Engineering Journal of University of Qatar , Vol. 10, 1997, p. 81 - 91

PROPERTIES OF THE OMANI SAROOJ

Abdel Wahid Hago and Amer Al-Rawas
Lecturers, Dept. of Civil Engineering, Sultan Qaboos University
P.O. Box 33, Al-Khod 123, Sultanate of Oman.

ABSTRACT

The fundamental properties of the Omani sarooj have been studied. Sarooj samples were collected from different sites to assess their pozzolanic activity. A laboratory testing program covering chemical and physical properties (consistency, setting times and compressive strength) were carried out. The effect of burning at different temperatures and durations on strength development was studied. The properties of sarooj were found to be dependent on the type of the clay, chemical composition, temperature and duration of burning. The controlling factors were viewed simultaneously in analyzing the test results. The optimum temperature that achieved the maximum compressive strength was found to be between 700°C and 800°C. At the optimum temperature, longer duration of burning produced shorter setting times.

Keywords: Pozzolan, Omani sarooj, Setting time, Compressive strength.

INTRODUCTION

In the past, when today's known cement was not available in the Middle East, the Omani people used to produce a building material, known locally as Sarooj. Sarooj is a hydraulic binder used primarily in the construction of hydraulic structures (such as Falajs) and military defensive structures (such as forts and castles). The Falajs are massive hydraulic tunnels and channels, mainly horizontal in layout, used to collect underground water from inside the mountains, and deliver it through long distances for irrigation purposes. In some cases, the length of the underground tunnel can reach up to 15 km, while the conveying channel can sometimes be up to 20 km. The need to preserve the highly precious and costly collected water caused them to invent the Sarooj. The material was produced by burning special types of clays in kilns using date trees as a fuel. No recorded information has been found about this material, though extensively used nowadays by different authorities in Oman. This paper describes this material, and the laboratory tests conducted by the authors to determine some of its properties.

As a Pozzolanic material, the reactivity of sarooj depends on the quantity of the reactive silica and alumina available. They are reactive only when they are in an amorphous form. They react with lime forming calcium silicates and aluminates hydrates to which is attributed the binding nature of the sarooj. The amorphous products have a high surface energy and chemical reactivity and in a way similar to colloidal silica can react with lime and water to form calcium silicate hydrates and calcium aluminate hydrates of the type found in hydrated Portland cement and hydrated high alumina cements respectively.

Therefore it appears desirable to produce the greatest possible amount of amorphous silica and alumina with corresponding maximum activity when obtaining artificial pozzolanas like sarooj from clays.

According to the Indian Standard (1,2) for good pozzolan, the CaO content should not be greater than 10%, and additionally, the pozzolan should contain a total silica and alumina content greater than 50%. For high reactivity, the silica should be greater than 40%, alumina greater than 30%, iron oxide 20%, magnesia plus SO_3 less than 3% and loss on ignition less than 12%.

Rio and Celani (3) have studied the amount of lime fixed by pozzolanas and put the value at 15 - 20% by weight. They regarded a silica /alumina ratio of 6 or more to be necessary for a good pozzolana, showed the advantage of fine grinding, and preferred the use of a 1 : 3.5 lime to pozzolana mixtures. In general, it can be expected that a clay is a potentially good sarooj if it has a high silica content and can be dehydroxylated and disordered at a temperature sufficiently below a recrystallisation temperature for practical preparation.

EXPERIMENTAL

Sarooj samples were collected from different sites. The soil used in the production of these samples was collected from very shallow depth about 0.2 m from the ground surface. The mineralogical composition of the raw soil was studied using X-ray diffraction. The results were interpreted for the identification of clay minerals (4). Chemical analysis was carried out on sarooj samples to determine the percentages of silica, alumina, iron oxides, loss on ignition and other compounds. The consistency, setting times, and compressive strength tests were carried out on sarooj samples burned at different temperatures (600°C to 800°C) and durations (30 and 60 minutes). The compressive strength development was measured for 7 days, 14 days and 28 days and is presented in Figs. 1 and 2.

