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An Investigation into the Traditional Method of Production of Omani Sarooj

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دراسة الطريقة التقليدية لإنتاج الصاروج العُماني

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خلاصة : في الماضي كان الصاروج العُماني هو المادة المستخدمة في بناء الحصون والقلاع والأفلاج (وهو نظام الري المستخدم في سلطنة عُمان) وفي أماكن كثيرة من العالم توجد مواد تشبه الصاروج العُماني اشتهرت بقلة نفاذيتها للماء، ومقاومتها لعوامل التعرية المختلفة تدخل كلها تحت التصنيف العلمي «بوزولان» ، ومن أجل هذه الخواص كثر استعمالها في كثير من الإنشاءات المائية ، وبالرغم من توفر الإسمنت البورتلاندي هذه الأيام فقد أنشأت مصانع خاصة لإنتاج مواد شبيهة بالصاروج العُماني عند بناء كثير من السدود المشهورة في العالم .

عند خلط الصاروج مع الإسمنت البورتلاندي أو الجير في وجود الماء ينتج هايدروكسيد الكالسيوم والذي يجب تثبيته داخل الخلطة مما يزيد من قوتها ويقلل من نفاذيتها ويكسبها ديمومة لمدة أطول . وينتج الصاروج العُماني بحرق أنواع معينة من الطين تحتوي على نسبة عالية من أكاسيد السيليكا والألومينا والتي تتفاعل مع الجير المطفأ في الخلطات الصاروجية الإسمنتية منها والجيرية . والبحث الحالي يصف طرق إنتاج واستعمال الصاروج العُماني كما يلقي الضوء على الأبحاث الجارية الآن على خواصه وطرق نتاجه .

ABSTRACT: In the past, sarooj had been used as the basic cementing material with which the Aflaj system (the irrigation system used in Oman) was built. Worldwide, materials like sarooj existed and were known for their good impermeability and long durability. For this reason it was extensively used in hydraulic structures. Even in this century and with the ready availability of Portland cements, special plants were erected to produce materials like sarooj for major dams in the world. In the process of hydration in sarooj-lime mixes or in sarooj-cement mixes, free lime is released which causes distress through the expansion of the mortar if allowed to accumulate. If free lime is stabilized within the structure of the mortar, it imparts additional strength and durability to it. The mortar becomes less permeable to water, which increases its resistance to weathering. The stabilization is possible through the presence of a reactive silica/alumina in the mix so that it reacts with the free lime to form calcium silicates/aluminates. The properties of sarooj depend largely on the type of the raw material and the calcination parameters. This paper describes this material, its method of production and uses, and highlights research currently conducted to improve its properties.

Sarooj has been used for centuries in construction of castles, forts and Aflaj (a system of irrigation used in Oman for distributing water to villages by gravity) due to its cementitious and durability properties. Harsh sarooj was utilized as mortar which was placed between bricks or stones as a binding material whereas fine sarooj was used for plastering. Sarooj has been used with bricks and stones in building castles, forts and houses. Figure 1 shows sarooj used at one of the entrances of Al-Hazim castle. The sarooj has remained for hundreds of years as in Burj Kisra, Al-Rastaq castle, as shown in Fig. 2, and can distinctly be seen when compared with the new cement plaster at the bottom. Sarooj has been used extensively in building the walls and ceilings of Aflaj as shown in Fig. 3. It was also used in building the Aflaj channels to prevent water ingress into the ground, Fig. 4.

The characteristics of sarooj have not been previously researched. Hence, this study was undertaken to investigate the fundamental properties of the Omani sarooj and to find a suitable engineering mechanism for its production.

Traditional Method for the Production of Sarooj

Detailed information about the sarooj were collected. This stage required great efforts in searching for these information through interviews with the Omani old people expert in sarooj, and by conducting several visits to places where sarooj either produced or used. These sources of information can be listed as follows:

1. Interviews with the Omani old people who had wide experience with the sarooj. The aim of these interviews was to identify the correct traditional method that the Omanis used in the past for producing the sarooj.

Figure 1. Use of sarooj in buildings.

Figure 2. Sarooj used in building Kisra tower in Rustaq castle of sarooj in buildings.

