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ORIGINAL ARTICLE

Compressive Strength of Scoria Added Portland Cement Concretes

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This paper presents the results of preliminary studies investigating the potential effects of using scoria as supplementary and its amount on compressive strength of concrete. Concrete mixtures containing 5, 10, 20, 30, 40 and 50 % scoria type natural pozzolan by mass of the total cementitious material were prepared. In addition, a conventional portland cement concrete mixture with the same w/cm ratio was prepared as a reference. Preliminary results indicated that the compressive strength of the concrete mixtures with scoria added up to 30% exceeded the strength of the conventional mixture at 3, 7, 28 and 91 days, whereas the compressive strength of the 40 and 50% scoria added concrete mixtures decreased at 3, 7, 28 and 91 days. It was found that early strength of scoria added (up to 30%) concrete mixtures showed higher compressive strengths up to 112%.

Keywords: compressive strength, porosity, scoria, structural concrete, specific surface area.

1. INTRODUCTION

Scoria is a natural material of volcanic origin used in cement industry as natural pozzolan. Pozzolans are generally defined as amorphous silicate or aluminosilicate material that reacts with calcium hydroxide formed during the hydration of cement in concrete to create additional cementitious material in the form of calcium silicate and calcium silicoaluminate hydrates in the presence of moisture. Pozzolans must be finely ground in order to expose a large surface area to the alkali solutions for the reaction to proceed [1].

It has been reported by many researchers that natural pozzolans provide a way for an economic production of concrete and can improve the properties of concrete, such as durability. In this regard, a considerable amount of research was conducted to investigate potential utilization of volcanic scoria in cement and concrete industry [2, 3, 4]. Although natural pozzolans are available at limited regions of the world, because of the recent volcanic activities, 56% of natural pozzolan reserve of Turkey is in the East Anatolia Region [5, 6, 7, 8]. Scoria found in eastern part of Turkey is currently being used as a cement additive in cement industry [9].

This study was carried out to develop structural concrete mixtures containing 5, 10, 20, 30, 40 and 50 % scoria type natural pozzolan by mass of the total cementitious material. Concrete mixtures were prepared with 300 kg/m^3 total cementitious material content and 0.5 water-cementitious material ratio (w/cm). For comparison purposes, a conventional portland cement concrete mixture was also prepared with the same mixture proportions. The concrete mixtures were tested for compressive strength on 3rd, 7th, 28th and 91st day after casting.

1.1. Research Significance

It was reported by several researchers that the most obvious disadvantage of the natural pozzolan used as substitutes for Portland cement is that early strength is normally decreased [10]. The strength of the pozzolanic cement is directly affected by the structural features (amorphous/crystal), characteristics (micro-meso porous), dimensions, surface areas, and reactive components of the pozzolan particles. In an ongoing research project at Yuzuncu Yil University (YYU), shorter initial and final

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setting times have been experienced in high volume pumice blended cement (30% pumice + 66% clinker + 4% gypsum) when compared to ordinary portland cement specimens. Additionally, ongoing studies at YYU, have also identified several pumice types that mitigate retardation in hydration when particle size decreases. Published literature contains limited information on concrete mixtures containing scoria type natural pozzolan as supplementing cementitious materials. Therefore, the main objective of the present study is to examine and document the potential effects of using scoria as supplementing cementitious material and its amount on compressive strength of concrete.

2. EXPERIMENTAL WORKS

2.1. Materials

Ordinary portland cement – CEM – I 32.5 N portland cement, produced in accordance with the TS EN 197-1 [11] standard in Van Askale Cement Factory (Van/Turkey), was used in the study. Its physical properties are given in Table 1.

Scoria as supplementary cementing material — Scoria used in this study was obtained from a quarry in Patnos (PTS), Eastern Turkey, shown in Fig. 1. Scoria was ground by a laboratory type ball-mill to have approximately 80% passing through a 45 µm sieve and specific surface area of samples were determined using Blaine test apparatus as shown in Fig. 2. The chemical composition and physical properties of scoria are given in Table 2 [9] and Table 3 respectively.

Table 1: Properties of cement used in the concrete mixture.

