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Possible Use of Diatomite and Pumice-Amended Mortar and Plaster in Agricultural Structures[#]

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ABSTRACT

This study was conducted to investigate the potential use of diatomite (a natural pozzolana) and pumice in plasters and mortars to be used in agricultural buildings. Compacted and loose unit weights, specific weight, water absorption, organic matter content, abrasion resistance of aggregate (sand and pumice) and pozzolana were investigated and materials were found to comply with the relevant standards. Test results on fresh (unit weight and slum test) and hardened (unit weight, capillary water absorption, total water absorption, bending and compressive strength, vapor diffusion test) mortar samples revealed that pumice and diatomite could be used in agricultural structures. Diatomite and pumice should be heat-treated and grounded before to use in mortars. In plasters to be made with abundant pumice and diatomite sources, high water holding capacity of the materials should be taken into consideration and further researches should be carried out about their compliance with the other materials.

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Introduction

Agriculture is an industry as old as history of humanity and have been practiced to meet plant and animal originated needs of humans in an economic and quality fashion. It is an ever-growing economic activity. Such practices can meet the demands and needs only with proper production facilities, product storage and preservation structures. All these facilities or structures are called as agricultural structures. Agricultural structures are so constructed with the materials as to meet water, heat and noise insulation of the structures just to provide sufficient or optimum conditions for the animals or plants grown inside these buildings (Alkan, l972).

Mortars are used over the walls and ceilings as plaster to protect these structural members from external conditions. They should be easily processed and applied smoothly over the surfaces. Mortars are usually used over the surfaces which was desired to be smooth, to have esthetic appearance, to protect against water and moisture, to have sufficient strength against the forces and not to deform easily. Such attributes make strength and imperviousness as the prominent attributes of the mortars. Structural mortars are also used for decorative and esthetic purposes. In such mortars, this time workability, adherence and easy preparation become prominent attributes. In these cases, usually gypsum mortars are used. However, since gypsum mortars are sensitive against water or moisture, they should not be used over highly moist surfaces or over the surfaces with direct contact with water (Mavi, 2000).

Mortars are used in agricultural buildings to provide an integrity of the structure, to protect structural members against external factors like sun, water and wind, to provide protection against internal factors like evaporation, moisture and fermentation, to prolong life span of structural members and thus to economic life of the buildings and to provide proper environmental conditions. Aggregates are the greatest component of mortars and plasters used in constructions and building insulation. Usually light-weight aggregates are used in agricultural buildings to reduce the loads over the structural members, thus to reduce construction costs. Such light-weight aggregates also provide quite well heat and moisture insulation in agricultural buildings. Locally available natural materials are commonly used as light-weight aggregate and such uses bring about significant advantages in improving social welfare levels of the local people. Turkey has great diatomite and pumice reserves in some regions of the country. They may constitute a great source for light-weight aggregates.

The present study was conducted to investigate possible use of natural pozzolana diatomite and pumice in making plaster mortar and to investigate potential use of these mortars in agricultural structures. The study will probably increase the use of diatomite and pumice in making mortars. Such uses will then provide sufficient insulation, economy and safety in agricultural buildings. Natural resources will also be used economically, materials with high heat insulation capacity will be produced and such materials will be used in agricultural buildings in which heat-moisture balance and environmental factors are the critical issues.

Material and Method

Material

In this study, sand was used as aggregate; pumice was used as light-weight aggregate; diatomite mined from quarries was used a pozzolana; Portland calcareous cement and air slaked lime were used as binding agent and municipal water was used as mixing water.

The sand used in experiments was supplied from sand quarries over Yeşilırmak River in central town of Tokat province. Grain size was smaller than 4.0 mm. Pumice used in the experiments was supplied from the pumice quarries in Şıhbarak village of Tomarza town of Kayseri province. The pumice was processed mechanically in Develi town of Kayseri and supplied from commercial dealers of Develi.

