Potential Use of Locally and Traditionally Produced Bending Construction Material

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Abstract. The use of various mineral admixtures, natural or artificial pozzolan as well as any alternative construction material that could partially or fully replace the conventional Portland cement concrete/mortar with quite similar or even improved performances is receiving nowadays more attention and highly encouraging practice. Back to nature and to ancient and traditional materials that are locally available is not a new vision but it is a strategy largely accepted and adopted to lower the environmental impact of construction sector. Using some locally available materials such as natural pozzolana may require an additional activation process such a calcination at relatively high temperature or a chemical activation by some known activators. Sarooj (SRJ) is a popular name given to a locally produced traditional or artificial pozzolana that has been extensively used as traditional construction material in several countries such Oman and some neighbouring countries like Iran. In modern days however; the usage of Sarooj material is limited to the plastering work and restoration of ancient castles and forts. Sarooj has large variety of chemical composition depending on the location from where it has been extracted and thus, the reactivity and the resulted mechanical performances vary to a large extent. This paper investigates the chemical and physical properties of a sample of Sarooj traditionally prepared and extracted from Wadi AL-Mawal region. The chemical analysis and XRD results indicate a great reactivity potential of this material if properly treated and designed. The traditional heat treatment applied seems to be not the appropriate way to reach the full activation of this clayey material. Although traditionally designed, the results of thermal conductivity showed a net decrease compared to normal Portland cement mortar. Combining the use of a locally produced material with an enhanced engineering properties could further promote sustainability in construction industry.

1. Introduction

For long time, the Omani people used locally available materials that are manufactured using a traditional process. One of these commonly used material is named “Sarooj” and in other neighboring countries such as India is called “Surkhi”. For decades even centuries, Sarooj was largely used as a primary material for constructing family houses, castles, forts and defensive buildings, and ancient water channels used as irrigation system called Aflaj. At present and with the rapid development of modern Portland cement and concrete, the use of Sarooj is mostly limited to restorations works of ancient forts and castles. Sarooj could be described as a clayey material with a chemical composition quite similar to Portland cement. Its main
constituents are silica, alumina and lime. This chemical composition of Sarooj gave it a potential use as a hydraulic binder [1-4]. However, for Sarooj to be considered as cementation material it should react with water and form a solid hydrate product while to be considered as a pozzolanic material it should be able to react with lime to form calcium silicates hydrates or aluminates as per ASTM C618. Indeed, the use of different types of pozzolana (natural or artificial) is well recognized and worldwide spread in nowadays construction sector such as dams, bridges, buildings, marine constructions, and even small family [5-7].

Sarooj, as a final product is produced by burning clay that has adequate content of silica, lime and alumina as discussed above. Traditionally, Sarooj material is produced by a large amount of energy most of which is wasted by blowing winds, this system of burning is thermally inefficient [2].

The traditional Omani method of producing Sarooj consists of extracting the raw material from agricultural farms and lands. The collected sarooj material is sieved to remove coarse size particles and any other unwanted substances to obtain a homogenous and certain particle size distribution. The soil is then mixed with water and left to stand for one to three day to absorb as much as possible water to reach its full potential of water absorption. Dry logs from date trees are arranged in three layers, dry leaves are placed between the logs of dates to help boosting the burning process. The soil material is packed in a form of bed on the top of the third layer and the fire is set in the package. The package is to be visited after four days from burning where the burning process has completed and the logs of the date trees are completely turned into ashes and automixed with the burned soil. The burned soil (Sarooj) must be left at the site for a period of about two months before it can be collected, ground and used [2, 3].

Hago and Al Rawas [1, 3-4] carried out an experimental study on different types of sarooj traditionally prepared and burned. Their investigation revealed that Sarooj has approximately 43% of total silica, alumina and iron oxides. The authors concluded that the chemical composition, calcination temperature and duration are the major parameters affecting the compressive strength of the sarooj mortar. The overall performances were strongly related to chemical compounds and hence to the location from where the soil was extracted.