Range dimension (over sieve %)		Fineness (cm^2/gr)	Setting Time		% Water	Specific gravity, g/cm^3	Compressive Strength (MPa)			
90	*45*		*Initial*	*Final*			*1 day*	*2 day*	*7day*	*28 day*
0.5	9.5	4126	200	260	29.4	2.99	6.83	14.27	28.34	36.49

Figure 1. Scoria cone and the scoria quarry.

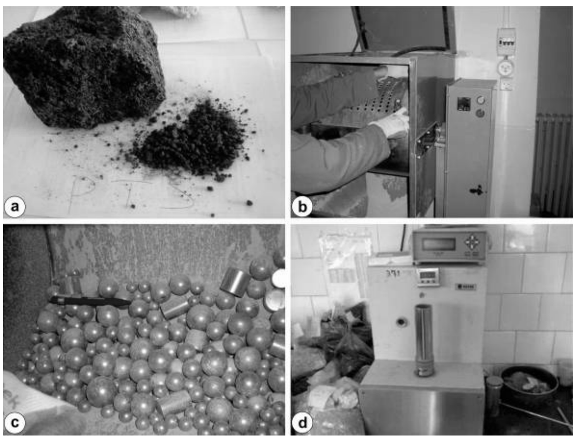

Figure 2: Preparation of scoria used as supplementary cementing material (a-d).

Table 2: Chemical composition of scoria samples.

	Scoria
SiO_2 (%)	54.92
TiO_2 (%)	2.55
Al_2O_3 (%)	16.92
Fe_2O_3 (%)	10.31
MgO (%)	2.01
CaO (%)	6.47
Na_2O (%)	2.17
K_2O (%)	1.87
P_2O_5 (%)	0.39
SO_3 (%)	0.29
LOI (%)	0.86
Reactive SiO_2 (%)	31.52
Pozzolanic Reactivity (kgf/cm^2)	100

Reactive SiO_2 content of the silica which is defined as "the fraction of the silica which, after the treatment with hydrochloric acid (HCl) is soluble in boiling potassium hydroxide (KOH) solution" was determined in accordance with TS 25 [12]. The soluble amount indicates the reactive silica and this value should be greater than 25 % according to TS 25 [12] standard to use in cement industry. The reactive silica content of the scoria is found to be 31.52 %.

Pozzolanic activity of the scoria was determined according to Turkish TS standards [12] and the compressive strength was obtained as 100 kgf/cm^2 (9.8 MPa), which is greater than 4 MPa [12].

The total percentage of SiO_2 Al_2O_3 Fe_2O_3 content, the reactive silica content and the pozzolanic activity of scoria indicate that the scoria fulfill the requirements of the TS 25 [12] standard and therefore it can be used in cement industry as a cement additive.

Thin section view and SEM micrograph of the scoria are given in Fig. 2. Thin section of scoria samples indicate that main phase is glassy form and phenocrystals of plagioclases in matrix show polysynthetic twin and minerals are classified as long rod-shaped. The scoria sample has irregular morphology, non uniform plate shape and glassy form in SEM micrograph. Generally, it can be said that as seen in Fig. 3, main phase is glassy form (amorphous).

The structure of the scoria is also checked with the XRD and ended up with the same conclusion. The XRD pattern (Fig. 4) shows that the sample has not a crystalline structure and broad reflection (peak) between 20° and 30° (2θ) which is confirmed the presence of amorphous quartz but some little crystalline mineral phases, anorthite (JCPDS Card File No:73-1435), hornblend (JCPDS Card File No:71-1062) and crystalline quartz (JCPDS Card File No:76-0823) are also observed in the XRD pattern [9].

Table 3: Physical properties of scoria.

	Range dimension (over sieve %)			Fineness, cm^2/g	Specific gravity, g/cm^3
	>45mm	>90mm	>200mm		
Scoria*	14.8	1.2	0.2	5263	2.75

* Scoria was ground for 90 minutes in a laboratory type ball-mill, physical properties were obtained and then used as a supplementary cementing material in the concrete mix.

