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Özgür Eren,[1] Khaled Marar,[2] Osman İlter,[3] and Tahir Çelik[4]

Experimental Study on Engineering and Thermal Properties of Mortar and Plaster Produced With Pumice Aggregate

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[1] Dept. of Civil Engineering, Faculty of Engineering, Eastern Mediterranean Univ., Gazimağusa, Mersin 10, Turkey, e-mail: ozgur.eren@emu.edu.tr

[2] Dept. of Civil Engineering, European Univ. of Lefke, Lefke, Mersin 10, Turkey (Corresponding author), e-mail: kmarar@eul.edu.tr

[3] Civil Engineer, Dept. of Civil Engineering, Faculty of Engineering, Eastern Mediterranean Univ., Gazimağusa, Mersin 10, Turkey.

[4] Dept. of Civil Engineering, Faculty of Engineering, Cyprus International Univ., Haspolat, Lefkoşa, Mersin 10, Turkey.

Reference

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ABSTRACT

Now, it is widely accepted by civil engineers and architects that walls and masonry building units, which are made of pumice, can insulate buildings against both heat and sound, and also reduce the dead load of the building compared to traditional buildings. In this study, pumice was used as a fine aggregate in mortar and plaster instead of traditional crushed limestone sand. This study shows that the properties of pumice mortars indicate lower values compared to limestone mortars for workability durations, time of settings, and fresh and hardened unit weights. Other properties of pumice mortars indicate higher values compared to limestone mortars, such as water absorption, coefficient of capillary water absorption, drying shrinkage, flexural strength, and compressive strength. Also, wall systems made with pumice mortar and plaster show significant benefits in terms of thermal conductivity.

Keywords

pumice, compressive strength, drying shrinkage, flexural strength, thermal conductivity

Introduction

The properties of materials that form building walls are important because they enclose and protect buildings from the exterior and, hence, determine the thermal comfort of the occupants [1]. The protection against climatic conditions has always been a concern of people all over the world; for example, the high summer temperatures and low winter temperatures cause discomfort [2]. Because of the large number of voids in the lightweight aggregate, the resulting lightweight concrete possesses a higher thermal insulating efficiency than normal concrete. As a result, lightweight concrete has superior properties such as lightness and good thermal insulation, but has the disadvantage of low mechanical properties, which makes them unsuitable for a load-bearing wall [3]. Pumice is of igneous origin with a cellular structure; therefore, lightweight and insulating properties of pumice have been extensively used as a building construction material [4]. Pumice is abundant in Mediterranean countries, such as Turkey, Italy, Spain, and Greece. Although it has traditionally been used for structural elements, pumice is currently being used as a non-structural element [5]. It is estimated that, in north Cyprus, 45 % of the total amount of energy is consumed for heating and cooling processes in residential buildings.

The various types of lightweight aggregates available allow the density of concrete to range from 300 kg/m^3 to 1850 kg/m^3, with a corresponding compressive strength range between 0.3 MPa and 40 MPa. Compressive strengths of up to 60 MPa can also be obtained with very high cement content (560 kg/m^3). The suitability of a lightweight concrete is ruled by its desired properties such as density, cost, strength, and low thermal conductivity. Low thermal conductivity of lightweight aggregate concrete is advantageous especially for applications where good thermal insulation is required [6].

Classification of structural lightweight concrete is based on the minimum strength, and, according to ASTM C330 [7], the 28-day cylinder compressive strength should not be less than 17 MPa. The essential feature of insulating concrete is its coefficient of thermal conductivity, which should be below ~0.3 W/mK, while its density is generally lower than 800 kg/m^3 and strength is between 0.7 and 7 MPa [6]. Gündüz and Uğur [8] investigated the effect of different pumice aggregate/cement ratios on the structural properties of concrete. They concluded that: (1) the higher the amount of pumice aggregates in the mixture, the lower the thermal conductivity of the pumice aggregate concrete; (2) the measured thermal conductivity of the mixtures for different aggregate/cement ratios mainly depend on the dry density, cement content, and fines content; (3) thermal conductivity values for normal weight concretes are between 0.85 and 1.4 W/mK based on the aggregate type size and cement amount in the mixture; and (4) thermal conductivity of pumice aggregate concrete was 2.5 to 4 times lower than equivalent normal weight concrete.

According to TS 3234 [9], pumice is defined as a volcanic-origin, natural lightweight aggregate, containing up to 80 % air voids, where the voids are disconnected from each other. It is spongy looking and silicate essential. Its unit weight is usually less than 1000 kg/m^3, specific gravity generally more than 2100 kg/m^3, and Mohs hardness scale in the range between 5.5 and 6.0 (glassy texture and contains no water crystals).

The absorption by the masonry unit is an important factor that affects the fresh mortar and initiates the development of bond to plaster. Mortars having higher water retentivity are desirable for use in summer, and mortars having lower water retentivity are desirable for use in the winter. Shrinkage and swelling of the masonry unit affects the quality of the mortar joint, and protection should be provided to reduce wetting, drying, heating, and cooling until mortar achieves its final set [10]. Many civilizations have built structures with concrete and masonry walls that provide comfortable indoor temperatures. Housing systems have been developed that provide resistance to weathering, temperature changes, fire, and noise. Many wall systems are made from lightweight concrete in which the wall thickness is often determined by the thermal characteristics rather than the structural requirements [11].

All previous investigations and studies have concentrated on only a couple of specific properties of building units made of pumice. Conversely, in this paper, an expanded understanding of engineering properties is studied and discussed to give engineers an intimate knowledge of what they would need and understand to use in the design of structural units. This paper presents the test results pertaining the properties, such as consistency of fresh joint mortar, time of setting, fresh unit weight, hardened unit weight, water-absorption capacity, coefficient of capillary water absorption, percentage of drying shrinkage, flexural strength, compressive strength, and coefficient of thermal conductivity of wall systems constructed.

