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Rehabilitation of Al-Shawbak Castle Using El-Lajjun Bituminous Limestone Ash Mortars and Plasters.

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Abstract

Al-Shawbak castle mortars and plasters were characterized through physical, mechanical and chemical analysis. The studied masonry and plaster mortars have shown intensive weathering and erosion features, low compressive strength, and high absorption and disintegration behavior when soaked in water. Limy ash has been prepared from the El-Lajjun bituminous limestone by direct combustion at 950 ^{0}C in an attempt to rehabilitate Al-Shawbak castle. The ash has been mixed with sand and water to prepare self cementitious mortar material that gain strength at normal ambient temperature. The laboratory tests have been selected with respect to construction needs in various remedial works in archeological sites to replace weathered and eroded masonry and plaster mortars.

The limy ash mortar has similar color, chemical and mineralogical composition similar to the tested ancient mortar and plaster samples. The mortar has a higher compressive strength and resistively to disintegration under saturation conditions. The ash mortars could be used to rehabilitate various damaged archeological parts of AL-Shawbak Castle.

Keywords: Rehabilitation, Al-Shawbak Castle, El-Lajjun, Bituminous Limestone, Ash Mortars.

1. Introduction

Al-Shawbak castle, an important historical and archeological site, located in the southern part of Jordan (Fig. 1a) and built in the first half of the eleventh century at the Crusader time (Brown, 1988).). Random parts of the castle were subjected to sever damage over the past 800 years due to earthquakes, weathering processes, denudations and erosion, hence the castle became under immanent danger.

The creativity of the ancient cultures is reflected in the stability of the major parts of these ruins against weathering and earthquakes of various intensities over the past centuries (Amrat, 1992)

Natural sculpted limestone and dimension silicified limestone blocks of various sizes were used as building materials in long and high stable walls, arches, domes in addition to the other architectural features in the castle. Materials similar to the masonry and plaster mortars that were used during the construction of the castle could be prepared and used in recent remedial and restoration activities in Al- Shawbak castle.

Huge quantities of solid waste ash are expected to be produced through utilization of bituminous limestone as an energy source through direct combustion in thermal power stations.

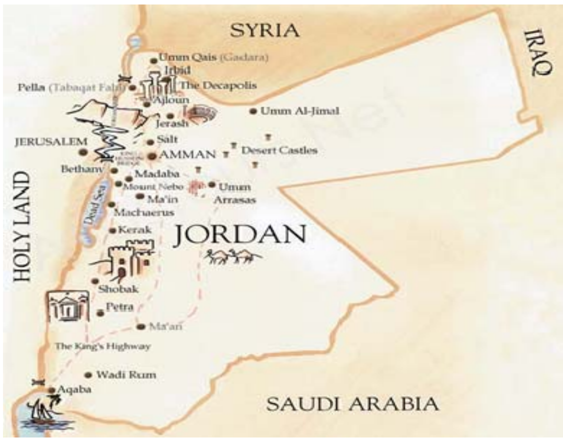

Fig. 1a Location map shows Al Shobak area. (www.atlastours.net)

This ash can be utilized as a self cementitious material when mixed with water at normal ambient temperature and hence transferring the friable ash wastes into useful material in various construction activities. Various mortars utilizing limy ash and glass sand will be prepared from El-Lajjun oil shale deposit which is located 110 km southwest of Amman, Roman legionary camp (Parker, 1985), to be

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compared with masonry and plaster mortars that were used during the construction of the castle.

All studies conducted so far were limited to the description of the monument ignoring the intrinsic value of its restoration.

The following study aims to rehabilitate Al-Shawbak castle using limy ash mortars. It concentrates on determining the physical, chemical, and mechanical properties of the masonry and plaster mortars that were used during the construction of the castle. The results are expected to reveal the possibility of utilizing the limy ash from El-Lajjun area as a self cementing material in restoration and remedial work in the weathered, eroded and collapsed portions of the castle.

