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The Effect of Replacing Fine Silica with Stone Cuttings' Powder on the Compressive Strength of Concrete: A Case Study in Jordan

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ABSTRACT

Stone wastes from cutting chainsaws in stone crushers have a negative effect on the environment. The reuse of these wastes is achieved in this study, as the fine sand of silica was replaced with stone wastes from Ajloun and Madaba with the following by-weight percentages: 0%, 10%, 25% and 100%. Standard compressive strength tests were performed at the Royal Scientific Society, Jordan to check the compressive strength of the new mixes. The tests performed in this paper are conducted on the following samples: (50 * 50 * 50 mm) mortar samples, (150 * 150 * 150 mm) concrete cubes and (150 * 300 mm) concrete cylinders. Tests are performed for the periods of 3, 7 and 28 days. The results show that the use of Ajloun stone wastes increased the compressive strength of mortar by 13%, while it was reduced by 3% by using Madaba stone wastes. In concrete cubes, the use of Ajloun stone wastes increased compressive strength by 37%, while it was reduced by 20% by using Madaba stone wastes. In concrete cylinders, the use of Ajloun stone wastes increased the compressive strength by 32%, while it was decreased by 23% by using Madaba stone wastes. Consequently, Ajloun stone wastes are suggested to be used as an alternative to fine silica and they proved their quality through the basic aggregate tests. The increase in compressive strength is attributed to Ajloun stone being of least absorption of liquids, as well as to the bonding force between the inner particles of the stone.

KEYWORDS: Ajloun (A) and Madaba (M) stones, Ordinary (silica) (O), Waste, Compressive strength, Cost, Environment, Quality control, Pollution.

INTRODUCTION

Ajloun and Madaba stones are usually used to decorate and protect building facades, where stones are cut in smaller blocks in order to obtain the desired shapes and sizes. Through the cutting process using the stone saw, non-abrasive parts are obtained for use, as well as very fine powder. This powder, when mixed with water, forms stone slurry as a semi-liquid substance consisting of particles originating from the sawing and polishing processes. These products were considered as an obstacle in terms of economy, since they need a high cost of disposal. Moreover, these materials have a significant effect on environmental pollution, so that it is necessary to find proper scientific ways to handle this problem. In this research, Ajloun and Madaba stone wastes are used in concrete and mortar productions to improve the compressive strength of concrete and to enhance workability and durability. However, a stone waste material with different ratios to replace the fine aggregate is the concern of this paper.

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This paper presents the results of an experimental investigation on the effect of using Ajloun and Madaba stone wastes as fine aggregate in mortar and concrete cube samples. Ajloun and Madaba stone wastes were used as 10%, 25% and 100% replacement of fine aggregate in mortar and concrete mixtures. Standard compressive strength tests were performed at the Royal Scientific Society, Amman, Jordan to check the compressive strength of the new mixes. The tests performed in this paper are conducted on the following samples: (50 * 50 * 50 mm) mortar samples, (150 * 150* 150 mm) concrete cubes and (150 * 300 mm) concrete cylinders. Tests are performed at the age of 3, 7 and 28 days. The results show that the use of Ajloun stone wastes increased compressive strength of mortar by 13%, while it was reduced by 3% by using Madaba stone wastes. In concrete cubes, the use of Ajloun stone wastes increased compressive strength by 37%, while it was reduced by 20% by using Madaba stone wastes. In concrete cylinders, the use of Ajloun stone wastes increased compressive strength by 32%, while it was decreased by 23% by using Madaba stone wastes.

Figure (1): Fine Ajloun (F.A.) stone wastes

Figure (2): Fine Madaba (F.M.) stone wastes

LITERATURE REVIEW

This literature review provides the necessary background information on concrete technology in general, along with materials used for mortar and concrete manufacturing with strong focus on fine and coarse concrete aggregates in terms of their properties, as well as the testing techniques used in the characterization of concrete aggregates.

