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Use of finely ground basalt as a mineral admixture in blended portland cement production

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KEYWORDS

Finely ground basalt
Mineral admixture
Blended portland cement
Properties; fineness

ABSTRACT

Basalt powder is an active mineral admixture used commonly in the production of mixed Portland cement in Vietnam. Addition of basalt powder may improve many important properties of cement and cement concrete: increasing compressive and flexural strength at late age, increasing sulphate sulfate resistance, increasing freeze-thaw resistance, reducing water absorption, and reducing heat of hydration. However, the use of basalt powder with the same fineness as cement currently has the disadvantage of reducing the compressive strength of cement from the initial stage up to 90 days or 180 days. The magnitude of the decrease was greater at earlier ages than at later ages. This disadvantage of basalt power limits its amount that can be added in blended Portland cement production. In theory, increasing the fineness can increase the activity of basalt powder. Therefore, the objective of this study was to evaluate the possibility of using finely ground basalt powder as a mineral admixture in the production of blended Portland cement, by determining the influence of basalt powder of different fineness (Blaine 3600 cm^2/g, 4800 cm^2/g and 6000 cm^2/g) on some properties of Portland cement. The investigated properties of cement included water of consistency, setting time, compressive strength at 1, 3, 7, and 28 days, and soundness. The results show that, increasing the fineness of basalt increased slightly the water demand and setting time of cement. Increasing the fineness of basalt powder increased significantly the strength of cement at early ages and increased less significantly at late ages. Therefore, the use of finely ground basalt can minimize the disadvantage of basalt powder, then allow to increase its content that can be added in the production of blended Portland cement.

1. Introduction

The cement industry annually emits a large amount of CO_2, causing environmental pollution. The cement production process emits about 0.7 to 1.1 tons of CO_2/ton of cement [1]. In cement production, the process of producing clinker emits the most amount of CO_2. Therefore, in order to minimize the impact on the environment, one of the popular ways is to use mineral admixtures to reduce the clinker content in cement. In Vietnam, basalt powder is a natural mineral admixture commonly used in the production of blended Portland cement. Basalt is a type of igneous rock formed from the cooling of volcanic lava after an eruption. Basalt has the main chemical composition of SiO_2, Al_2O_3, and exists mainly in the amorphous phase. When added into cement, basalt powder shows pozzolanic properties, SiO_2 in basalt reacts with $Ca(OH)_2$ from the hydration of Portland cement to form C-S-H [2]. Besides reducing environmental pollution, the use of basalt powder as a mineral admixture also reduces production costs and improves many important properties of cement and cement concrete.

The results of some studies show that the use of basalt powder at appropriate concentrations can increase the compressive, flexural and tensile strength of cement paste, mortar, and cement concrete at late age [3-5]. In the study of Moawad et. al. [3], basalt powder was used to replace Portland cement at the ratio of 7.5 %, 15 % and 22.5 % in concrete making. The results of this study show that, when replacing cement at the rates of 7.5 % and 15 %, basalt powder increased the compressive strength of concrete at the age of 90 days, with the corresponding increases compared to samples without basalt powder was 19.9 % and 18.6 %. The results also show that when replacing cement at the rate of 22.5 %, basalt powder increased the flexural strength of concrete at 90 days of age, increasing by 4.7 % compared to samples without basalt powder. At all three ratios, basalt powder increased the tensile strength of concrete at ages of 28 and 90 days. Moawad et. al. explained that the increase in compressive strength was due to the strengthening of the structure of the interfacial transition zone between the cement matrix and the aggregate, and the increase in the flexural and tensile strength of the concrete was due to the irregular shape and rough surface of basalt grains. In Saraya's research [4], basalt powder was used in making blended Portland cement. The results of this study showed that the use of 20 % basalt powder increased the compressive strength of cement paste at the age of 360 days, increasing by 1.8 % compared to the sample without basalt powder. Dobiszewska et. al. [5] used ground waste basalt powder to replace cement in making mortar, at basalt powder ratios of 5 %, 10 %, 15 % and 20 %. The results showed that all samples using ground waste basalt powder increased the flexural strength of the mortar at the age of 90 and 180 days.