2. The studied Area

Al-Shawbak Castle is a Crusader, Ayyubid, Mamluk castle of the 12 th and 13 th centuries, located in southern Jordan, 120 Km. south of Karak and 35 km. north of the fabulous Nabataean city of Petra. In 509 A.H/ 1115 AD Baldwin I, founder of the Latin kingdom of Jerusalem, led a major expedition into the region south east of the dead sea. He crossed Wadi Araba and marched to the fertile, wooded district of Al-Shawbak. There a top a steep mountain overlooking a well-watered valley, Baldwin erected a huge castle, which he named " la Carc de Montreal") (fig. 1b).

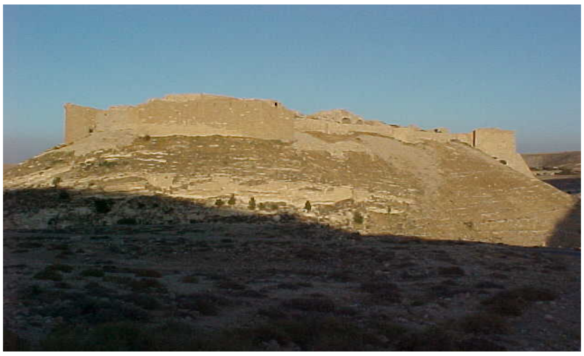


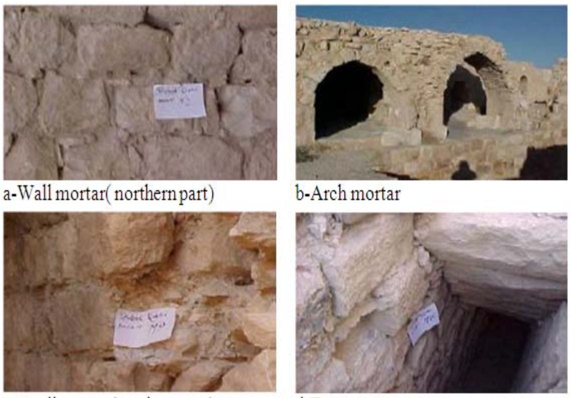
Fig. 1b. Al-Shoubak Castle, general view.

The construction of the castle of Al-Shawbak, along with smaller ones in and around Petra, al-Habis and Wa'airah, gave the Crusaders a loose control over the territory between the Dead Sea and the Gulf of Aqaba, and had the further advantage of hindering both the commercial and military connection between Syria, Egypt and the Hejaz. Al-Shawbak fell to the soldiers of Saladin in 584 A.H / 1188 A.D. And was refortified several times by both the Ayyubids (1174-1250) and the Mamluks (1250-1517). The castle was occupied throughout the late Ottoman period (18^{th} -19^{th} centuries) (Brown, 1988)

Considerable remains of all these periods fill the interior numerous Arabic inscriptions in Naskhi (cursive) script record the various reconstructions of the castle.

3. Materials and Methods

Random mortar samples from different locations in the castle where collected. fig. (2) illustrates the sample locations. Whitish, grayish and reddish mortars were used in ancient building activities.



a-Wall mortar(northern part) b-Arch mortar c- wall mortar(southern part) d-Entrance mortar

Fig. 2.The sampling sites of mortars from Al-Shoubak Castle

The samples were labeled M1...M17 (Table 1)

