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Use of perlite as a pozzolanic addition in producing blended cements

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Abstract

There are ~6700 million tons of perlite reserves in the world and two thirds of this amount takes place in Turkey. Although perlite possesses pozzolanic properties, it has not been so far used in producing blended cements. This study focuses on the use of natural perlites in blended cement production. For this purpose, after examining the suitability of the perlites as pozzolans and their ease of grindability, 16 types of blended cements having 320 m^2/kg or 370 m^2/kg Blaine fineness were produced by using 20% or 30% perlite additions. Production of the blended cements were accomplished either by intergrinding or separate grinding. The performance of the cements was evaluated by conducting the following tests: particle size distribution by laser diffraction, normal consistency, setting time, soundness and compressive strength. The results showed that perlites possess sufficient pozzolanic characteristics to be used in production of blended cement.
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1. Introduction

Perlite is a glassy volcanic rock that contains approximately 70–75% SiO_2 and 12–18% Al_2O_3. Its 2–6% chemically combined water causes it to expand and become a cellular material of extremely low bulk density when heated to a temperature of ~900 °C. Thus the expanded perlite is used in various constructional, horticultural and industrial applications [1–3].

Due to its glassy structure and high SiO_2 and Al_2O_3 contents, perlite is a pozzolan, obviously. Although its pozzolanic characteristics have been mentioned in some limited numbers of technical papers [3–6], no investigation has so far been made on the use of natural perlite in manufacturing blended cements.

There are a large number of publications in the literature which discuss the benefits of using mineral admixtures in cement and concrete industry. Depending on the type and amount, one or more of the following advantages can be achieved through their use: reduction in portland cement (PC) consumption, improved workability, lower permeability, higher durability, higher strength, etc. Moreover, each of these items can result in further benefits. For example, reduction in PC consumption helps decrease the CO_2 emission and the cost due to the lower energy consumption during calcining and grinding. Since over 50% of the total electrical energy consumption during cement production is used for grinding raw materials and clinker, improvements in the grinding operation should be appreciated [7].

The overall objectives of this study can be summarized as follows: With its relatively high amount of cement production (around 40 million tons/year), Turkey is one of the leading countries in Europe and can be considered as an important producer in the world [8]. In addition, there are very large perlite deposits in the world (~6700 million tons) and approximately two thirds of those are in Turkey [9]. Therefore, if it is shown in this study that the natural perlites investigated have pozzolanic properties, are easily grindable and the cements produced with these perlites conform to the standard specifications for the blended cements, then these perlites can be used as a pozzolanic

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addition in cement production in Turkey. This will enable to reduce the PC consumption, and therefore, cost and CO_2 emission through the use of easily available perlites. Moreover, it can be expected that perlites can provide the other benefits of the commonly used admixtures discussed above and further studies can be conducted to investigate this.

For these purposes, natural perlites from two different regions of Turkey (İzmir and Erzincan) were tested to determine their conformance to the standard specifications for pozzolanic materials. After obtaining satisfactory results on those tests and investigating the grindability properties of them, their performance as a pozzolan in blended cements were investigated. Several cements with different Blaine fineness values (320 m^2/kg and 370 m^2/kg) and different perlite amounts (20% and 30%, by weight of cement) were produced. Either intergrinding or separate grinding methods were used to produce the blended cements. Following tests were conducted to determine the performance of the cements: particle size distribution by laser diffraction, normal consistency, setting time, soundness and compressive strength.

2. Experimental study

2.1. Materials and methods of producing cements

Two different Turkish perlites, one from İzmir (P1) and the other from Erzincan (P2), and an ordinary portland cement clinker were used. Their chemical compositions are given in Table 1.

Two ordinary portland cements (PC/320 and PC/370) with 320 ± 5 m^2/kg and 370 ± 5 m^2/kg Blaine fineness were produced for control purposes. The blended cements with the same fineness values (320 ± 5 m^2/kg and 370 ± 5 m^2/kg) were obtained by using 20% or 30% (by weight of cement) perlite replacement either by intergrinding or separate grinding and mixing. Thus, in addition to the two types of control portland cements, 16 types of blended cements were produced using the two types of perlites. Table 2 gives a list of the cements produced. The gypsum content was kept constant in all cements as 4%.

Before the grinding operation, portland cement clinker and gypsum were crushed, and sieved through 9.5 mm sieve. Gypsum was dried at 40 °C prior to crushing. The perlites were dried at 110 °C, crushed and sieved through 4.75-mm sieve. The purpose of sieving was to keep the uniformity between each grinding operation through using the same feed sizes.

