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Influence of ground pumice powder on the mechanical properties and durability of self-compacting mortars

Mehmet Karataş [a], Ahmet Benli [b,*], Abdurrahman Ergin [a]

[a] Department of Civil Engineering, Firat University, 23100 Elazig, Turkey
[b] Department of Civil Engineering, Bingol University, 12100 Bingol, Turkey

HIGHLIGHTS

- Hardened properties of binary mixes of SCMs containing GPP were investigated at the curing age of 3, 28 and 90 days.
- Fresh properties of SCMs with GPP were evaluated.
- Durability properties of SCMs were investigated at the curing age of 28 days.
- GPP15 has the highest pozzolanic activity at the curing age of 28 and 90 days.

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ABSTRACT

The aim of this study is to investigate the mechanical properties and durability of self-compacting mortars (SCMs) produced from ground pumice powder (GPP) as a mineral additive. In this scope, 8 series of SCMs including control mixture were prepared that consist of 5%, 10%, 15%, 20%, 25%, 30% and 35% of ground pumice powder by weight of cement. A total of 72 specimens of 40 × 40 × 160 mm were produced and cured at the age of 3, 28 and 90-day for compressive and tensile strength tests and 24 specimens of 50 mm cube specimens were prepared and cured at 28 days for water absorption, sorptivity, porosity and density tests. Flexural tensile strength and compressive strength of 40 × 40 × 160 mm specimens were measured at the curing age of 7, 28 and 90-day. Mini V-funnel flow time and mini slump flow diameter tests were also conducted to assess rheological properties. The best strength results were obtained from the samples containing between 10% and 25% of GPP as compared to control specimens. GPP15 has the highest pozzolanic activity at the curing age of 28 and 90 days. Replacement of the cement with 10–20% of GPP resulted in mortars which caused a decrease in water absorption, sorptivity and porosity when compared to the control mortar.

1. Introduction

Mineral additives replace cement in mortar mixtures and in some concrete types such as self-compacting, reactive powder, roller-compacted concrete and lightweight concrete. They are used to improve the mechanical properties of the mixture due to pozzolanic and/or hydraulic. Pumice is a light and porous type of pyroclastic igneous rock formed from the lava during the explosive volcanic eruptions. The pumice has a cellular structure formed by the presence of molten lava flowing through volcanoes, bubbles or air gaps when cooled [1,2]. Lightweight Pozzolanic materials may have some cementitious properties when made into very fine powder. At the same time, their binding property increases when mixed with cement and lime [1,3]. The pumice is in fact an aluminum silicate shaped by a cellular structure of explosive volcanism and is widely used as building material due to its cellular structure, lightweight and insulation properties [4–7]. In 2014, pumice and pumicite production used or sold increased to 285.000 metric tons which was 269.000 metric tons in 2013. Turkey and Italy are the leading producers of pumice and pumicite. The pumice was used in building block production of approximately 56%; Gardening consumption is 18%; Concrete admixture and aggregate, 12%; Abrasives, 10%; the remaining 4% was used for absorbent, filtration, washing stone washing and other applications [5,8,9]. Self-compacting concrete (SCC) has recently emerged as a new concrete technology and its use has increased rapidly over the last three decades and reflected in the number of published works. Self-compacting mortar (SCM) exhibits similar mechanical and durability properties of SCC and can be used to examine the

* Corresponding author.
E-mail addresses: ahbenli@hotmail.com, abenli@bingol.edu.tr (A. Benli).

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performance mechanisms of the SCC [10]. Mortar forms the basis of the workability properties of self-compacting concrete (SCC) and these properties can be evaluated with self-compacting mortars (SCM). In fact, evaluating the properties of the SCM is an integral part of the SCC design [10,11]. Self- Compacting Concrete (SCC), which offers benefits in workability, reduces labor costs and provides higher strength compared to conventional concrete, is one of the latest developments in concrete technology [10,12]. Superplasticizer, powder material and/or viscosity regulators which reduce water at high levels in SCC production are used [13–15]. While the use of superplasticizer maintains fluidity, it ensures the stability of the fine-content mixture and thus obtains resistance against bleeding and segregation. Due to the low density of aggregate used in concrete, strength and workability decrease and segregation occurs in concrete. High strength, durability and segregation resistance properties of SCC can fix mentioned problems of lightweight concretes. Unlike conventional concrete, using of chemical admixtures, superplasticizer and pozzolanic mineral additive are needed in SCC. New standards and test methods are being developed for the selection and use of these materials in concrete design [16]. In this study, standards issued by EFNARC were utilized. According to EFNARC; workability of self-compacting concrete can be provided with filling capability, suitable viscosity determined by the flow rate, the ability to pass through the narrow section and the segregation resistance [16,17]. Limiting amount of coarse aggregate is common method to achieve the high fluidity of SCC. Besides, it is necessary to increase the proportion of fine material. For this purpose mineral additives such as ground pumice, fly ash, limestone powder, slag and silica fume can be used in concrete [18–20]. Furthermore, the benefits of using mineral additives in concrete are protecting nature and providing economy. According to previous studies, ground pumice powder (GPP) can be used as an additional cementitious material in blended cement.