Table 1.Physical, mechanical and total dissolved salts for the mortar samples

Sample No.	T.D.S Mg/l	Color	SG	Absorption %	Comp. strength Kg/cm2	Gradation %		
						Sand	Silt	clay
M1	160	Yellow	2.02	21.70	-	81.6	13.1	5.3
M2	112	White	2.10	29.04	-	62.6	31.6	5.8
M3	367	=	1.80	41.07	12.3	66.7	23.3	10
M4	2730	=	1.62	22.02	-	61.3	26.5	12.2
M5	4610	Grey	2.07	35.11	15.6	61.9	27.3	10.8
M6	1250	White	1.91	40.93	22.1	52.2	31	16.8
M7	8256	=	1.71	47.42	29.29	36.4	57.8	5.8
M8	1148	=	1.88	43.48	19.29	82	14	4
M9	-	=	1.95	38.39	-	44.2	49.9	5.9
M10	-	=	1.85	35.68	37.83	54.1	37.3	8.6
M11	-	Grey	1.89	37.08	18.53	54.1	37.3	8.6
M12	-	White	2.08	39.27	18.78	76.7	15.2	8.1
M13	120	White	1.70	45.30	6.12	73.9	17	9.1
M14	-	Grey	1.91	44.12	-	69.1	21.6	9.3
M15	-	White	2.08	38.99	5.8	55.1	38.6	6.3
M16	-	Grey	1.65	42.46	-	-	-	-
M17	-	White	2.16	36.10	-	47.4	39.3	13.3

Red, brown, gray mortar samples were collected as slices from some locations in which these mortars were used as a plaster. The samples were labeled P1, P2, P3, P4, P5, and P6 (Table 2).

Table 2. Physical, mechanical and total dissolved salts for plaster samples

Sample No.	Color	Specific Gravity	Absorption %	Porosity %	Gradation %		
					Sand	Silt	Clay
P1	White	2.35	17.86	29.5	-	-	-
P2	Red & white	2.21	23.06	33.8	-	--	--
P3	Brown	-	-	--	-	-	-
P4	White-Brown	-	-	--	7.8	50.2	42
P5	Grey	1.95	35.7	41.0	-	-	-
P6	Creamy-white	1.86	17.10	24.0	-	-	-

The thickness of the ancient mortars is variable and range from 2-4 cm. It was very difficult to get enough bulk samples to determine the compressive and tensile strength on standard dimensional samples. Therefore, Point Load

Strength Index was used to estimate the compressive strength of some bulk ancient mortars.

Various mortars utilizing limy ash from El-Lajjun area and glass sand were prepared. These mortars were analyzed using necessary chemical, mineralogical and physical testing. Porosity, specific gravity, moisture content, compressive strength, and absorption tests were carried out for the ancient and prepared mortars. X-ray diffraction, X-ray fluorescence were used to determine the mineralogical and chemical composition of ancient and prepared ash mortars.

The physical and mechanical properties of the prepared ash-sand mortars were determined using standard cubic samples of 5x5x5 cm according to (ASTM C109. 1999). Curing is carried out at laboratory temperature under successive wetting and drying conditions to determine the compressive strength at 28 days. The analyses were carried out at the Department of Civil Engineering; Al- Balqa Applied University and the Natural Resources Authority, Amman.

A bulk representative sample of about 100 kilograms was collected from various outcrops from El-Lajjun deposits.

The sample was crushed using a jaw crusher to obtain bituminous limestone aggregates of 9 mm nominal size particles. The whole aggregates were mixed and combusted 925 ^{0}C by using an automatically controlled electrical muffle furnace.

The sample was allowed to cool down to the ambient temperature (30 ^{0}C) and then was grounded under dry conditions to obtain the possible minimum grain size. Small ball mills and Los Angles machine were used. The moisture content of the combusted ash samples was checked directly after cooling and was found to be around 0.2%. The fine ash (nominated as S1) was filled immediately in tight plastic bags for further trial mixes of ash-sand mortars according to (ASTM C 109, 1999).

The chemical composition of the ash samples is clearly dependent on the original composition of the parent bituminous limestone and the temperature of combustion (Abdul Hadi et al., 2007).

Glass sand and tuff were mixed with variable percentages with S1 ash sample. The ash-glass sand mixtures are designated as S1-1, while S1-T is ash-tuff mixtures.

