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# Utilisation of Sepidrud dam basin sediments in fired clay bricks: laboratory scale experiment

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**ABSTRACT:** The prevailing disposal methods for dam basin sediments are not free from the environmental pollution and the ecological imbalance. At present, a new way to treat the dredged sediments to manufacture bricks is being investigated, prioritizing waste recovery over its deposition in landfills. However, construction materials such as clay bricks must comply with the international and local standards. Considering the perpetual availability of the sediments, particle sizing and their chemical composition and the results of physical and qualification tests on Sepidrud Dam basin sediments it can be concluded that the utilization of basin sediments as a full or partial replacement in clay brick production will lead to the production of quality bricks that meet all the regulatory limits in the standards. This research is novel in view of both increasing the reservoir effective volume capacity and preventing the use of alternative land quarries which are mainly covered by green land.

**KEYWORDS:** Sepidrud Dam; Basin sediments; Clay brick; Dune sand; Sawdust

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**RESUMEN:** *Utilización de los sedimentos de la cuenca de la presa Sepidrud para fabricación de ladrillos de arcilla: experimentos a escala de laboratorio.* Los métodos actuales de eliminación de los sedimentos de las cuencas de las presas no están exentos de problemas de contaminación ambiental y ecológicos. En la actualidad, se está investigando la posibilidad de utilizar los sedimentos dragados para la fabricación de ladrillos, dando prioridad a su valoración como residuos frente a su depósito en vertederos. Sin embargo, los ladrillos, como otros materiales de construcción, deben de cumplir con las correspondientes normas nacionales e internacionales. Teniendo en cuenta la disponibilidad permanente de los sedimentos, el tamaño de sus partículas y su composición química y los resultados físicos de las pruebas de calificación de los sedimentos de la cuenca Sepidrud Dam, en este estudio se ha concluido su viabilidad como materiales de reemplazo total o parcial de las materias primas convencionales, para la producción de ladrillos. Estos ladrillos cumplen además con las normas vigentes. Este es un estudio novedoso ya que incrementa la reutilización de los sedimentos y reduce el uso de materiales procedentes de cantera, con lo que se consigue unas mejoras medioambientales.

**PALABRAS CLAVE:** Presa Sepidrud; Sedimentos de cuenca; Ladrillo de arcilla; Duna de arena; Serrín

## 1. INTRODUCTION

Settlement and accumulation of sediments in dam basins is one of the most controversial issues in water management plans worldwide nowadays. In Iran sedimentation leads to 175–250 million $m^3$ reductions in effective dam basin volume annually (1).

The Sepidrud Dam is one of the benchmark sedimentation dams located in the north of Iran. Over the years, the dam basin sedimentation has caused severe environmental and water supply problems. Almost 40% of the effective reservoir volume has been filled with sediments. In order to dredge out the accumulated sediments from the dam basin, "flushing" operation which are based on the utilization of the hydrodynamic energy of water has been carried out in several phases. However, this dredging method has many disadvantages, namely, dam instability threats, sliding potential due to sedimentary mass movement toward the dam body, outlet steel and concrete segments erosion due to the increase in outflow water consistency and finally an increase in downstream water consistency and turbidity that causes serious damages to downstream ecosystems (1). Dredged material has to be managed and, as international and local regulations become more stringent; its management has become an environmental and economic concern for the country. Proper dredging of sediments instead of "flushing" operation means that it is possible to use the recovered sediments as an added-value product in several industries.

The requirements of finding an environmentally attractive valorization solution for the sediments has led to a beneficial contribution to the conservation of traditional brick-making raw materials. Recently, several types of waste materials have been introduced as full or partial replacment of raw materials for brick making, for example fly ash (2), granite sawing waste material (3), steel dust (4), waste bricks (5), limestone dust and wood sawdust (6) dried sludge collected from industrial waste water treatment (7–9), incinerated sewage sludge ash (10–12), processed waste tea (13), water treatment residual with excavation waste soil (14), lightly contaminated harbor sediments (15), reservoir sediments, mixed with fly ash (16) and stabilized polluted river sediments (17).

Considering their mineralogical content, chemical characteristics, particle sizes and also their availability, sediments are regarded as a suitable raw material for the brick production (17). On the other hand, the use of soil as a raw material to make bricks is a traditional form of building construction material in many developing countries. In Iran economic growth and the construction boom have created the increasing demands for bricks and other building materials quickly.

Consistency limits of sediments are usually so that it is possible to valorize it into brick making process. Making the fired clay bricks consumes large quantities of clay which is also very important for farmers. To save land for cultivation, new building raw materials are always welcome in the brick making industry.

The application of Sepidrud Dam reservoir sediments as a full replacement material in brick making process has previously been investigated (18). Sharafi (19) also attempted to produce LECA by mixing Sepidrud dam basin sediments with 0–5% of admixtures such as charcoal, petroleum, motor oil and sawdust. A non-rotary laboratory kiln was then used to produce the lightweight expanded clay aggregate (LECA) with mixed success.

Over the last 20 years, due to the accumulation of basin sediments in Sepidrud Dam and 40% loss in effective reservoir capacity, special attention has been focused on the feasibility of using the sediments in construction materials (clay bricks, tile and light weight aggregates).

In order to reduce the shrinkage potential, different provisions have been examined before. Some of these provisions include the use of admixtures such as dune sand, mazut, etc. Nowadays, many admixtures such as sawdust, limestone and coal dust are used in the brick making industry in order to improve the engineering properties of productions. Due to their abundance in the region, sawdust and dune sand are preferred.