Grinding operation was performed by a laboratory type grinding mill having a length of 450 mm and a diameter of 420 mm. The speed of the mill was 30 rev/min. The charge of the grinding mill consisted of steel spherical balls and cylpebs. The total weight of the charge (98 kg) and the amount of material to be ground (7 kg) were kept constant in all of the grinding operations. During the grinding operation, samples of approximately 100 g were taken at regular intervals to determine some properties such as specific gravity, Blaine fineness, and amount of material retained on 45 μm sieve.

2.2. Tests conducted

The chemical compositions of the portland cement clinker and the two types of perlites were determined. The amorphous character of the perlites was observed by XRD. The tests listed in Table 3 were conducted to examine the conformance of the perlites to the requirements

Table 1
Chemical composition of the clinker and the perlites

Oxides	Amount (%)		
	Clinker	P1	P2
CaO	63.58	0.51	0.60
SiO_2	21.00	76.57	75.30
Al_2O_3	4.98	9.99	9.35
Fe_2O_3	3.57	0.96	1.36
MgO	1.86	0.03	0.05
K_2O	0.74	5.58	4.82
Na_2O	0.14	0.00	0.00

Table 2
Cements produced in this study

Cement name[a]	Method of grinding	Source of perlite	Perlite amount (%)	Fineness (m^2/kg)
PC/320	–	–	0	320
PC/370	–	–	0	370
I P1-20/320	Intergrinding	İzmir	20	320
S P1-20/320	Separate grinding	İzmir	20	320
I P2-20/320	Intergrinding	Erzincan	20	320
S P2-20/320	Separate grinding	Erzincan	20	320
I P1-30/320	Intergrinding	İzmir	30	320
S P1-30/320	Separate grinding	İzmir	30	320
I P2-30/320	Intergrinding	Erzincan	30	320
S P2-30/320	Separate grinding	Erzincan	30	320
I P1-20/370	Intergrinding	İzmir	20	370
S P1-20/370	Separate grinding	İzmir	20	370
I P2-20/370	Intergrinding	Erzincan	20	370
S P2-20/370	Separate grinding	Erzincan	20	370
I P1-30/370	Intergrinding	İzmir	30	370
S P1-30/370	Separate grinding	İzmir	30	370
I P2-30/370	Intergrinding	Erzincan	30	370
S P2-30/370	Separate grinding	Erzincan	30	370

[a] The letters PC, I, S, P1 and P2 in the table represent portland cement, intergrinding, separate grinding, İzmir perlite and Erzincan perlite, respectively. The numbers 20 and 30 following the dash show the % of perlite used; the numbers 320 and 370 show the Blaine fineness in m^2/kg.

Table 3
Conformance of the perlites to ASTM C 618

	P1	P2	ASTM C 618
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	87.52	86.01	Min. 70.0
SO_3 (%)	0.04	0.06	Max. 4.0
Loss on ignition (%)	4.22	4.13	Max. 10.0
Fineness: amount retained when wet-sieved on 45 μm sieve (%)	31	31	Max. 34
Strength activity index			
7-d (% of control)	80.3	85.1	Min. 75
28-d (% of control)	81.9	85.9	Min. 75
Water requirement (% of control)	103	100	Max. 115
Soundness: autoclave expansion or contraction (%)	0.05	0.07	Max. 0.8

prescribed in the standard specification ASTM C 618 for natural pozzolans [10].

Grindability of the materials was investigated by obtaining ''fineness-grinding time'' relationships for the perlites and the cements produced with them. Fineness was determined by measuring the Blaine fineness and amount of material retained on 45 μm sieve after wet sieving. Particle size distributions of the perlites and the cements with Blaine fineness of 320 m^2/kg and 370 m^2/kg were determined by using Malvern Mastersizer laser particle size analyzer.

Following tests were carried out on the cements: particle size distribution by laser diffraction, normal consistency, setting time, soundness by autoclave method and compressive strength.

The amount of water necessary for the cements to have normal consistency was determined according to ASTM C 187 [11]. Then, the pastes having normal consistency were used to determine the setting time and soundness (autoclave expansion) through conducting tests described in ASTM C 191 and C 151 [12,13], respectively.

Compressive strength and flow values of the mortars were determined according to ASTM C 109 [14]. In these tests, 500 g of cement and 1375 g of standard sand were used. PC mortars were prepared with 242 ml of water whereas the water content of the blended cement mortars were adjusted to give a flow of 110 ± 5 as stated in this standard. The compressive strength of the mortars was determined at 2, 3, 7, 28, 56 and 91 days. Three 5 cm × 5 cm × 5 cm cube specimens were tested for each day.

3. Results and discussion

3.1. Evaluation of the pozzolanic properties of perlite

Chemical and physical properties of P1 and P2 perlites having 370 m^2/kg Blaine fineness were determined and compared with the requirements given in ASTM C 618 [10] (see Table 3). Blaine fineness of the portland cement used in the determination of the strength activity index was 320 m^2/kg. As can be seen from Table 3, both P1 and P2 conform to the requirements of this standard.

