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Flexural and Shear Capacities of Reinforced Concrete Beams with Volcanic Tuff

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Abstract

An experimental investigation was carried out to study the effect of volcanic tuff (V.T.), as a fine aggregate on the flexural and shear capacities of reinforced concrete beams. Three different types of volcanic tuff which is a local material that is available at different locations in Jordan (known as yellow, gray and brown volcanic tuff) were used in this study. Four grades of concrete compressive strengths (20, 30, 40 and 50 MPa) are also used. The experimental program consisted of testing 64 beams (16 beams with 0% of volcanic tuff and 16 beams with 20% volcanic tuff as a fine aggregate for each type of volcanic tuff). The analysis showed that replacing the fine aggregate by 20% volcanic tuff will improve the flexural and shear capacities of the reinforced concrete beams by 6% to 16% for brown tuff, 3% to 8% for gray tuff and 10 % to 26 % for yellow tuff for the four concrete strength grades.

Key Words: Pozzolan (Volcanic tuff), flexural and shear capacities, Reinforced concrete beams

Introduction

Pozzolan (Volcanic tuff) is a siliceous or siliceous/aluminous material which, when mixed with lime and water, forms cementations compounds. Natural pozzolan are found in many parts of the world and have been used in concrete. Volcanic tuff is a local material that is available at different locations in Jordan.

A comprehensive experimental investigation was carried out by Amjad A. Yasin et al.(1) to evaluate the effect of volcanic tuff, as a fine aggregate, on the concrete compressive strength. This investigation showed that replacing the fine aggregate by 20% volcanic tuff will improve the concrete compressive strength by 10% for brown and grey tuff and 15% for yellow tuff.

H. Marzouk and S. Langdon (8) conducted an experimental study to evaluate the potential reactivity of the volcanic tuff aggregates and the effect of alkali silica reaction (ASR) on the mechanical properties of concrete containing both a highly reactive and a moderately reactive aggregate obtained from different aggregate quarries. Their study also introduces the use of the direct tension test to evaluate the ASR effects on the mechanical properties of concrete.

Morgan et al.(7) carried out a study to describe the petrology and whole-rock, mineral, matrix glass and glass inclusion compositions of the Morococala (Bolivia) volcanic rocks and tuff to provide more data on this insufficiently studied rock type.

G. Marcari et al.(4) conducted experimental diagonal tests on tuff masonry panels strengthened with cement matrix- fabric (CMF) system externally applied to the panels. A comparative experimental analysis between as built and strengthened panels is also studied in their research.

Actually many of the previous investigations concentrate on studying the chemical, physical and mechanical properties of volcanic tuff rock.

In this study, the effect of volcanic tuff on the flexural and shear capacities of the reinforced concrete beams is to be investigated using the three different types of this material (known as yellow, grey and brown volcanic tuff).

Materials

Concrete mixtures are proportioned from cement, water, fine aggregate, coarse aggregate and volcanic tuff materials. As soon as the components of concrete have been mixed together, the cement and the water react to produce a cementing gel that bonds the fine and the coarse aggregate into a stone material. The chemical reaction between the cement and water, an exothermic reaction producing significant quantities of heat, is termed hydration.

Aggregates , which constitute approximately **75 %** of the concrete volume ,are usually composed of well-grades gravel or crushed stone , aggregates passing from **No.4** sieve are classified as fine aggregate, large aggregates are classified as coarse aggregates.To produce a high-quality concrete mixture a **20 %** of volcanic tuff (as mentioned before) will be added to the mixes for all beams.

Concrete mixture consists of cement, water, fine aggregates, coarse aggregates; volcanic tuff and super plasticizer SP432MS (for workability). These components have been mixed together and special beam moulds with the dimensions of (150 x 100 x 1250) mm shown in Figure 1 were prepared for this investigation .Beams are casted to be tested after 28 days. Four grades of concrete compressive strengths (20, 30, 40 and 50 MPa) are also used in this study.

Figure 1 : Beams Moulds

Mix design proportions for the three different types of volcanic tuff were designed to produce the required concrete compressive strengths. The mix proportions are given in Tables 1, 2 and 3.