## 2. MATERIALS AND METHODS

Sedimentation in the Sepidrud Dam basin takes place according to the grain sizes. Gravel and sand are settled in upper areas in the reservoir but some areas in lower regions are filled by fine-grained sediments.

The experiments consist of 16 laboratory scale tests by mixing the naturally occurring silty clay sediments with fine sand and sawdust in different proportions. Laboratory tests were conducted to assess the physical and mechanical properties of the produced brick samples.

The following raw materials were used to prepare brick samples:

- Sediments, passing through the 75 μm sieve
- Sand, passing through the 1.18 mm sieve
- Sawdust, having minus 425 μm size.

First, the chemical composition analyses were carried out to determine the main chemical components of fine-grained sediments. The following tests were then carried out on all samples:

- Drying shrinkage test
- Firing shrinkage test
- Water absorption test
- Bulk density test
- Compressive strength test.

The produced bricks successfully passed the different tests required by the Iranian codes for assessing the suitability of a brick for use in the construction projects. The results of the qualification tests undertaken on laboratory scale sedimentary bricks arepresented and compared to the standards.

In order to confirm the full-scale practical usage as the brick raw material, a supplementary experiment, which is qualitative in nature, was carried out in Ajor va Sofale Bame Roudbar (ASBR).

### 2.1. Characterization of sediments

Physical characteristic tests were carried out on the fine-grained sediments in order to classify them based on the Unified Soil Classification System (USCS). Then, the fine-grained sediment was subject to mineralogical and chemical analysis in order to pinpoint its main constituents.

#### *2.1.1. Physical characteristics*

In order to make different soil samples with specified mix designs, fine-grained sediment was mixed with dune sand or sawdust admixtures in different weight proportions to meet the required mix designs. Sediments were washed in a sieve No. 200 in accordance with ASTM D422 (20) to eliminate the coarse size fraction and impurities. However, sieve analysis showed that almost 100% of the fine-grained sediments pass through sieve No. 200 and is considered fine-grained soils.

The following tests were conducted on fine-grained sediments:

1. The liquid limit test according to the Casagrande method (ASTM D4318) (21).
2. The plastic limit test according to the conventional 3 mm thread method (ASTM D4318) (21).
3. The shrinkage limit test according to ASTM D427 (22).
4. Grain size distribution test by wet sieving and hydrometer analysis according to ASTM D422 (20).

The results show that the fine-grained sediement consists of 51% clay and 49% silt. It is however, considered as the clay with high plasticity (CH). Liquid and plastic limits for fine-grained sediments are 51.3% and 25% respectively and its shrinkage limit is equal to 21.7%.

The grain size distribution test was also carried out by sieving analysis on sand admixture found in upper areas of dam basin as stated before. It was classified as poorly graded sand (uniformly graded fine sand). The grain size distribution curve for sand admixture is shown in Figure 1.

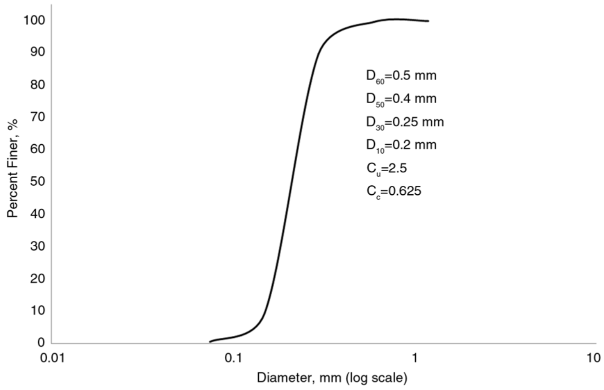


FIGURE 1. Grain size distribution curve for sand admixture.

#### *2.1.2. Mineralogical analyses*

The procedure introduced by Mehra and Jackson (23), Kittrick and Hope (24) and Jackson (25) was followed to remove the chemical cementing agents and to separate the clay fractions. The removal of salts was also achieved by repeated washing and then the carbonates were removed using 1 N sodium acetate buffered at PH 5. The injection of sodium acetate was stopped when no more effervescence was observed with 1 N HCl (25). The treatment of the carbonate-free soils with 30% $H_2O_2$ was done in order to oxidize the organic matter. $MnO_2$ was also dissolved in the same treatment procedure. Dithionate citrate bicarbonate method of Mehra and Jackson (23) was followed to remove iron oxides from the samples and atomic absorption spectroscopy of the filtrated solution was used to determine iron. The iron oxide-eliminated sample was then centrifuged in order to separate the clay fraction.

The fractions of the clay minerals were determined according to Johns et al. (26). Smectite (montmorillonite), illite, and kaolinite are the major clay minerals of the fine-grained sediments with 64, 17 and 14% mineral percentages respectively. Furthermore, XRD studies of the fine-grained sediments revealed that smectite is the dominant clay mineral.

#### *2.1.3. Chemical composition*

The chemical analyses were carried out to determine the main chemical components of the fine-grained sediments and weight loss due to ignition (LOI). The soil was sampled and dried at 110 °C. Then, 600 g of dry soil fraction less than 150 μm was kept for the chemical analysis after sieving and grinding. The results are shown in Table 1.

The proportions of different components are within the regulatory limits for brick making soil based on ISIRI 1162 (27). Thus, the dredged sediments are considered suitable materials for use in brick making industries.