Mixture Composition and Experimental Procedure

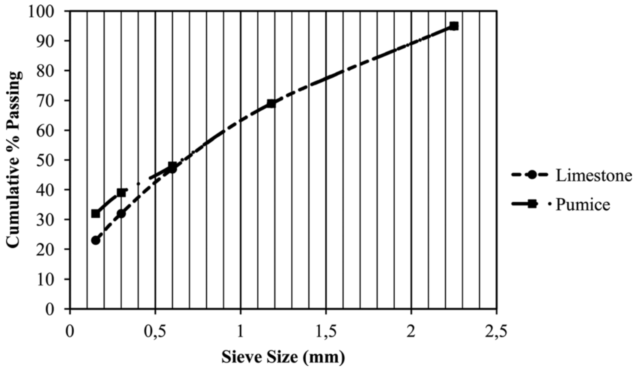
MATERIALS

The cement used for this investigation is Portland pozzolanic cement (class 32.5), meeting ASTM C150 [12]. The chemical composition and physical properties of the cement used are shown in **Table 1**. The limestone crushed aggregates were obtained from the Beşparmak Mountains of Cyprus. The gradings of limestone aggregate and pumice aggregate are shown in **Fig. 1**. The chemical composition of pumice aggregate used in

TABLE 1 Chemical composition of pumice and cement, and physical properties of cement.

Composition	Pumice	Cement	Physical Properties of Cement	
SiO_2	74.00	46.80	Fineness (m^2/kg)	451
Al_2O_3	13.00	5.30	Initial setting time (min)	90
Fe_2O_3	1.40	3.46	Final setting time (min)	135
FeO	0.00	—	Specific gravity	3.28
CaO	1.17	38.00	Compressive strength (MPa) 3 days	18.30
Na_2O	3.70	0.15	Compressive strength (MPa) 28 days	35.70
K_2O	4.10	—		
MgO	0.07	4.00		
SO_3	—	3.00		
LOI	—	3.00		

FIG. 1 Grading curve of pumice and limestone aggregate.



this investigation is shown in **Table 1**. Tap water was used in all experiments.

The compacted and uncompacted bulk densities, bulk specific gravities, and absorption percentages of pumice and limestone aggregates used in this investigation are shown in **Table 2**.

Three different sizes of pumice blocks (hollow), meeting the requirements of TS EN771-3 [13], were used in this investigation. The symbols and dimensions used for pumice blocks are shown in **Table 3** and **Fig. 2**. **Table 4** shows the properties of pumice blocks.

MIXTURE DESIGN OF MORTAR AND PLASTER

In this investigation, mainly two types of mortars and plasters were produced by using pumice and limestone aggregates. It is well known that plasters are applied in three coats for wall construction. Ready-mixed plasters are usually used as a third coat. The plasters produced in this investigation were typically used for the first and second coat, which were made with two different aggregate types, such as pumice and limestone. **Table 5** shows the mix design proportions used in this investigation for the traditional limestone plaster and joint mortar, and for the pumice plaster and joint mortar.

Experiments on Mortar and Wall Specimens

EXPERIMENTS ON FRESH AND HARDENED MORTAR

The experiments undertaken on fresh and hardened mortar were as follows:

TABLE 3 Dimensions (mm) of pumice blocks used.

Symbol							
L	b	h	a1	C	d1	e	a2
Type 1: 150 × 390 × 185 mm (h × L × b)[a]							
390	150	185	25	20	45	15	20
Type 2: 190 × 390 × 185 mm (h × L × b)[a]							
390	190	185	25	20	130	20	25
Type 3: 250 × 390 × 185 mm (h × L × b)[a]							
390	250	185	25	25	190	20	25

[a] h, thickness; L, length; b, width.

(a) Consistency of fresh mortar was analyzed by using the flow table according to TS EN1015-3 [14].

(b) Test for time of setting of mortars were determined according to ASTM C191 [15].

(c) Fresh unit weight of mortar and hardened unit weight of mortar were determined according to ASTM C138 [16].

(d) Percentage of water absorption of mortars was determined according to ASTM C20-10 [17].

(e) Capillary water absorption of mortars was determined according to TS 4045 [18]. Three samples were prepared for each type of mortar. Time-dependent coefficient of capillary water absorption of mortars was calculated by using Eq 1.

$$C_{w,s} = [m_{so,s} - m_{\mathrm{dry},s}]/[A_s\sqrt{t_{so}}] \times 10^6 \tag{1}$$

where:
$C_{w,s}$ = coefficient of capillary water absorption (g/m^2 s$^{0.5}$),
$m_{so,s}$ = wet mass (g),
$m_{\mathrm{dry},s}$ = dry mass (g),
A_s = surface area of specimen sunk into water (mm^2), and
t_{so} = contact time of water (s).

(f) Drying shrinkage of mortar was determined according to ASTM C596 [19]. Three specimens were prepared for each type of mortar to be tested at 4, 11, 18, and 25 days in an air-storage condition.