Table 1 : Mix design proportions for 20 % Gray volcanic tuff

		Cement	SP432MS	W/C	Water	Volume (C & W)	Volume (Agg.)	Aggregate19mm	Aggregate 15mm	Aggregate 10mm	Volcanic tuff	Sand	**Total Unit**
Specific Gravity		3,15	(=)		1,0			2,599	2,591	2,604	2,211	2,568	2,585
Coarse & Fine content			Cement*2%					0,63			0,37		
C & F proportion								0,30	0,60	0,10	0,00	0,37	
Proportion of Job Mix								0,19	0,38	0,06	0,07	0,30	1,00
Units		min. kg	cm^3		Kg	Liter	Liter	kg	kg	kg	kg	kg	kg
Class	Tuff Mix												
206	0%	195		0,77	150	209	776	381	759	127	0	740	2352
Each Part Mass Kg		5,265	105		4,050	5,696	20,899	10,246	20,428	3,421	0,000	19,929	63,339
206	20%	195		0,77	150	209	776	381	759	127	127	592	2331
Each Part Mass Kg		5,265	105		4,050	5,696	20,899	10,246	20,428	3,421	3,432	15,943	62,785
338	0%	245		0,61	150	224	761	373	744	124	0	725	2361
Each Part Mass Kg		6,615	132		4,050	6,119	20,477	10,039	20,016	3,352	0,000	19,526	63,598
338	20%	245		0,61	150	224	761	373	744	124	125	580	2341
Each Part Mass Kg		6,615	132		4,050	6,119	20,477	10,039	20,016	3,352	3,363	15,621	63,055
436	0%	270		0,56	150	232	753	369	736	123	0	718	2366
Each Part Mass Kg		7,290	145		4,050	6,330	20,265	9,935	19,809	3,317	0,000	19,325	63,727
436	20%	270		0,56	150	232	753	369	736	123	124	574	2346
Each Part Mass Kg		7,290	145		4,050	6,330	20,265	9,935	19,809	3,317	3,328	15,460	63,190
501	0%	295		0,51	150	240	745	365	728	122	0	710	2371
Each Part Mass Kg		7,965	159		4,050	6,541	20,054	9,832	19,603	3,282	0,000	19,124	63,856
501	20%	295		0,51	150	240	745	365	728	122	122	568	2351
Each Part Mass Kg		7,965	159		4,050	6,541	20,054	9,832	19,603	3,282	3,294	15,299	63,325

Table 2 Mix design proportions for 20 % Yellow volcanic tuff

		Cement	SP432MS	W/C	Water	Volume (C & W)	Volume (Agg.)	Aggregate 19mm	Aggregate 15mm	Aggregate 10mm	Volcanic tuff	Sand	**Total Unit**
Specific Gravity		3,15	(=)		1,0			2,599	2,591	2,604	2,164	2,568	2,585
Coarse & Fine content			Cement*2%					0,63			0,37		
C & F proportion								0,30	0,60	0,10	0,00	0,37	
Proportion of Job Mix								0,19	0,38	0,06	0,07	0,30	1,00
Units		min. kg	cm^3		Kg	Liter	Liter	kg	kg	kg	kg	kg	kg
Class	Tuff Mix												
206	0%	195		0,77	150	209	776	381	759	127	0	740	2352
Each Part Mass Kg		5,265	105		4,050	5,696	20,899	10,246	20,428	3,421	0,000	19,929	63,339
206	20%	195		0,77	150	209	776	381	759	127	125	592	2328
Each Part Mass Kg		5,265	105		4,050	5,696	20,899	10,246	20,428	3,421	3,358	15,943	62,711
338	0%	245		0,61	150	224	761	373	744	124	0	725	2361
Each Part Mass Kg		6,615	132		4,050	6,119	20,477	10,039	20,016	3,352	0,000	19,526	63,598
338	20%	245		0,61	150	224	761	373	744	124	122	580	2338
Each Part Mass Kg		6,615	132		4,050	6,119	20,477	10,039	20,016	3,352	3,290	15,621	62,982
436	0%	270		0,56	150	232	753	369	736	123	0	718	2366