Mortar is a workable paste used to bind building blocks, such as stones, bricks and concrete masonry units, together, fill and seal irregular gaps between them and sometimes add decorative colors or patterns in masonry walls. In its broadest sense, mortar includes pitch, asphalt and soft mud or clay used between mud bricks. Mortar comes from the Latin word *mortarium* meaning crushed (mortar holding weathered bricks).

Concrete is presented including its acoustic characteristics with reference to coarse aggregate and conventional concrete, where porosity has been identified as one of the most decisive properties affecting physical, mechanical and acoustic characteristics of concrete. Therefore, literature on porosity of coarse aggregate and concrete is reviewed (Mehta and Monteiro, 1993).

Concrete is a mixture of paste and aggregates (rocks). The paste is composed essentially of Portland cement and water; it coats the surface of fine (smaller) and coarse (larger) aggregates. Through a series of chemical reactions called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete (Office of Engineering Construction and Maintenance Division (Materials Branch)).

Jordanian stone features include several advantages and properties in terms of strength and beauty, qualifying it to compete and enter the global architecture market strongly. Jordanian stone industry has evolved and became a product equivalent to international standards, so that Jordan's exports over the past years reached about 30 million dollars. Stone exports are expected to increase after overcoming the obstacles facing the stages of extraction and processing in Jordan. Ajloun stone is globally known for its very low absorption of liquids at the world level; therefore, it has been used in many of the big businesses and big buildings in Europe and America (Journal of Environmental Science and Engineering).

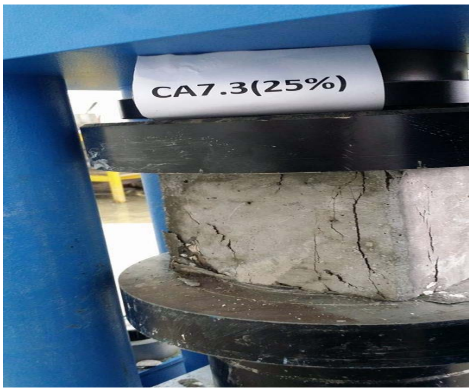
Head of Department of Laboratories at the Royal Scientific Society, Dr. Bashar Nabulsi stated that it is currently sought to adopt international standards to help exporters of Jordanian stone and marble to enter global markets with ease through meeting the tests of the European standards. He said that the Building Research Center at the Society performs full laboratory tests on stone in terms of disintegration modulus, water absorption specific weight, gaps and pockets of sand in addition to external appearance, among other tests. Engineer Munir Kakish stated that in Jordan there are about 260 stone quarries stretching from the south to the north-east of the Kingdom distributed extensively in the south and east. He said that the stone is extracted either by blasting or drilling. Jordan's most important stone types are Ajlun stone (Lithostratigraphy and Microfacies Analysis of the Ajloun Group in Wadi Sirhan Basin) and Madaba stone (Madaba Institute for Mosaic Art and Restoration), both types with high lime content. In addition, there are other types existing in different parts of the Kingdom, such as: Hayyan stone, Deir Alla stone, Irbid stone and Al-Azraq stone,among others (RSS).

Stone slurry is a semi-liquid substance consisting of particles originating from the sawing and polishing processes and water is used to cool and lubricate the sawing and polishing machinery. The generated wastes cause environmental, health and economical drawbacks (Almeida et al., 2007). On the one hand, when stone slurry is disposed of in landfills, its water content is drastically reduced and the resulting stone dust presents several environmental impacts. In other words, in dry seasons, the stone powder is suspended in the air and sticks on vegetation and crops. This significantly affects the environment and local systems. In some cases, stone dust disposed of around the production facilities causes reduction in porosity and permeability of the topsoil and results in water logging. Moreover, fine particles result in poor fertility of the soil due to increase in alkalinity (Montero et al., 2009). In addition, destroying vegetation cover, regional topographic changes, soil erosion and changing of landscape are other negative environmental impacts. On the other hand, waste from quarry and fabrication operations can be unsafe and environmentally detrimental. Runoff from the scrap mounds can cause erosion problems and fines introduced into natural waterways can suffocate local ecosystems (Elham Shirazi).