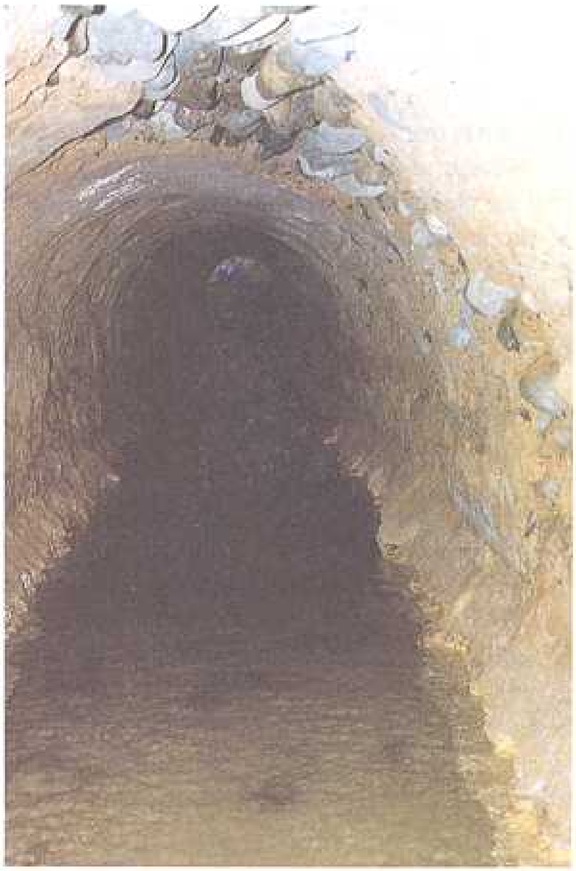

Figure 3. Use of sarooj in Aflaj.

Figure 4. Sarooj used in lining Aflaj channels (Hammam Falaj in Bosher).

2. Interviews with the Officials responsible for the castles and forts in the Ministry of National Heritage and Culture, and the team commissioned by the Ministry for the restoration of castles and forts in Oman.
3. Interviews with the Officials responsible for the Aflaj in the Ministry of Water Resources.
4. Visits to Nakhal Sarooj Factory which is owned by the Ministry of National Heritage and Culture, and Nizwa Sarooj Factory, which is a private property, in order to see the methods in use for producing sarooj at these two factories and compare them with those reported by the Omani old people expert in sarooj.
5. Visits to Al-Rustaq Castle, Al-Hazim Castle and Jabrin Fort in order to study the sarooj used in building and maintaining these castles and forts.
6. Visits to the Aflaj of Al-Maiser, Ain Al-Kisfah, Al-Muhdath, Al-Kamil, Asseeh, Al-Hububiah, Al-Aswad, Al-Hamam, Halban and Daris to see the sarooj used in building and maintaining these Aflaj.

As a result of the extensive investigation aforementioned, the traditional method that the Omanis had used in the past for producing the Omani sarooj was identified as follows:

1. The soil used in producing sarooj was usually brought from farms and lands that were used for agricultural purposes, and perhaps other non-agricultural lands. However, it should be noted that the soil used differs in its clay content and in its chemical and mineralogical composition from one area to another. The soil was sieved in order to remove gravel and other undesirable materials.
2. The sieved soil was mixed thoroughly with water to form "ghailah" (soil paste) and left to cure for one day. This step was repeated for two consecutive days and finally circular disks of soil were made and left to dry. The process of drying the circular disks might take a week.
3. Dry logs of date trees were arranged in three layers. Small openings were left between the logs of trees to allow for air circulation. Dry leaves were placed between logs of date trees to help in the burning process. This arrangement is known as "Mahabba".
4. The prepared soil disks were stacked on the top of the third layer of the date trees. They could reach a height of one meter.
5. A layer of white Wadi stones was placed between the soil disks for the production of "Al-Nourah" which will be mixed with the soil during the burning process and give it its white colour.

Samples of sarooj and the soil from which it was produced were collected during site visits to different regions. Samples were collected from Nakhal factory and Nizwa factory. Soil samples were also collected from Nakhal and Nizwa which represented major sources for the said factories. The objective was to conduct scientific experiments on them in order to study and improve the properties of sarooj and its method of production.