The main objective of this research is to investigate the potential of using Sarooj in mortar production with or without the addition of other components. The chemical and physical properties of Sarooj has to be investigated along with mechanism of reaction of Sarooj when used as a single component or combined in binary or ternary systems. Possible thermal or chemical activation of Sarooj is also to be investigated.

2. Methodology

2.1. Materials and mix design

Sarooj material used in this study was extracted from a town named Wadi Al Mawal located on the west of Muscat, the capital of Sultanate of Oman. The collected sarooj material traditionally produced by burning raw soil and grinding it (figure. 1) was subjected to series of experimental testing to determine chemical composition and physical properties. First, the material was subjected to screening and categorization to separate the particles into various family sizes of 600-450 μm, 450-300 μm, 300-150 μm, 150-75 μm and passing 75 μm. The latest was used as a partial replacement of Portland cement in mortar production while the coarser particles were used as a natural sand replacement. The chemical composition of sarooj is given in table 1. The specific gravity of sarooj is 2.77 and its grain size distribution is shown in figure 2. Sarooj was introduced in the mix of lime-cement mortar as a partial replacement of Portland cement to examine its ability to react with the presence of a normal Portland cement and assess its cementing contribution. Three replacement levels of 10, 20 and 50% were adopted.

A standard sand graded between 600 μm and 150 μm as per ASTM C778-17 standard requirements with a specific gravity of 2.75, a sand equivalent of 64% and a granularity curve illustrated in figure 3 was used for mortar production.
Figure 1. Typical Sarooj sample as received from the plant

The mortar mixes were designed using the following combination: cement: lime: sarooj: water. For the control mix, the basic proportions are 2:1:0:0.93. The w/c ratio of 0.93 was kept constant for all mixes as well as the lime content (one part). The only variable was the substitution amount of Portland cement by sarooj.

Figure 2. Particle size distribution of Sarooj using dry sieve analysis
2.2. Testing methods

Both sarooj and sand materials were subjected to physical and chemical characterization. Sarooj was also subjected to geotechnical tests to determine its liquid limit and plasticity index. To determine the type of crystalline structure and degree of amorphousness of the sarooj material, XRD analysis was performed.

The control mortar mix was prepared with the following proportions of cement:lime:sand:water 2:1:2.75:0.93. The lime and water contents were kept constant for all mixes while the sarooj was introduced as a partial replacement of Portland cement at 10, 20 and 50%. Mortar was prepared in a laboratory pan mixer. Dry ingredients were first mixed for 30 s and the water was then added gradually and mixed for another 2 minutes and 30 s. immediately after mixing, plasticity or workability of the sarooj mortar mixes was assessed using flow table as described by ASTM C230-14.

The compressive strength was tested on cube measuring 50×50×50 mm at 1, 7 and 28 days while the flexural strength was tested using 40×40×160 mm prisms. The load was continuously applied with a load rate of 0.9 kN/s as per ASTM C109-13.

3. Results and discussions

3.1. Chemical composition and crystalline structure

The chemical composition of sarooj traditionally produced by a local plant shown in table 1 indicates that Silica and lime are the two dominants oxides components of this material. The sum of “SiO₂+Al₂O₃+Fe₂O₃” is equal to 44.33% which is far lower than the 70% required amount by ASTM C618 to declare a material as a pozzolanic one. The 44.33 % proportion does not also satisfy the minimum required amount of 50 % of the above three compounds for fly ash (FA) to be classified as FA class C. Nevertheless, the chemical composition given in table 1 showed that this material has appreciable amount of main reactive components (silica, alumina and lime) with a possible potential of reactivity and likely to act as a cementitious and pozzolanic material. The XRD pattern shown in figure 4 supports this claim. In fact, the XRD pattern showed some sharp peaks mainly of quartz and calcite but still exhibits certain degree of amorphousness with a tendency to produce flat peaks. A proper mechanical and thermal treatment of raw sarooj may increase the degree of amorphousness and hence, its reactivity.