The various ash S1-glass sand and S1-tuff were tested at variable ash content (mention these percentages) and different curing periods (mention them also); the following tests were carried out according to the indicated standards:

1. Density - (ASTM C 29, 2003).
2. Specific gravity and absorptions (ASTM C128, 2007) .
3. Grain size analysis (ASTM C136, 2006)
4. 4. Compressive strength of hydraulic cement mortars (ASTM C109, 1999).

4. Results and Discussion

4.1. Physical Properties of Ancient Mortar

The tested ancient mortar has white, cream, gray, and yellow colors. The apparent specific gravity varies between 1.62 and 2.07. Some samples have shown a very high water absorption value up to 47%. Compressive strength of the tested mortar is estimated using the point load strength index test because it is not possible to get standard testing samples dimensions. The compressive strength values ranged from 5.8 Kg/cm^2 to 37.83 Kg/cm^2. Some samples have shown complete disintegration when immersed in water to determine absorption, and hence the compressive strength is not determined for these samples. The disintegrated samples were dried and sieved. The ancient mortars are composed of sand, silt and clay fractions. The weight percent of these ingredients varies from one sample to another. Total dissolved salts (TDS) have revealed that the salt content is very high in some samples as M5 and M7 (Porosity was measured and have shown a random pattern. The results of grain size distribution and total dissolved salts for the tested mortar samples are given in table (1).

4.2. Mineralogical and Chemical Composition of Ancient Mortars

The X-ray diffraction results are given in table (3).

Table . 3.X-ray diffraction results of the mortar samples

Sample No.	Sample type	Quartz	Calcite	Gypsum	Bassanite
M1	Mortar	-	***	**	*
M2	=	*	***	**	*
M3	=	*	***	*	*
M4	=	*	***	**	*
M5	=	*	***	*	-
M6	=	*	***	*	*
M7	=	*	***	**	*
M8	=	*	***	**	*
M9	=	*	***	*	-
M10	=	*	***	-	-
M11	=	*	***	*	-
M12	=	*	***	**	-

The results have indicated that calcite as the major constituent. Gypsum, quartz and bassanite as minor constituents. Moreover, the X-ray fluorescence results have shown that CaO is the major oxide while other oxides as Al_2O_3, Fe_2O_3, K_2O, Na_2O, and MgO are minor or absent as shown in table(4).

Table . 4. X-ray fluorescence results of the tested mortar

Sample No.	Sample type	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	K_2O %	Na_2O %	CaO %	L.O.I %
M1	Mortar	3.61	0.12	0.39	0.01	1.77	0.29	50.4	43.3
M2	=	3.44	0.11	0.39	0.01	1.94	0.19	50.4	43.5
M3	=	3.32	0.12	0.37	0.01	1.97	0.15	50.0	44.0
M4	=	3.41	0.20	0.43	0.01	1.99	0.23	49.4	44.2
M5	=	6.10	0.29	0.81	0.67	4.73	0.45	43.5	43.4
M6	=	3.44	0.11	0.44	0.01	1.79	0.21	49.7	44.2
M7	=	3.37	0.12	0.40	0.01	2.16	0.61	49.8	43.4
M8	=	3.52	0.15	0.39	0.01	1.91	0.01	49.6	44.3
M9	=	6.17	0.32	1.05	0.45	4.68	0.33	43.6	43.3
M10	=	3.98	0.06	0.50	0.01	4.77	0.01	45.6	44.9
M11	=	6.21	0.37	0.75	0.49	4.81	0.20	43.1	43.9
M12	=	6.21	0.37	0.75	0.49	4.81	0.20	43.1	43.9

Some of mortar samples were divided into two portions, one was dissolved in 0.1 HCl solutions and the other portion was dissolved in distilled water.

The soluble components in 0.1 HCl solutions are given in Table (5), and indicate that CaO is the major soluble oxide.

Meanwhile, the dissolved ions for the soaked disintegrated mortar and plaster samples in distilled water are given in Table (6), and shows that Ca, SO_4 and CO_2 are the most soluble components.