Field Experiment for the Production of Sarooj

After thorough investigations about the method for production of sarooj, it was clear that scientific experiments should be conducted on sarooj samples produced according to the traditional method used in the past. Hence, with the cooperation of the Ministry of Heritage and Culture, a special Mahabba was set up in which a selected soil was used and the traditional method of production of sarooj was followed. The objective of setting up this Mahabba was to get deeper insight in the process of making sarooj and to estimate the required energy for burning.

At the beginning of the project, it was essential to locate a suitable area from which the soil would be brought. According to the advice of old sarooj experts in selecting soils for sarooj production, Wadi Al-Mawal was selected as the most suitable area, depending only on visual identification of the soil. Enough quantities of soil (about 30 tons) were brought from Wadi Al Mawal to the site of the factory in Nakhal. The method followed for the production of sarooj was as follows (Hago et al. 1995):

1. One tanker of water (650 gallons) was added to the soil, mixed thoroughly, and was left over night. This process was repeated for two consecutive days, then circular disks were made out of the soil paste (each circular disk had an average diameter of 15 cm and thickness of 5 cm) and were left to dry for about ten days.
2. The Mahabba was erected from logs of date trees arranged in three layers (each log had an average diameter of 0.28m and a length of 6m). In average, each layer contained 20 logs.
3. The prepared soil disks were packed on the top of the third layer of the date trees. The height of these disks reached about 1 m, as shown in Fig. 5. A layer of white wadi stones was placed between the soil disks.

Figure 5. Arrangement of "Mahabba" for sarooj production.

4. After completing all the preparation of the Mahabba, the burning process was started (Fig. 5). Large amounts of fumes were produced in the process and with time they disappeared. The Mahabba was visited after four days from burning, no traces of fire could be seen, but the burned soil disks were still hot. The logs of the date trees were completely destroyed by the fire, turning them into ashes. Water was then sprayed over the Mahabba, in order to extinguish any fire that could not be detected.
5. As suggested by the foreman of the site, the sarooj was left at the site for a period of two months, before it was used. It was believed that this period would give the sarooj more strength.

This field experiment used the same traditional method for the production of sarooj. Samples were collected and were taken to the laboratory for testing.

Disadvantages of Sarooj

Properties of sarooj are influenced by the properties of the soil from which it is made. Since no scientific criteria were followed in the selection of the soil, the properties can not be standardized. For this reason, wide scatter and differences exist in sarooj produced in different areas of the country. Nevertheless, common features underlying the shortcomings in the different species can be summarized in the following points:

* Low strength
* Reduced rate of gain of strength
* Increased drying shrinkage
* Increased water requirement
* Slow setting and hardening.

Efforts to Improve the Properties of Sarooj

An extensive research started three years ago in the laboratories of Sultan Qaboos University with the objective of studying and improving the properties of Omani sarooj. The need for the research arose from the well established fact that as an artificial pozzolan, sarooj provides the following advantages over normal Portland cements (Spence et al. 1983):

* Improved workability
* Low heat of hydration and thermal shrinkage
* Greater imperviousness to water
* Higher resistance to sulphate attack in foundations and sea water
* Reduced alkali-aggregate reaction
* Reduced chloride penetration
* Low cost in construction

TABLE 1

Locations of Tested Samples.

SAMPLE DESIGNATION	LOCATION	DESCRIPTION
SN8	NAKHAL	Nakhal factory
SZC1	NIZWA	Nizwa factory
WMSC1	WADI AL-MAWAL	Experimental Mahabba
HAMRA1	AL-HAMRA	Laboratory production

The scope of the test program included testing samples collected from various parts of the country. Up to now, clay soil has been collected from nineteen sites, but due to space limitation, only four samples will be presented here. The samples were subjected to the following tests:

* Moisture content
* Specific gravity
* Liquid limit
* Plastic limit
* Permeability test
* Clay content
* Chemical test
* X-ray diffraction (XRD)
* Differential thermal analysis (DTA)
* Consistency test
* Setting times
* Compressive strength

The samples are designated by SN8, SZC1, WMSC1, and HAMRA1. The locations from which these samples were collected and their description are given in Table 1. The sample designated HAMRA1 was prepared in the laboratory, using soil from Al-Hamra. Parameters for sarooj production for this sample were determined by pre-testing the soil (chemical analysis, XRD, DTA), determining the burning parameters by DTA curves and burning in an electric oven in the laboratory.