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The results of some studies show that the use of basalt powder could reduce the heat of hydration of cement and reduce water absorption, increase the sulfate resistance and feeze-thaw resistance of concrete [2, 6]. Laibao et. al. [2] measured the heat of hydration of cement using 30 % basalt powder during the first 72 hours. The results of this study show that basalt powder significantly reduced the heat of hydration, the total heat of hydration in 72 hours was reduced by 21.2 % compared to the sample without basalt powder. Binici et. al. [6] studied the use of basalt powder to replace cement in concrete, at the rates of 5 %, 10 %, 15 % and 20 %. The results of this study show that when compared with samples without basalt powder, all concrete samples using basalt powder have lower water absorption, higher strength after immersing in sulfate environment, and higher strength after freeze-thaw cycles.

However, studies also show a disadvantage of basalt powder with fineness similar to cement is that it reduces the compressive strength of cement from the initial stage upto the age of 90 days or 180 days [2, 4-5, 7-8]. The compressive strength decrease in comparison the sample without basalt powder at the early days was greater than that at the later days. The results of Saraya [4] show that samples using 20 % basalt powder to replace cement reduced the compressive strength of cement paste at the ages of 3, 28, and 90 days, with corresponding decreases of 17.9 %, 11.5 %; 7.7 % and 5.4 %. In the study of Laibao et. al. [2], basalt powder was used to replace cement at ratios of 5 %, 10 %, 15 %, 20 %, 25 %, and 30 %. The results of compressive strength measurement show that the samples using basalt powder had lower strength than those without basalt powder at the ages of 7, 28, 90, and 180 days. For the sample using 30 % basalt powder, the degradation levels at 7, 28, 90, and 180 days old were 23.7 %, 24.3 %, 17.8 % and 13.6 %, respectively.

This decrease in compressive strength significantly limits the amount of basalt that can be added in the production of blended Portland cement. Theoretically, to increase the basalt powder content that can be added to cement, it is possible to minimize the early strength loss of cement by using basalt with higher fineness. When increasing the fineness of basalt powder, the pozzolanic activity of basalt also increases and the reaction to form C-S-H takes place faster, so it could improve early strength for cement.

The objective of this study was to evaluate the possibility of using finely ground basalt as an active mineral admixture in the production of blended Portland cement by determining the influence of basalt with different fineness on some properties of Portland cement. The three Blaine finenesses of basalt powder used were 3600 cm^2/g, 4800 cm^2/g and 6000 cm^2/g. The investigated properties of cement included water of consistency, setting time, compressive strength at the ages of 1, 3, 7, 28 days of age, and soundness.

2. Materials and experimental procedure

2.1. Materials

The clinker used in this study was produced by VICEM But Son cement company. The chemical and mineral compositions of clinker are shown in Tables 1 and **2**. The gypsum used was a natural gypsum whose chemical composition is shown in Table 3. Basalt used was a natural basalt whose chemical composition is shown in Table 4.

Table 1. Chemical composition of clinker.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
Content (%)	21.36	5.52	3.39	64.73	2.94	0.26	0.73	0.13

Table 2. Mineral composition of clinker.

Mineral	C_3S	C_2S	C_3A	C_4AF	free CaO
Content (%)	47.3	25.8	8.9	10.3	2.7

Table 3. Chemical composition of gypsum.

Composition	SO_3	$CaSO_4.2H_2O$	combined H_2O	residue
Content (%)	45.63	90.20	18.88	1.98

Table 4. Chemical composition of basalt.

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss on ignition
Content (%)	38.00	9.77	10.50	13.85	5.78	13.93

2.2. Experimental procedure

The cement samples were prepared as follows:

- Step 1: Preparation of Portland cement

Clinker and gypsum were crushed separately by using a jaw crusher until all particles passed a 5 mm sieve. Clinker and gypsum were weighed at the ratio of 95 % clinker and 5 % gypsum, then put into a ball mill and ground until the Blaine fineness was 3400 cm^2/g (determined according to TCVN 4030:2003 [9]).

- Step 2: Preparation of finely ground basalt

Basalt was crushed by using a jaw crusher until all particles passed a 5 mm sieve, then ground in a laboratory ball mill to Blaine finenesses of 3600 cm^2/g, 4800 cm^2/g and 6000 cm^2/g (determined according to TCVN 4030:2003 [9]).

- Step 3: Preparation of basalt-Portland cement mixtures

Basalt-Portland cement mixtures were prepared by weighing and mixing (by machine) Portland cement and finely ground basalt powder at the ratio of 80 % Portland cement and 20 % basalt powder.