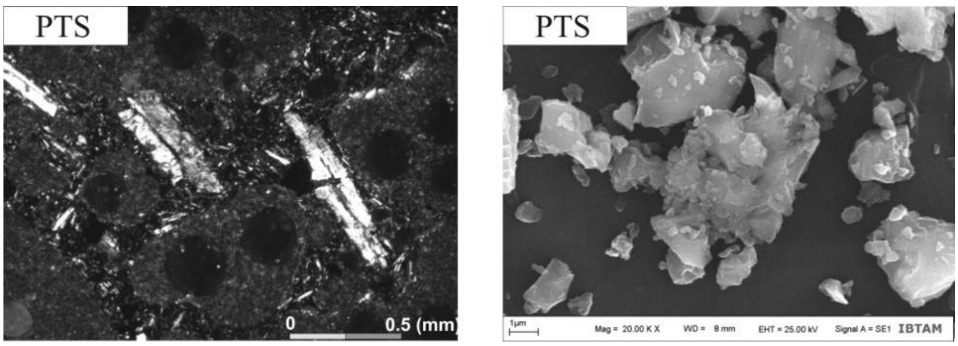

Figure 3: Thin section view and SEM micrographs of scoria.

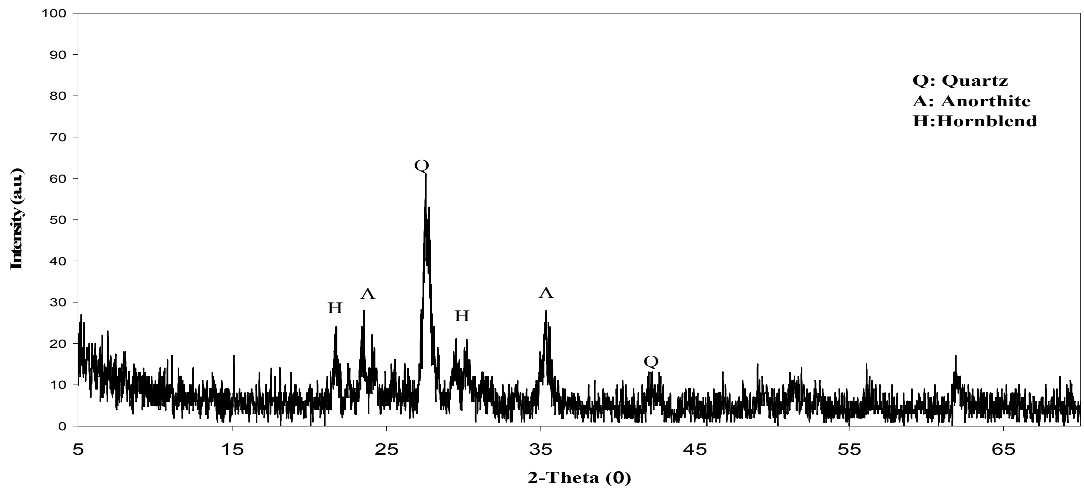

Figure 4: XRD pattern of scoria.

Surface area, pore size distribution and pore volume of the scoria were measured from nitrogen adsorption isotherms at 77 K in the range of 10-6 to 1 relative pressures by a Tri Star 3000 (Micromeritics, USA) surface analyzer and BET equation was used to calculate total surface area and average pore-diameter. This method, when compared to the Blaine test, gives a better indication of the true surface area of the material [10]. The results are given in Table 4 showing that the scoria (> 200 mesh) has lower specific surface area and porosity.

Set-accelerating / plasticizer admixture — A polynaphthalene sulfonate and nitrate salt based set accelerating/plasticizer concrete admixture suitable for cold weather conditions that increases set acceleration and early strengths by increasing the reaction between water and cement especially at the start of set was used because of cold weather conditions in Eastern Turkey.

Aggregates — A crushed dolomite type aggregate was used in the study with nominal maximum aggregate size of 22 mm. Three different size groups of aggregates (0-4 mm, 4-12 mm, 12-22 mm) were combined to obtain proper gradation. The gradation curve for the combined batch is shown in Fig. 5.