Mineralogical Investigation

Mineralogy is a controlling factor determining the characteristics of the particles in a soil. It is related to soil properties in much the same way the composition and the structure of cement and aggregates are to concrete. The common clay minerals are montmorillonite (smectite group minerals), illite (mica group minerals), chlorite, palygorskite and kaolinite. In general, montmorillonites and palygorskites are associated with the most plastic clays, illites are intermediate and the kaolinites confer the least plastic properties.

An investigation was carried out to determine qualitatively the mineralogical composition of the soil using the X-ray diffraction (XRD). The X-ray diffractometer used in this investigation was the PW1700 Automated Powder Diffractometer. The generator settings were 40 kV and 40 mA and the wavelength was equal to 1.5418A°. The procedures used for the preparation of samples were as suggested by Wittig and Allardice (1986). The data presented by Brown and Brindley (1980), were used as a guide for the identification of clay and non-clay minerals. A randomly oriented sample and three oriented clay samples were tested.

A randomly oriented sample was tested in order to obtain a complete set of diffraction spacings of clay and non-clay minerals present in the sample. The results indicated the presence of quartz, calcite and dolomite as well as illite, chlorite, montmorillonite and palygorskite clay minerals. The most intense reflections were shown by calcite followed by quartz and dolomite in descending order. The clay minerals were first identified from oriented clay samples and then peaks corresponding to these minerals on the randomly oriented sample were identified. The results indicate the presence of illite, chlorite, montmorillonite and palygorskite.

Oriented clay samples (approximately less than 2 μm) were prepared and tested in three forms; untreated, treated with ethylene glycol and heated to 720 °C for two hours. Sample XRD patterns are shown in Fig.6. The results showed the presence of illite, chlorite, montmorillonite and palygorskite. However, from the intensity of the reflections of the minerals, it appeared that these minerals were present in relatively small quantities as compared with non-clay minerals.

The results of the other geotechnical tests are shown in Table 2. Mineralogical composition, particle size and size distribution, fabric and pore fluid characteristics all influence permeability. The typical values reported in the literature for silty clay and clay natural soils is about 10^{-3} to 10^{-5} cm/sec and less than 10^{-6} cm/sec respectively. For clay minerals, the permeability are in the order: montmorillonite < palygorskite < illite < kaolinite. Based on the permeability values; all samples were classified as clayey silt.

TABLE 2

Summary of geotechnical properties of raw materials and sarooj from sites in Oman.

Site	Sample	Description	W (%)	γ (kN/m³)	W_L (%)	W_P (%)	I_P (%)	Silt (%)	Clay (< 2μm) (%)	A	G_s	K (cm/sec)	USC	BS 5930 (1981)
Nakhal	RN	Brownish clay	2.2	-	24	19	5	-	-	-	2.7	-	ML	ML
	SN	light brown sarooj	2.4	13.2		-	-	94	5	-	2.7	$2X10^{-4}$	-	-
Nizwa	RZ	Light brown clay	4.1	13.9	28	22	6	68	9	0.7	2.7	$48X10^{-4}$	CL-ML	ML
	SZ	Dark brown sarooj	1.6	13.2	31	25	6	64	15	0.4	2.7	-	ML	ML
Wadi Al-Mawil	RWM	Light brown clay	0.9	13.0	22	14	8	66	26	0.3	2.7	$10X10^{-4}$	CL	CL
	SWM	Lihgt brown sarooj	3.8	11.4	38	29	9	91	7	1.28	2.7	$28X10^{-4}$	CL	CL
Al-Hamra	RH	Red clay	2.5	13.7	34	20	14	51	40	0.4	2.7	$4.26X10^{-4}$	CL	CL

R = raw material, S = sarooj, W = natural water content, (= unit weight, WL = liquid limit, WP = plastic limit, IP = plasticity index, A = activity, Gs = specific gravity, k = permeability, USC = Unified Soil Classification.