X-ray diffraction pattern of crystalline structures consists of many sharp peaks while those of the non-crystalline solids show diffuse humps. A hump indicates a short-range structure due to the irregular and non-repetitive arrangement of the atoms. Therefore, a hump in the XRD pattern indicates amorphous nature of the material. Figs. 1 and 2 show the X-ray diffractograms of P1 and P2, respectively. Closeness of the two humps in the diffractograms to the two major peaks of quartz (2 theta = 26.82 and 50.12) is an indication of the siliceous nature of the amorphous phase of both perlites. As seen from these figures, the XRD patterns of P1 and P2 are similar to each other. The difference between the XRD patterns of the two perlites is the presence of some crystalline quartz and hauyne in P2. However, as will be observed in the rest of the paper, this difference has no considerable effect on the performance of the perlites in the blended cements since these perlites yielded similar results for the tests conducted in this study.

Urhan [6,15] investigated the pozzolanic reactions of expanded perlite aggregate concretes. Pozzolanic reactions were observed mainly on the fine perlite particles. Improved paste–aggregate interface was also noted by other researchers for both fine perlite aggregates [3,6] and other lightweight aggregates [16,17].

As a result, chemical composition of the perlites showing the siliceous nature (Table 1), their XRD patterns showing the amorphous structure (Figs. 1 and 2), conformance of the perlites to the standard specification for natural pozzolans, ASTM C 618 (Table 3), and the previous studies [3–6] on the pozzolanic properties of the perlites prove, from many aspects, that perlites possess certain pozzolanic characteristics, and they can be used as a portland cement replacement in concrete.

3.2. Grindability

Fineness of cements or pozzolans are evaluated by several methods such as determining their Blaine surface area, by finding out the amount retaining on 45 μm sieve or by seeing the particle size distribution using laser diffraction. All these methods have some advantages and disadvantages in showing the fineness of the materials: It is claimed that Blaine air-permeability method may give misleading results especially for porous materials [18]. Moreover, only the continuous paths throughout the cement contribute to the measured surface area [19]. On the other hand, the method for determination of the amount retained on 45 μm sieve may be insufficient in showing the fineness of the material since that method provides only a single value and supplies no information on the size of grains smaller than 45 μm [19]. It is stated that using laser diffraction method is a more informative method since it shows the particle size distribution of the materials [20]. However, this technique is based on volumetric measurements and it is difficult to compare the data obtained with the results of conventional sieve analysis [21]. Since all of the above

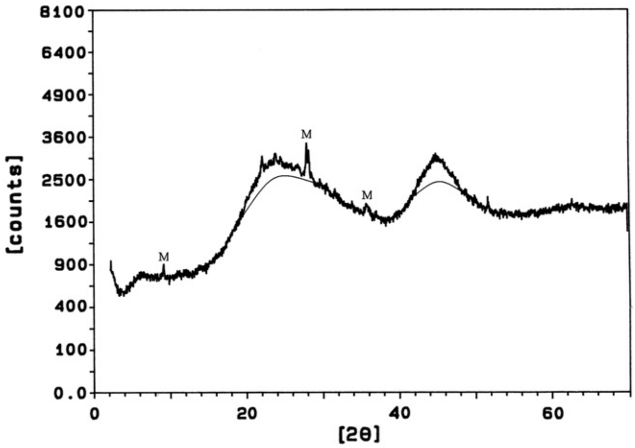

Fig. 1. X-ray diffractogram of P1 (M: muscovite).

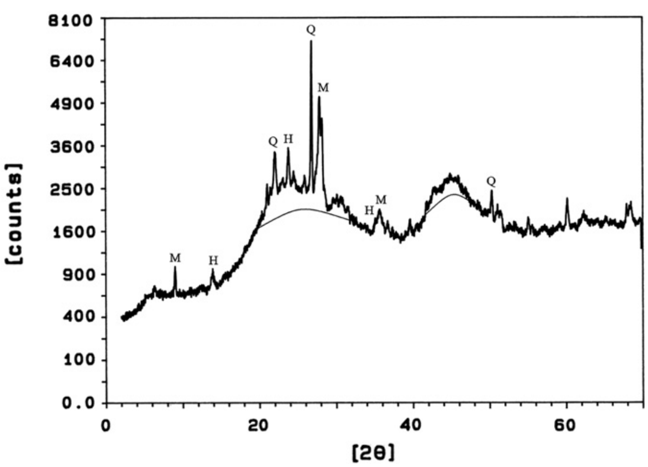

Fig. 2. X-ray diffractogram of P2 (Q: quartz, M: muscovite, H: hauyne).

three methods had their advantages and disadvantages for determining the fineness of cements and pozzolans, all of these methods were decided to be used in this investigation.