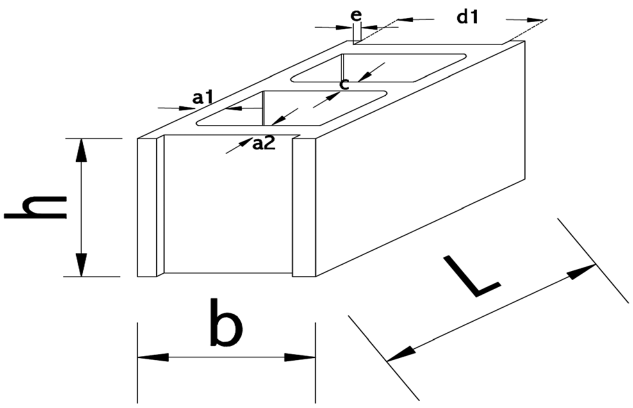
(g) Flexural strength of mortars was determined according to TS EN1015-11 [20]. Six specimens were tested for each type of mortar at 7 and 28 days.

(h) Compressive strength of mortars was determined according to TS EN1015-11 [20]. Three specimens were tested at 7 and 28 days.

TABLE 2 Bulk densities of pumice and limestone aggregates.

Type of Aggregate	Compacted Bulk Density (kg/m^3)	Uncompacted Bulk Density (kg/m^3)	Bulk Specific Gravity	Bulk Specific Gravity (SSD)	Apparent Specific Gravity (SSD)	Absorption (%)
Pumice	860	808	1.151	1.621	2.173	40.840
Limestone	1990	1777	2.350	2.430	2.550	3.360

FIG. 2 Dimensions and symbols of pumice block.



THERMAL CONDUCTIVITY EXPERIMENTS ON WALL SPECIMENS

In this investigation, seven different wall systems, by means of different applied mortar/plaster and block types, were built to determine the coefficient of thermal conductivity of walls (see **Table 6**). The sizes of the walls built were 1200 × 1200 mm (surface area was 1.44 m^2). Three different sizes of pumice blocks were used in this investigation. Two different types of mortar and plaster, namely, lightweight pumice mortar/plaster and limestone mortar/plaster, were applied on masonry units. Three walls made of pumice block and pumice mortar/plaster and three walls made of pumice block and limestone mortar/plaster were built. Moreover, one wall made of clay bricks of sizes 100 × 200 × 300 mm together with applied limestone mortar/plaster was built.

Prior to the consecutive application of each of the three coats, the walls were kept in a moist condition for 3 days. The thickness of the applied coats was about 5, 20, and 5 mm, respectively. The second coat of plaster applied to the walls was produced according to a mixture of pre-determined proportions and the third coat applied was a ready-mixed plaster, which did not contain any aggregate, and which was produced by adding the required amount of water.

A hot-box device was used to determine the coefficient of thermal conductivity of the walls. This test was performed according to TS EN ISO8990 [21]. The hot box consists of two highly insulated chambers, namely, the cold chamber and the hot chamber, which clamped tightly together to surround the test walls. The air in each chamber was conditioned by heating and cooling equipment to obtain the desired temperatures on each side of the walls. These temperature cycles can be programmed to simulate indoor and outdoor climatic conditions. Temperatures were measured by thermo-couples with 0.1°C sensitivity. There were nine thermo-couples on each chamber to measure the surface temperature of the wall specimen and three thermo-couples available on each chamber to measure the ambiance temperature of chambers. All data (surface and ambient temperatures) were transferred to a personal computer, where the coefficient of thermal conductivity was calculated using a software application. **Figure 3** shows the schematic diagram of the hot-box test mechanism.

The wall specimen was placed in between the hot chamber and cold chamber of the hot-box device (see **Fig. 4(*a*)**). Exterior surfaces (edges) of wall specimens were covered by a high insulating material to minimize the heat loss within the wall specimen (see **Figs. 4(*b*)** and **4(*c*)**). In this investigation, the temperature of the hot chamber was programmed to be 42°C and the temperature of the cold chamber was programmed to be 20°C. The duration of the test was set to 12 h. Therefore, wall specimens were exposed to hot and cold weather conditions, 42°C and 20°C, for 12 h.

TABLE 4 Properties of pumice blocks.

Property	Type 1	Type 2	Type 3
Surface area (mm^2)	58 500	74 100	97 500
Empty surface area (mm^2)	20 325	27 800	40 500
Solid surface area (mm^2)	38 175	50 300	57 000
Proportion of solid surface area (%)	65.25	62.00	58.50
Unit weight (kg/m^3)	740	712	675

TABLE 5 Mixture design by weight for traditional limestone plaster and joint mortar and pumice plaster and joint mortar.

Traditional Limestone Plaster and Joint Mortar

Type	Cement	Lime	Limestone	Water
First coat	1	0	4.44	1.12
Second coat	1	1	11.80	2.65
Joint mortar	1	1	11.80	2.65

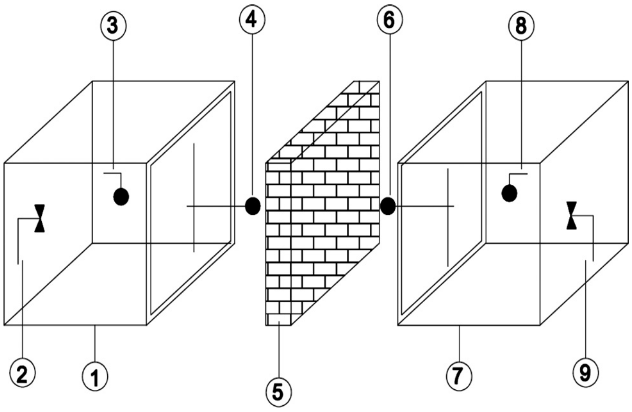
Pumice Plaster and Joint Mortar

Type	Cement	Lime	Pumice	Water
First coat	1	0	2.02	1.40
Second coat	1	1	5.38	3.20
Joint mortar	1	1	5.38	3.20

TABLE 6 Wall forms.