Table 1. Chemical composition of the sediments

| Element | $SiO_2$ (%) | $Al_2O_3$ (%) | $Fe_2O_3$ (%) | CaO (%) | MgO (%) | $SO_3$ (%) | LOI (%) |
|---|---|---|---|---|---|---|---|
| **ISIRI Standard** | 40–60 | 9–21 | 3–12 | Max 17 | Max 4 | Max 0.5 | Max 16 |
| **Basin Sediments** | 49.34 | 15.20 | 7.00 | 14.84 | 0.40 | 0.00 | 12.47 |

### 2.2. Laboratory brick-making process

The Building and Housing Research Center (BHRC) is a participating partner in this study. It operates a laboratory scale dryer and kiln used in this study to perfrom the brick making experiment. Fine-grained sediments, sand and sawdust were first sampled and dried at 110 °C. A dry soil fraction passing sieve No. 40 was kept for the brick-making process after sieving and grinding. Different components were mixed in dry state in accordance with mix designs and the tempering process then took place where water was added to transform the mixture into an adequate plastic state. At this stage, the paste is moulded manually and formed into individual bricks which are then stacked into trays for drying.

Before the bricks can be fired, as much moisture as possible must be removed or they will explode in the kiln. Drying involves the removal of water from the wet brick as slowly and as uniformly as possible. If the outer skin of the brick dries first, it becomes impossible for the moisture inside to escape. In the kiln, the extreme temperature will force this moisture out and some cracking may occur. To prevent this happening, the dryers are kept at a temperature of about 35–110 °C and the atmosphere is very humid in order to keep the exterior of the brick as moist as possible. This is monitored very closely to reduce the surface cracking. The bricks will shrink in the dryers as the clay particles come together and they become strong enough to be stacked, but at this stage they have no weather resistant qualities.

The drying schedule for the samples lasted about 60 hours in the laboratory. The dry bricks are then set into the kiln. During firing, the bricks undergo a physical change. Clay particles and impurities are fused together to produce a hard durable and weather resistant product. This is usually accompanied by further shrinkage and a color change. The firing temperature varies in the range of 0–1000 °C. Obviously, bricks cannot suddenly be subjected to these temperatures, so firing is in multiple stages with a maximum temperature of 1000 °C. The drying and firing programs are given in Figure 2.

A sample batch containing 16 mix designs, repeated in 3 trials for each individual test scheme underwent a series of tests including drying and firing shrinkage, water absorption, density and compressive strength.

### 2.3. Factory brick-making process

The Ajor va Sofale Bame Rudbar (ASBR) is another participating partner in this study. It operates a chamber drying factory in Guilan province (North of Iran).

In its in-situ brick-making operation, the ASBR uses fine-grained sediments. The clay is removed from the stockpile and is carried by conveyer-belt to a crusher before it is sent to a twin-shaft blender for thorough mixing and water addition. The mixture then is carried by conveyer-belt to high speed fine rollers for fine crushing. This double-roller crushing machine consists of two circular crushing rollers revolving reciprocally. The tempering process takes place at this stage where additional water is added to the mixture in a high efficiency blender and the material is further mixed transforming it into an adequate plastic state after which it is formed into shape through a double stage vacuum extruder.

A rectangular beam emerges from the vacuum extruder and is subsequently separated into individual hollow bricks of a specified size via an auto bar cutter and green brick cutter that slices vertically through the beam. The bricks are then stacked into carts and transported to dryer chambers by finger cars. The dried bricks are then moved to a Huffman kiln where they reach a maximum temperature of 1100 °C.

Approximately 100,000 hollow bricks of two different sizes (10 cm×20 cm×20 cm and 15 cm×20 cm ×20 cm) were fired through the factory Huffman kiln during this experiment (Figure 3). The choice of the type and sizes of the produced bricks was based on their high selling rate. It is not customary to conduct and perform mechanical qualification tests on produced hollow bricks. The produced bricks were only launched to the market after visual inspection of the product for efflorescence and performing some simple tests like water absorption and bulk density which proved within regulatory limits as discussed subsequently.

## 3. RESULTS AND DISCUSSION

### 3.1. Drying and firing shrinkage

The quality of the brick can be evaluated according to the degree of drying and firing shrinkage. Soil shrinkage is defined as the specific volume change of soil relative to its initial water content and this is

