Asian Journal of Natural & Applied Sciences   Vol. 7(3) September 2018

THE INFLUENCE OF USING COCAMIDOPROPYL BETAINE AS CHEMICAL ADDITIVE ON THERMAL AND PHYSICAL PROPERTIES OF FOAM MORTAR

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ABSTRACT

Gaza Strip suffers from a real problem in the sources of energy needed while a heavy use of electric power has become essential for Air conditioning purposes and comfort inside buildings where outdoor temperatures fluctuate in summer and winter. The use of insulating materials is not popular in Palestine, in spite of their long-term financial benefit, due to the fact that installation of such materials is expensive and requires skilled labor so the development of simply handled mortar blocks with high thermal insulation properties becomes a necessity. The present paper aims to evaluate the thermal and physical properties,namely, thermal conductivity, density, morphology and mechanical strength of foam mortar which used to manufacture a Lightweight Blocks. Six different mortar mixes were produced, Cocamidopropyl Betaine (CB) used as an air entraining agent. Morphology, compressive strength, as well as density, were determined for 28 days samples, thermal conductivity is also determined after 28 days. The results show that as the air content increase the compressive strength, density, and thermal conductivity decreases,and reach its maximum at 8% (CB) with a thermal conductivity lower from 0.76 to 0.12 W/ m.k. The SEM Analysis shows that the addition of (CB) produces consistent bubble structure with a uniform and homogenous bubble structure. Building blocks with performance improved in these ways will be beneficial for developing low-cost insulation building for local people.

Keywords: foam mortar, thermal conductivity , compressive strenght , density, SEM, lightweigh building blocks

INTRODUCTION

Gaza Strip suffers from a severe shortage of energy resources, especially electric power, where the power blackouts between 12-16 hours a day which makes the air conditioners ineffective in summer as well as heating in winter. Therefore necessitated developing the thermal insulation currently used in buildings. The light bricks, which are used in insulating walls, are the most efficient thermal insulation technique used in the buildings as a way of energy conservation, which plays an important role in national energy strategies, minimizing the substantial pressure on resources and the environment (Peng et al.,2008 and Xu and Wang,2007) . In the building, the external wall area occupies a larger proportion, compared with the building roof, doors, windows, and so forth (Harvey, 2009 and Sepp¨al¨a et al., 2008). The thermal preservation performance of the exterior wall is the key to achieving energy efficiency in buildings (Lai and Wang, 2015). Exterior wall differs among building materials, structural types and varies with environmental conditions. Traditional bricks, being widely used in many existing buildings, has poor thermal properties. (Zhou, et al (2012). Therefore, it is necessary to pay more attention to research directed at energy-saving

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buildings in terms of their thermal preservation and thermal insulation performance. Foam mortar provides low density, which reduces dead loads in constructions and good thermal conductivity, which allows using it in building envelope construction elements as effective thermal insulation and load-bearing material. the foam mortar reduces building costs, eases construction and has the advantage of being a relatively ‘green’ building material (Bumanis, 2013).

The insulation has two aims, the first aim is to retard the flow of heat from one place to another, and the second is to maintain temperatures such that condensation does not occur on inside surfaces. In the winter, insulation retards the flow of heat from the inside of the building to the outside, and in the summer retards the flow of heat from the outside to the inside. Also in the winter, it helps keep the inside surface warm enough that condensation will not occur. Insulation should be installed in the walls and ceiling of all confinement-type buildings for better control of temperature and moisture. (Meletse, 2005).

The thermal conductivity of hardened mortar depends mainly on its density and moisture content, also affected by the size and distribution of the pores, chemical composition, the crystallinity of the solid components and temperature (Bremner et al., 2000). The reduced thermal conductivity of the air present in foam mortar pores is the main reason for the higher insulation capacity of lightweight building blocks.

Regarding the contribution of the cement matrix, thermal conductivity tends to decrease with increments of the w/c ratio of the mixtures (Uysal, 2004). According to Bessenouci (2011), thermal conductivity is inversely proportionate to porosity. In turn, the variation of porosity is directly related to the density, which is once again emphasizing the main influences this characteristic has on the thermal conductivity of concrete (ACI213R, 2003).