Mortar/plaster	Wall No.	Type of Masonry Unit	Dimensions (mm)	Thickness (mm)
Pumice	1	Pumice block	150 × 390 × 185	150
	2	Pumice block	190 × 390 × 185	190
	3	Pumice block	250 × 390 × 185	250
Limestone	4	Pumice block	150 × 390 × 185	150
	5	Pumice block	190 × 390 × 185	190
	6	Pumice block	250 × 390 × 185	250
	7	Clay brick	100 × 200 × 300	200

FIG. 3 Schematic of hot-box test mechanism. The explanation of the numbered figure parts are as follows: ① cold chamber, ② freezer fan, ③ thermo-couples (3 unit) to measure the ambient temperature of cold chamber, ④ thermo-couples (9 unit) to measure the surface temperature (cold) of wall specimen, ⑤ wall specimen (1200 mm x 1200 mm), ⑥ thermo-couples (9 unit) to measure the surface temperature (hot) of wall specimen, ⑦ hot chamber, ⑧ thermo-couples (3 unit) to measure the ambient temperature of hot chamber, and ⑨ heater fan.



Results and Discussion

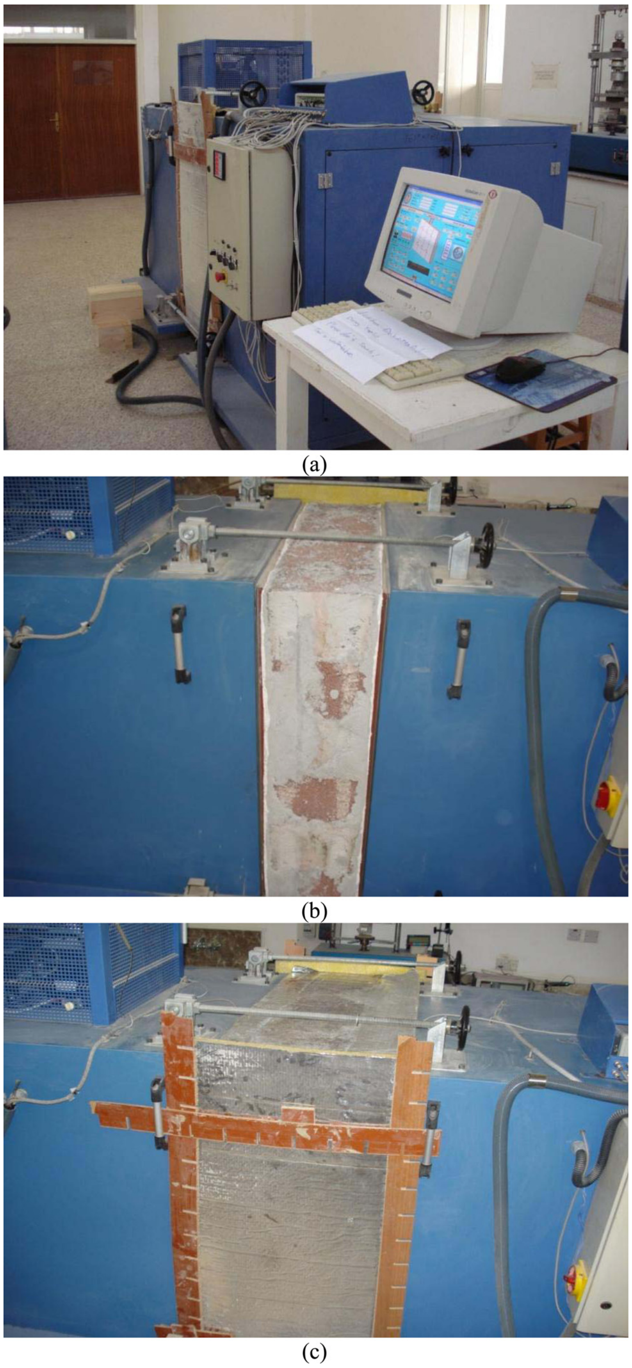
CONSISTENCY OF FRESH MORTAR

The test results for the consistency of fresh first coat plastering mortar and joint mortar, in addition to second coat of plastering mortar, made of pumice and limestone aggregates, are shown in **Fig. 5**. The maximum flow diameter limit was specified as 130 mm according to the test method; hence, the duration times for all test results were taken only at a flow diameter of 130 mm. The traditional limestone first coat plastering mortar and joint mortar/second coat plastering mortar had higher workability periods compared to pumice first coat plastering mortar and joint mortar/second coat plastering mortar. The reason for this was the rate of stiffening, which was higher in the pumice mortar because of the higher water absorption capacity of pumice aggregate. The consistency of first coat plastering mortars were much higher compared to the second coat plastering/joint mortar, which depended also on the application technique, because the first coat plastering was applied on the walls in rough form.

SETTING TIME OF MORTARS

The results of setting times of limestone mortars (traditional) and pumice mortars are shown in **Fig. 6**. Limestone mortars (traditional) had higher initial and final setting times compared to pumice mortars for both the first coat and second coat of plastering/joint mortars. Although lime causes an increase in the setting time, first coat plastering mortars contain more water compared to the second coat plastering mortars.

FIG. 4 The computerized hot-box setup: hot-box device connected to computer (*a*), wall specimen placed tightly between hot chamber and cold chamber (*b*), and exterior edges of a wall specimen covered by insulating material to minimize the heat loss (*c*).

