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OPTIMUM PERCENTAGE OF VOLCANIC TUFF IN CONCRETE PRODUCTION

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ABSTRACT

The Tafila area (Jabal Al Hala) is covered with volcanic tuff, which has been tested and studied for its possible use as a construction material in the production of ordinary concrete. The volcanic tuff material was used at 10, 20, 30, 40, and 50% mix proportion of the materials in the concrete mix.It was subsequently tested for density, compressive strength, and flexural strength. The density of volcanic concrete (VC) ranged from 2195 to 2297 kg/m^3. At 20% of volcanic tuff or volcanic aggregate (VA), the density of VC was 2285 kg/m3 and 2310 kg/m^3, the compressive strength was 17 MPa and 21 MPa, flexural strength was 5 MPa at the 7th and 28th days, respectively. The results showed that the volcanic tuff can be used in concrete production by replacing part of the aggregate (fine and coarse) by the VA, with the proportion of 20% of VA as the optimal value. The VA can be used for VC production where lower density is required for loading, and the VC shows a remarkable density and strength during the testing and construction at sites.

Keywords: *Volcanic Aggregate (VA), Volcanic Concrete (VC), Volcanic Tuff.*

1. INTRODUCTION

The concrete and related industrial constructs are the most common material used in the construction in Jordan. These materials are available in the form of different resources, such as crushed limestone in Karak and Tafila area, and rounded and volcanic tuff found in the Tafila area. The analysis of density, compressive strength, and flexural strength are the basic tests to determine the performance, measurements, and indicators for the construction materials in order to be selected and used for concrete production. The diversity in resources of aggregates and materials for construction gives variety for the concrete mix depending on the required property and performance. The high density, high strength, lightweight, and low strength concretes are required for different purposes at the construction sites. The improvements are required throughout the production stages, including the fresh and hardened states of concrete.

The current research aims at determining the optimum point in using volcanic tuff in concrete production. The volcanic concrete (VC) could be used in the construction of architectural details, linings, and walls that do not require high strength concrete, such as beams, columns, and bearing walls with or without the use of white stones.

The volcanic tuff had been obtained from Al-Hala mountains of Tafila area in the Southern part of Jordan that is 200 km to the South of Amman. Figure (1) presents the X-ray diffraction (XRD) spectra for the volcanic tuff used in the concrete mix in the current research.

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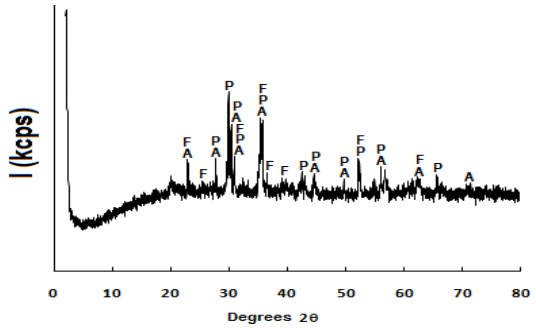

Fig.1. X-ray diffraction spectra of volcanic tuff.[A: Plagioclase feldspar (Anorthite), F: Olivine (Forsterite) and P: Pyroxene (Augite)], Analysis in Royal Scientific Society Labs (April, 2014)

TABLE 1: CHEMICAL COMPOSITION OF VOLCANIC TUFF. ANALYSIS IN ROYAL SOCIETY LABS (APRIL, 2014)

Description: Volcanic tuff								
April / 2014	MgO	Fe_2O_3	TiO_2	SiO_2	CaO	K_2O	P_2O_5	Al_2O_3
Result (%)	9.55	13.42	3.94	35.64	9.56	0.77	0.71	10.45

Table 1 represents the chemical composition of volcanic tuff used in the concrete production, and Table (2) represents the percentage of water content in the natural sample.

Cobanoglu et al. (2003) have tested and studied the engineering properties of the Sandikiziolithic tuffs that are found in the Western parts of Central Anatolia in Turkey. The study also investigated the possibility of using tuffs in concrete production. The concrete samples were prepared and tested for28 days in order to examine the physic-mechanical properties of the tuff aggregates in concrete used as lightweight aggregates. The results of the study are promising to the limit to use tuffs as lightweight aggregate for the production of lightweight concrete.