The change of Blaine fineness of PC, P1 and P2 in relation to grinding time is shown in Fig. 3 with solid lines. As seen from this figure, for the same grinding time, PC resulted in the lowest fineness value, and P2 was finer than both P1 and PC. In other words, the required time (or energy) to achieve a given fineness was greatest for PC and least for P2. Moreover, the milder slope of the curve for PC reveals that PC required more time to increase the fineness of the product when compared to P1 and P2. For example, the time necessary to increase the fineness from 320 to 370 m^2/kg was 30 min for PC, but it was 10 and 15 min for P1 and P2, respectively. In the same way, as the grinding time increased, the curve for PC approached a horizontal line indicating that it became harder and harder to make the PC finer. In other words, the efficiency of grinding operation decreased with time. However, such a behaviour was not observed for the perlites. Therefore, the above discussions yield that the grindability of P2 was better than P1, and PC was less grindable than both perlites.

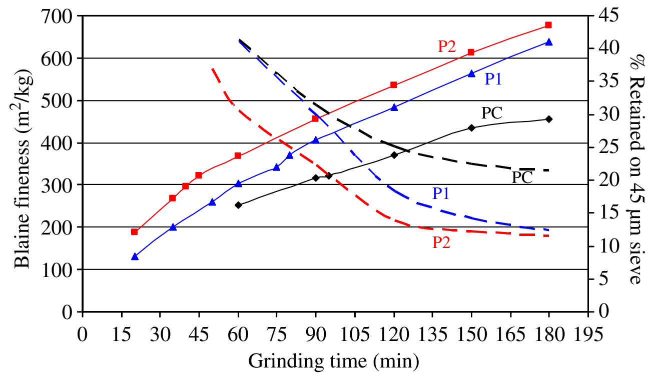

Fig. 3. "Grinding time–Blaine fineness" and "grinding time–amount of material retained on 45 μm sieve" relationships for P1, P2 and PC.

The "grinding time–amount of material retained on 45 μm sieve" relationships for PC, P1 and P2 are also shown in Fig. 3 with dashed lines. These curves revealed that P2 was easier to be ground than both P1 and PC. While the grindabilities of P1 and PC were similar at early stages, grinding P1 became easier than grinding PC in time.

Figs. 4a and b show the particle size distribution of the materials with 320 and 370 m^2/kg finenesses, respectively. Although the materials had the same Blaine fineness, their

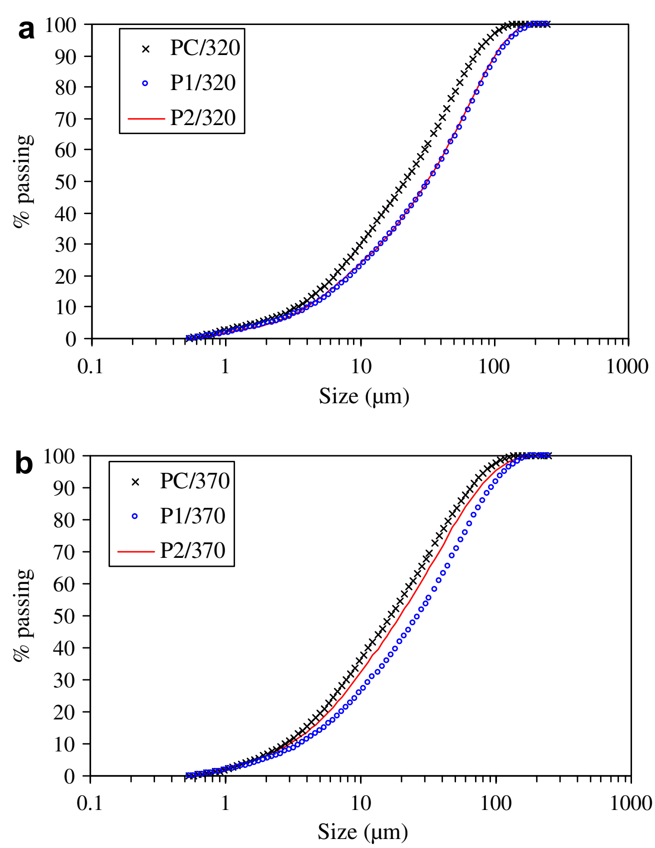

Fig. 4. Particle size distribution of the materials with Blaine fineness of (a) 320 m^2/kg and (b) 370 m^2/kg.