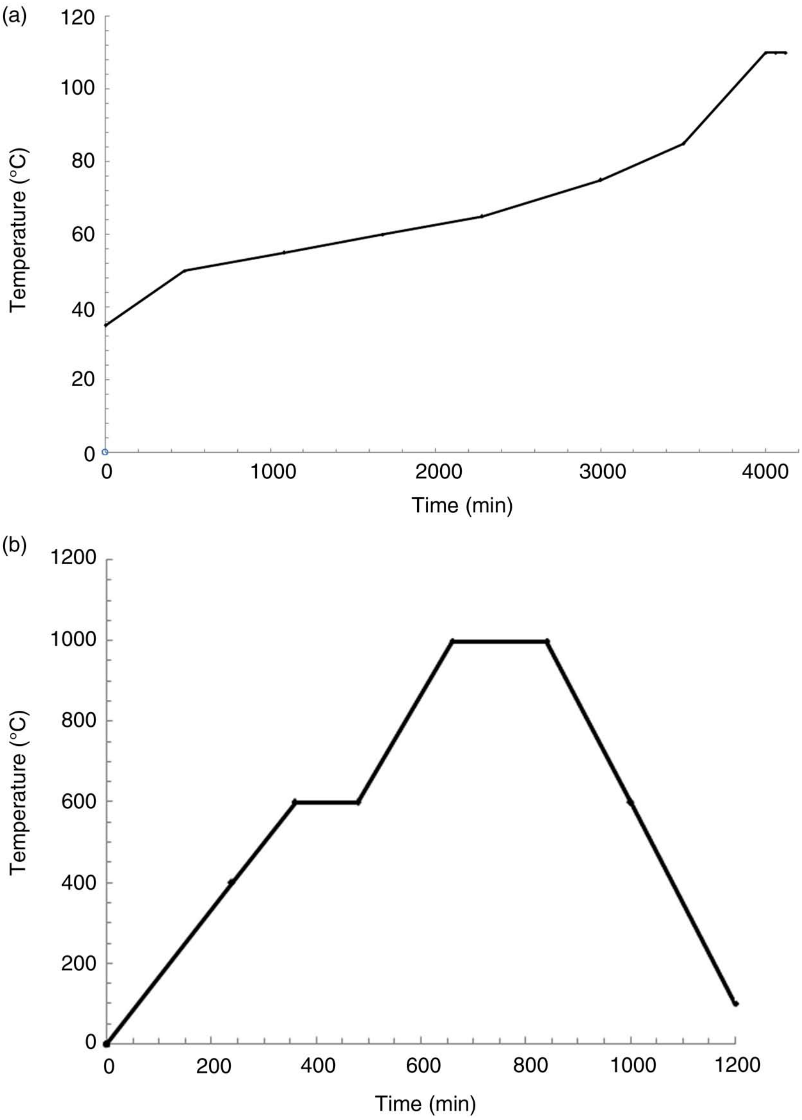


FIGURE 2. Temperature plan utilised in production process; a) drying program of brick; b) heating program of bricks.

thought to be mainly due to clay swelling properties (28–29). However, recent research has clearly ruled out the possibility of considering the drying shrinkage as one of the plasticity characteristics of a soil. Instead, they highlight the validity of the hypothesis that explains the shrinkage limit based on the relative grain size distribution of the soil and the packing phenomenon in other words (30).

The 16 brick samples described earlier for the laboratory brick-making process were made from silty clay sediments mixed with sand and sawdust as admixtures. Table 2 provides the mix designs for the laboratory brick making process along with the information on drying, firing and total shrinkage of the produced bricks and other measured physical and mechanical properties. Drying and firing shrinkages were measured in bricks exposed to 110 °C and 1000 °C respectively. For each mix design, the drying and firing shrinkages were measured for 3 trial samples and the results where then averaged out.

It is evident from Figure 4(a) that increasing the fine-grained content results in an increase in the total shrinkage of the bricks. It also shows howthe sand content affects the shrinkage behaviour of the brick samples made from sediments mixed with fine sand as an admixture. It is noted that increasing the percentage of sand results in a decrease in total brick shrinkage. This is probably due to the fact that sand inclusions accelerate the packing phenomenon pointed out by Sridharan and Prakash (30). At least for the dune sand under study which is perpetually available in the Sepidrud Dam basin it was shown to be effective in terms of shrinkage reduction. However, authors believe that the effectiveness of sand inclusion on the

Figure 3. Examples of factory-scale produced sedimentary clay bricks.

shrinkage properties of produced brick will depend on the uniformity coefficient of the sand, the average particle size and the angularity of the particles.

It was also shown that the sawdust-amended brick samples exhibit less shrinkage in comparison to the plain brick samples made from the silty clay sediments due to the reinforcing effect of the sawdust fibers and their bonding action in other words (Figure 4(b)). In effect, sawdust inclusion will increase the shearing resistance of the soil mixture at the particle level as explained by Sridharan and Prakash (30).

An important observation from the total shrinkage data provided in Table 2 is that the joint utilization of dune sand and sawdust in clay brick production will lead to even less shrinkage. This is due to the fact that both sand and sawdust contribute to the shrinkage reduction and their joint inclusion will accelerate this effect. The minimum shrinkage of 8.86% occurred when there was 80% fine-grained sediments (clay+silt) mixed with 10% dune sand and 10% sawdust. Another important indication from Table 2 is that the dry shrinkage contributes most to the total shrinkage of the sample clay bricks. This means that firing shrinkage in this case is negligible.

### 3.2. Water absorption

Water absorption is a key factor affecting the durability of brick. A high absorption results in vulnerability to volume changes that would result in cracking of the bricks and the structural damage in buildings. It would also lead to cracking in the event of freezing and thawing of the water inside the pores. The less water infiltration into the brick occurs, the greater durability of the brick and resistance to the natural environment is expected. Too little absorption, however, is also not desired. This is because rain water would tend to run off very quickly towards the joints rather than getting partially absorbed by the brick and may find its way into the building as well as reducing the durability of the mortar joints. The water absorption was determined by using the procedures described in ASTM C67-87 (31). Figure 5(a) shows the results of the water absorption tests for clay

