical, mineralogical and microstructural changes after heat treatment (HT). This study presents (i) characterisation of Kütahya Volcanic Tuff (KVT), (ii) effect of (HT) on its above mentioned properties and (iii) cost analysis of the HT. Corundum and leucite were formed at 1200 °C. According to SEM observations, homogeneous distribution of micro crystalline structures and densification of the structure enhanced the strength of KVT considerably. HT of bulk KVT provided them the required strength for building stones, with reasonable cost and maintaining their natural and aesthetic appearance.

1. Introduction

Considering sustainability principles, the building material, structural and non-structural element or an entire construction must be designed in order to resist to mechanical, chemical and physical damages, and not affecting air, water and soil quality during entire lifecycle [1]. Volcanic tuffs have been used as building stones in many countries since ancient times, for example, Italy [2], Hungary [3], Netherlands [4] and Germany [5]. Low strength of tuff stones researched in this study limits their use as building stone. It has been shown that volcanic tuffs undergo structural changes after heating which open possibilities to be used in different fields related to their chemical and physical properties, such as building stone [6], ceramic and porcelain tiles [7,8], lightweight aggregate [9,10] and additive in puzzolonic cements [11].

The chemical composition of zeolitic tuffs make possible the liquid phase formation during heat-treatment (HT), through the supplement of alkaline oxides [12]. Quartz controls deformation and shrinkage of the fired bodies. Alkaline rich feldspar, acting as a flux, forms the quasi-liquid phase that affects the densification process and final porosity [13–15].

Cooling and welding of an ash-flow tuff occurs after an eruption and the creation of gravity driven density currents of hot ash and gas. As soon as hot ash comes to rest, compaction of a tuff starts.

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Table 1
Physical properties and UCS of KVT [19].

Series code	AD (g/cm^3)	RD (g/cm^3)	TP (%)	(OP) (%)	CP (%)	UCS (MPa)
CS1	1.222	2.352	48.041	30.344	17.697	7.400
CS2	1.243	2.372	47.606	32.348	15.258	7.150
CS3	1.235	2.386	48.247	34.298	13.949	7.783
CS4	1.227	2.358	47.975	33.951	14.024	6.727
AVERAGE	1.232	2.367	47.967	32.735	15.232	7.265

Table 2
Physical and mechanical properties of heat treated KVT [19].

Core code	HT (°C)	AD (g/cm^3)	RD (g/cm^3)	TP (%)	(OP) (%)	CP (%)	UCS (MPa)
HTS1	900	1.198	2.380	49.648	34.525	15.123	10.533
HTS2	1000	1.237	2.408	48.637	36.003	12.634	12.687
HTS3	1100	1.412	2.461	42.565	24.830	17.736	12.530
HTS4	1200	1.952	2.373	17.744	2.973	14.771	46.653

The process of welding the tuff is dependent on the temperature and pressure distribution within the sheet of volcanic material [16]. Increased temperature dramatically enhances welding, as expressed by the density increase accompanying sintering. Temperatures above 900 °C are unrealistic for most natural settings as they are at or above the magmatic temperature of most rhyolites. By heating Rattlesnake Tuff ash in alumina ceramic crucibles at 1 At in a muffle furnace, compared to HT at 1030 °C, density icreased by 50% and 100% at 1100 and 1200 °C respectively [17]. Alkaline basaltic tuffs sintered at 1000, 1040 and 1060 °C for 30 min had 36%, 30% and 24% open porosity and no closed porosity. At 1080 °C, open porosity has decreased to 17% and the formation of closed porosity has started. At 1100 and 1120 °C, no open porosity has ben detected, while the amount of closed porosity has increased to 8–9% by volume [18]. Densification of tuffs with HT would enhance their strength, leading up their usage as building stone.

The Kutahya volcanic tuff (KVT) is a welded rhyolitic and rhyodacidic tuff that was created during the volcanic eruption that formed the Phrygian Valley within the boundaries of Kütahya, Afyon and Eskişehir. These low strength and highyly porous tuffs contain pumiceous, glassy fragments and small quartz, alkali feldspar, biotite, hornblend, etc. Despite the wide occurrence of these tuffs around Kütahya, there are no studies examining their mineralogical and physical–mechanical properties. The purpose of this paper is (i) to investigate the properties of KVT before and after HT processes (ii) evaluation of HT as a process to enhance the strength of bulk (as it is) tuff samples (iii) analyse the cost and applicability of the HT [19].