On the other hand, the chemical analysis showed also a high Loss on Ignition (LOI =22.29%) which is a sign of a pre-hydration or the presence of high amount of burnt organic materials and eventually carbon. In fact, the traditional firing process used to produce sarooj material uses organic substances (dry logs from date trees); these logs are completely burnt and turned into ashes mixed with the burnt clay (sarooj).
This high LOI of sarooj impede its ability of full reactivity and contribution as a cementitious/pozzolanic material. The ASTM C150-16 limit the LOI of Portland cement to 3%.

**Table 1. Chemical composition of traditional sarooj material**

| Compounds | Proportions in % |
|-----------|-----------------|
| SiO₂      | 31.33           |
| Al₂O₃     | 7.85            |
| Fe₂O₃     | 5.15            |
| CaO       | 27.72           |
| MgO       | 1.5             |
| Na₂O      | 0.61            |
| K₂O       | 0.58            |
| LOI       | 22.29           |
| Total %   | 97.08           |
| Moisture (%) | 2.36          |

**Figure 4.** XRD pattern of a Sarooj sample used

### 3.2. Mortar workability

The results showed a decrease of the workability of the lime-cement-sarooj mortar when introducing sarooj at various contents. The higher the sarooj content, the lower the workability of the mortar. The clayey nature of sarooj gives it a high ability to absorption water and hence, higher water demand to reach the same workability as the control mortar. It is recommended to use some water reducing agents or superplasticizers to enhance the workability of sarooj mortar and reduce the water demand while keeping the same strength properties.
3.3. Compressive and flexural strengths
Compressive strength of control mix and mortar mixes produced with 10, 20 and 50% of sarooj introduced as a partial replacement of Portland cement were assessed on cubic samples at 1, 7 and 28 days of wet curing. The results obtained are shown in figure 5. The partial substitution of Portland cement by various contents of sarooj has resulted in a compressive strength reduction. The higher the sarooj content in the mortar mix, the lower the compressive strength. This strength reduction was more important when 50% replacement was implemented. On the other hand, the partial/full replacement of natural sand by sarooj has also led to strength reduction proportional to the replacement amount as shown in figure 6.

![Figure 5](image5.png)

**Figure 5.** Effect of Sarooj content used as substitute of cement on the compressive strength of mortar

![Figure 6](image6.png)

**Figure 6.** Effect of Sarooj content used as substitute of natural sand on the compressive strength of mortar
Meanwhile, flexural strength behaviour showed a very similar trend to the compressive strength. The use of sarooj as a partial substitute of Portland cement led to loss in the flexural strength of mortar. Embedding high content of sarooj as replacement of Portland cement resulted in a significant reduction of the flexural strength as could be seen in Figure 7.

![Figure 7. Effect of Sarooj content used as substitute of cement on the flexural strength of mortar](image)

### 4. Conclusions

The use of this traditional binder (sarooj) was considered as an economic choice used in construction of traditional houses and buildings as well as defensive structure in the past. Producing traditional sarooj requires a process of burning similarly to the calcination of clay in kilns in the past.

The need of an economic hydraulic material used as binder to enhance the properties of other materials such as cement and to be used in construction has been one of the priorities in construction industry. Sarooj could be considered as one of those cementing materials that can be used in construction sector and may improve the properties and performance of existing construction materials. Also, the need to lower the environmental impact of construction industry requires using as much as possible locally available materials rather than transporting materials for long distance with all implications in terms of carbon dioxide emissions.

The results of this research indicated an appreciable potential of reactivity of this material if properly ground and burnt. The sarooj traditionally produced and used in partial replacement of Portland cement in mortar production has led to strength decreases proportional to the replacement level.

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