Table. 5. Soluble ions and oxides in 0.1 HCl solution.

Sample No.	Type of Material	0.1 HCL soluble oxides WT. %					
		Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
M1	Mortar	0.12	0.01	19.60	0.30	0.72	0.59
M2	=	0.11	0.01	26.60	0.31	0.84	0.59
M3	=	0.12	0.01	19.60	0.31	0.72	0.59
M4	=	0.20	0.01	18.20	0.29	0.72	0.56
M5	=	0.29	0.02	18.20	0.71	2.70	1.20
M6	=	0.11	0.01	18.20	0.25	0.84	0.56
M7	=	0.12	0.01	19.60	0.31	0.72	0.59
M8	=	0.15	Nil	18.20	0.25	0.84	0.55
M9	=	0.32	0.01	16.80	0.64	2.60	1.20
M10	=	0.06	Nil	18.20	0.44	2.60	1.20
M11	=	0.14	0.01	19.60	0.36	2.70	1.20
M12	=	0.16	0.01	16.80	0.30	06.0	0.56

Table. 6.Distilled water soluble ions of the mortar samples.

Sample No	Type of Material	Na %	K %	Ca %	Mg %	Cl^- %	SO_4- %	CO_2 %
M1	Mortar	0.30	0.87	3.60	0.24	0.71	3.55	31.08
M2	=	0.30	0.90	3.26	0.48	1.07	3.55	30.59
M3	=	0.30	0.85	4.20	0.60	1.07	4.22	28.13
M4	=	0.32	0.90	4.00	0.18	1.07	3.74	27.15
M5	=	0.80	2.42	1.30	0.36	1.42	1.63	30.10
M6	=	0.32	0.92	2.78	0.66	1.07	3.07	31.41
M7	=	0.25	0.55	2.43	0.14	1.42	5.09	26.99
M8	=	0.30	0.95	1.50	0.31	1.42	4.61	31.41
M9	=	0.84	1.90	0.48	0.48	0.75	1.44	29.95
M10	=	0.95	2.10	0.72	0.5	0.82	1.92	30.0
M11	=	0.99	2.2	0.68	.53	1.53	1.63	30.8
M12	=	0.36	1.48	3.52	0.24	0.78	3.74	30.70

4.3. Ash as a Mortar and Plaster in Remedial work

The chemical composition of S1 ash sample is given in Table (7). The sample is compared with the Ordinary Portland Cement (OPC).

Table. 7. Chemical composition of S1 ash sample and standard OPC.*

Oxide Wt. %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	Na_2O	TiO_2
S1 ash (950 ⁰C)	25.30	2.35	137	45.21	1.63	5.47	0.85	0.14
OPC	23	4	2	64	2	-	-	-

*Analysis was done using XRF technique.

The physical properties of the ash sample S1 are given in Table (8). The chemical composition (high CaO and relatively high SiO2 content) and physical characteristics of S1 ash sample enables the use of ash as a self-cementing material.

Table. 8.Physical properties S1 ash.

Ash type	Specific gravity ASTM D 854-05	Moisture content %	Bulk density g/cm^3
S1	2.48	0.9	1.13

Ash, sand size crushed tuff and glass sand, are used in various ash-mortar mixtures.

The physical properties for the used raw materials are given in table (9).

Table. 9. properties of tuff and glass sand .

Material	Specific gravity	Absorption %	Passing #200 sieve %
Tuff fractionfraction	2.6	4.0	50
Glass sand	2.56	1.8	4

According to ASTM standards, the S1 ash sample has a lower pozzolanic content than both classes F and C ash and a very high CaO content relative to the ASTM classification. This indicates that the El-Lajjun ash can be used efficiently in some proper aspects other than that indicated for both fly ashes of type F or type C in the international standards. The production of various construction materials that can fulfill the international standards in which OPC can be substituted with proper percentages of the self-cementation ash was discussed by (Leonard and Baily, 1982). Although the El-Lajjun ash is not complying with the classification proposed by (Ferguson and Levorson, 1999), however, the S1 samples have a unique chemical composition that is characterized by its very high CaO (Abdul Hadi et. al., 2007). Sampling and testing procedures were carried out following (ASTM C109, 1999) for testing compressive strength of hydraulic cement sand mortar.