Aggregates were sampled in accordance with TS 706 EN 12620+A1 (2009) by using the method of quartering. Samples were then subjected to specific gravity and water suction tests (Memiş, 2007), unit weight tests (TS EN 1097-3, 1999; Memiş, 2007), aggregate grain size distribution tests (TS ISO 3310-1, 2009; TS EN 933-1, 2012; TS ISO 3310-2, 2015), aggregate fine materials ratio tests (TS 706 EN 12620+A1, 2009; TS EN 933-10, 2010; Anonymous, 2012b).

The pozzolana and diatomite used in the experiments were supplied from Kahraman Kazan town of Ankara province. It was not containing any organic materials and grain size range was 0.04-0.14 mm. Physical characteristics of diatomite are provided in Table 1 and chemical characteristics are provided in Table 2 (Anonymous, 2015).

Cement: CEM II/B-M(P-L)32.5R N Portland cement produced in accordance with TS EN 197-1 standard and air slaked lime produced in accordance with TS EN 459-1 standard were used in preparation of experimental test specimens. Chemical characteristics of the cement used in experiments are provided in Table 3.

Municipal water without silt, organic matter and salt was used as mortar mixing water.

Method

The mixtures used in the experiments were determined with the aid of cement flow table in accordance with masonry wall mortar consistency tests with binder/aggregate ratios specified in TS EN 13914-2 (2016) and TS EN 13914-1 (2007) standards and mixing water ratio specified in TS EN 1015-3 (2000) (Table 4). Mortar mixture ratios were used based on cubing calculations as recommended in TS EN 998-2 (2011) standard. Sand and pumice passed through 0-4 mm sieves were used in equal volumes. Cement was used as the binding agent. Diatomite quantities were arranged as 0% (control group), 10, 20 and 40% of cement. A total of 32 mixtures were prepared (Table 5).

In fresh plaster mortar experiments, flow ratio was taken into consideration to determine water requirement of the mixtures. Amount of water getting into the mixture (mortar consistency) was determined separately for each class with the aid of the values recommended in ASTM-C1437-5 (2001) and data obtained from vibratory table tests as to have 110±5% flow (TS EN 1015-3, 2000; TS EN 1015-9, 2000; TS EN 998-2, 2017). Unit weight of fresh plaster mortars was determined in accordance with TS EN 998-2 (2017) standard. Unit weight of hardened mortar was determined in accordance with TS EN 1925 (2000) standard, capillary water suction was determined in accordance with Ünsal and Şen (2008) and Çakır (2010) with total water suction tests. Bending and compression strength tests were carried out over 40x40x160 mm test specimens (Memiş, 2007; TS EN 1015-11/A1, 2013).

Table 1 Physical characteristics of diatomite

Colour	Oyster white – Yellowish
Crystal structure	Amorphous
Crystal water	None
Hardness (mohs)	5.5-6.0
Maximum density (g/cm^3)	0.44
Specific density (g/cm^3)	0.36
Moisture content (%)	< 0.5
pH	5.10

Table 2 Chemical characteristics of diatomite

Silica (SiO_2)	95
Phosphorus pentaoxide (P_2O_5)	0.0158
Potassium oxide (K_2O)	0.351
Sodium oxide (Na_2O)	0.0637
Calcium oxide (CaO)	0.826
Magnesium oxide (MgO)	0.293
Aluminum oxide (Al_2O_3)	1.42
Iron oxide (Fe_2O_3)	1.77
Sulphur (S)	0.05
carbon (C)	0.17
Titanium oxide (TiO_2)	0.171

Table 3 Chemical characteristics of the cement

Chemical composition (%)	Cement type CEM II/B-M(P-L)32.5R
SiO_2	26.14
Al_2O_3	6.34
Fe_2O_3	4.08
CaO	49.13
MgO	2.99
Na_2O	0.55
K_2O	0.67
SO_3	2.26
Cl	0.0089
Ignition loss	6.8
Imponderable residue	1.05
Free lime	0.012