Table 4. Surface area and porosity values of the scoria

Sample	SBET (m^2/g)	Sext (m^2/g)	Smic (m^2/g)	Smezo (m^2/g)	Vt (cm^3/g)	Vmic (cm^3/g)	Vmeso (cm^3/g)	Dp (nm)
Scoria (PTS)	0.67	0.22	0.45	0.22	0.003	0.0003	0.0027	15.41

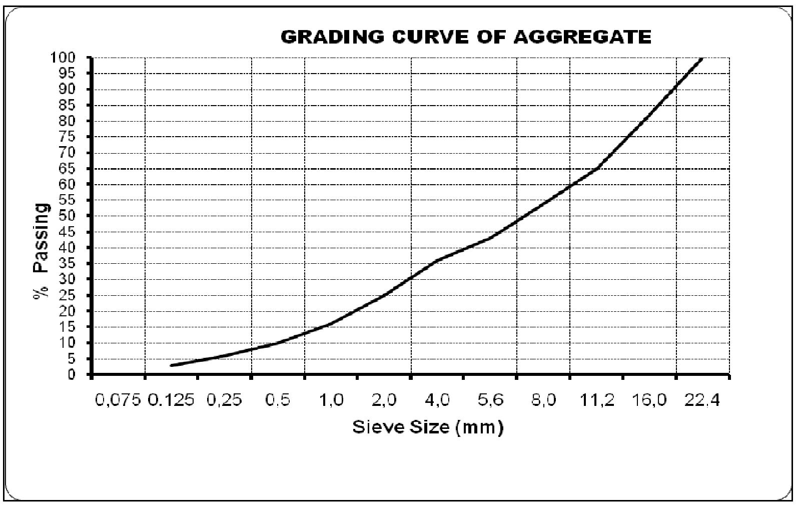

Figure 5: Grading curve of aggregate used in the concrete mixtures.

2.2. Proportions of concrete mixtures

One concrete mixture for each percentage of scoria and also a conventional portland-cement concrete mixture were prepared as shown in Figure 6. The proportions of the concrete mixtures are given in Table 5. A conventional mixture was designed to achieve 20 MPa compressive strength at 28 days. Structural concrete mixtures were prepared containing 5, 10, 20, 30, 40 and 50 % scoria type natural pozzolan by mass of the total cementitious material. All mixtures were made with the same w/cm ratio in order to directly observe the effects of using scoria as supplementing cementitious material on the compressive strength of the concrete.

Figure 6: Preparation of concrete mixture (a-d).

Table 5: Concrete mix design for test specimens.

	Control Mixture	SC5	SC10	SC20	SC30	SC40	SC50
CEM – I 32.5 N Portland Cement, (kg/m^3)	300	285	270	240	210	180	150
Scoria (Supplementing Cementitious Material), (kg/m^3)	0	15	30	60	90	120	150
W/C	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Water, (kg/m^3)	150	150	150	150	150	150	150
Coarse Aggregate (12 – 22mm), (kg/m^3)	433	433	433	433	433	433	433
Medium Aggregate (4 – 12mm), (kg/m^3)	435	435	435	435	435	435	435
Fine Aggregate (0 – 4mm), (kg/m^3)	1003	1003	1003	1003	1003	1003	1003
Plasticizer – POZZUTEC 1* (%of the binder)	1.2	1.2	1.2	1.2	1.2	1.2	1.2

*Used as a set accelerater/plasticizer because of cold weather conditions.

3. RESULTS and DISCUSSION

The compressive strength of the mixtures is given in Figure 7. The compressive strength of the concrete mixtures with scoria added up to 30% exceeded the strength of the conventional mixture at 3, 7, 28 and 91 days, whereas the compressive strength of the 40 and 50% scoria added concrete mixtures decreased at 3, 7, 28 and 91 days.