Water of consistency, setting time and soundness of cements were determined according to TCVN 6017:2011 [10]. The compressive strengths of cements were determined according to TCVN 6016:2011 [11].

3. Results and discussion

3.1. Water of consistency

The results of water of consistency of cement samples are shown in Figure 1.

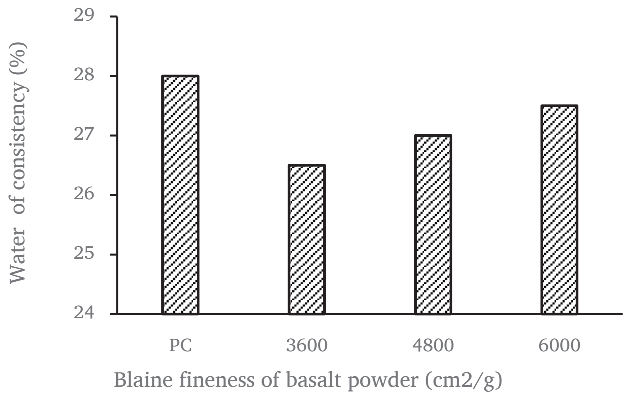

Figure 1. Water of consistency of Portland cement sample and basalt-Portland cement samples.

The results in Figure 1 show that increasing the fineness of basalt powder increased the water of consistency of the cement samples using 20 % basalt powder, but they were lower than the water of consistency of the Portland cement sample. Cement samples using basalt powder with the fineness increased from 3600 cm^2/g to 4800 cm^2/g and 6000 cm^2/g had water of consistency increasing from 26.5 % to 27 % and 27.5 %, respectively, while water of consistency of the Portland cement sample was 28 %. This increase could be explained that increasing the fineness of basalt powder increased the fineness and specific surface area of the basalt-Portland cement mixtures. Therefore, more water was needed to lubricate the surface of the particles for the cement pastes to reach the standard consistency [12].

3.2. Setting time

The experimental results of initial and final setting time of the cement samples are shown in **Figure 2**.

Initial and final setting times of cement samples using 20 % basalt powder were higher than those of the Portland cement samples and all satisfied the requirements of setting time for blended Portland cement specified in TCVN 6260:2020 [13]. The initial setting time of the basalt-Portland cement samples increased by 10 minutes to 15 minutes, while the final setting time increased by 15 minutes to 20 minutes in comparison with Portland cement samples. This increase in setting time could be due to the dilution effect of basalt powder. Because basalt powder has low pozzolanic activity at early ages, the use of 20 % basalt reduces the Portland cement content and reduces the hydration rate of the basalt-Portland cement mixture.

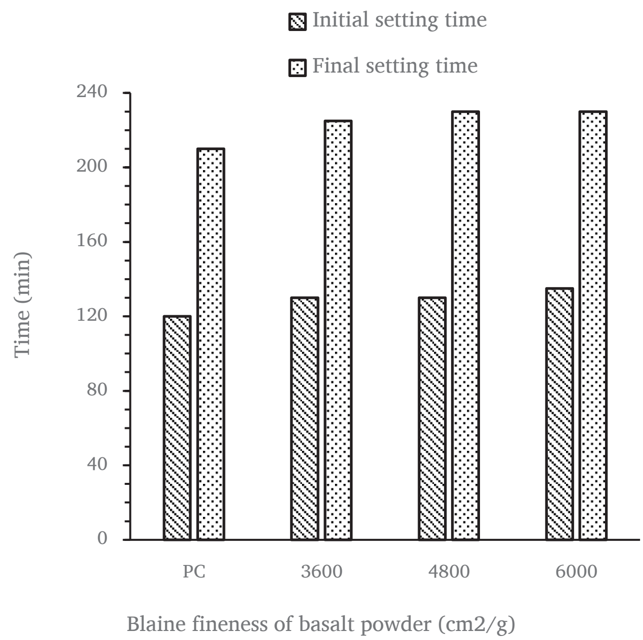

Figure 2. Setting time of Portland cement sample and basalt-Portland cement samples.