METHODOLOGY

To achieve the research goals, some experimental tests were conducted. Basic materials such as aggregates and sand were obtained in order to get the engineering properties of these materials. The conducted tests were: sieve analysis test (WSDOT FOP for WAQTC T27/T11), specific gravity test (AASHTO T85 and ASTM C 127), absorption test (AASHTO T85 and ASTM C 127), moisture content test (TR-106-11) and abrasion test (AASHTO T96 or ASTM C 131). In order to obtain a suitable amount of fine aggregate that gives improvement of mortar (ASTM C109/C 109M-16a) and concrete properties, samples were divided into six categories according to the ratio of fine. Each category has three cubes and two cylindrical specimens that were prepared and tested. The categories were: three cube specimens with null fine (Ajloun, Madaba), two cylindrical specimens with null fine (Ajloun, Madaba), three cube specimens with fine (Ajloun), two cylindrical specimens with fine (Ajloon), three cube specimens with fine (Madaba) and two cylindrical specimens with fine (Madaba). Tests conducted on mortar and concrete after preparation were compressive test and slump test (ASTM C143).

(a)



(b)

(c)

Figure (3): Compressive strength testing of (a) Ajloun fine mortar cubes, (b) Ajloun fine concrete cubes and (c) Ajloun fine concrete cylinders

In this section, a total of twenty-seven (mortar), thirty-two (cube) and twenty (cylindrical) classified mortar samples were prepared.

First, all mortar samples were classified into three main categories depending on the ratio of fine aggregate (O, A, M): three cube specimens with null fine (O), three cube specimens with fine (Ajloun) (A) and three cube specimens with fine (Madaba) (M), with cement (0.25gm): sand (fine) (0.7gm): water (0.125ml).

Note: MO3.1: mortar (ordinary), age: three days, cube number one; MA7.2: mortar (Ajloun), age: seven days, cube number two and MM28.3: mortar (Madaba), age: twenty-eight days, cube number three.

Second, all concrete samples were classified depending on the ratio of fine aggregate (O, A, M): three cube specimens with null fine (O), three cube specimens with a ratio of fine (Ajloun) of (10%) (A), three cube specimens with a ratio of fine (Ajloun) of (25%) (A), one cube specimen with a ratio of fine (Ajloun) of (100%) (A), three cube specimens with a ratio of fine (Madaba) of (10%) (M), three cube specimens with a ratio of fine (Madaba) of (25%) (M), one cube specimen with a ratio of fine (Madaba) of (100%) (M), two cylindrical specimens with null fine (O), two cylindrical specimens with a ratio of fine (Ajloun) of (10%) (A), two cylindrical specimens with a ratio of fine (Ajloun) of (25%) (A), two cylindrical specimens with a ratio of fine (Madaba) of (10%) (M), two cylindrical specimens with a ratio of fine (Madaba) of (25%) (M).

Note: CM: Cube (Madaba), CCM: Concrete, Cylindrical (Madaba), CO: Cube, Ordinary (silica), CCO: Concrete, Cylindrical, Ordinary (silica), CA: Cube (Ajloun), CCA: Concrete, Cylindrical (Ajloun).

Tables 1 and 2 present the details of coarse and fine aggregates and cement ratio used to prepare the specimens.