Tupco and Uygunoglu (2010) used the volcanic tuff and dolomite aggregates, in addition to the pumice and limestone aggregates, in the production of concrete. The cement content was taken constant, but different combinations of water to binder ratio and plasticizers dosage were prepared for the mixes. The following properties were studied: 1) Physical properties including thermal conductivity, dry unit weight, porosity, and capillarity; and 2) Mechanical properties including compressive and splitting tensile strength, modulus of elasticity, and abrasion resistance were measured in the hardened stages. The results showed that the hardened, self-consolidated concrete with lightweight aggregate in lower unit weight exhibited lower mechanical and physical properties except for the thermal properties when compared to the properties of self-consolidated concrete.

Abali et al.(2006) addressed the usage of the waste of volcanic tuff, in addition to the waste of the tincal waste, fly ash, and bentonite as a cement admixture. The authors examined the following properties that included 1)setting time, 2)expansion, 3)water requirement, 4) specific surface, and 5) compressive strength of the cement mixtures. The results stated that the early compressive strength decreased with increasing tincal waste and increasing initial setting time of the cement. The tincal waste and volcanic tuff of cement mixtures increased, whereas the compressive strength decreased. With the increase in the tincal waste, the retardation also increased. The initial setting time may be attributed to the high B_2O_3 and MgO content. The employment of volcanic tuff increased the compressive strength and decreased the initial setting time.

TABLE 2: WATER CONTENT IN NATURAL VOLCANIC TUFF SAMPLE, ANALYSIS IN ROYAL SOCIETY LABS (APRIL, 2014)

Date	Mass of Can (g)	Total Mass Wet (g)	Total Mass Dry (g)	Wet Mass (g)	Dry Mass (g)	Water Mass (g)	% Water Content	Average Water Content%
4/2014	3.006	122.83	115.99	119.8	112.9	6.84	5.70	5.92
	3.00	151.99	142.84	148.9	139.8	9.15	6.14	

Papadakis and Tsimas (2002) discussed that volcanic tuff and other fine materials, such as fly ash, silica fumes, and slag, exhibited cementaceous properties when blended into the concrete mix. These materials could be considered as additional cementaceous agents with different physical and chemical properties because of the variations that make the development and renewability viable in the design and construction. The performance of concrete mixes and the resultant compressive strength was compared to the quality of the cement. Moreover, a high volume of natural pozzolan (50% of total fine cementateous materials) was used in concrete mix for structure application. Other two additional mixes with a high-volume of low-calcium fly ash and granulated blast-furnace slag were also prepared for comparison between the mixes used in performance. In addition to the conventional Portland cement, the concrete mix was prepared as a reference and for comparison basis. The dosage required for a high-range water-reducing admixture for a given slump, air content, setting time, compressive strength, splitting tensile strength, and resistance to chloride-ion penetration were determined for the mixes. The inception of results indicated that the high-volume of natural pozzolan concrete mixes were suitable for structural concrete applications with 1740 to 2030 psi (12 to 14 MPa) and 4210 to 5510 psi (29 to 38 MPa) compressive strengths at 3 and 28 days, respectively (Uzal et al., 2004).

Rodriguez-Camacho and Uribe-Afif (2002) have discussed the role of natural pozzolan in concrete durability. The importance of application led to the further use of the pozzolanic cement in concrete production. The different pozzolan cement containing natural pozzolan were used in mixes and compared to type I, II, and V cement. The pozzolanic activity, composition, susceptibi-lity to sulfate attack, and expansion of mortar were evaluated and studied. It was noticed that the pozzolan cement with high activity and low alumina content had improved resistance to sulfate attack. Hence, the amount of pozzolan used in the cement is considered to be important.

Turanli et al. (2005) also highlighted the effect of the usage of natural pozzolan (35, 45, and 55%) on the properties of the blended cement paste and mortar. The blended cement of 450 m^2/kg fineness was produced from the Turkish volcanic tuff in the laboratory mill through the inter-grinding of Portland cement clinker with natural pozzolan and gypsum. The cement tests applied are as follows: particle size distribution, setting time, heat of hydration, compressive strength, alkali–silica activity, sulfate resistance, $Ca(OH)_2$ content, and XRD analysis for the crystalline hydration products. The compressive strength of the mortars made with blended cement containing large amounts of natural pozzolan was lower than that of the Portland cement at all tested ages up to 91 days. The blended cement containing large amounts of pozzolan exhibited much less expansion with respect to Portland cement in accelerated alkali–silica test and 36-week sulfate immersion test.