The results also show that increasing the fineness of basalt powder slightly increases the initial and final setting time of cement. When the fineness of basalt powder increased from 3600 cm^2/g to 6000 cm^2/g, the initial and final setting time increased by only 5 minutes, increased from 130 minutes to 135 minutes and from 225 minutes to 230 minutes, respectively. The main reason for the increase in setting time would be that the higher water of consistency of samples using finer basalt powder prolonged the induction period in the hydration of cement [14]. Figure 2 also shows that the initial and final setting time of the samples using basalt powder met TCVN 6260:2020 standard (initial setting time not less than 45 min and the final setting time not greater than 420 min) [13].

3.3. Compressive strength

The results of the compressive strength of the cement samples are shown in Figure 3.

The results in Figure **3** show that the strengths of cement samples using 20 % basalt powder were lower than that of Portland cement samples at all four ages due to the dilution effect of basalt powder. However, when the fineness of basalt powder increased, the strength of cement samples using basalt powder increased. At the age of 3 days, the strengths of cements using basalt powder with fineness of 3600 cm^2/g, 4800 cm^2/g and 6000 cm^2/g were 28.8 MPa, 30.3 MPa, and 31.9 MPa, respectively. At the age of 28 days, the strengths of cements using basalt powder with fineness 3600 cm^2/g, 4800 cm^2/g and 6000 cm^2/g were 45.6 MPa 46.2 MPa and 46.8 MPa, respectively. The reason for thes increases in compressive strength could be that increasing the fineness of basalt powder increased the surface area of basalt grains that can participate in the pozzolanic reaction with $Ca(OH)_2$ to form C-S-H with higher strength [2]. In addition, the fine basalt particles can show filling effect that increases the packing density of the cement paste and contributes to the increase in cement strength [15]. Fine basalt particles can also act as nucleation sites for hydration products, helping to promote the hydration of minerals in cement [15].

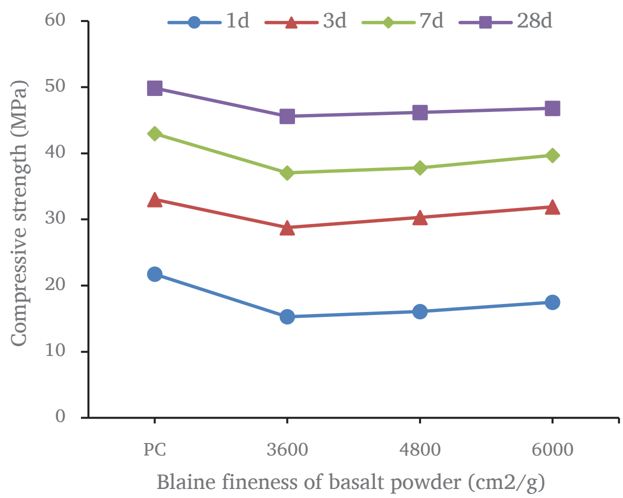

Figure 3. Compressive strength of Portland cement sample and basalt-Portland cement samples.

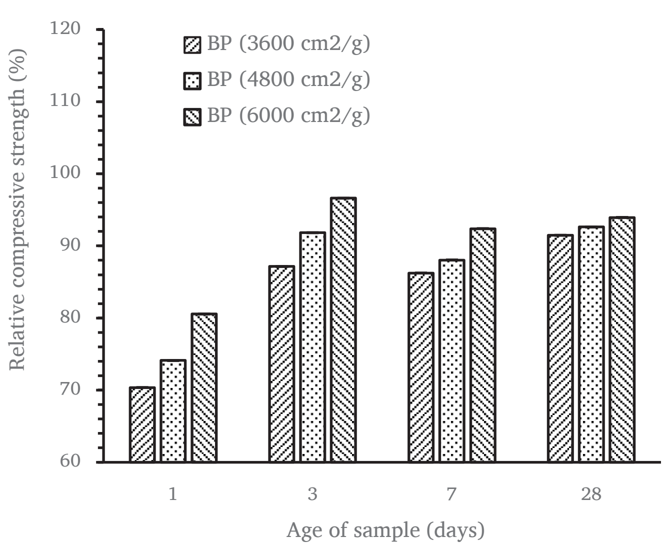

Figure 4. Relative compressive strengths of basalt-Portland cement samples in comparison with Portland cement sample.