Table 4 Mortar mixture ratios*

Mixture Ratio Types		External plaster			Internal plaster		
		Cement	Air slaked lime	Aggregate	Cement	Air slaked lime	Aggregate
Rough rendering layer	1st Option*	1 scale	-	3 scale	1 scale	-	3 scale
	2nd Option*	1 scale	2 scale	9 scale	1 scale	1.5 scale (LP)	9 scale
	3rd Option	1 scale	1.5 scale (LP)	9 scale	1 scale	1.5 scale (LP)	3 scale
Brown coat	1st Option*	1 scale	2 scale	10 scale	1 scale	2 scale	3 scale
	2nd Option	1 scale	1.5 scale (LP)	10 scale	1 scale	1.5 scale (LP)	3 scale
Finish coat	1st Option*	1 scale	2 scale	11 scale	1 scale	2 scale	4 scale
	2nd Option	1 scale	1.5 scale (LP)	11 scale	1 scale	1.5 scale (LP)	3 scale

*(TS EN 13914-2, 2016; TS EN 13914-1, 2016), LP: Lime Putty, *Mixture ratios

Table 5 Mortar Mixtures

Mixture Types		Cement (scale)	Air slaked lime (scale)	Aggregate Sand – Pumice (scale)		Diatomite (%)
External Rough Rendering	External Rendering - 1					
	SDS 1.1.	1	-	1.5	1.5	0
	SDS 1.2.	1	-	1.5	1.5	10
	SDS 1.3.	1	-	1.5	1.5	20
	SDS 1.4	1	-	1.5	1.5	40
	External Rendering - 2					
	SDS 2.1.	1	2	4.5	4.5	0
	SDS 2.2.	1	2	4.5	4.5	10
	SDS 2.3.	1	2	4.5	4.5	20
	SDS 2.4	1	2	4.5	4.5	40
External Brown Coat	External Rendering - 3					
	KDS 3.1.	1	2	5	5	0
	KDS 3.2.	1	2	5	5	10
	KDS 3.3.	1	2	5	5	20
	KDS 3.4	1	2	5	5	40
External Finish Coat	External Rendering - 4					
	İDS 4.1.	1	2	5.5	5.5	0
	İDS 4.2.	1	2	5.5	5.5	10
	İDS 4.3.	1	2	5.5	5.5	20
	İDS 4.4	1	2	5.5	5.5	40
Internal Rough Rendering	External Rendering - 1					
	SİS 1.1.	1	-	1.5	1.5	0
	SİS 1.2.	1	-	1.5	1.5	10
	SİS 1.3.	1	-	1.5	1.5	20
	SİS 1.4	1	-	1.5	1.5	40
	External Rendering - 2					
	SİS 2.1.	1	-	4.5	4.5	0
	SİS 2.2.	1	-	4.5	4.5	10
	SİS 2.3.	1	-	4.5	4.5	20
	SİS 2.4	1	-	4.5	4.5	40
Internal Brown Coat	External Rendering - 3					
	KİS 3.1.	1	2	1.5	1.5	0
	KİS 3.2.	1	2	1.5	1.5	10
	KİS 3.3.	1	2	1.5	1.5	20
	KİS 3.4	1	2	1.5	1.5	40
Internal Finish Coat	External Rendering - 4					
	İİS 4.1.	1	2	2	2	0
	İİS 4.2.	1	2	2	2	10
	İİS 4.3.	1	2	2	2	20
	İİS 4.4	1	2	2	2	40

SDS: External Rough Rendering; KDS: External Brown Coat; İDS: External Finish Coat; SİS: Internal Rough Rendering; KİS: Internal Brown Coat; İİS: Internal Finish Coat

Samples were prepared with 7 cm diameter and 2 cm thick molds and rapidly poured into cups with $CaCl_2$ and Styrofoam as filling agent. The empty spaces between cup inner surface and samples were filled with melted wax and air exposure of $CaCl_2$ was prevented. Following this process, each sample was weighted. Ambient temperature and relative humidity were measured with the aid of hygrometer and daily water vapor pressure values were calculated by using "temperature-dependent saturated water vapor pressure values" (Mavi, 2000).