Kabay et al. [1] found out that while the addition of GPP and FA exhibited lower mechanical strength at an early age, it provided comparable strength when compared to reference concrete at later ages. Replacement of GPP, FA and blends thereof produced reduced water absorption, sorptivity and void content and resulted in concrete with higher magnesium sulfate resistance compared to the control concrete. Kizilkanat et al. [21] reported that Due to the porous and rough structure of the pumice powder, the viscosity of the paste is adversely affected. On the other hand, pumice powder and mortars provide higher strength development and sulfate resistance, lower drying shrinkage and chloride ion penetration compared to mortars with fly ash. Granata [22]studied the rheological and mechanical properties of self-compacting concrete with pumice powder used as filler additive. The pumice pozzolanicity has resulted in a marked increase in the compressive strength after 28 days of curing. Kurt et al. [23] investigated the effects of pumice powder, different water/(cement + mineral additive) ratios and pumice aggregates on some physical and mechanical properties of self-compacting lightweight aggregate concrete. Guneyisi et al. [24] noted that increasing the level of replacement level of volcanic pumice powder (VP) generally leads to an increase in the fluidity of SCCs without loss of uniformity and without segregation. Moreover, the addition of SF provided a significant increase in compressive strength, where VP resulted in a systematic decrease.

The main objective of this paper is to examine the mechanical and durability properties of SCMs containing ground pumice powder. In this study, eight mixtures were used, where cement was substituted with ground pumice powder, and a mixture was used as a control. The fresh characteristics of the SCMs were determined by mini-slump flow diameter and mini and V-funnel flow time. Hardened properties were evaluated by 3, 28, and 90 days of compressive strength and flexural tensile strength tests. Durability properties including water absorption, porosity, sorptivity and density were investigated.

2. Experimental program

In this study, it was aimed to investigate the mechanical and durability properties SCMs incorporating GPP. For this purpose, 8 mixtures including control sample were prepared. Three samples were produced from each of these mixtures for each experiment. Self-compacting mortars (SCMs) incorporating GPP at the rates of 5%, 10%, 15%, 20%, 25%, 30% and 35% of the cement by weight were considered. In order to determine the mixing ratios of SCMs according to these pumice rates, mini slump flow test and the V-funnel flow test were conducted. As the GPP ratio increases, the workability is deteriorated, the segregation is prevented, and the stickiness is increased. For this reason, GPP ratio is limited to 35%. Three series of specimens with the dimensions of 40 × 40 × 160 mm (Fig. 1) were cast with various GPP contents for compressive and flexural testing of SCMs. after demolding the specimens, they were cured at the age of 3, 28 and 90-day at 20 ± 2 °C. After curing, they were tested to measure the compressive and flexural tensile strength. To investigate sorptivity, total water absorption and porosity of SCMs, 50 × 50 × 50 mm cube samples (Fig. 2) were prepared.

2.1. Materials

An ordinary Portland cement (CEM I 42.5 N) was used to produce SCM mixtures. The pumice used for the study was obtained from the Ahlat region of Bitlis. The amount of grinding pumice passing through the 0.125 mm sized sieve was determined to be 85% used as mineral additive. The chemical components and physical properties of cement and GPP are presented in Table 1. Fig. 3 illustrates the ground pumice powder (GPP) and the SEM micrographs of GPP.

The fine aggregates used in the mixtures were natural river sand with specific gravity, fineness modulus and water absorption of 2.63 gr/cm^3, 3.27 and 1.94% respectively. The maximum particle size of sand was 4.00 mm (Fig. 4).

In addition, a modified polycarboxylate-based polymer type superplasticizer (SP) is required to achieve a suitable consistency with a low water/binder (W/B) ratio. The specific weight of SP used was about 1.06 g/cm^3 and pH in the range of 3–7. The used SP was kept constant in all the blends and was set at 7 kg/m^3 (Table 2).

2.2. Mix proportions and fresh mortar tests

A total of 8 different mixtures containing 650 kg/m^3 binder, including the control sample, were prepared to observe the behaviour of the SCM in fresh and hardened states. To determine the rheological properties of SCMs containing GPP, mini slump flow diameter and mini V-funnel flow time tests were applied. SCM is produced with binary mixes of GPP instead of cement by weight, by the ratios of 5%, 10%, 15%, 20%, 25%, 30% and 35%. The mixing ratios of the produced blends (for 1 m^3 by weight) are given in Table 3. The SCMs are designed to give a slump flow diameter of 240–260 mm obtained by modifying the SP quantities. The water/binder ratios of the mortars were also determined to be between 0.38 and 0.42. Experimental batches were produced for each mix to obtain the desired sump flow diameter. Slump flow diameter and V-funnel flow time were measured according to the procedure recommended by the EFNARC committee. GPP denotes mortars

Fig. 1. Casting of 40 × 40 × 160 mm prismatic specimens and 50x50x50 mm cube specimens.