4.4. Engineering Characteristics of the Ash

All standard testing for strength determination of ash as a self-cementing material has shown a high stability. No minor features of disintegration or disturbance of the prepared samples during the curing stage in water at normal ambient temperature (28 C^0) were observed. On the contrary of normal soil behavior, it could sustain under saturation conditions. On the other hand, ash behaves as cementitious material that has the possibility to gain strength under normal curing time and conditions as the other different types of cements. This is confirmed through the compressive strength results of standard 5x5x5 cm cubic samples. The compressive strength results at 7, 28, and 56 days for the S1, S1 and S3 samples are given in table (10).

Table. 10. Compressive strength results of S1, S1 and S3 ash samples.

Mix designation	Glass sand (g)	Ash (g)	Water (g)	Density g/cm^3	7 days strength kg/cm^2	28 days strength kg/cm^2	56 days strength kg/cm^2
S1-1	1375	500	560	1.87	20.4	55.2	68.3
S1-1	1375	500	560	1.88	18.6	53.9	64.4
S1-1	1375	500	560	1.86	19.2	56.8	65.9

The average strength builds up at 7, 28 and days for the S1 ash sample has shown an increasing trend with increasing the curing period. The strength buildup in S1 ash mixtures is due to the chemical reactions that take place under the dominant ambient temperature. The addition of water under surface normal conditions would lead to the following hydration reactions:

$CaO+H_2O \rightarrow Ca(OH)_2$ (Portlandite) (1)

$SiO_2+Ca(OH)_2+H_2O \rightarrow CaSiO_2.2H_2O$ Calcium Silicate Hydrate (CSH) (2)

$SiO_2+Al_2O_3+Ca(OH)_2+H_2O \rightarrow CaSiO_2.Al_2O_3.H_2O$ Calcium Aluminates Hydrate (CAS) (3)

The compressive strength results of ash glass sand mortars have shown that the compressive strength at 7 days is low when compared with the 28 days results, this is related to the longer curing time which gave the opportunity to the ash alkalis to react with the silica to form extra cementitious matrix.

The strength increment from 28 days to 56 days is considered minor, this is due to the continuous decreasing in the free CaO content in the mix and hence the parallel decrease in the pH of the mixture which is considered an important factor that controls the rate and intensity of the ash-alkalis-silica reaction.

The compressive strength results for mortars made of S1 ash mixed with different ratios of ground tuff are summarized in table (11). The results show an ascending trend for S1 ash-tuff when mixing ratio is (1:1). The compressive strength results of S1-tuff mortars have shown higher strength than S1- glass sand mixtures. This is an expected result due to relatively high concentrations of the pozzolanic part (Al_2O_3, Fe_2O_3 and SiO_2 in the tuff sample which reacts with the alkaline part of the used ash. Such a reaction produces a self-cementing material that gains strength gradually with increasing curing time.

Table. 11.Compressive strength of S1 ash-Tuff mortars.

Mix designation	Tuff sand (g)	Ash type	Ash Wt(g)	Density g/cm^3	7 days strength kg/cm^2	28 days strength kg/cm^2	56 days strength kg/cm^2
S1-T-200	500	S1	1000	1.85	19	57	63
S1-T-200	500	S1	1000	1.86	20.5	58	62.5
S1-T-200	500	S1	1000	1.85	18	59.3	61
S1-T-100	500	S1	500	1.87	21.2	60.5	69.4
S1-T-100	500	S1	500	1.86	22	59.2	72.1
S1-T-100	500	S1	500	1.85	24.1	63	71

4.5. *Comparison between Ash as a Mortar and Plaster*

The ancient masonry and plaster mortars used in Al-Shawbak castle are very weak, sometimes friable even under dry conditions. This is revealed from the low compressive strength results using the Point Load Strength Index method Table (1). The tested samples showed high absorption values due to their high porosity. The high porosity may be a result of dissolution of gypsum and or bassinite through long term chemical weathering.