Vapor diffusion coefficient;

$$\mu = \frac{1}{hort} \left(6h \; x \; A \; x \; \frac{P1-P2}{G} - \; dh\right)$$

$$6h \; = \frac{0{,}083}{Rb.T} \; x \; \frac{Po}{P} \; x \; \left(\frac{T}{273}\right)^{1{,}81}$$

G = F_{ort}/24 h

Where;
h_{ort} =Sample thickness (m)
$6h$ =Water vapor conductivity of air (kg/mhPa)
A =Sample surface area
G =Water vapor transmission rate
d_h =Air thickness beneath the sample
T =Ambient temperature (°C)
P_o =Normal atmospheric pressure (mmHg)
P =Average air pressure (mmHg)
F_{ort} =Sample weight difference between two measurements
μ =Vapor diffusion resistance coefficient
P_1,P_2 =Water vapor pressures.

Results and Discussion

Sieve analysis was performed to determine grain size distribution of aggregates and analysis results are provided in Table 6.

Aggregate compacted and loose unit weights were determined respectively as 1.56 g/cm^3 and 1.37 g/cm for sand and respectively as 0.72 g/cm^3 and 0.62 g/cm^3 for pumice. Aggregate specific gravity was identified as 2.45 g/cm^3 for sand and as 1.84 g/cm^3 for pumice. Since aggregate unit weight and specific gravity values were within the recommended values, they were found to be suitable for mortar making. Aggregate water suction ratio was identified as 0.89% for sand and 44.0% for pumice.

Test Results for Fresh Mortar

Flow test; Consistency water and thus workable consistency of the mortar increased with increasing diatomite content of the mortar. Increasing diatomite contents increased water suction ratios, thus increased water requirements, then flow quantities decreased with increasing diatomite quantities. In mixtures with high free lime quantities, high silica quantities (85%) of diatomite gets into chemical reaction with free lime and gets binding quality. Therefore, Internal Finish Coat 4 and Internal Brown Coat 3 with high lime contents had higher flow ratios (Figure 1).

Unit weight; Unit weights of mortar mixtures varied greatly with diatomite quantities in mixtures. The primary reason of such variations was uncompleted chemical reactions among the mixture materials and unfinished setting duration. Loose unit weight of the mortars generally varied between 1.55-1.60 g/cm³ and compacted unit weights varied between 1.70-1.75 g/cm³ (Figure 2).

Hardened Mortar Test Results

Unit weights; Light-weight aggregate with a porous nature had lower unit weights than the normal aggregates. Unit weights of oven-dried and air-dried hardened mortars increased with increasing diatomite quantities in mixtures. Air-dried unit weights of mortar samples varied between 1.34-1.90 g/cm^3 and unit weights of oven-dried samples varied between 0.82-1.55 g/cm^3. Grounded pozzolanic materials in mixtures increased specific gravity of the mortar samples. The difference between unit weights was 0.33 g/cm^3 at 0% diatomite and the value was identified as 0.36 g/cm^3 at 10%, 0.35 g/cm^3 at 20% and finally 0.39 g/cm^3 at 40% diatomite content. The primary reason for such differences was high water suction capacity of diatomite because of porous nature and binding quality of diatomite through chemical reactions with free lime (Figure 3)

Table 6 Sieve analysis results

Sieve analysis for sand				
Sieve size (mm)	Amount retained over the sieve (cumulative) (g)	Amount passed from the sieve (cumulative) (g)	Amount retained (%)	Amount passed (%)
4	0	1000	0	100
2	53.44	946.56	5.34	94.66
1	379.68	620.32	37.97	62.03
0.500	530.20	469.80	53.02	46.98
0.250	799.97	200.03	80.00	20.00
0.100	900.52	99.48	90.05	9.95
Sieve analysis for pumice				
Sieve size (mm)	Amount retained over the sieve (cumulative) (g)	Amount passed from the sieve (cumulative) (g)	Amount retained (%)	Amount passed (%)
4	0	1000	0	100
2	46.03	953.97	4.60	95.40
1	409.86	590.14	40.99	59.01
0.500	665.27	334.83	66.50	33.5
0.250	945.11	54.89	94.11	5.49
0.100	999.78	0.22	99.98	0.02