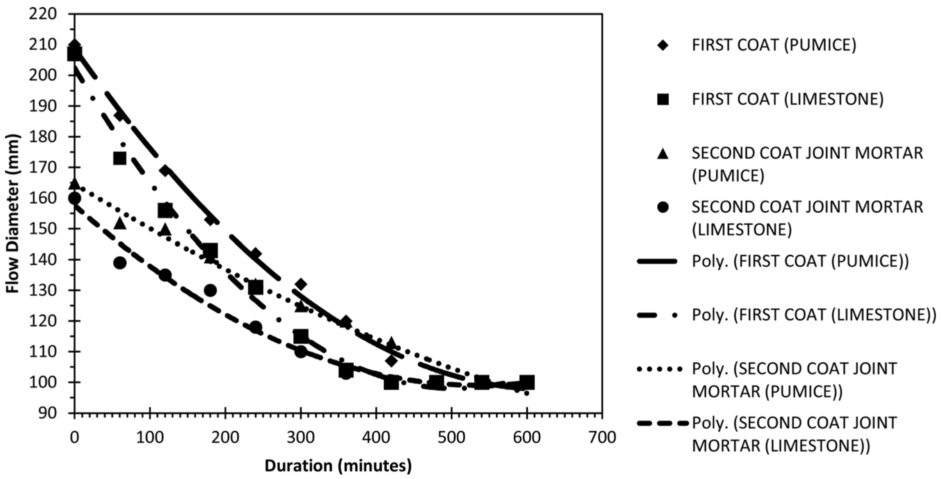


FRESH UNIT WEIGHT TEST

The results of fresh unit weight of limestone mortars (traditional) and pumice mortars are shown in **Table 7**. Limestone mortars (traditional) had higher fresh unit weight compared to pumice mortars for the first coat and second coat plastering/joint mortar. The fresh unit weight of limestone mortars was 1.5 times higher than pumice mortars because bulk density of

FIG. 5

Flow diameter of mortars.



pumice aggregate is lower compared to that of limestone aggregate.

HARDENED UNIT WEIGHT TEST

The results of hardened unit weight of limestone mortars (traditional) and pumice mortars are shown in **Table 7**. Limestone mortars (traditional) had higher hardened unit weight compared to pumice mortars for the cases of both first coat and second coat plastering/joint mortar. Hardened unit weight of limestone mortar was 1.65 times higher compared to pumice mortars because the bulk density of pumice aggregate is considerably lower compared to that of limestone aggregate.

WATER ABSORPTION TEST

The results of percentage of water absorption of limestone mortars (traditional) and pumice mortars are shown in **Table 7**. Pumice mortars had a higher percentage of water absorption compared to limestone mortars for both first coat and second coat plastering/joint mortars. In the case of the first coat plastering, the percentage of water absorption of pumice mortars was three times higher compared to limestone mortars. For the second coat plastering/joint mortar, the percentage of water absorption of pumice mortars was 1.5 times higher compared to that of limestone mortars.

COEFFICIENT OF CAPILLARY WATER ABSORPTION TEST

The results of coefficient of capillary water absorption of limestone mortars (traditional) and pumice mortars are shown in **Fig. 7**. Pumice mortars have a higher coefficient of capillary water absorption compared to limestone mortars in the case of both first coat and second coat plastering/joint mortar. For the case of first coat plastering, the coefficient of capillary water absorption of pumice mortars was 1.18 times higher compared to limestone mortars. In the case of second coat plastering/joint

FIG. 6

Comparison of initial and final setting times of mortars.

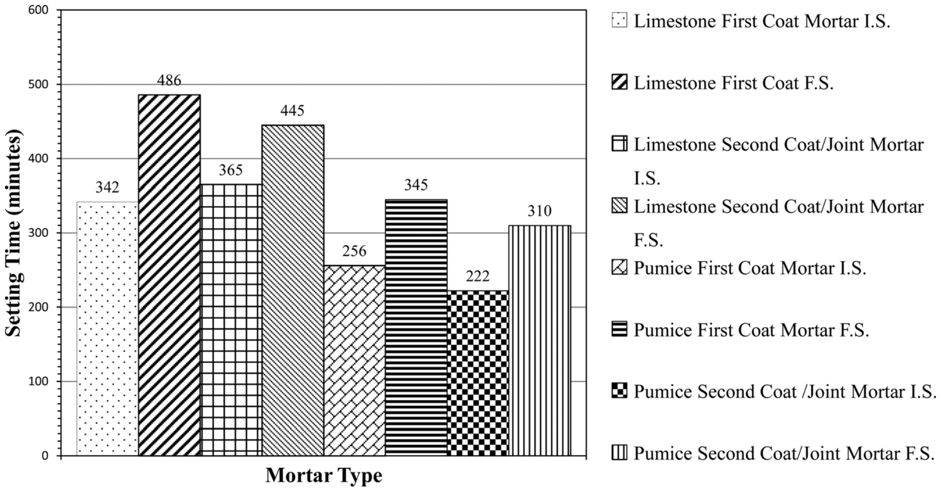
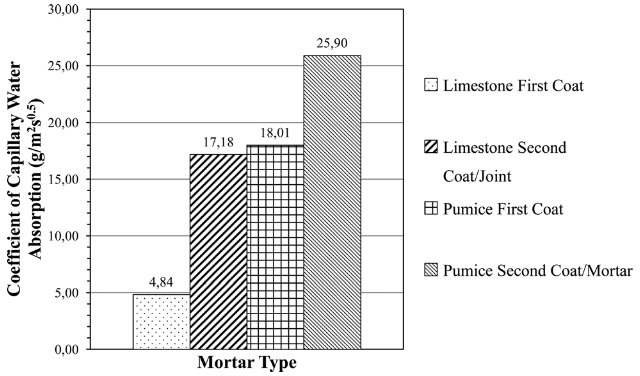


TABLE 7 Physical and mechanical properties of mortar specimens determined from different tests.