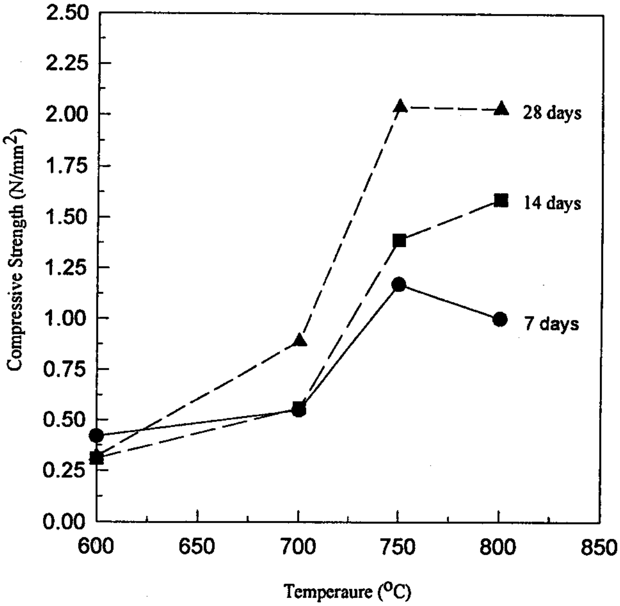

Fig. 1. Variation of compressive strength with temperature for 30 min. duration

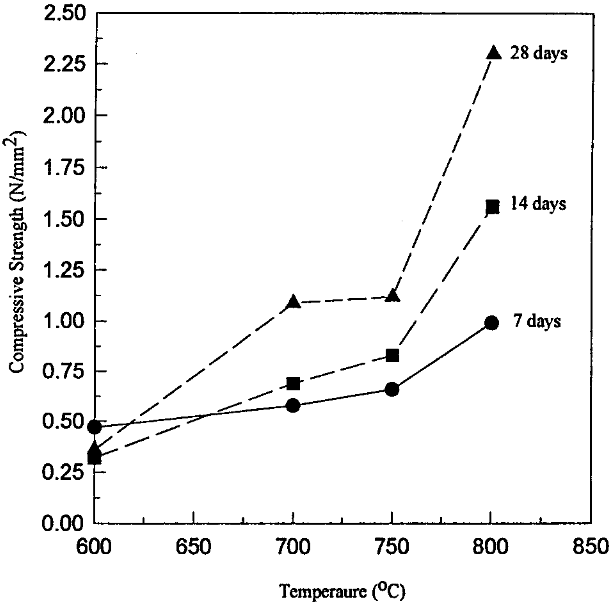

Fig. 2. Variation of compressive strength with temperature for 60 min. duration

RESULTS AND DISCUSSION

The following are the results obtained from the tests performed on sarooj made from three different sources and were prepared in different ways. They were classified according to their source and method of production in the following way : The sample designated SN was obtained from Nakhal and was manufactured by the Ministry of National Heritage and Culture in their factory at Nakhal. The sample designated SZ was obtained from Nizwa and was manufactured by the Nizwa factory (private). Two samples designated WMS1 and WMS2 were made from soils obtained from Wadi Al Mawil: WMS1 sample was manufactured in Nakhal factory, while WMS2 sample was prepared in the laboratories of the College of Engineering of Sultan Qaboos University.

Samples SN, SZ and WMS1 were prepared as follows:

1. The soil was brought from farms and lands that were used for agricultural purposes. Then, it was sieved to remove gravels. The sieved soil was mixed thoroughly with water and circular disks of soil were made and left to dry.

2. Dry logs of date trees were arranged in three layers and dry leaves were placed between the logs to help in the burning process. This arrangement is known as *Mahabba*.

3. The dry soil disks were placed on the top of the third layer of the date trees and then the burning process started. Then water was sprayed after four days to ensure that the fire was extinguished. Then the burnt soil disks were broken and crushed into powder.

Sample WMS2 was prepared in a different way. Soil was collected and fired directly in an oven at 600°C for 30 minutes. Then it was used directly for testing. It should be noted that the soil used differs in its clay content and chemical and mineralogical composition from one area to the other.

The chemical tests were performed in accordance with the Omanian Standards (5). The consistency, setting times and compressive strength tests were performed in accordance with the Omanian Standards (6). Table 1 gives the results of the chemical analysis of the four soil samples. As can be seen, the amount of silica and alumina are higher for the samples obtained from Nizwa and Wadi Al Mawil. 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, and other factors like temperature and duration of burning will be discussed in the subsequent sections. But these chemical results can be taken as an indication for the potential reactivity of the sarooj.