Gennaro etal. (2005) have tested the applicability of using the Italian zeolitizedvolcanoclastites for the production of lightweight aggregates in the industrial construction. The aggregate used with pozzolan had a low density of 0.9–1.1 gm/cm^3 (lightweight-expanded aggregate) to produce lightweight concrete. The aggregate tests included grain size analysis, lose weight, the mean density of the single grain, water absorption after 30 min and 24 h, and particle strength. Subsequently, the light weight

aggregates were mixed with sand, cement, and water to prepare concrete cubes to determine the unit weight and compressive strength on the 28th day. The investigated measurements and properties were tested and compared to the trade material produced and sold in the Italy market.

Yasin etal. (2012) had studied the volcanic tuff as local material for construction. They used three different materials known as yellow, grey, and brown volcanic tuff. The effect of fine volcanic tuff on concrete strength was studied. The volcanic tuff was studied in terms of percentage ranging from 10 to 80% of the aggregate in the concrete mix by producing the concrete on four grades: 20, 30, 40, and 50 MPa. The results showed that the use of grey and brown volcanic tuff (20%)improved the strength by 10% while the use of yellow volcanic tuff (20%) improved the strength by 15%.

Yeginobali etal. (1998) have studied the usage of natural lightweight aggregate in producing high strength concrete instead of special artificial aggregate with minerals and chemical admixtures. The replaced ingredients by the natural aggregate and admixtures can significantly reduce the cost of concrete production. The produced concrete strength from volcanic tuff and pumice concrete present the values of 30 and 16 MPa, respectively. The binding medium was produced by Portland cement, silica fume, and super-plasticizing mixtures. The concrete tests included workability, unit weight, compressive and splitting tensile strengths at various ages, modulus of elasticity, and thermal conductivity measures. The tests were conducted to touch the optimum proportions of quantities of the tested materials. The tests showed that a 55 MPa of concrete could produce the required strength in 28 days by using a natural lightweight aggregate, and a dry unit weight in the range of 1700–2100 kg/m^3, in addition to the coefficient of thermal conductivity value of about 0.55 W/m^2 K. Based on the experimental results, mathematical equations were analytically regressed and used for relating and optimizing concrete mixtures for specified unit weight and compressive strength.

The studies showed the ability to use volcanic tuff aggregate in the production of the concrete for architectural uses, lining for stone construction, partitions, and light decorations.

2. RESULTS AND DISCUSSION

The volcanic tuff aggregate had an apparent specific gravity of 2.24 and saturated surface dry specific gravity of 2.18 while the bulk specific gravity is 2.04 according to ASTM C127-84, ASTM C128-84, and ASTM C330-82a.

In relation to the gradation of the aggregate for ordinary control concrete and VC samples, Table (3) shows the gradation of the aggregate (coarse, medium, fine, and combined) according to the ASTM C 136-84. The concrete mix was designed to 20Mpa grade with the cement content of 308 kg/m^3, and water content of 185 kg/m^3 of the mix, and approximately 0.6 water/cement ratio. The aggregate was replaced by volcanic tuff aggregate at the ratios 10, 20, 30, 40, and 50%.

The density of lightweight aggregate is an important property of the concrete that aims at the specific purpose of the construction (BS 1881: Part 107: 1983). Figure (2) represents the density of concrete using the volcanic tuff or volcanic lightweight aggregate (VLA) and fine materials at ratios of 10% to 50%, by an increment of 10% for each patch of the mix. The results were obtained for the same at 7th and 28th days.

TABLE 3: SIEVE ANALYSIS FOR CONTROL CONCRETE SAMPLE AND VOLCANIC TUFF CONCRETE SAMPLES

Sieve Size (in.) / No.	Sieve Size (mm)	C.agg	M.agg	Sand		Specification	
		33%	33%	34%	Combined		
		%Pass	%Pass	%Pass		Min.	Max.
1	25.4	100	100	100	100	90	100
3/4"	19.0	95.3	100	100	98.4	70	100
3/8"	9.5	7.2	81.4	99.9	63.2	50	75
No. 4	4.8	1.1	26.8	99.5	43.0	35	60
No. 8	2.4	0.4	13.8	70.3	28.6	27	45
No. 16	1.2	0.3	12.2	63.4	25.7	20	35
No. 30	0.6	0.2	5.1	28.3	11.4	12	25
No. 50	0.3	0.2	2.7	19.5	7.6	5	15
No. 100	0.2	0.2	1.2	11.3	4.3	1	5
No. 200	0.1	0.1	0.5	3.8	1.5	0	5