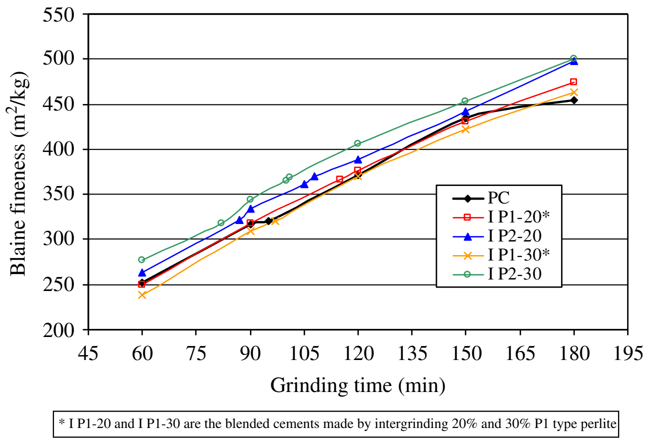

Fig. 5. "Grinding time–Blaine fineness" relationships for the cements.

particle size distributions were significantly different. Both perlites were coarser than PC for a given Blaine fineness. However, the difference in particle size distributions becomes less for smaller sizes.

The "grinding time–Blaine fineness" relationships for the PC and the interground blended cements are given in Fig. 5. This figure shows that interground cements containing P1 yielded a similar curve to that of PC. However, for the same grinding duration, blended cements containing P2 were finer than PC and blended cements with P1. This shows that replacement with P2 increased the efficiency of the grinding operation and promoted the grindability as it enabled to reach higher fineness values in shorter grinding periods resulting in lower energy requirement. This result was consistent with the results of a research by Opoczky in which the grindabilities of several composite cements were better than that of the clinker [22]. Improvements in the grinding efficiency are very important for the cost of the cement since over 50% of the total electrical energy consumption during cement production is used for grinding raw materials and clinker [7].

Particle size distributions of the blended cements were also determined. Since the effect of grinding method on the cements having the same perlite type, perlite amount, and Blaine fineness was similar to each other, only the representative curves were given in Figs. 6 and 7 for 320 and 370 m^2/kg fineness values, respectively. Each of these figures compares intergrinding and separate grinding for some selected cements. The values for separately ground blended cements were calculated by the weighted sum of the size fractions of the PCs and perlites given in Fig. 4. As illustrated in Figs. 6 and 7, the grading curves for separate grinding were generally below the curves for intergrinding. This indicates that separate grinding yielded coarser particles when compared to intergrinding. The difference in the particle size distribution of the separately ground and interground cements proves the interactions between the ingredients, that is clinker and perlite, during intergrinding. In this study, these interactions affected the final product positively since interground blended cements

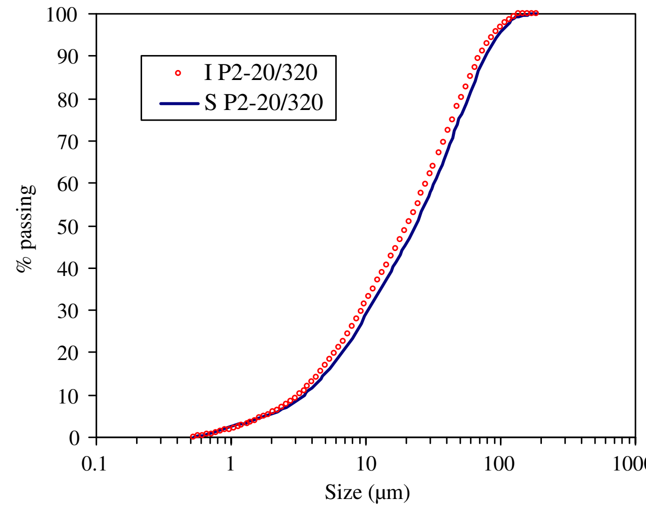

Fig. 6. Particle size distributions of two selected cements with Blaine fineness of 320 m^2/kg.

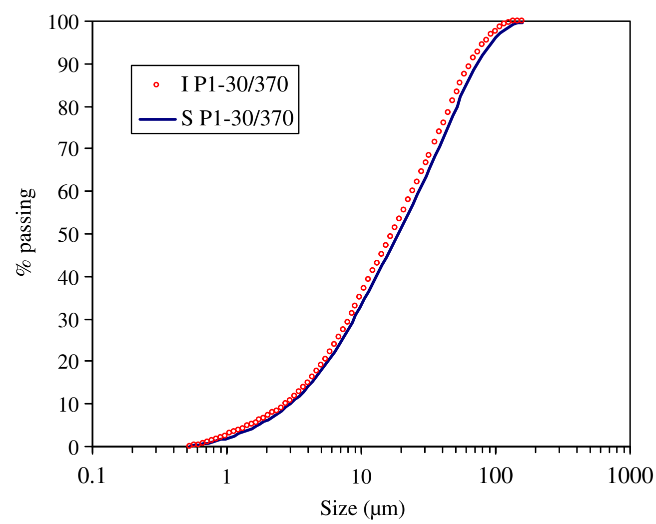

Fig. 7. Particle size distributions of two selected cements with Blaine fineness of 370 m^2/kg.

had finer particles while their Blaine fineness values were the same.