Table 2. Mix designs for laboratory making process

| Mixtures | Clay+Silt (%) | Sand (%) | Sawdust (%) | Dry Shrinkage (%) | Firing Shrinkage (%) | Total Shrinkage (%) | Water Absorption (%) | Density (gr/cm$^3$) | Compressive Strength (Kg/cm$^2$) |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 100 | 0 | 0 | 10.95 | 0.95 | 12.00 | 23.88 | 1.54 | 186.0 |
| **2** | 95 | 5 | 0 | 9.52 | 1.76 | 11.28 | 21.50 | 1.57 | 191.6 |
| **3** | 90 | 10 | 0 | 11.43 | 1.07 | 12.50 | 21.31 | 1.55 | 197.3 |
| **4** | 85 | 15 | 0 | 11.43 | 0.33 | 11.76 | 21.17 | 1.57 | 232.6 |
| **5** | 80 | 20 | 0 | 11.43 | 0.00 | 11.43 | 20.36 | 1.61 | 235.7 |
| **6** | 75 | 25 | 0 | 10.00 | 0.28 | 10.28 | 19.81 | 1.60 | 237.7 |
| **7** | 70 | 30 | 0 | 8.57 | 1.05 | 9.62 | 19.06 | 1.66 | 250.6 |
| **8** | 97.5 | 0 | 2.5 | 11.43 | 0.57 | 11.90 | 23.88 | 1.41 | 162.0 |
| **9** | 95 | 0 | 5 | 11.43 | 0.00 | 11.43 | 24.18 | 1.31 | 116.2 |
| **10** | 92.5 | 0 | 7.5 | 10.00 | 0.29 | 10.29 | 24.59 | 1.22 | 88.3 |
| **11** | 90 | 0 | 10 | 10.00 | 0.14 | 10.14 | 30.58 | 1.12 | 83.6 |
| **12** | 90 | 7.5 | 2.5 | 10.67 | 0.05 | 10.71 | 20.08 | 1.45 | 177.5 |
| **13** | 90 | 5 | 5 | 11.43 | 0.33 | 11.75 | 22.84 | 1.33 | 149.6 |
| **14** | 80 | 10 | 10 | 8.86 | 0.00 | 8.86 | 30.74 | 1.13 | 61.6 |
| **15** | 80 | 15 | 5 | 9.43 | 0.36 | 9.79 | 23.40 | 1.36 | 125.0 |
| **16** | 90 | 2.5 | 7.5 | 11.43 | 0.14 | 11.57 | 26.18 | 1.21 | 99.0 |

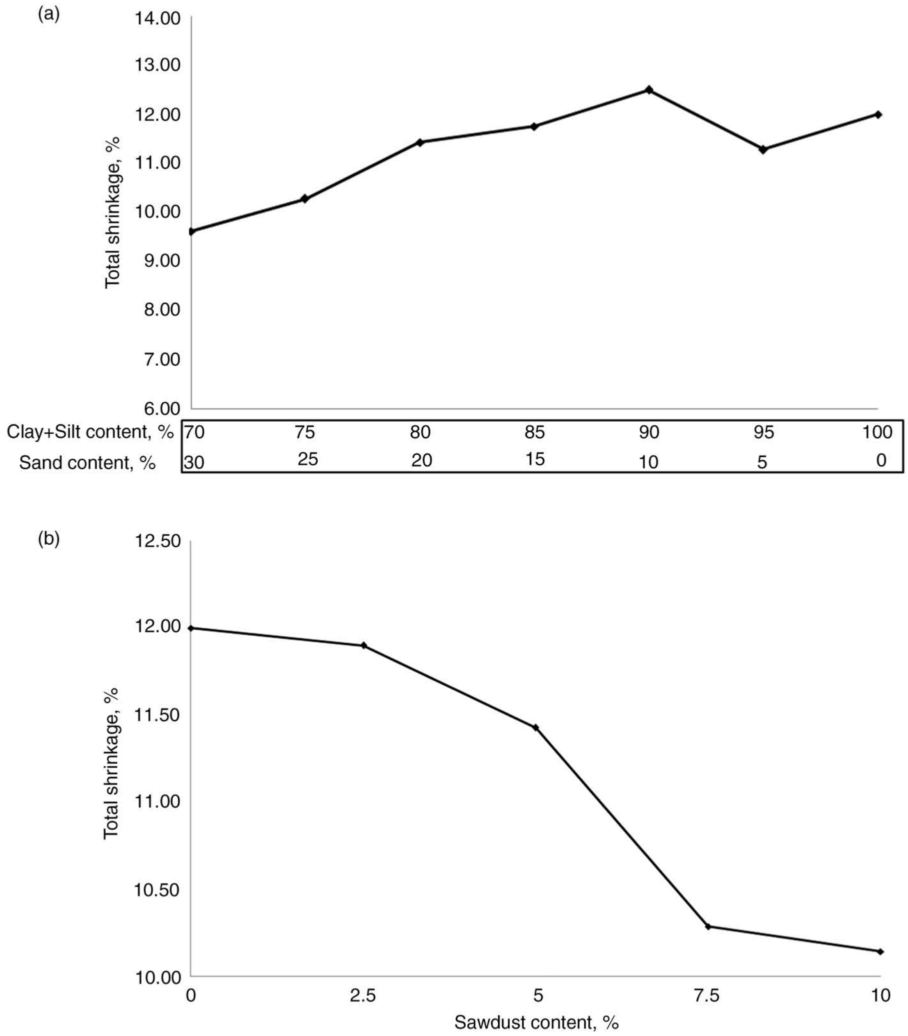


FIGURE 4. Total shrinkage variation with; a) fine-grained (clay+silt) soil and sand content; b) sawdust inclusion.

bricks with various sand contents fired at 1100 °C. It indicates that the plain clay bricks absorb more water than sand-amended ones and thus less porosity is expected for sand-amended brick in comparison to plain clay bricks.