Table 1. Chemical Composition (in %) of Samples Tested

COMPOUND	SN	SZ	WMS1	WMS2
SiO_2	15.99	32.16	26.21	33.51
Al_2O_3	4.13	7.52	8.67	7.12
Fe_2O_3	2.47	2.46	0.98	2.46
CaO	34.45	26.84	36.58	22.74
MgO	10.20	5.40	5.42	8.43
SO_3	0.60	1.40	1.87	1.59
K_2O	0.85	-	-	-
Na_2O	0.75	-	-	-
CL	0.43	-	-	-
LOI	30.12	23.37	19.63	23.59

The chemical analysis also gives the results of the loss on ignition (LOI). 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 had been shown by an X-ray diffraction analysis for the same samples (7), the carbonate content was very high in the soil. The lime produced in this way requires an additional amount of water to hydrate. As can be seen from Table 1, the Nakhal samples contain higher percentages of lime and magnesia and a higher loss on ignition as well. It can be concluded that the water requirement for such a sarooj will be higher, which can adversely affect the strength characteristics of the final product.

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. Such effects are the object of the study described below.

The pozzolanic activity results from the reaction between the reactive clay and lime ($Ca(OH)_2$)in the presence of water to form calcium silicate and calcium aluminate or calcium aluminium silicate. The reaction of lime is a function of the temperature and time of firing; of the two variables, temperature has the greatest effect on reactivity. The reactivity of lime with sarooj depends on the nature of the amorphous material which is in turn depends on the minerals making up the raw clay. Hence, an optimum calcination temperature exists for each soil which will produce maximum compressive strength from the lime-pozzolanic activity point of view and that this temperature is in the range between the dehydroxylation and crystallization temperatures (8). The reason is that at low temperatures the clay structure is still intact while at higher temperatures beyond the optimum recrystallization begins and both temperatures can reduce the pozzolanic activity.

Table 2 gives the results of the physical tests done on sarooj samples which were from the same samples shown in Table 1. Here the objective was to study the effect of the temperature of calcination and the duration of burning for the clays obtained from Wadi Al Mawil. As has been stated above, that, potentially Wadi Al Mawil soils are expected to produce good sarooj if burnt correctly. The temperature of burning was varied from 600°C to 800°C at intervals of 50°C (i.e. 600, 650,700,750 and 800°C). For most clays, recrystallization starts at temperatures above 800°C (9,2). Mortar mixes were prepared from the sarooj obtained by burning the soil to these temperatures. Two time durations were considered at each temperature, 30 minutes and 60 minutes. The samples were designated WMS3, WMS4, WMS5, WMS6, WMS7, WMS8, WMS9, WMS0. All mixes had the following proportions:

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

Table 2 shows the effect of temperature and duration of burning on the reactivity of sarooj. As can be seen that with the exception of WMS3 and WMS4, there is a gain in strength with time, although it may be slow in some samples. The deterioration in strength of WMS3 and WMS4 indicates that they still acted as a normal clay, and were not sufficiently activated by heat. The burning temperature for these two samples was 600°C for 30 and 60 minutes. This shows the effect of inadequate burning. The rest of the samples show an appreciable increase in strength with time. Biggest increase was attained by WMS7, WMS8, WMS9 and WMS0, which were burnt at 750°C and 800°C. While both of the first two samples showed an increase in strength, WMS8, which was burnt for 60 minutes gave a lower strength than WMS7 which was burnt for 30 minutes. WMS9 (burnt at 800°C for 30 minutes) showed a similar strength at 28 days. Even after 28 days, it just reached the strength attained by WMS7. Apparently, the gain in its strength over the period of 28 days did not match the difference in energy expended beyond 750°C. This also shows the importance of the duration of burning. It appears that for this

Table 2. Results of Physical Characteristics Tests

Sample No.	Temp/. Time °C/min	Density kgf/m^3	Slump mm	Compressive Strength in N/mm^2			Consistency (%)	Setting Times in Minutes	
				7d	14d	28d		Initial	Final
WMS3	600/30	1875	collapse	0.42	0.31	0.32	33	525	2805
WMS4	600/60	2040	200	0.47	0.32	0.36	35	485	3245
WMS5	700/30	1875	125	0.55	0.56	0.89	45	450	-
WMS6	700/60	2040	85	0.58	0.69	1.09	62	625	3980
WMS7	750/30	2110	30	1.17	1.39	2.04	37	630	1700
WMS8	750/60	2114	40	0.66	0.83	1.12	35	338	1445
WMS9	800/30	2060	40	1.00	1.59	2.03	41	500	3075
WMS0	800/60	2020	60	0.99	1.56	2.30	56	300	1248