Each Part Mass Kg		7,290	145		4,050	6,330	20,265	9,935	19,809	3,317	0,000	19,325	63,727
436	20%	270		0,56	150	232	753	369	736	123	121	574	2343
Each Part Mass Kg		7,290	145		4,050	6,330	20,265	9,935	19,809	3,317	3,256	15,460	63,118
501	0%	295		0,51	150	240	745	365	728	122	0	710	2371
Each Part Mass Kg		7,965	159		4,050	6,541	20,054	9,832	19,603	3,282	0,000	19,124	63,856
501	20%	295		0,51	150	240	745	365	728	122	120	568	2348
Each Part Mass Kg		7,965	159		4,050	6,541	20,054	9,832	19,603	3,282	3,222	15,299	63,254

Table 3: Mix design proportions for Brown volcanic tuff at 20 %

		Cement	SP432MS	W/C	Water	Volume (C & W)	Volume (Agg.)	Aggregate 19mm	Aggregate 15mm	Aggregate 10mm	Volcanic tuff	Sand	**Total Unit**
Specific Gravity		3,15			1,0			2,599	2,591	2,604	2,053	2,568	2,585
Coarse & Fine content			Cement*2%					0,63			0,37		
C & F proportion								0,30	0,60	0,10	0,00	0,37	
Proportion of Job Mix								0,19	0,38	0,06	0,07	0,30	1,00
Units		min. kg	cm^3		Kg	Liter	Liter	kg	kg	kg	kg	kg	kg
Class	Tuff Mix												
206	0%	195		0,77	150	209	776	381	759	127	0	740	2352
Each Part Mass Kg		5,265	105		4,050	5,696	20,899	10,246	20,428	3,421	0,000	19,929	63,339
206	20%	195		0,77	150	209	776	381	759	127	118	592	2322
Each Part Mass Kg		5,265	105		4,050	5,696	20,899	10,246	20,428	3,421	3,186	15,943	62,539
338	0%	245		0,61	150	224	761	373	744	124	0	725	2361
Each Part Mass Kg		6,615	132		4,050	6,119	20,477	10,039	20,016	3,352	0,000	19,526	63,598
338	20%	245		0,61	150	224	761	373	744	124	116	580	2332
Each Part Mass Kg		6,615	132		4,050	6,119	20,477	10,039	20,016	3,352	3,121	15,621	62,814
436	0%	270		0,56	150	232	753	369	736	123	0	718	2366
Each Part Mass Kg		7,290	145		4,050	6,330	20,265	9,935	19,809	3,317	0,000	19,325	63,727
436	20%	270		0,56	150	232	753	369	736	123	115	574	2337
Each Part Mass Kg		7,290	145		4,050	6,330	20,265	9,935	19,809	3,317	3,089	15,460	62,951
501	0%	295		0,51	150	240	745	365	728	122	0	710	2371
Each Part Mass Kg		7,965	159		4,050	6,541	20,054	9,832	19,603	3,282	0,000	19,124	63,856
501	20%	295		0,51	150	240	745	365	728	122	114	568	2342
Each Part Mass Kg		7,965	159		4,050	6,541	20,054	9,832	19,603	3,282	3,057	15,299	63,089

Reinforced Concrete Beams

Special moulds for beams were prepared with the dimensions mentioned before, these beams were reinforced by G40 (f_y=276 MPa) reinforcing steel bars as follows:

a) Bottom steel:
- 2 Ø 10 mm (for grade 20 MPa).
- 2 Ø 12 mm (for grade 30 MPa).
- 2 Ø 14 mm (for grade 40 MPa).
- 2 Ø 16 mm (for grade 50 MPa).

b) Top steel:
- 2 Ø 8 mm (for all grades).

c) Stirrups:
- Ø 3 mm @ 200 mm (for all grades).

The concrete mixture was prepared and casted in the moulds. 64 beams were casted (16 beams with 0% of volcanic tuff and 16 beams with 20% for each type of volcanic tuff). After 24 hours, beams were cured in water at a temperature of 25 C° and tested after 28 days of casting. The load was applied by a two-point load testing machine as shown in Figure 2.