The results of the water absorption tests for sawdust-amended brick samples are shown in Figure 5(b). It can be seen that the level of water absorption is directly proportional to the quantity of amended sawdust. Increasing the sawdust content resulted in an increase in water absorption. This is because the spaces occupied by the sawdust fibers are left void during and after the burning process when the organic sawdust fibers burn completely. The voids are water absorbent elements increasing the water absorption capacity of the produced brick.

According to the criterion of water absorption of bricks in ASTM C62-05 (32), the threshold limit is 17% for the first-class brick (bricks under severe weathering condition-SW) and 22% for second-class brick (bricks under moderate weathering condition-MW). However, there is no limit for water absorption under no-weather (NW) conditions. Bricks in this case should not be exposed to weather. This means that these bricks can be used for indoor applications or even used for exterior walls as long as they are covered and coated by impermeable facade materials and are not directly exposed to weathering. Hollow bricks are used widely in Iran as NW brick and they are used to construct both interior and exterior walls and the exterior walls are finally covered by a selection of facade elements so as to impede water intrusion. Iranian standard No. 1162 considers no limits for NW conditions.

### 3.3. Bulk density

The bricks made from the natural clay have a bulk density of 1.8 to 2.0 g/cm$^3$. The measured bulk density of brick samples made with different proportions of

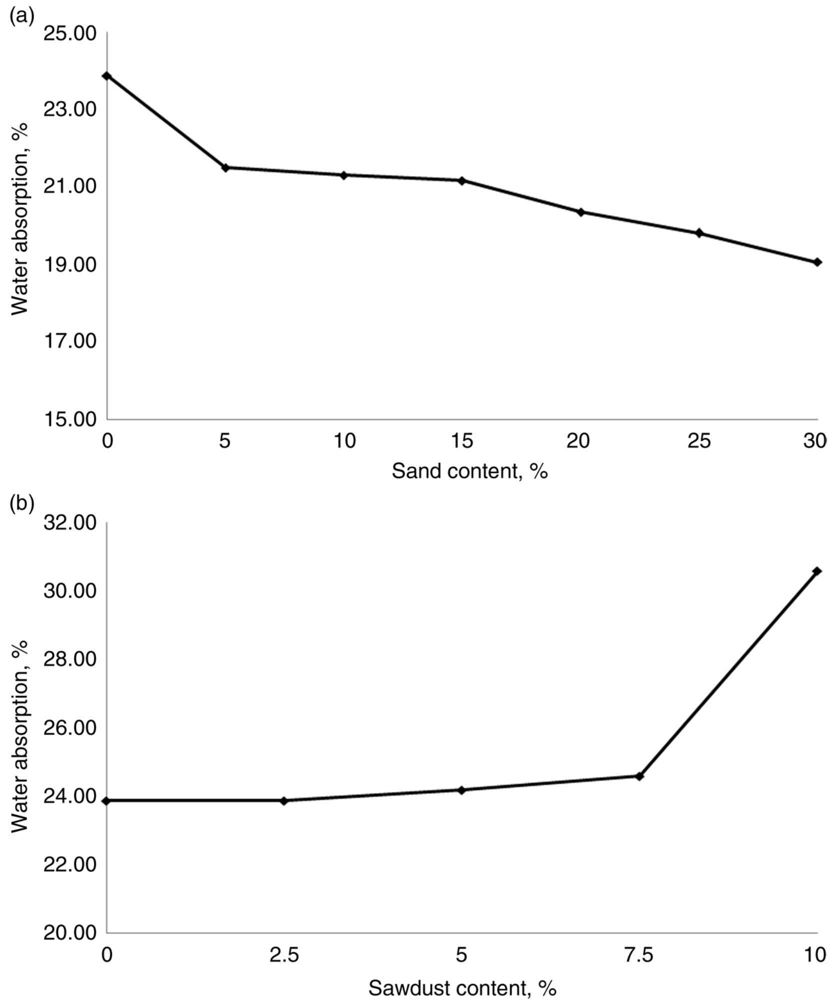


FIGURE 5. Water absorption variation with; a) sand content; b) sawdust content.

fine-grained sediments as the main raw material and sand or sawdust admixtures are provided in Table 2. Figure 6(a) shows the bulk density variation with sand content. It can be observed that the sand-amended brick exhibits a higher bulk density than the plain sedimentary one as this parameter is directly related to the porosity and the water absorption as discussed earlier. It is also worth noting that sand-amended bricks have a bulk density of 1.54 to 1.66 g/cm$^3$; lending support to the contention that using fine-grained sediments mixed with dune sand will lead to brick production which can be considered lightweight enough in comparison to the bulk density ranges recommended by standards. This also emphasizes the fact that there will be no need to add lightweight making admixtures such as sawdust, however, if it is used, it will introduce a further reduction in the bulk density of the produced bricks which is taken for granted.

In Table 2 it can be seen that the bulk density of the bricks is inversely proportional to the quantity of sawdust added to the mixture. This finding is closely related to the water absorption ratio. As demonstrated in Figure 5(b), the sawdust-amended bricks absorb more water, exhibiting more porosity. As a result, the bulk density becomes smaller (Figure 6(b)). Figure 6(b) also shows that the density ranges for sawdust-amended bricks lies within 1.1 to 1.4 g/cm$^3$.