Table 1. Mix design ratio details of cube specimens

Fine (M, A) (kg)	Fine aggregate (O) (kg)	Coarse aggregate (kg)	Cement (kg)	Water (kg)	Fine (%), Ordinary
0	8.046	10.44	3.67	1.824	0%
0.8046	7.2576	10.44	3.67	1.824	10%
2.016	6.048	10.44	3.67	1.824	25%
8.046	0	10.44	3.67	1.824	100%

Table 2. Mix design ratio details of cylindrical specimens

Fine (M,A) (kg)	Fine aggregate (O) (kg)	Coarse aggregate (kg)	Cement (kg)	Water (kg)	Fine (%), Ordinary
0	8.4	10.87	3.8225	1.9	0%
0.84	7.56	10.87	3.8225	1.9	10%
2.1	6.3	10.87	3.8225	1.9	25%

RESULTS AND DISCUSSION

Specific Gravity and Absorption

Table 3. Specific gravity and absorption

Waste stone	Ajloun	Madaba
Apparent SP. G	2.6	2.54
SSD SP. G	2.58	2.47
Absorption (%)	0.5	1.86

Table 3 shows that the readings of specific gravity of Ajloun stone are larger than those of Madaba stone and this is an evidence on the strength of Ajloun stone. The absorption rate values of Ajloun stone are less than those of Madaba stone and this indicates the good quality of Ajloun stone.

(a) **(b)** **(c)**

(d) **(e)**

Figure (4): Specific gravity and absorption (a) specific gravity for coarse aggregate, (b) specific gravity for fine aggregate, (c) oven dry, (d) SSD for fine **aggregate, (e) SSD for coarse aggregate**

Los Angeles (LA) Abrasion Testing Machine

Table 4 shows that the abrasion reading of Ajloun stone is less than that of Madaba stone and this is an evidence on the strength of Ajloun stone because of the interconnection of the particles of the interior of this stone.

Table 4. Abrasion

Waste stone	**Ajloun**	**Madaba**
Abrasion (%)	17.74	26.33

(a) (b)

Figure (5): (a) Los Angeles (LA) abrasion testing machine, (b) samples after abrasion

Table 5. Average compressive strength of cement mortar (Ajloun, Madaba and ordinary)

Samples	3-day average (MPa)	7-day average (MPa)	28-day average (MPa)
A	11.6	17.81	21.1925
M	7.88	14.2633	18.23
O	9.7133	15.9666	18.7

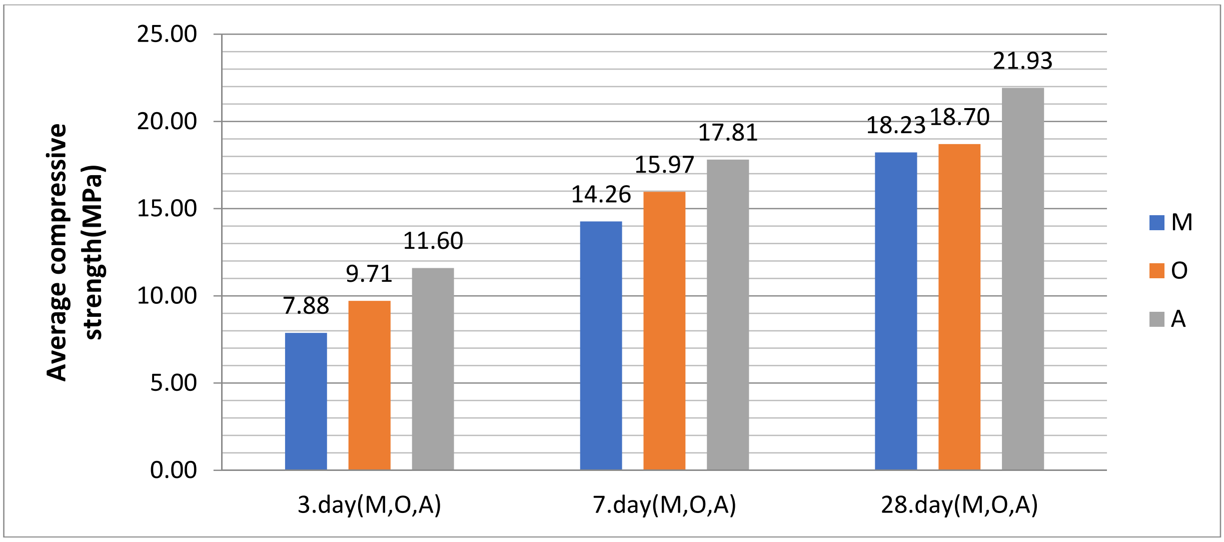


Figure (6): Average compressive strength according to tests conducted on mortar (A: Ajloun, M: Madaba, O: Ordinary)