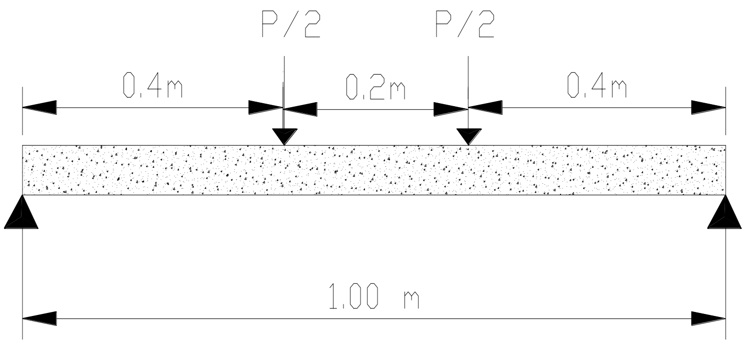

Figure 2: Testing Load Configuration

Test Results and Discussion

Reinforced concrete beams casted for this study were tested by a two-point load testing machine. The maximum shear is equal to the applied load ***P/2*** and the maximum moment is calculated from the simple equation $\mathbf{M}=\frac{p}{2}\,a$ where a: is the distance from the applied load to the support which is equal to **0.40 m** as shown in Figure 2. The test results of the three volcanic tuff materials (Brown, Gray, and Yellow) are shown in Table 4.

The analysis showed that replacing the fine aggregate by 20% volcanic tuff will improve the flexural and shear capacities of the reinforced beams by 6% to 16% for brown tuff,3% to 8% for gray tuff and 10 % to 26 % for yellow tuff for the four concrete strength grades as shown in Tables 5,6,and 7 and summarized in Table 8.

Table 4: Test Results of Beams

Compressive strength of Concrete (MPa)	Average applied load(P/2) (kN)			
	0% Volcanic Tuff	20% volcanic Tuff		
		Brown V.T	Gray V.T	Yellow V.T
20	15.00	16.00	15.5	17.50
30	20.00	23.25	23.0	25.25
40	25.00	27.00	27.0	29.50
50	28.00	30.75	30.0	31.00

Table 5: Test Results of Beams with (20 %) Brown Volcanic Tuff

Concrete Compressive strength (MPa)	Avg.Applied load(kN) 0%V.T	Avg.Applied load(kN) 20%V.T	Maximum shear (kN)	Maximum Moment (kN.m)	% Increase in Shear and Moment
20	15.00	16.00	16.00	6.4	6.67
30	20.00	23.25	23.25	9.3	16.25
40	25.00	27.00	27.00	10.8	8.00
50	28.00	30.75	30.75	12.3	9.82

Table 6: Test Results of Beams with (20 %) Gray Volcanic Tuff

Concrete Compressive strength (MPa))	Avg.Applied load(kN) 0%V.T	Avg.Applied load(kN) 20%V.T	Maximum shear (kN)	Maximum Moment (kN.m)	% Increase in Shear and Moment
20	15.00	15.5	15.5	6.2	3.33
30	20.00	23.0	23.0	9.2	6.00
40	25.00	27.0	27.0	10.8	8.00
50	28.00	30.0	30.0	12.0	7.14

Table 7: Test Results of Beams with (20 %) Yellow Volcanic Tuff

Concrete Compressive strength (MPa))	Avg.Applied load(kN) 0%V.T	Avg.Applied load(kN) 20%V.T	Maximum shear (kN)	Maximum Moment (kN.m)	% Increase in Shear and Moment
20	15.00	17.50	17.50	6.2	16.66
30	20.00	25.25	25.25	10.1	26.25
40	25.00	29.50	29.50	11.8	18.00
50	28.00	31.00	31.00	12.4	10.71

Table 8: Percentages of Increase in Flexural and Shear Capacities of The Tested Beams for The Three Types of Volcanic Tuff

Concrete Compressive strength (MPa)	Brown Volcanic Tuff	Gray Volcanic Tuff	Yellow Volcanic Tuff
20	6.67 %	3.33 %	16.66 %
30	16.25 %	6.00 %	26.25 %
40	8.00 %	8.00 %	18.00 %
50	9.82 %	7.14 %	10.71 %

Conclusions and Recommendations

Replacing the fine aggregate partially in the concrete mixes by volcanic tuff materials improves the flexural and shear capacities of the reinforced concrete beams since it increases the compressive strength of concrete itself due to the interlock action between the volcanic tuff aggregate and the cement paste in the concrete mix. The use of volcanic tuff materials decreases the workability of concrete due to its water high absorption percentage (11% to 25%), so the use of super plasticizers is a must with such concrete mixes.

For further researches on these materials to improve its properties, it is recommended to add other materials to the volcanic tuff such as fly ash. The use of volcanic tuff and fly ash materials in concrete reduces its bad environmental effect.

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