Figure 4 shows the relative compressive strength of cement samples using basalt powder in comparison with that of the Portland cement samples. The results showed that, when increasing the fineness of basalt powder, the strength of cement at the early ages (1, 3 and 7 days) increased at greater extents than at the late age (28 days). When increasing the fineness of basalt powder from 3600 cm^2/g to 4800 cm^2/g and 6000 cm^2/g, the increases in cement strength at early ages were as follows: 3.8 % and 10,2 % at the age of 1 day, 4.7 % and 9.4 % at the age of 3 days, 1.8 % and 6.2 % at the age of 7 days, while at 28 days old they were only 1.1 % and 2.5 %. The better strength improvement in the early ages could be due to that the finer basalt powder exhibits better filling effect and create more nucleation sites for C-S-H, and increase the pozzolanic activity of basalt powder.

3.4. Soundness

The results of soundness of cement samples determined by the Le Chatelier method are shown in Figure 5.

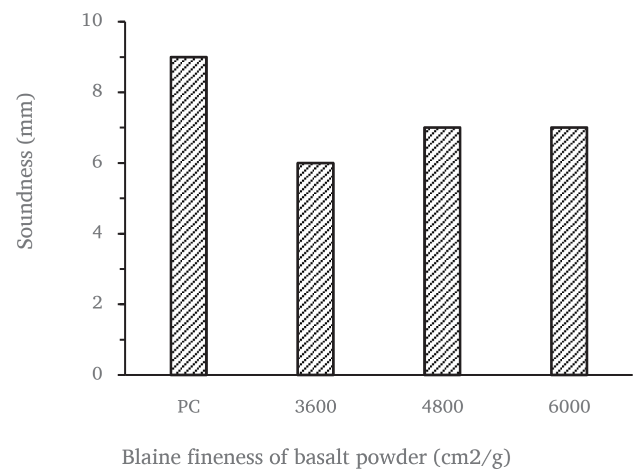

Figure 5. Soundness of Portland cement sample and basalt-Portland cement samples.

The results show that the cement samples using 20 % basalt powder have lower expansion than Portland cement samples, and all met the requirements of soundness for blended Portland cement specified in TCVN 6260:2020 [13]. This could be due to the dilution effect of basalt, which reduces the content of expansive minerals (free CaO and free MgO) in the cement mixture. When increasing the fineness of basalt powder from 3600 cm^2/g to 4800 cm^2/g and 6000 cm^2/g, the expansion of cement increased by 1 mm. This may be because finer basalt powder has better filling effect, resulting in denser cement matrix, so the hydration products of the expansive reaction ($Ca(OH)_2$ and $Mg(OH)_2$) have less room to fill and cause stronger expansion.

4. Conclusions

Based on the research results of Portland cement samples and cement samples containing 20 % basalt powder with fineness of 3600 cm^2/g, 4800 cm^2/g, and 6000 cm^2/g, we can have the following conclusions:

- Water of consistency of cement samples using basalt powder are lower than Portland cement samples. When increasing the fineness of basalt powder from 3600 cm^2/g to 4800 cm^2/g and 6000 cm^2/g, the water of consistency of cement samples using basalt powder increased from 26.5 % to 27 % and 27.5 %, respectively.
- Initial and final setting time of cement samples using basalt powder are higher than those of Portland cement samples. When increasing the fineness of basalt powder from 3600 cm^2/g to 4800 cm^2/g and 6000 cm^2/g, the initial and final setting time of the cement samples using basalt powder increased slightly (only by 5 minutes), increased from 130 minutes to 135 minutes and from 225 minutes to 230 minutes, respectively. The initial and final setting time of cement samples using basalt powder satisfied the requirements for blended Portland cement specified in TCVN 6260:2020.
- The strength of the cement samples using basalt powder was lower than that of Portland cement samples at early ages (1, 3, and 7 days) and late age (28 days). When increasing the fineness of basalt powder from 3600 cm^2/g to 4800 cm^2/g and 6000 cm^2/g, the strength of cement samples using basalt powder increased at all four ages, at early ages (1, 3 and 7 days) increased more than at late age (28 days).
- The expansions of cement samples using basalt powder are lower than Portland cement samples. When increasing the fineness of basalt powder from 3600 cm^2/g to 4800 cm^2/g and 6000 cm^2/g, the expansion of cement samples using basalt powder increased slightly, from 6 mm to 7 mm, all met the requirements for blended Portland cement specified in TCVN 6260:2020.

The research results show that the finely ground basalt powder can be used as a mineral admixture in the production of blended Portland cement, to improve the early age compressive strength of blended Portland cement using basalt powder.

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