Compressive Strength Test Result

Table 5 and Figure 6 show the results of compressive strength of cement mortar specimens at an age of 3, 7 and 28 days. Results showed that Ajloun stone increased the compressive strength of cement mortar by a ratio of 19, 11 and 13% at an age of 3, 7 and 28 days, respectively. The compressive strength of cement mortar with Madaba stone at an age of 3, 7 and 28 days decreased by a ratio of 9, 11 and 3%, respectively as compared with ordinary stone.

Table 6. Average compressive strength of concrete cube and cylindrical specimens (Ajloun, Madaba and ordinary)

28-day average (MPa)			7-day average (MPa)				
100%	25%	10%	100%	25%	10%	Samples	Concrete
—	42.37	37.8	22.66	31.997	25.15	A	
—	24.886	28.29	14.22	21.47	17.379	M	C
31.03	—	—	20.96 / 20.4*	—	—	O	
—	31.27	28.8	—	20.937	25.46	A	
—	18.245	23.48	—	14.156	18.65	M	CC
23.75	—	—	18.39	—	—	O	

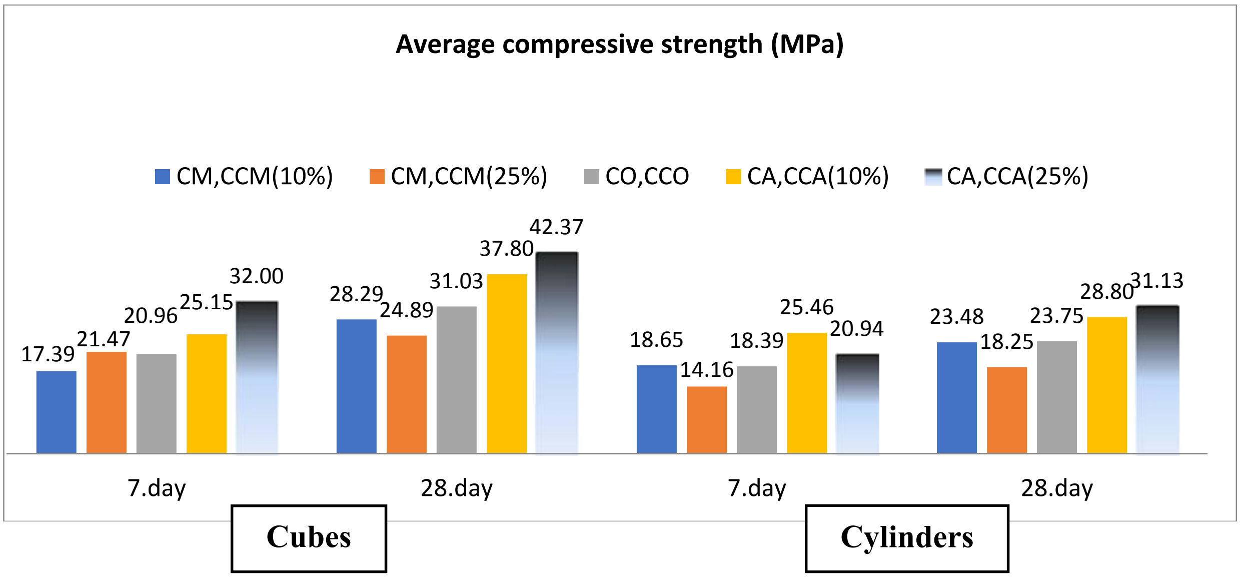


Figure (7): Average compressive strength according to tests conducted on concrete cubes and cylindrical specimens (A: Ajloun, M: Madaba, O: Ordinary)