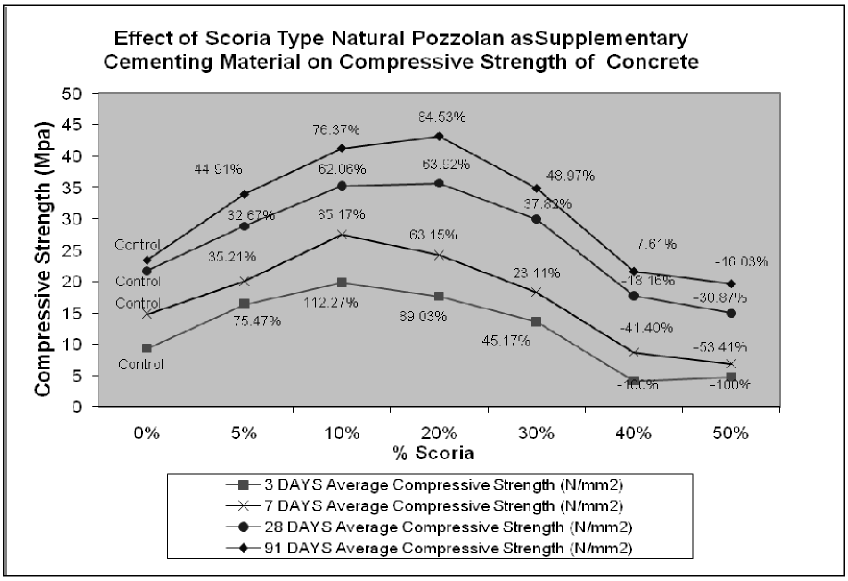

Figure 7: Compressive strength of scoria added concrete mixtures.

Previously published researches state that, the rate of pozzolanic reaction shortly after contact with water depends to a great extent upon the minor minerals present whereas the long-term rate of reaction depends more upon the nature of the bulk glassy material. Since pozzolans react with calcium hydroxide formed during the hydration of cement in concrete to create additional cementitious material in the form of calcium silicate and calcium silicoaluminate hydrates in the presence of moisture it is almost a common result to say that natural pozzolans, do not start to contribute to improvement of engineering properties of concrete at early ages [10]. In this research, it was found that early strength of scoria added (up to 30%) concrete mixtures showed higher compressive strengths up to 112% which is inconsistent with such findings. Ogawa et al; [13] published a paper stating that some pozzolans start to chemically react very shortly after contacting with water, as it is in this study. In that research the pozzolanic reaction of 5 Japanese pozzolans started after only 1-3 days, as shown by the decrease in calcium hydroxide content [13]. The authors concluded that, the hydration of C3S was accelerated by the addition of pozzolan as which is caused by the absorption of Ca+2 ion by the pozzolan which depresses the calcium ion concentration in solution. The result of current research is consistent with these uncommon results.

On the other hand, it was reported by several researchers that, the pozolanic reaction of pozzolans depend upon the materials BET surface area at early ages but at later ages depends more upon the reactive silica and alumina content [14]. In another research [15] reactivity of highly porous (56-68%) pozzolans having high surface area of 10-68 m^2/g were examined by thermal analysis and no proportional relationship between surface area and reactivity was found. Scoria used in this study is non-porous pozzolan having low specific surface area. Since, early strength of scoria added (upto 30 %) concrete mixtures showed higher early strengths, authors conclude that there is a relationship between early strength of pozzolan added concretes and the porosity of the pozzolans. High porous pozzolans absorb the water required for cement hydration and therefore may decrease early strength.

4. CONCLUSIONS

Based on the experimental results, the following conclusions are drawn concerning scoria added concrete mixtures;

1. It was found that early strength of scoria added (up to 30%) concrete mixtures showed higher compressive strengths up to 112%.

2. Due to their non-porous structure scoria added concretes showed higher early compressive strengths (3, 7 days) upto 30% cement replacement when compared with the conventional mixture.

3. Due to its amorphous structure, concrete mixtures with scoria up to 30% showed higher compressive strengths at 28 and 91 days when compared with the conventional mixture.

4. 40 and 50 % cement replacement with scoria resulted in lower compressive strengths at 3, 7, 28 and 91 days. Therefore, more than 30% scoria replacement is not suitable for structural concrete.

5. Based on the results, it appears that the result of this study is inconsistent with most of the published data except for one. Scoria added concrete mixtures (upto 30%) does not have the disadvantage of lower early strengths and therefore are suitable for structural concrete. Use of this type of scoria in concrete will promote green concrete.

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