The interactions originate from the differences in the grindabilities of the constituents. Previous studies have shown that in case of clinker–natural pozzolan mixes and slag–clinker mixes, clinker can grind natural pozzolan, and slag can act as a grinding medium to the clinker [22–24]. In the light of this information, the finer particle size distribution of the interground cements can be explained as follows: as shown in Fig. 4, for a given Blaine fineness, the perlites had a coarser particle size distribution when compared to the clinker. When ground clinker (i.e., PC) and ground perlite were mixed, the perlite remained coarser than PC. On the other hand, during intergrinding the perlite was ground not only by the steel charges but also by the clinker. These interactions eliminated the relatively coarser perlite particles and yielded a finer particle size distribution for interground cements.

Figs. 6 and 7 also show that although the difference between intergrinding and separate grinding was high for larger sizes, it decreased as the particle size got smaller. Such a trend was an indication of the higher interactions for larger particles [25].

Further analysis of the particle size distributions revealed that for a given fineness and perlite amount, interground cements containing P1 was slightly coarser than those containing P2. Moreover, 20% and 30% replacements resulted in almost the same particle size distribution for the interground cements with the same fineness and perlite type.

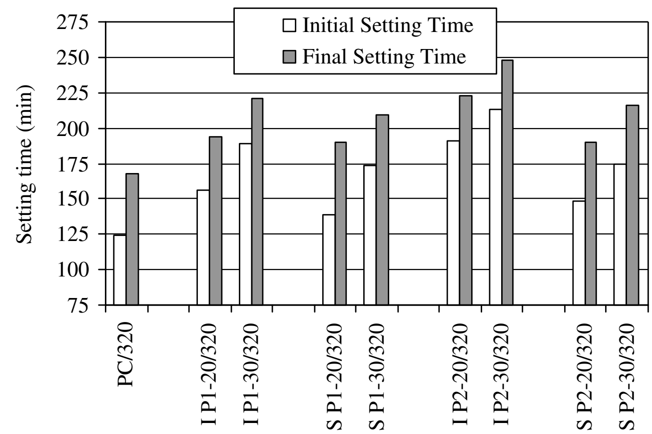

Fig. 8. Setting time of the cements (for fineness = 320 m^2/kg).

3.3. *Effects of perlites on cement properties and evaluation of the cements*

In the previous sections, the pozzolanic and grindability properties of the perlites were shown to be sufficient for using them in blended cement production. However, in order to propose that perlite can be used in blended cements, the performance of the cements containing perlite has to be investigated, too. Moreover, these cements have to satisfy the requirements given in standard specifications. For this purpose, the cements produced were tested to check their conformity with the three most widely used cement specifications given in ASTM and EN standards [26–28]. The cements investigated can be classified as "type IP (portland-pozzolan)" according to ASTM C 595, "type GU (General Use)" according to ASTM C 1157, and "CEM II/A-P 32.5 R" or "CEM II/B-P 32.5 R" according to EN 197-1.

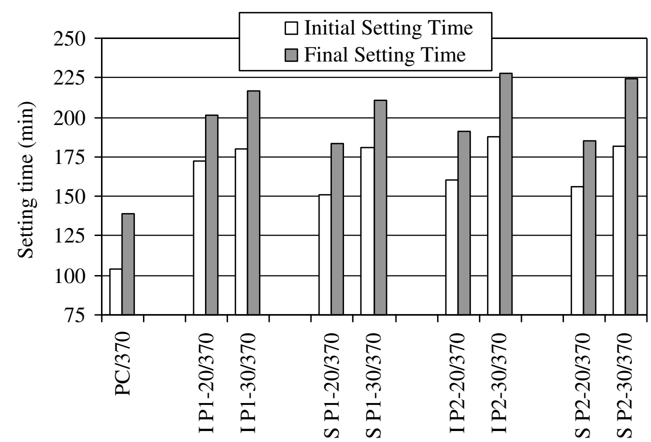

Fig. 9. Setting time of the cements (for fineness = 370 m^2/kg).

3.3.1. *Normal consistency, setting time and soundness*

Water-to-cement ratios (w/c) for normal consistency and the results of the soundness tests are given in Table 4. Figs. 8 and 9 show the setting time values of the cements.