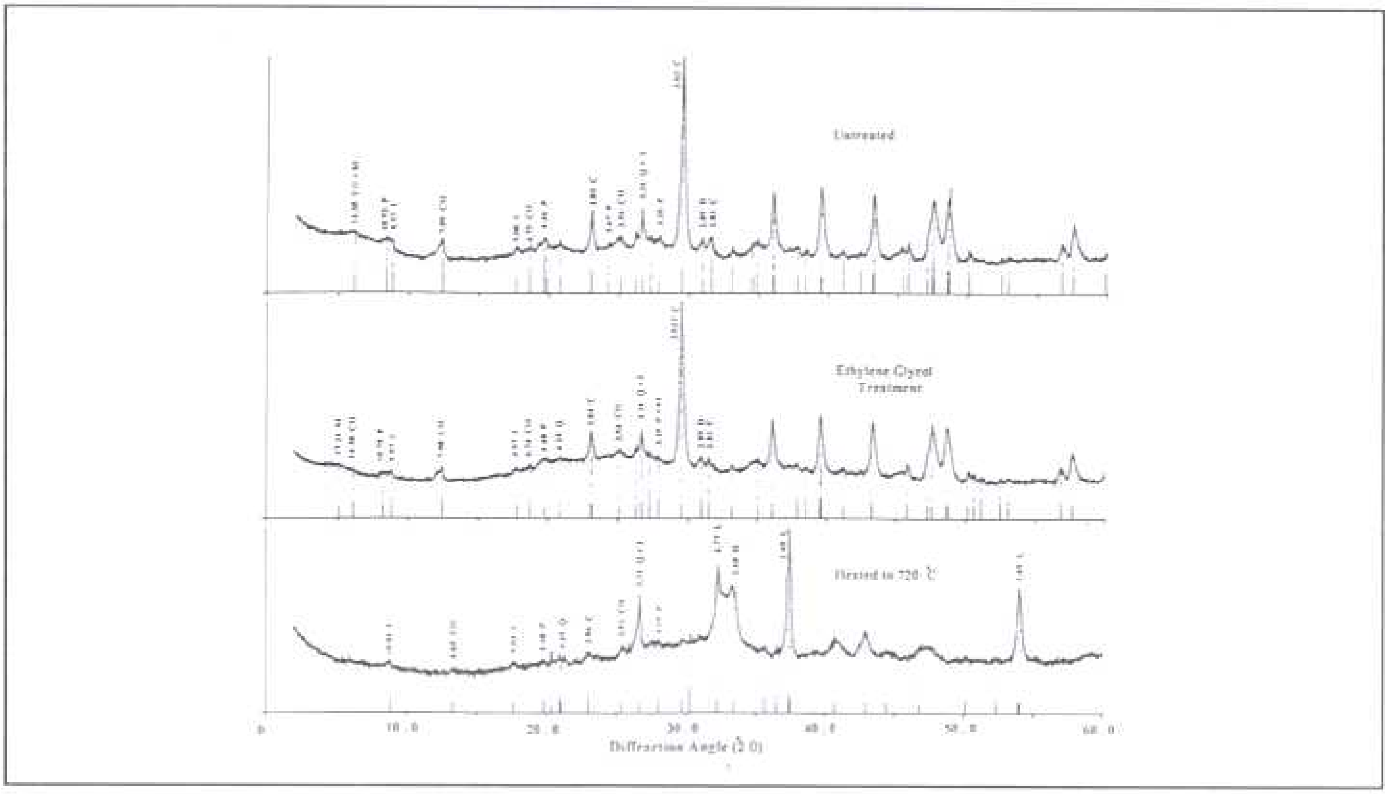

Figure 6. X-ray diffraction patterns of clay size fraction with different treatments for a sample from Wadi Al-Mawal.

TABLE 3

Chemical composition (in %) of samples tested.