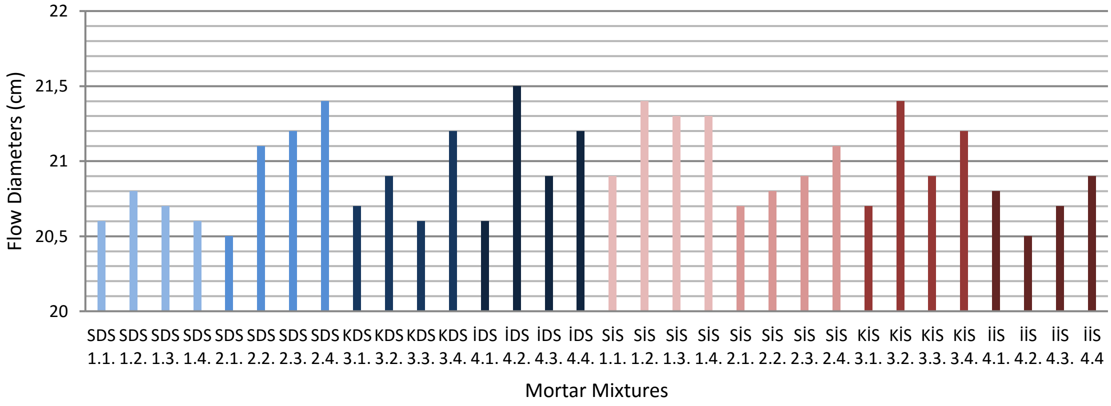

Figure 1 Flow diameters of fresh mortars

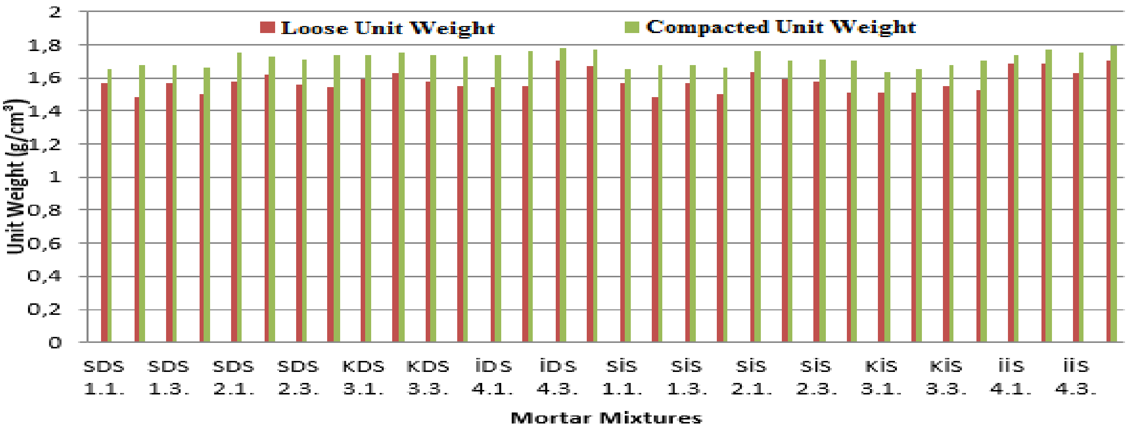

Figure 2 Loose and compacted unit weights of mortars

Capillary water absorption; Since the variation in sample weights was less than 1% from 49th minute, capillary water absorption tests were terminated and capillary absorption coefficients were calculated with these values. Fractures were observed in lime-containing External Rough Rendering 2 and External Finish Coat 4 mixtures and therefore they were weighted.

There was a reverse relationship between diatomite quantities and capillary water absorption of lime-containing mortar mixtures. Diatomite has a quite high pozzolanic activity, thus reacts with lime in mixtures and gets binding quality and finally gets a solid structure. Less interconnected pore quantity increase insulation capacity of the mixtures. On the other hand, in mixture without lime, diatomite used at 0 and 10% of the cement decreased capillary absorption of the mixtures, but 20 and 40% diatomite increased capillary water absorption. Therefore, diatomite quantities should be selected based on the type of binding agents.

Total water absorption tests; Total water absorption of hardened mixtures varied between 15.86-21.77% for External Rough Rendering 1; between 20.43-24.34% for External Rough Rendering 2; between 19.39-23.32% for External Brown Coats; between 21.64-22.14% for External Finish Coat 4; between 15.86-21.77% for Internal Rough Rendering 1; between 20.38-22.47% for Internal Rough Rendering 2; between 22.22-29.04% for Internal Brown Coat 3; between 19.19-26.01% for Internal Finish Coat 4.