Table 3. Comparison between Different Types Of Sarooj

Sample No.	Temp/. Time °C/min	Density kgf/m^3	Slump mm	Compressive Strength in N/mm^2			Consis-tency (%)	Setting Times in Minutes	
				7d	14d	28d		Initial	Final
WMS7	750/30	2110	30	1.17	1.39	2.04	37	630	1700
SN	Nakhal	1958	70	0.55	0.80	0.94	72	525	-
SZ	Nizwa	1835	55	0.43	0.84	1.54	38	374	-
WMS1	Mahaba	1910	48	0.26	0.47	0.57	48	689	-

specific soil, the optimum temperature of burning should be 750°C and the duration of burning should be 30 minutes. It can be seen that the maximum activity is produced by heating at 750°C for about 30 minutes. A longer duration only affects the setting time, making it shorter. At lower temperatures there is less activity produced (WMS3 and WMS4), and at higher temperatures activity falls off after reaching a maximum in short time (WMS0). As all these temperatures are above the dehydroxylation temperature, the increase in activity with temperatures up to 750°C is likely to be due to a disordering of the clay structure. Above 800°C recrystallisation destroys activity. Accordingly, to obtain a good sarooj the clay must be heated to a temperature between that required to remove lattice water and collapse the structure and that where recrystallisation begins.

In Table 3, sarooj produced in the laboratory with the optimum temperature of 750°C and duration of 30 minutes (WMS7) was compared with Nakhal sarooj (SN), Nizwa sarooj (SZ), a sarooj made specially for the university by Nakhal factory from Wadi Al Mawil soils (WMS1). The results indicated that the sarooj produced under controlled conditions in the laboratory (WMS7) achieved the maximum strength. The effect of the properties of the raw soil is clearly seen by comparing Nizwa (SZ) and Nakhal (SN) samples. Although they are close to each other, 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 shows that, although the Nizwa sarooj is less reactive (shown by the consistency and setting times and confirmed by the 7 day strength) than the Nakhal sarooj, it is only slow in attaining strength, but ultimately reaches the same level of strength or higher than that of Nakhal sarooj. This effect may be attributed to the burning parameters, which will be further investigated.

CONCLUSIONS

1. The properties of sarooj are dependent on the type of the clay used, influenced by its chemical composition, temperature and duration of burning.

2. The temperature of burning has the major effect, as it causes great changes in the structure of the calcined soil. For a good sarooj, only a limited structural change is required.

3. The optimum temperature required to produce good physical properties varies from one type of soil to the other, but for most of the clays tested here, it might be between 700°C and 800°C.

4. The duration of burning affects the 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 about 5579 MJ/ton of soil.

5. Considering the limited data presented in this paper, further investigation on sarooj samples from other sites in Oman is required in order to obtain conclusive results, which is currently undertaken.

REFERENCES

1. **Varshney, R.S., 1982.** Concrete Technology. Oxford, IBH Company.

2. **Spence, R.J.S. and Cook, D.J., 1983.** Building Materials in Developing Countries. John Wiley & Sons.

3. **Forrester, J.A., 1975.** Burnt Clay Pozzolanas. Proceedings of the Meeting on Small Scale Manufacture of Cement Materials. Intermed Technol. Publ., London, pp. 53-59.

4. **Brown, G. and Brindley, G.W., 1980.** X-ray Diffraction Procedures for Clay Minerals Identification. In Brindley, G.W., Brown G. (eds.): pp. 305-359. Clay Structures of Clay Minerals and Their X-Ray Identification. Mineralogical Society, London.

5. **Omanian Standard 25, 1979.** Methods of Testing Cement - Chemical Tests. Ministry of Commerce and Industry, Directorate General for Specifications and Measurements, Muscat, Sultanate of Oman.

6. **Omanian Standard 26, 1981.** Methods of Testing Cement - Physical Tests. Ministry of Commerce and Industry, Directorate General for Specifications and Measurements, Muscat, Sultanate of Oman.

7. **Hago, A.W., Al-Rawas, A.A. and Al-Harthy, A.S., 1995.** The Omani Sarooj. Unpublished Report. Department of Civil Engineering, Sultan Qaboos University, Sultanate of Oman.

8. **He, C., Makovicky, E. and Osbaeck, B., 1994.** Thermal Stability and Pozzolanic Activity of Calcined Kaolin. Applied Clay Science, Vol. 9, pp. 165-187.