	Consistency of Fresh Mortar (min)	Initial/Final Setting Times of Mortars (min)	Fresh Unit Weight Test (kg/m^3)	Hardened Unit Weight Test (kg/m^3)	Water Absorption Test (%)	Coefficient of Capillary Water Absorption Test ($g/m^2s^{0.5}$)	Drying Shrinkage Test (%)	7 Days—Flexural Strength Test (MPa)	28 Days—Flexural Strength Test (MPa)	7 Days—Compressive Strength Test (MPa)	28 Days—Compressive Strength Test (MPa)
Limestone first coat	312	342–486	2128	1970	4.84	66.84	0.195	1.45	2.83	6.02	8.92
Limestone second coat/joint mortar	252	365–445	2299	1901	17.18	188.42	0.070	1.06	1.79	2.15	2.83
Pumice first coat	246	256–345	1380	1107	18.01	78.92	0.247	1.40	2.78	6.55	9.48
Pumice second coat/joint mortar	180	222–310	1502	1196	25.90	226.11	0.170	0.78	0.98	3.21	5.20

FIG. 7 Comparison of coefficient of capillary water absorption capacity of limestone and pumice mortars.



mortar, the coefficient of capillary water absorption of pumice mortars was 1.2 times higher compared to limestone mortars.

DRYING SHRINKAGE TEST

The results of percentage of drying shrinkage of limestone mortars (traditional) and pumice mortars are shown in **Fig. 8**. Drying shrinkage results indicate that pumice mortars have a higher percentage of drying shrinkage compared to limestone mortars for the case of both first coat and second coat plastering/joint mortars. For the case of first coat plastering, the percentage of drying shrinkage of pumice mortar was 1.27 times higher compared to limestone mortar. For the case of second coat plastering/joint mortar, the percentage of drying shrinkage of pumice mortar was 2.42 times higher compared to limestone mortars. Drying shrinkage of mortars was because of the loss of water in the drying process, which caused a decrease in the volume (contraction) of mortars. Drying shrinkage is directly proportional to the water/cement ratio. Therefore, voids and pores filled up with water in pumice aggregates caused a higher loss of water during drying. This resulted in a higher decrease in volume (contraction) in the case of pumice mortar.

FIG. 8 Comparison of percentage drying shrinkage of limestone and pumice mortars.

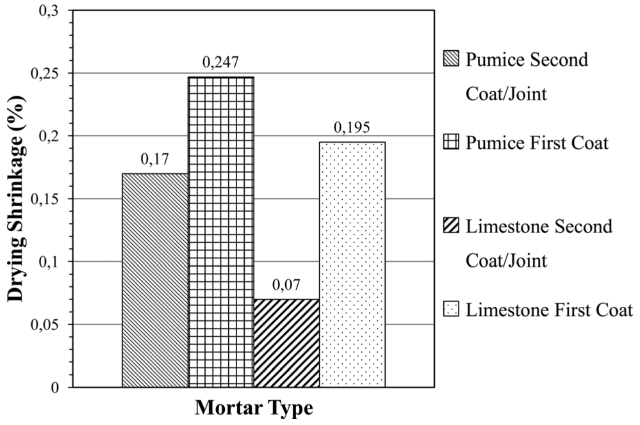
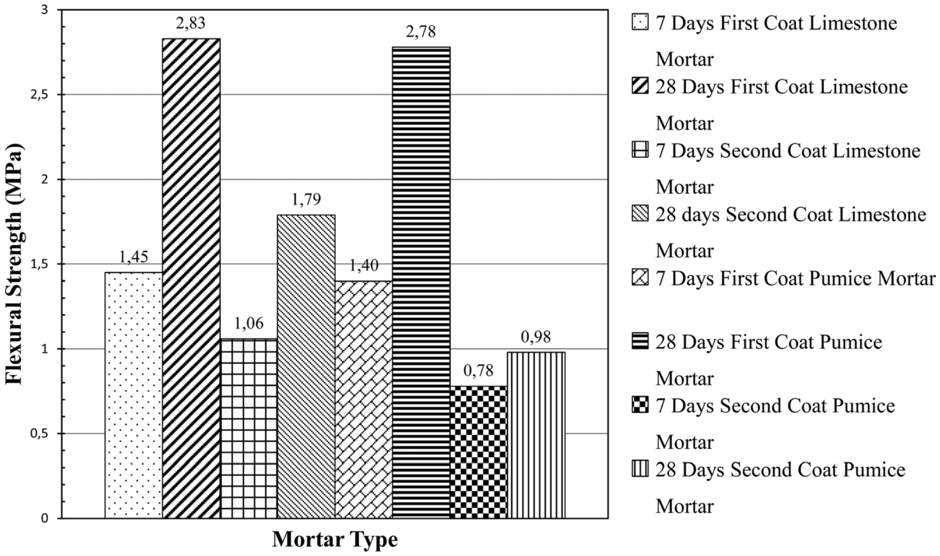


FIG. 9

Comparison of flexural strength of limestone and pumice mortars.



FLEXURAL STRENGTH TEST

The test results of flexural strength of limestone mortars (traditional) and pumice mortars for 7 and 28 days are shown in **Fig. 9**. For the case of first coat plastering, the 7 and 28 days flexural strength of pumice mortar was 1.04 and 1.01 times higher compared to limestone mortars, respectively. For the second coat plastering/joint mortar, flexural strength of pumice mortar at 7 and 28 days was 1.36 and 1.83 times higher compared to limestone mortar, respectively.