There was a reverse relationship between total water absorption and diatomite content of the lime-containing mixtures. In other words, total water absorptions of lime-containing mixtures decreased with increasing diatomite quantities. But water absorption of the other mixtures increased with increasing diatomite quantities. In mixtures with high volumes of lime and less volume of aggregate (IBC 3.1, IFC 4.1), increasing diatomite quantities also increased water absorption quantities. Biricik (1999) investigated variations in volumetric water absorption of mortar mixtures with time and pozzolana quantities and reported increasing water absorption quantities with increasing time and pozzolana quantities.

Vapor diffusion tests; 20% diatomite content increased vapor diffusion of 1st and 2nd samples of all internal and external plaster mixtures. The greatest value was observed in 10% diatomite- containing Internal Plaster 4 and values varied with diatomite contents. The greatest values were obtained from Internal Finish Coat 4, Internal Rough Rendering 2, Internal Rough Rendering 1 and External Rough Rendering 1 mixtures. High silica content of diatomite reacts with lime thus gets binding quality and fill up the capillary voids. Therefore, increasing vapor diffusions were observed in diatomite-containing mortars. Vapor diffusion coefficients of the samples are presented in Figure 4.

Bending and compressive strength tests; Bending and compressive strength of lime-containing hardened mortars under axial loads increased with increasing diatomite quantities. Bending and compressive strength of the other hardened mortars without lime also increased with increasing diatomite quantities and the best outcomes were reached at 20% diatomite content (Figure 5). Binding quality of diatomite improved compressive strength of the samples and diatomite-containing samples had higher bending and compressive strengths than the mortars without lime. Some samples did not exhibited a bending strength, thus these samples were not recommended to be used in mortars.