COMPOUND	SN8	SZC1	WMSC1	HAMRA
S_iO_2	15.99	32.16	26.21	42.7
Al_2O_3	4.13	7.52	8.67	20.11
Fe_2O_3	2.47	2.46	0.98	7.61
CaO	34.45	26.84	36.58	14.16
MgO	10.2	5.40	5.42	1.76
SO_3	0.6	1.40	1.87	0.88
K_2O	0.85	-	-	1.22
Na_2O	0.75	-	-	0.91
CL	0.43	-	-	0.05
LOI	30.12	23.37	19.63	9.5

Chemical Analysis

As far as the composition is concerned, the results of the chemical composition of the four analyses are given in Table 3. The chemical analysis was done in accordance with the Omani Standard OS25 (1979). As it can be seen, the amount of silica and alumina are higher for the samples obtained from Wadi Al Mawal and Al-Hamra. The Nizwa sample contains a higher percentage of silica than that of the Nakhal sarooj. Potentially, one expects sarooj made in Nizwa to have higher reactivity than those made from Nakhal soils. As the presence of the silica and alumina are not the only controlling factors, final conclusion can not be drawn at this stage, other factors like temperature, duration of burning and grinding (surface area) will be discussed in subsequent publications. But these results can be taken as an indication for the potential reactivity of the sarooj. The chemical analysis also gives the results of the loss on ignition. When viewed with the percentage of CaO and MgO contents, it can be clearly seen that the high percentage of loss in weight comes from the burning of the calcium and magnesium carbonates. As it had been shown by the results of the X-ray diffraction analysis in the previous section, the carbonate content was very high in the first three samples. The lime produced in this way requires an additional amount of water to hydrate. As it can be seen from Table 3, the Nakhal samples contain higher percentages of lime and magnesia which resulted in higher loss on ignition as well. It can be said that the water requirement for such a sarooj will be higher, which can adversely affect the strength characteristics of the final product. However, it is always iterated that the chemical analysis alone is not sufficient to guarantee that the soil can produce a good sarooj. It can only provide an indication of the potential quality of the sarooj when other factors associated with calcination are judiciously adjusted, which can be certified by physical tests.

Physical Analysis

Physical tests performed on the samples gave the results shown in Table 4. Physical tests were done in accordance with Omani Standard OS26 ,1981. Mortar mixes were prepared and were tested at ages of 7, 14, and 28 days. Consistency tests were made on pure sarooj pastes, while strength tests were done on mortar mixes having the following proprtions for all samples:

Sarooj=1: Lime=0.333: Sand=0.667: Coarse Aggregate=0.0:Water=0.5

Results for the first three samples were close to each other. Of the two samples from the factories, the Nakhal sarooj appears to be better than that of Nizwa only at early ages, but at a later age, the Nizwa sarooj shows a better behavior. This effect is also clear from the consistency and setting times and is confirmed by the strength tests. The sample from

TABLE 4

Comparison between different types of Sarooj.

Designation	SN8	SZC1	WMSCI	HAMRA
Location	NAKHAL	NIZWA	WADI ALMAWAL	AL-HAMRA
Density (Kg/m^3)	1958	1835	2110	1770
Consistency %	72	38	37	50
Slump (mm)	70	55	30	50
Setting time (Hour)	8.75	6.23	10.5	3.25
7-day Strength (N/mm^2)	0.55	0.43	1.17	4.0
14-day Strength (N/mm^2)	0.80	0.84	1.39	7.5
28-day Strength (N/mm^2)	0.94	1.54	2.04	8.39

Wadi Al-Mawal gives results stightly better than the previous two samples, but still on the low side. The effect of the soil properties and preparation procedure can clearly be seen in Al-Hamra sample. The strength of this sample is at least four times higher than the other samples.

Conclusions

1. Soil properties have a major effect on the qualities of sarooj produced. Soil should contain high percentage of silica and alumina of more than 62%.
2. The temperature of burning controls the reactivity of sarooj, as it causes some changes in the structure of the calcined soil. For a good sarooj, only a limited structural change is required.
3. The duration of burning affects the setting and hardening properties of the sarooj. At the optimum temperature, longer duration of burning produces shorter setting times. For the soils tested here, the duration was controlled by a fixed rate of heat supply. An estimated heat requirement was on average about 5579 MJ/ton of soil.

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