### 3.4. Compressive strength

The compression test is the most important test to assure the engineering quality of a building material. The results of the compressive strength test on the brick samples made with different mix designs provided earlier in Table 2 indicate that the compressive strength is greatly dependent on the amount of sand and also the sawdust admixtures in the brick.

The results indicate that the optimum mix design at which the maximum compressive strength is acheived, is 70% fine-grained sediments mixed with 30% sand. ASTM C62-05 specifies 210 kg/cm$^2$ for the

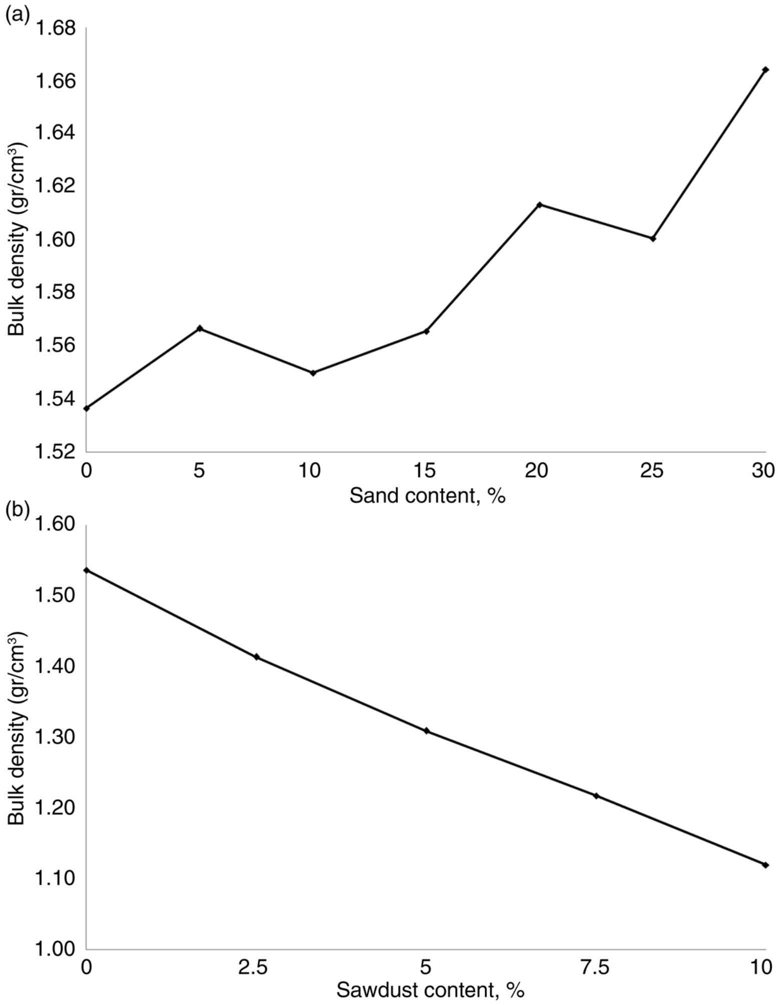


FIGURE 6. Bulk density variation with; a) sand content; b) sawdust content.

compressive strength of a first-class brick, 175 kg/cm$^2$ for a second-class brick and 105 kg/cm$^2$ for a NW brick. The Iranian standard for the clay bricks also specifies 250 kg/cm$^2$ for the compressive strength of an engineering brick, 120 kg/cm$^2$ for a facade brick, 80 kg/cm$^2$ for load bearing indoor application and 40 kg/cm$^2$ for non-bearing bricks with indoor application (In accordance with ISIRI 1162).

The results of the compressive strength tests provided in Table 2 indicate that the inclusion of sand gives rise to an increase in the compressive strength of the clay brick. This is directly related to the porosity and water absorption capacity and it has been stated that the porosity of the sand-amended bricks is lower than that of the plain clay brick, which induces an increase in its compressive strength. Figure 7(a) shows the variation in the compressive strength of the produced brick with the dune sand content.

It is apparent from Figure 7(a) that adding dune sand to the fine-grained sediments in a proportion of more than 15% will lead to the production of a first-class brick according to ASTM C62-05. Lower sand proportions will always guarantee the second-class brick production.

Sawdust, on the other hand, was found to have an inverse effect on the compressive strength of the clay bricks. It is evident from Table 2 and Figure 7(b) that the compressive strength of sawdust-amended bricks decreases with the increase in the sawdust admixture content; however, hollow bricks are mainly used for non-bearing wall applications and according to the Iranian standard, all the mix designs listed in Table 2 can be used with confidence. For the non-bearing applications such as interior and exterior walls, the thermal insulation is the most important issue to be considered. Previous research has shown that sawdust admixture will dramatically improve the thermal insulation properties of the produced brick and sawdust-amended bricks best suit applications where thermal insulation is crucially important (33).