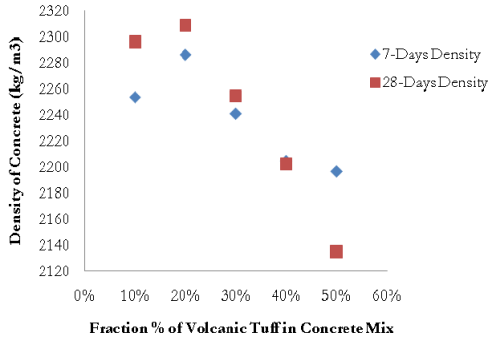

Fig.2. Density of volcanic lightweight concrete at 7- and 28-days

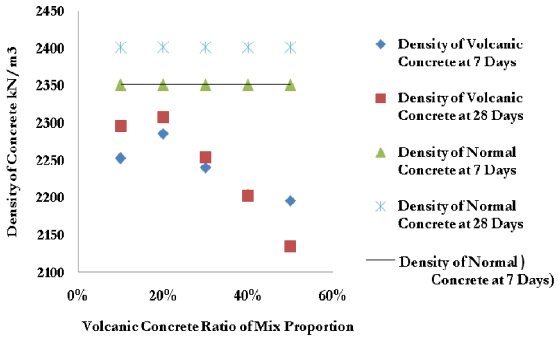

Fig.3. Comparison of density of volcanic concrete (kN/m^3)

It is shown that the higher density is achieved at 20% of the volcanic aggregate (VA). At 7-day specimens' test, the density was found to be 2285 kg/m^3, and at 28-day specimens' test, it was 2310 kg/m^3.

The density of volcanic lightweight concrete (VLC) was also compared with the density of normal weight concrete. Figure (3) presents the density of VLC at 10, 20, 30, 40, and 50% compared to the density of normal weight concrete at 7th and 28thdays, respectively. It is obvious that the density of normal weight concrete is higher than the density of VLC for all proportions of VA. The density of normal concrete was found to be 2350 kg/m^3 at 7-day specimens' test, and 2400 kg/m^3 at 28-days for the normal concrete. Compression strength of VC is another distinguishing property of the material.

Figure (4) presents the compression strength of VC on 7 and 28 days crushing test (BS 1881: Part 108: 1983). It is obvious that the compressive strength of VLC is optimum at 20% proportion of VA in the mix. The compressive strength of VC was found to be 17 MPa at 7-day specimen's test and 20.5 MPa at 28-day specimen's test. In addition, the compressive strength is compared to that of the normal weight concrete.

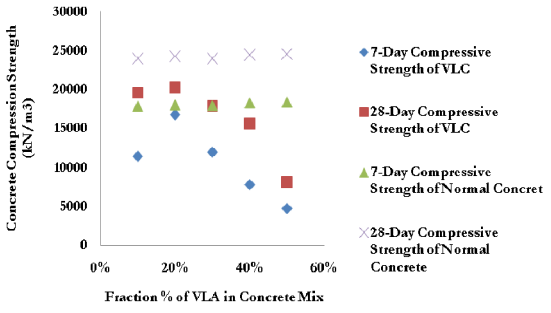

Fig.4. Compression Strength of Volcanic Concrete on 7 Days

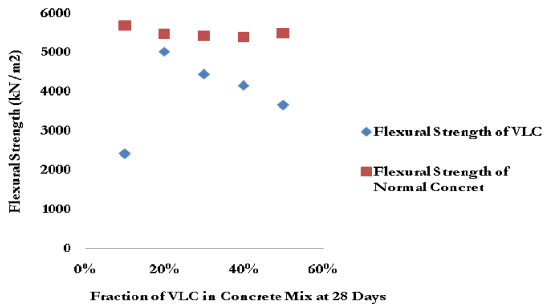

Fig.5. Flexural Beam of Volcanic Concrete (kN/m^3)