2. Experimental procedure

Total 12 tuff cores (9.4 cm in diameter and 25–30 cm in length) were taken from Kırgıllı area, Phrygian Valley-Kütahya, Turkey. Two equivalent (9.4 × 9.4 cm) cores were obtained from each one in order to use as characterisation core (CC) and heat treatment core (HTC). CC and HTC were labelled as CC1, CC2, CC3…CC12 and HTC1, HTC2,…HTC12 respectively. Four characterisation series symbolised as CS1, CS2, CS3 and CS4 were constitued by using CC1-3, CC4-6, CC7-9 and CC-10-12 respectively. The HT series (HTS1, HTS2, HTS3 and HTS4) were composed smilarly. The HTS1, HTS2, HTS3 and HTS4 were heated to 900, 1000, 1100 and 1200 °C respectively in a chamber furnace with a heating rate of 10 °C/min and by a soaking time of 1 min, then allowed to cool in it to 20 °C. Density and porosity (TS EN 1936) [20], uniaxial compressive strength (sulphur-graphite cap, 0.6 MPa/s loading rate) tests, TG–DTA (50 to 1200 °C, at heating and cooling rate of 10 and 20 °C/min respectively, 100 mg powder sample, in dry air atmosphere with the flow rate of 40 ml/min), XRF, XRD, optical microscopy and SEM analyses were conducted on characterisation and HT series [19].

3. Results and analysis

3.1. Evaluation of physical and mechanical properties

The appearent density (AD), real density (RD), total, open and closed porosity (TP, OP and CP) and uniaxial compressive strength (UCS) of characterisation series were given in Table 1. The high porosity and the low UCS make KVT not suitable as building stones.

Physical properties and UCS at different HT temperatures were given in Table 2. AD decreased by 2% and 0.5% at 900 and 1000 °C respectively, because mass losses were bigger than the volume reduction at KVT for these temperatures. At 1200 °C due to the densification of the structure, AD enhanced by 59%. RD of the KVT did not change significantly with respect to HT temperature. When sintered up to 900 and 1000 °C, TP increased about 3% and 2% respectively. İncrease in TP interpreted as the enhancement of pores due to disappearence of the clay structure. Due to sintering effect at 1200 °C most of the pores were filled and TP were reduced by 63%. HT at 900, 1000, 1100 and 1200 °C enhanced the UCS of KVT by 42%, 77%, 61% and 594%. HT enhances the strength of tuff due to welding of the particles and filling of the pores with the the vitreous phase. But at 1100 °C deep cracks formed during cooling of the structure lowered the strength. It is obvious that as the

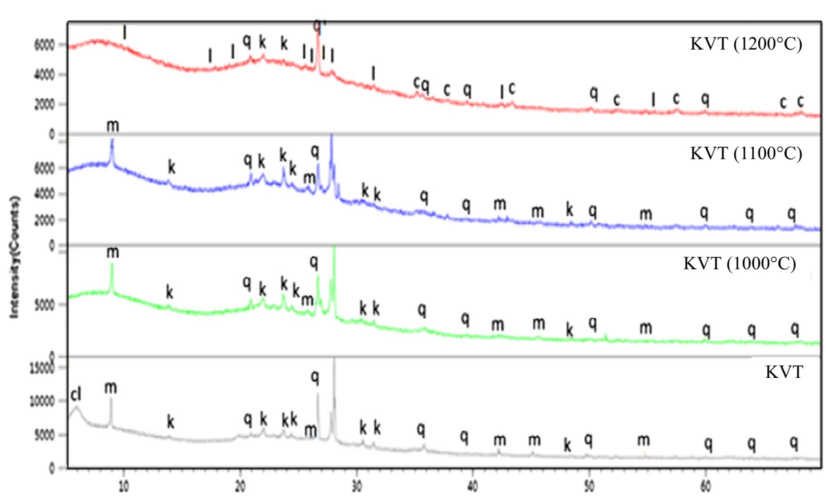

Fig. 1. The XRD patterns of KVT and heat treated KVT at 1000 °C, 1100 °C, 1200 °C [19]. cl: clay, m: mica, l: leucite, k: K-feldspar, q: quartz, c: corondum.