It was observed that lime causes a considerable decrease in flexural strength. The test results indicate that the 7 days flexural strength of first coat plastering mortars is 1.4 times higher compared to second coat plastering/joint mortar for both limestone and pumice mortars. The 28 days flexural strength of first coat limestone mortars was 2.83 times higher compared to second coat limestone plastering mortar. Likewise, the 28 days flexural strength of first coat pumice mortar was 1.58 times higher compared to second coat pumice plastering mortar. This increment in flexural strength could be attributed to the fact that pumice is a pozzolanic material [22], and pozzolans are siliceous and alumni-siliceous volcanic tuffs. When they are alone, they do not show any hydraulic characteristics. On the other hand, these materials present their hydraulic bonding behavior by a chemical reaction with calcium hydroxide at normal temperatures and moist conditions, which leads to an increase in flexural strength.

FIG. 10

Comparison of compressive strength of limestone and pumice mortars.

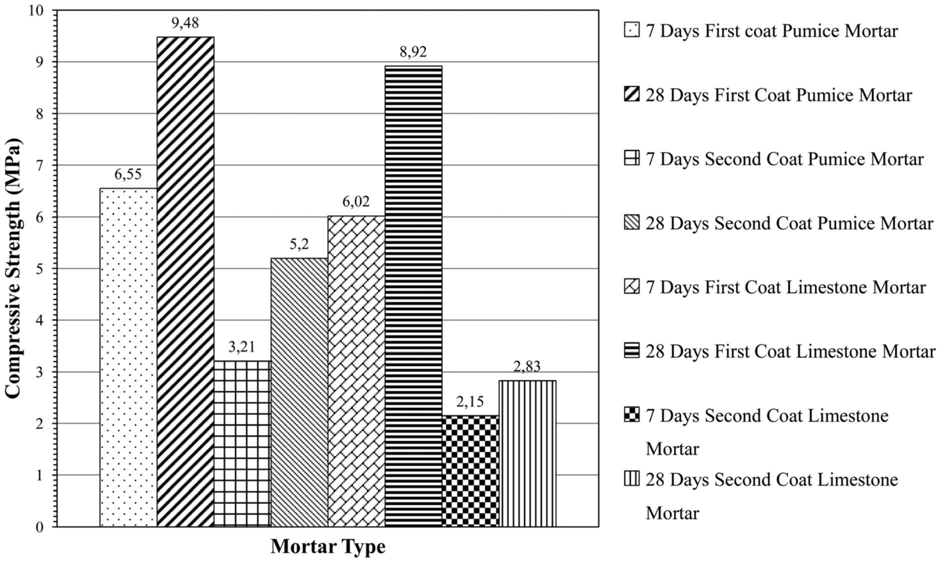


TABLE 8 Physical properties of walls.

Wall Type No.	Type of Mortar/Plaster	Dimensions of Pumice Block (t × L × h), mm	Number of Hollow File of Pumice Block	Proportion of Solid Surface Area of Pumice Block (%)	Unit Weight of Pumice Block (kg/m^3)
1	Pumice	150 × 390 × 185	2	65	740
2	Pumice	190 × 390 × 185	3	62	712
3	Pumice	250 × 390 × 185	3	58	675
4	Limestone	150 × 390 × 185	2	65	740
5	Limestone	190 × 390 × 185	3	62	712
6	Limestone	250 × 390 × 185	3	58	675
7	Limestone	200 × 300 × 100	8	1100	0.4156

COMPRESSIVE STRENGTH TEST

The test results of compressive strength of limestone and pumice mortars are shown in **Fig. 10**. The 7 and 28 days compressive strength of first coat pumice plastering mortar was 1.1 and 1.06 times higher compared to limestone mortar, respectively. The 7 and 28 days compressive strength of second coat pumice plastering mortar was 1.5 and 1.85 times higher compared to limestone mortars, respectively. It was observed that lime causes a considerable decrease in compressive strength. The test results at 7 and 28 days indicate that compressive strength of first coat plastering mortars is 2.5 and 3.15 times higher compared to second coat plastering mortars for limestone and pumice mortars, respectively. The higher test results for compressive strength of pumice mortars could be attributed to similar arguments as shown previously.