Table 6 and Figure 7 show the results of compressive strength of concrete cubes at an age of 7 and 28 days. Results showed that Ajloun stone with a fine aggregate ratio of 10%, 25% and 100% increased the compressive strength of concrete cubes by 20, 53 and 11%, respectively at an age of 7 days. The compressive strength of concrete cubes with Ajloun stone with a fine aggregate ratio of 10%, 25% and 100% increased by 22, 37 and 17%, respectively at an age of 28 days. The compressive strength of concrete cubes with Madaba stone with a fine aggregate ratio of 10%, 25% and 100% decreased by 17, 2.4 and 30%, respectively at an age of 7 days. The compressive strength of concrete cubes with Madaba stone with a fine aggregate ratio of 10% and 25% decreased by 9 and 20%, respectively at an age of 28 days, as compared with ordinary stone. The compressive strength of concrete cylinders with Ajloun stone with a fine aggregate ratio of 10% and 25% increased by 38 and 14%, respectively at an age of 7 days. The compressive strength of concrete cylinders with Ajloun stone with a fine aggregate ratio of 10% and 25% increased by 21 and 32%, respectively at an age of 28 days. The compressive strength of concrete cubes with Madaba stone with a fine aggregate ratio of 10% and 25% decreased by 1.4 and 23%, respectively at an age of 7days. The compressive strength of concrete cubes with Madaba stone with a fine aggregate ratio of 10% and 25% decreased by a ratio of 1.14 and 23%, respectively at an age of 28 days.

Evaluation of Statistical Quality Control of
Grade 25 Concrete at 28 Days

Table 7. (CA: Cube, Ajloun, CCA: Concrete, Cylindrical, Ajloun-10%, 25%)

Sample No.	Samples	Data casting	Data testing	Reading MPa			$\bar{x}$ MPa	$(X-\bar{X})$ MPa	$(X-\bar{X})^2$ MPa
				1st	2nd	3rd			
1	CA(10%)	21/3/2016	19/4/2016	39.77	35.46	38.22	37.8	2.8	7.84
2	CA(25%)	17/4/2016	16/5/2016	40	44	43.11	42.37	7.35	54.02
3	CCA(10%)	21/3/2016	19/4/2016	31.6	26	__	28.8	-6.22	38.7
4	CCA(25%)	17/4/2016	16/5/2016	30	32.25	__	31.125	-3.9	15.21
							$\sum\bar{X}$= 35.02		∑=115.77

Table 8. (CM: Cube, Madaba, CCM: Concrete, Cylindrical, Madaba-10%, 25%)

Sample No.	Samples	Data casting	Data testing	Reading MPa			$\bar{x}$ MPa	$(X-\bar{X})$ MPa	$(X-\bar{X})^2$ MPa
				1st	2nd	3rd			
1	CM(10%)	27/3/2016	25/4/2016	32.88	24.88	27.11	28.29	4.57	20.9
2	CM(25%)	29/3/2016	27/4/2016	25.33	23.11	26.22	24.886	1.166	1.36
3	CCM(10%)	27/3/2016	25/4/2016	24.33	22.63	__	23.48	-0.24	0.058
4	CCM(25%)	29/3/2016	27/4/2016	17.54	18.95	__	18.245	-5.47	30
							$\sum\bar{X}$ = 23.72		∑= 52.32

Table 9. (CO: Cube, Ordinary (silica), CCO: Concrete, Cylindrical, Ordinary (silica)

Sample No.	Samples	Data casting	Data testing	Reading MPa			$\bar{x}$ MPa	$(X-\bar{X})$ MPa	$(X-\bar{X})^2$ MPa
				1st	2nd	3rd			
1	CO	15/3/2016	13/4/2016	30.22	29.11	33.77	31.03	3.64	13.25
2	CCO	15/3/2016	13/4/2016	26	21.5	__	23.75	-3.64	13.25
							$\sum\bar{X}$ =27.39		∑=26.5