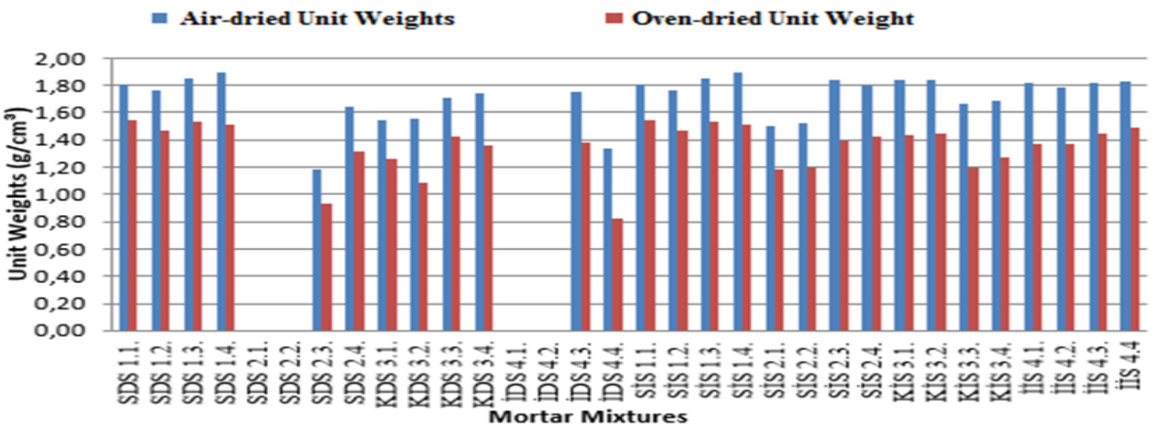

Figure 3 Unit weights of hardened mortar samples

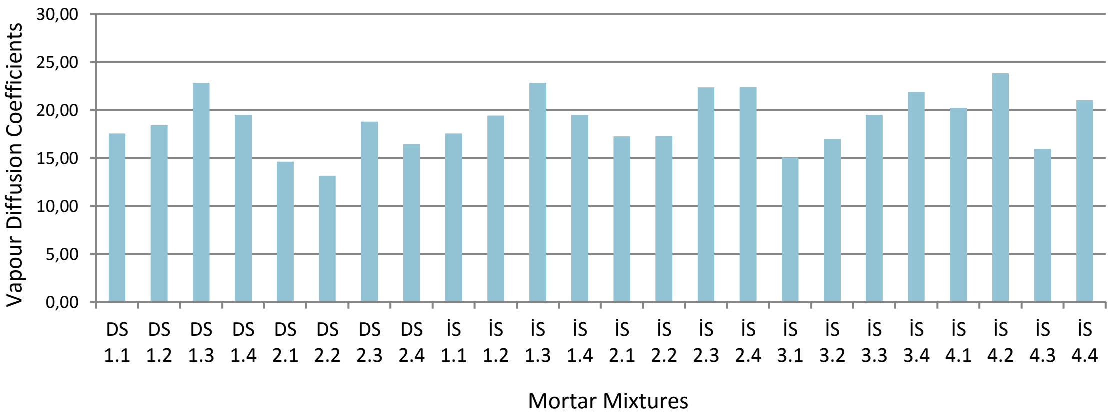

Figure 4 Vapor diffusion coefficients of the samples

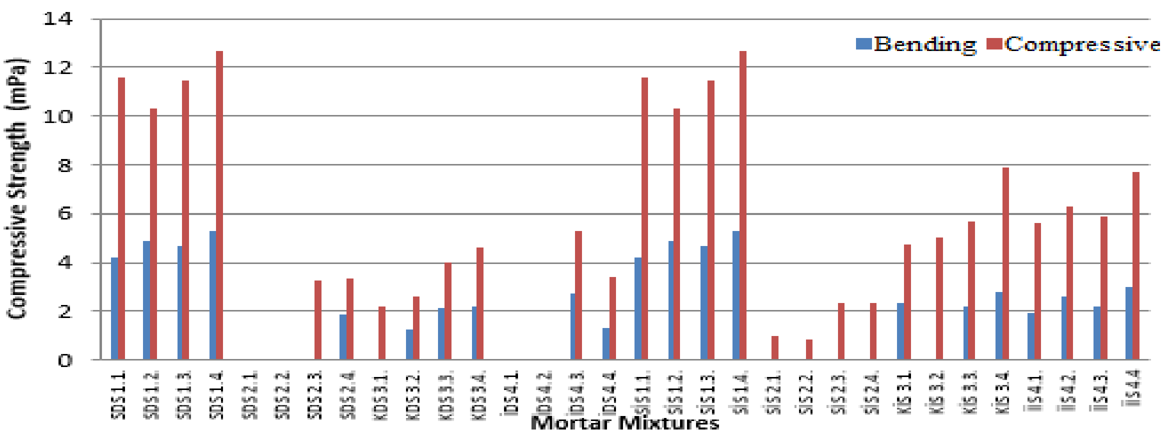

Figure 5 Bending and compressive strength of mortar samples

Conclusion and Recommendations

Aggregates constitute the greater portion of the plaster mortars used in agricultural buildings. However, certain quantities of pozzolanic materials are also supplemented to improve the heat and moisture insulation of plaster layers. In present study, easily supplied sufficiently resistant sand and energy-saving light-weight pumice were used as aggregate and diatomite with high pozzolanic activity and easy reactions with lime was used as the binding agent.

Potential use of light-weight aggregates in structural members of agricultural buildings was previously investigated. In present study, their potential use in plaster mortars was assessed through various physical tests. Pozzolanic activity of diatomite was tested in mortar mixtures with aggregate contents of between 50-90% and pozzolana contents of between 0-40%.

Present findings revealed that Internal Rough Rendering 1 and External Rough Rendering 1 with high bending and compressive strength and low capillary water absorption values were thought to be used in agricultural buildings. It was also concluded based on present findings that diatomite supplemented Internal Rough Rendering 1, External Rough Rendering 1, Internal Brown Coat 3 and Internal Finish Coat 4 could also be used in plaster mortars of agricultural buildings. It was also concluded that diatomite and pumice-supplemented mortars could be used in brown coats and finish coats and such uses might provide significant contributions to economy and environment.

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