The ancient mortar is composed mainly of calcium oxide with minor gypsum and quartz. Bassanite crystals have appeared in some samples in small amounts as revealed by X-ray diffraction analysis. Poor bonding in the tested mortar and plaster samples was reflected from disintegration when soaked in water. The total dissolved salts (TDS) for the disintegrated samples have indicated that the TDS value is ranging from 112 mg/L as in M1 sample to very high value of 12250 mg/L in the M6 sample.

The mineralogical and chemical composition of the tested ancient plaster and masonry have indicated that calcined mortars was used (direct combustion of carbonaceous rocks in the vicinity of the castle). Gypsum was added to calcium oxide and mixed with water to produce the mortars.

The low strength of these mortars indicates that these mortars were not used as a bonding agent between the built stone blocks. The masonry mortar was used to level the top of the irregular surfaces of hard limestone and silicified limestone blocks.

Weathering and erosion of the mortar due to wet and dry climates made the built blocks unstable under dead loads specially when external disturbances resulted by strong winds or vibrations caused by the earthquakes.

The bituminous limestone ash mortar is similar in color and composition to the tested ancient mortar and plasters samples, but it has higher compressive strength and resistively to disintegration under saturation conditions. Therefore, the ash mortars could be used to rehabilitate parts of the archeological features at AL-Shoubak castle.

El-Lajjun bituminous limestone ash has revealed a self cementitious behavior for the various prepared samples. The free lime content of fly ash contributes to self-hardening (Yudbir and Hunjo, 1991). The ash sample S1 is essentially composed of CaO. The alkali content which is presented by CaO, and the pozzolanic content is presented by (SiO_2 +Al_2O_3+ Fe_2O_3), and the variable content of SO_3 was found in both the ash sample and OPC raw material. The strength buildup in all the ash samples is related to the setting reactions of lime (CaO) with the pozzolanic constituents to produce calcium silicate hydrate (CSH) and calcium aluminates hydrate (CAH). High pH solution due to CaO hydration is highly reactive with amorphous Al-Si rich phases at normal room temperature.

The hydration products of the S1 as identified by the XRD technique are portlandite, ettringite, calcium silicate hydrate and calcium aluminum hydrate. The reactions are not spontaneous and are time dependent. Curing period of 28 days and more has influenced the compressive strength results. High compressive strength values were obtained with intact samples indicating no disintegration features under fully saturated conditions. All hydrated samples have shown a similar behavior to the hydrated OPC products but with lower compressive strength.

The compressive strength of the S1 mortar is 20.4, 55.2 and 68.3 kg/cm^2 at 7, 28 and 56 days respectively. Ash concrete mixes must be properly cured due to slow strength development, and hence moisture must be retained in the concrete for longer period of time (ACI, 1996).

Portlandite Ca $(OH)_2$ plays an important role in the setting reaction. Portlandite reacts with silicates and aluminum rich phases to form insoluble compounds which contribute to the strength formation (pozzolanic reactions). Excess portlandite reacts with atmospheric CO_2 to precipitate calcium carbonate that helps in strengthening the product after aging (Khoury and Nassir, 1982; and Khoury, 1993).

5. Conclusions

The study shows the suitability of bituminous limestone ash as self cementitious material in rehabilitation works of all archeological monuments in Jordan.

Utilization of ash in remedial works has advantageous characters as color, higher compressive strength and resistance to disintegration compared with old used masonry and plaster mortars in historical places.

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