For the same fineness values, water requirements of the blended cements to have normal consistency were higher when compared to PC. The effect of perlite type can be observed by comparing the cements having the same grinding method, same perlite amount and same fineness but different perlites (for example, S P1-20/320 and S P2-20/320). Such a comparison made by using Table 4 shows that w/c ratio did not change significantly with the perlite type (for example, it was 0.242 and 0.243 for S P1-20/320 and S P2-20/320, respectively). Similarly, method of grinding did not affect the water requirements of the cements having the same perlite type, same perlite amount and same fineness. Moreover, for a given grinding method, given perlite type and given fineness, the cements with 30% perlite required slightly more water than those with 20% replacement (for example, w/c ratio of I P1-30/370 was 0.252 while that of I P1-20/370 was 0.248).

The standard specifications ASTM C 595 and C 1157 limit the initial setting time to minimum 45 min and final setting time to maximum 420 min. On the other hand, EN 197-1 specifies a limit only for the initial setting time. It is 75 min for the cements like those produced in this study. As seen from Figs. 8 and 9, all cement types satisfied these requirements. Due to the lower clinker content, the setting time values of the blended cements containing 20% perlite were longer than those of PC, and 30% replacement with

Table 4
Water-to-cement ratios (w/c) for normal consistency and the results of the soundness tests

Cement type	w/c	Autoclave expansion (%)	Cement type	w/c	Autoclave expansion (%)
PC/320	0.234	0.07	PC/370	0.235	0.06
I P1-20/320	0.240	0.05	I P1-20/370	0.248	0.04
S P1-20/320	0.242	0.05	S P1-20/370	0.248	0.04
I P2-20/320	0.242	0.06	I P2-20/370	0.248	0.06
S P2-20/320	0.243	0.07	S P2-20/370	0.248	0.06
I P1-30/320	0.243	0.02	I P1-30/370	0.252	0.02
S P1-30/320	0.242	0.02	S P1-30/370	0.254	0.02
I P2-30/320	0.248	0.05	I P2-30/370	0.254	0.04
S P2-30/320	0.247	0.06	S P2-30/370	0.254	0.04

perlite increased the values further. For a given fineness and composition, the interground cements had longer setting times when compared to separately ground cements. This may be explained by the relatively coarser clinker particles in the interground cements [24].

The standard specifications C 595 and C 1157 allow an autoclave expansion value of maximum 0.80%. Table 4 shows that the results for the blended cements were below this limit. It can be stated from this table that incorporation of PC with perlite reduced the expansions. In addition, the increase in the perlite content decreased the expansion values.

3.3.2. Compressive strength

Portland cement mortars to be used for compressive strength testing were prepared to have a w/c of 0.485 as stated in ASTM C 109. The blended cement mortars were prepared to have a flow value of 110 ± 5. Table 5 shows the w/c and compressive strength values at 2, 3, 7, 28, 56 and 91 days.

When compared to the pertinent standards, it is seen from Table 5 that the strength requirements for type IP and type GU cements were satisfied by all of the blended cements produced. The test methods given in ASTM and EN standards for the determination of compressive strength (ASTM C 109 and EN 196-1, respectively) are not exactly the same; however, it can be stated that the blended cements also conform to EN 197-1 since w/c of the mortars were the same with or similar to what is required in EN 197-1 (i.e. 0.5).

Table 5 shows that for a given Blaine fineness and composition, the strengths of the mortars with interground cements were generally higher than those with separately ground cements. The higher strengths of the interground cements were due to their finer particles when compared to separately ground cements (Figs. 6 and 7). Another possible reason may be the more homogeneous products provided by intergrinding [25,29].

The effect of finer particle size distribution was also observed on the strengths of the mortars containing different perlite types: mortars with P2 produced higher strengths than those with P1. Moreover, this was an expected conclusion since the strength activity indices of P2 were higher than those of P1 (Table 3).

When the strengths of the mortars containing the cements with the same fineness, same perlite and the same grinding method are compared, it is seen from Table 5 that 20% replacement produced higher strengths than 30% replacement. The lower strengths of the mortars with the cements containing 30% perlite can be explained by their lower PC contents (especially for the earlier ages during which pozzolanic reactions were insignificant) and higher w/c.

Figs. 10 and 11 compare the strengths of PC and interground blended cements for Blaine fineness values of 320