An overview of results provided in preceding sections reveals that sand or sawdust inclusion leads

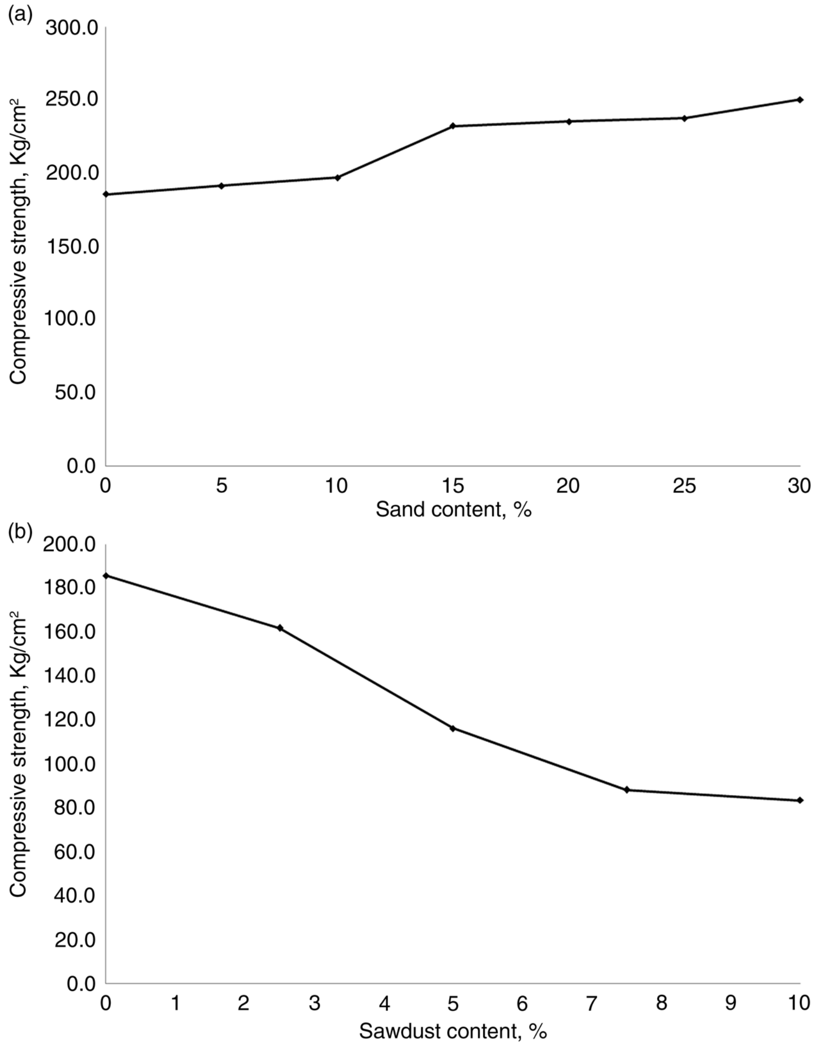


FIGURE 7. Compressive strength variation with; a) sand content; b) sawdust content.

to production of clay brick which meets the regulatory limits of standards individually and in average sense. However a look into the variability of results and the coefficient of variation defined as the ratio of the standard deviation of the properties to the average value, COV (Table 3) reveals that sawdust has the most effect on properties of produced clay brick in comparison to sand amendment especially when the compressive strength is of major importance. COV of 60% for the compressive strength is expected for clay bricks produced by sawdust-amended fine grained sediments. Another implication from Table 3 is that sand inclusion has minimal effect on bulk density of produced clay bricks.

TABLE 3. Statistical parameters involved with sedimetary brick production

| | Sand Inclusion | | Sawdust Amendment | |
|---|---|---|---|---|
| **Parameter** | **Average Value** | **COV (%)** | **Average Value** | **COV (%)** |
| Total Shrinkage (%) | 11.3 | 8.2 | 10.7 | 23 |
| Water Absorption (%) | 21.0 | 6.8 | 25.2 | 26.6 |
| Bulk Density (g/cm$^3$) | 1.59 | 2.6 | 1.28 | 34.5 |
| Compressive Strength (Kg/cm$^2$) | 218.8 | 11.1 | 118.1 | 60.9 |

## 4. CONCLUSION

The chemical tests performed on dredged dam basin sediments showed that the quantities of different components are within the regulatory limits and Sepidrud Dam basin sediments can be regarded as the suitable full replacement raw material for the clay brick production. Sediments were used in different proportions and fed into a laboratory and factory brick making process with and without any admixture treatments.

The novelty of current research is that the dam basin sediments are used as raw material with and without any amendment. This makes it interesting as its use offers two benefits: increases the reservoir effective volume capacity and prevents the use of land quarries which are mainly covered by green land.

The silty clay sediments as the main raw material along with dune sand and sawdust representing admixtures were mixed in 16 different mix designs to produce the laboratory scale clay bricks (6 cm×7 cm×7 cm). The produced bricks were subjected to several qualification tests (drying and firing shrinkage, water absorption, bulk density and compressive strength). The results obtained showed that the sedimentary bricks meet the "clay bricks" specifications and different requirements stipulated in the existing codes and standards. The results of shrinkage tests on bricks fired at 1000 °C show that the total shrinkage of the produced bricks is directly related to an increase in the fine-grained sediments content but it is inversely proportional to the sand and sawdust content.

It was also found that the substitution of dune sand by sawdust admixture results in a decrease in the brick compressive strength and density, and an increase in water absorption capacity. It was also shown that sawdust can be added to sediments in proportions of less than 7.5% to produce the quality brick that meets all the regulatory limits introduced in standards. Furthermore, bricks made in mix designs with 7.5–10% sawdust can be used for non-bearing wall applications (hollow bricks).

Furthermore, the virgin fine-grained sediments were implemented to a factory scale clay brick production scheme near the dam reservoir and hollow bricks of two different sizes were produced and showed very good and comparable quality products with no need to make use of any type of admixture in comparison to locally supplied non-bearing hollow bricks.

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