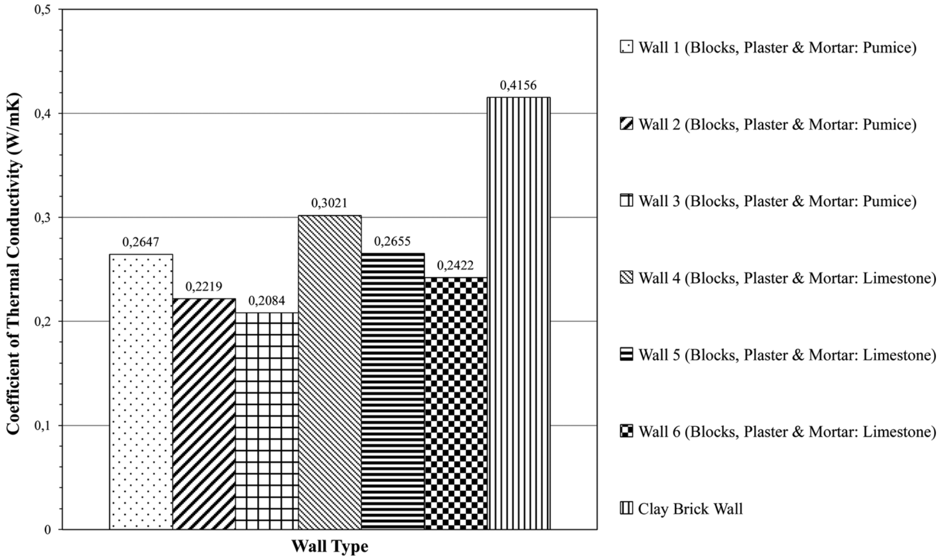
COEFFICIENT OF THERMAL CONDUCTIVITY OF WALL SYSTEMS

The coefficient of thermal conductivity is a measure of the amount of heat (energy) passing perpendicularly through a 1-m^2 area of homogeneous material of 1-m thickness for a temperature difference of a 1° between two surfaces for 1 h; λ is expressed as W/mK. The physical properties of the walls are shown in **Table 8**. **Figure 11** shows a comparison of thermal conductivity coefficient of wall systems, individually made with pumice mortar/plaster and limestone mortar/plaster, as well as clay brick wall system. The results of the coefficient of thermal conductivity indicates that the coefficient of thermal conductivity for types 1, 2, and 3 pumice block wall systems with limestone mortar/plaster are 0.3021 W/mK, 0.2655 W/mK, and 0.2422 W/mK, respectively. Coefficient of thermal conductivity of types 1, 2, and 3 pumice block wall systems with pumice mortar/plaster are 0.2647 W/mK, 0.2219 W/mK, and 0.2084 W/mK, respectively. Coefficient of thermal conductivity of clay brick wall system with limestone mortar/plaster is 0.4156 W/mK.

Coefficient of thermal conductivity of pumice block wall systems made with limestone mortar/plaster was 1.2 times higher compared to pumice block wall systems made with pumice mortar/plaster. Coefficient of thermal conductivity of

FIG. 11

Comparison of thermal conductivity coefficient of wall systems made with pumice and limestone mortar/plaster.



clay brick wall systems was 1.7 and 2.0 times higher compared to pumice block wall systems made with limestone mortar/plaster and pumice mortar/plaster, respectively.

It was observed that the use of pumice mortar/plaster in wall systems instead of limestone mortar/plaster provided about 16 % extra thermal insulation in walls. The unit weight of limestone mortar was 1.7 times higher compared to pumice mortars. In general, the most important influencing factor on thermal insulation capacity is the reduced unit weight of the material. This is because the lighter material provides better heat-insulating characteristics (lower coefficient of thermal conductivity) than a denser material. The unit weight of the mortar is influenced by the density of the aggregate and its particle size distribution. Coefficient of thermal conductivity increases with increasing unit weight of masonry units. Therefore, there is a direct relation between unit weight and coefficient of thermal conductivity of material.

To provide a good thermal insulation, lightweight concrete should have lower thermal conductivity values, provided that minimum strength and durability parameters are met [23]. There is a direct relation between proportion of the solid surface area and net unit weight of pumice block. Net unit weight decreases with decreasing proportion of solid surface area of pumice block.

The other important influencing factor is the geometry of pumice block. Coefficient of thermal conductivity decreases with increasing the hollow file number of pumice block. Therefore, longer distance of the heat-flow pathway results in a lower coefficient of thermal conductivity, which means better heat-insulating performance. The test results indicate that coefficient of thermal conductivity of wall systems made with two-file hollow pumice blocks was about 1.2 times higher compared to wall systems made with three-file hollow pumice blocks. As a result, increasing the number of hollow files in the pumice block provides better heat-insulation performance of the wall. The thermal conductivity coefficient of clay brick wall systems is significantly higher compared to pumice block wall systems. The most influencing factor is the higher unit weight of clay bricks. Unit weight of the clay brick was about 1.6 times higher compared to pumice blocks. Therefore, this factor reflects the test results of thermal conductivity coefficient of clay brick wall systems. In an investigation by Uysal et al. [24], it was found that the density of concrete decreased with an increase in pumice aggregate ratios (at a constant slump and cement content) and the reduction in the density because of pumice aggregate replacement was 12 %, 22 %, 34 %, and 42 % for 25 %, 50 %, 75 %, and 100 %, respectively. As a result of the reduction in density, the effect of pumice aggregate that replaced normal aggregates at 25 %, 50 %, 75 %, and 100 % by volume on thermal conductivity was about 8 %, 20 %, 28 %, and 47 %, respectively.

Conclusions

Based on the experimental study, the following conclusions can be made:

1. Workability duration, initial setting time, and final setting time of limestone mortars are higher compared to the pumice mortars in the case of both first coat and second coat plastering/joint mortars.
2. Fresh unit weight and hardened unit weight of limestone mortars are higher compared to pumice mortars in case of both first coat and second coat plastering/joint mortars.
3. Before any plastering operation, pumice aggregate should be saturated to reduce the water absorption capacity and coefficient of capillary water absorption of pumice mortars.
4. Percentage of drying shrinkage of pumice mortars is higher compared to limestone mortars. A lower shrinkage behavior is desirable in mortar/plaster for the reduction of the risk of shrinkage cracking.
5. Flexural strength and compressive strength (at 7 and 28 days) of pumice mortars are higher compared to limestone mortars in case of both first coat and second coat plastering/joint mortar.
6. The test results in this investigation show that the coefficient of thermal conductivity of wall systems made with pumice mortar/plaster is lower compared to wall systems made with limestone mortar/plaster.
7. In residential buildings, the use of pumice block instead of traditional materials (clay brick) provides about 35 %–45 % energy saving for the purpose of heating and cooling. In geometrical design, increasing the number of hollow files in pumice-block provides better heat insulation properties in wall systems.
8. In general, the most important influencing factor on thermal insulation capacity is the unit weight of the material. This is because lighter materials provide better heat-insulating characteristics.
9. Furthermore, the use of pumice mortar/plaster instead of limestone mortar/plaster (traditional) in pumice-block wall systems provides about 16 % extra contribution in the thermal insulation performance of the wall.

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