Table 5
w/c and compressive strengths of PC and blended cements

	w/c	Compressive strength (MPa)					
		2-d	3-d	7-d	28-d	56-d	91-d
PC/320	0.48	22.5	24.4	35.5	49.6	51.5	53.6
I P1-20/320	0.50	17.5	20.8	29.1	39.6	46.8	51.3
S P1-20/320	0.50	17.5	21.7	26.1	41.8	47.2	50.2
I P2-20/320	0.50	17.7	21.5	29.5	42.8	46.0	51.7
S P2-20/320	0.50	17.9	21.8	26.6	38.1	47.6	50.4
I P1-30/320	0.51	15.1	15.9	26.9	40.3	44.3	46.3
S P1-30/320	0.51	13.7	16.6	27.6	34.7	40.1	42.6
I P2-30/320	0.51	14.1	18.7	27.9	35.5	44.3	46.5
S P2-30/320	0.51	12.6	17.5	27.0	35.3	42.4	45.3
PC/370	0.48	25.4	28.5	38.5	50.8	52.8	54.2
I P1-20/370	0.50	22.0	22.8	30.4	44.9	47.8	53.4
S P1-20/370	0.50	17.8	22.3	30.0	43.3	48.1	53.4
I P2-20/370	0.50	18.9	24.4	32.1	47.7	50.3	56.7
S P2-20/370	0.50	20.7	22.7	31.7	43.7	50.4	53.1
I P1-30/370	0.52	16.9	19.9	30.6	41.0	45.3	48.6
S P1-30/370	0.52	16.7	19.1	28.6	40.0	46.0	48.2
I P2-30/370	0.52	19.1	18.9	30.6	41.9	47.0	50.7
S P2-30/370	0.52	18.6	19.5	28.3	39.8	44.6	49.8

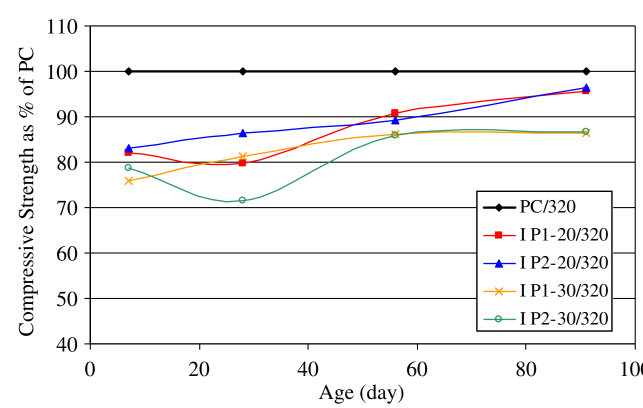

Fig. 10. Compressive strength of the blended cements as % of PC (fineness = 320 m^2/kg).

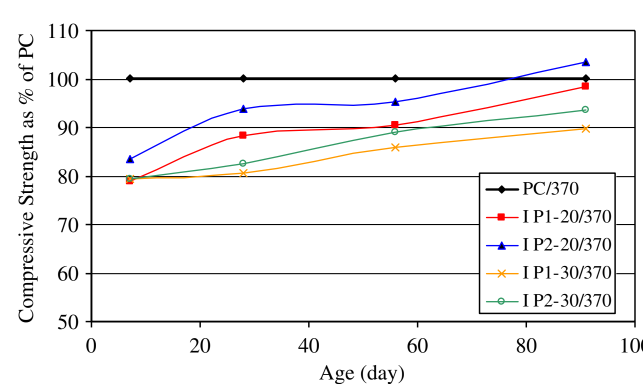

Fig. 11. Compressive strength of the blended cements as % of PC (fineness = 370 m^2/kg).

and 370 m^2/kg, respectively. In these figures, the strengths of the blended cements were expressed as percentages of the strength of PC at the same age. These figures show that strengths of blended cements were lower than those of PC. However, the differences became smaller for the later ages due to the ongoing pozzolanic reactions of perlite in the blended cements.

4. Conclusions

The following conclusions were derived as a result of the tests conducted on the two Turkish perlites and the cements produced with them:

(1) Turkish perlites investigated in this study have amorphous structure and conform to ASTM C 618. Therefore, they possess sufficient pozzolanic characteristics to be used in cement and concrete industry.
(2) The perlites investigated are easier to be ground than the portland cement clinkers. Therefore, they result in less energy requirement to produce blended cements by intergrinding the clinker and the perlite together, or by combining the separately ground perlite and clinker as compared to that required to grind only the clinker for portland cement production.
(3) ASTM C 595, ASTM C 1157 and EN 197-1 were used to evaluate the performance of the blended cements produced with the perlites. The cements were found to conform to the limitations given in these standard specifications such as setting time, soundness and compressive strength.
(4) For a given perlite type, perlite amount and Blaine fineness, blended cements produced by intergrinding gave slightly higher compressive strength values as compared to those produced by combining separately ground materials. This was attributed to the finer particles and more homogeneous mixes obtained through intergrinding.
(5) Blended cements with these perlites may cause strength losses especially at the early ages when compared to PC. However, the strengths become closer in time as a result of the ongoing pozzolanic reactions.
(6) Despite the early strength losses discussed above, the use of these perlites in blended cements will be beneficial since the improvements in the grinding efficiency by the perlites and availability of them will help reduce the PC consumption, and therefore, cost and CO_2 emission in Turkey which is a country producing considerable amounts of cement.

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