The flexural strength of volcanic lightweight concrete can be measured and evaluated to give a specific property of this material (BS 1881: Part 109: 1983). Figure (5) represents the flexural beam strength of VLC at 10, 20, 30, 40, and 50% proportion to normal aggregate. It is obvious that the flexural strength is the optimum at 20% proportion of the VLA, with a value of 5 MPa. In comparison to the flexural strength of normal weight concrete, it was obvious that it was higher for the last, and averaging at about 5.5 MPa. The use of natural pozzolan concrete mixes is considered suitable for structural concrete applications with 1740 to 2030 psi (12 to 14 MPa) and 4210 to 5510 psi (29 to 38 MPa) compressive strengths at 3rd and 28th days, respectively (Uzal et al., 2004). The produced VC in the current research at the optimum percentage (20%) has the range of 2285-2310 kg/m^3 in density, and for compressive strength, the results obtained have the range of 16 Mpa to 20 Mpa at the 7thand 28thday, respectively.

TABLE 4: PERMEABILITY TEST FOR VOLCANIC TUFF CONCRETE VS. ORDINARY CONCRETE, TESTED AT ROYAL SCIENTIFIC SOCIETY LABS (2014)

Sample ID	Water distance (cm)	Sample high (cm)	Pressure (KN)
Control B2	4	14.2	176
10% Volcanic tuff	4.8	14	163
20% Volcanic tuff	6.7	14.1	153
30% Volcanic tuff	11.9	14.3	86.7

The normal concrete produced had the range of 2350-2400 kg/m^3 between the 7thand 28thday, respectively. While the compression strength obtained for normal concrete had the range of 18-24 Mpa at the 7the and 28thday, respectively.

3. PERMEABILITY TEST

Permeability is another important property of concrete. Table (4) shows the permeability of 10, 20, and 30% volcanic tuff concrete compared to the control ordinary aggregate concrete sample. The results showed a reduction in pressure by 7.4, 13.07, and 50.74% related to the proportional mix of 10, 20, and 30% of volcanic tuff, respectively.

4. CONCLUSION

The current research presents the properties of VC by employing the VA in concrete mix in proportions of 10, 20, 30, 40, and 50%. The physical tests, such as sieve analysis and specific gravity for both VA and normal weight aggregates (all specific gravities of VA that is less than those of normal weight aggregate) were conducted. Another physical test included the analysis of the density of hardened concrete, for both VC and normal weight concrete at 7thand 28thday. The results for VC density were lower than that of the normal weight concrete. This resulted in the use of low-density VC where structural concrete was not required. The mechanical tests (compression strength and flexural strength) were also applied on VC and normal weight concrete. The permeability test was conducted for the normal concrete and VC. The values obtained for VC were low for compressive and flexural strengths, and permeability compared to that of normal weight concrete. The VA showed remarkable properties of specific gravities, and the VC also showed remarkable density, compressive

strength, and flexural strength, and permeability, which was low as compared to the normal concrete.

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النسبة المثلى للطف البركاني في إنتاج الخرسانة

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الملخص:

يتواجد الطف البركاني في منطقة الطفيلة في جبل الحلا، والمواد المفحوصة في الدراسة للنظرفي إمكانية استخدامها كمادة إنشائية في إنتاج الخرسانة العادية. والطف البركاني المستخدم بنسب 10، 20، 30، 40، 50% في مكونات الخلطة الخرسانية. وتم فحصها للكثافة، وقوة الكسر، وجهد الانحناء. وكانت كثافة الخرسانة من الطف البركاني تتراوح من 2,195 إلى 2,297 كغم/م3 على 7 أيام، وكذلك كانت كثافة خرسانة الطف البركاني على نسبة 20% من حصمة الطف البركاني في الخلطة 2,285 كغم/م3،و 2,310 كغم/م3،على 28 يوم. وكانت قوة الكسرعلى نسبة 20% لخرسانة الطف البركاني هي 17 ميجاباسكال على 7 أيام و 21 ميجاباسكال على 28-يوم. وكانت قوة العزم المفحوصة على نسبة 20% تساوي 5 ميجاباسكال. النتائج تبين أنالطف البركاني يمكن استخدامه في إنتاج الخرسانة باستبدال جزء من الحصمة (ناعم وخشن) بحصمة الطف البركاني، ونسبة 20% المستبدلة من حصمة الطف البركاني هي المثلى. حصمة الطف البركاني تستخدم في إنتاج الخرسانة بمختلف الكثافات بناء على الحمل في الأبنية، وخرسانةالطف تعرض كثافة وقوة كسر معتبرة خلال الفحص و الإنشاء في الموقع.