Table 10. σ: Standard deviation, V: Coefficient of variation for A: Ajloun, M: Madaba, O: Ordinary (silica)

	A	M	O
σ (Mpa)	5.38	3.62	3.64
V (%)	15.36	15.26	13.29

Table 11. Specific compressive strength or A: Ajloun, M: Madaba, O: Ordinary (silica)

f_{cu}(A)=26.2Mpa	f_{cu}(M)=17.78Mpa	f_{cu}(O)=21.42Mpa

It has been found according to the ASTM specifications that Madaba (M) stone is the best in terms of quality, followed by Ordinary (O) stone, then by Ajloun (A) stone. Madaba (M) stone is considered the best in terms of quality, but not economically, as Ajloun stone was the closest to the specific compressive strength of 25 MPa in terms of economy and in terms of quality, research showed that Ajloun (A) stone despite changes and mistakes was closer to the specific compressive design strength of 25MPa.

CONCLUSIONS

The following remarks can be summarized according to the experimental study. It was shown that Ajloun stone increased specific gravity by about 2.58%. Ajloun stone also affected abrasive resistance, where the abrasion percentage decreased by about 17.74%. Ajloun stone favorably affects absorption and increases the compressive strength of cement mortar and that of concrete as compared to ordinary aggregate. Using Ajloun stone increases the concrete compressive strength more than two times compared to its original strength. Finally, using Ajloun stone was recommended to produce lightweight concrete with high strength. The increase in strength is attributed to Ajloun stone as it has the least absorption of liquids worldwide, in addition to the bonding force between the inner particles of Ajloun stone.

REFERENCES

AASHTO T 85 and ASTM C 127: Specific gravity and absorption of coarse aggregate.

AASHTO T 96 or ASTM C 131: Resistance to degradation of small-size coarse aggregate by abrasion and impact in Los Angeles machine.

Almeida, N., Branco, F., Brito, J., and Santos, J.R. (2007). “High-performance concrete with recycled stone slurry”. Cement Concrete Res., 37, 210-220.

American Society for Testing Materials ASTM C39/C39M, ASTM C39/C39M – 17b: Standard test method for compressive strength of cylindrical concrete specimens.

ASTM C109 / C109M – 16a: Standard test method for compressive strength of hydraulic cement mortars (using 2-in. or [50-mm] cube specimens).

ASTM C143 in the United States; IS: 1199 – 1959 in India; EN 12350-2 in Europe.

Bashar Nabulsi (BRC Director at Royal Scientific Society).

Determining total moisture and free moisture in aggregates (coarse and fine aggregates), designation: TR-106-11.

Elham Khalilzadeh Shirazi, Department of Environmental Engineering, Graduate School of the Environment and Energy, Science and Research Campus, Islamic Azad University, Tehran, Iran.

Journal of Environmental Science and Engineering B 1. (2012). 720-727 Former Part of Journal of Environmental Science and Engineering, ISSN 1934-8932.

Lithostratigraphy and Microfacies' Analysis of the Ajloun Group (Cenomanian to Turonian) in Wadi Sirhan Basin, SE Jordan.

Madaba Institute for Mosaic Art and Restoration.

Mehta and Monteiro. (1993). "Concrete structure, properties and materials". Prentice-Hall, Inc., Englewood Cliffs, NJ.

Montero, M.A., Jordan, M.M., Almendro-Candel, M.B., Sanfeliu, T., and Hernandez-Crespo, M.S. (2009). “The use of calcium carbonate residue from the stone industry in manufacturing of ceramic tile bodies”. Appl. Clay Sci., 43, 186-189.

Mortar holding weathered bricks.

Munir Kakish (Owner, Ramallah Christian Outreach).

Office of Engineering Construction and Maintenance Division (Materials Branch).

Royal Scientific Society.

WSDOT FOP for WAQTC T 27/T 11: Sieve analysis of fine and coarse aggregates.