It is well known that the pore structure of the foam mortar strongly influences its physical properties. Pore-forming agents (such as air entraining agents) are now commonly for improving the thermal properties of block products (Vr´ana and Bj¨ork, 2008). Qaraman et al (2017) reported that a uniform distribution of small air voids in the cement paste might greatly improve the physical properties such as compressive strength and thermal insulation. Du and Folliard (2005) noted that there is a minimum dosage of air entraining agent required to entrain air in the cement paste. Leslie and Qingye (2004) concluded that the addition of air-entraining agent increased the air content up to a saturation level, above which no further increase in air content was observed. Qaraman et al (2016) stated that a number of factors influences entrained air. Examples of such factors include the duration of mixing and the nature and concentration of the air entraining agent.

Air entraining agents was first discovered in 1930, these agents could be based on natural (for example, animal and vegetable fats and oils, such as tallow, olive oil, and their fatty acids) or synthetic surfactants. The surfactants can be divided into anionic, cationic, nonionic and amphoteric types. The more widely used are anionic surfactants. Amphoteric surfactants are less widely used; one of these amphoteric surfactants, which is widely used in detergents is cocoamidopropyl betaine.

Contrary to true amphoteric, which form salts in alkaline media, cocoamidopropyl betaine does not exhibit an anionic behavior under alkaline conditions. This material is zwitterionic at neutral and alkaline pH while it is cationic below their isoelectric points (acidic pHs). It shows no anionic properties, compatible with all classes of surfactants at all pHs. In addition, hard water has no effect on their foaming properties in aqueous solution.

This research focuses on the efficiency of using Cocamidopropyl betaine (CB) as an air-entraining agent in producing foam mortar with enhanced properties that make it more suitable for construction (such as producing light weigh blocks) than materials used currently for this purpose. The objective of this research is to study the influence of Cocamidopropyl betaine on the properties of hardened foam mortar such as compressive strength, density, thermal properties, and morphology.

MATERIALS AND METHODS

Materials

Cement: Portland cement of mark CEM I 42.5N obtained from SANAD-Palestine cement factory. Its chemical composition is given in Table 1.

Sand: Locally available almawasi (Palestine) sand. Its physical and chemical composition is given in Table 2.

Water: Potable water available from local sources was used for mixing and curing of specimens.

Air entraining agent: The air-entraining agent used was cocoamidopropyl betaine (CB) purchased from Sigma Aldrich and used as received as given in Table 3.

Table 1. The chemical composition of the used ordinary Portland cement (OPC).

Oxide (%)	OPC
SiO_2	21.5
Al_2O_3	4.52
Fe_2O_3	5.22
CaO	63.5
Na_2O	0.26
K_2O	0.11
Cl^-	0.02
MgO	2.36
SO_3	0.91
Free CaO	0.92
Ignition Loss	0.68

Table 2. Physical and chemical composition of the used sand

Property		Sand
Physical	Unit Weight	1.656
	Water content	0.0316
	Bulk specific gravity (SSD)	2.66
	Bulk specific gravity (DRY)	2.64
	Bulk specific gravity (Apparent)	2.68
	Water Absorption %	0.48
	fineness modulus	1.543%
	% passing sieve 0.6 mm	98.5%
Chemical	Chloride %	0.01
	calcium carbonate %	9.6
	Sulfate %	0.0012

Table 3. Specification of Cocamidopropyl betaine (CB)

Specification	Cocamidopropyl betaine (CB)
Chemical formula	$C_{19}H_{38}N_2O_3$
Molar mass	342.52 g/mol
Appearance	Clear to slightly turbid, pale yellow liquid
Total dry matter	43.5 – 46.5 %
Active matter	38 – 40 %
Sodium chloride	5.7 – 6.5 %
pH at 25C^0	4.5 – 6
Character	amphoteric

METHODS

Paste preparation

The mortar specimens are prepared by dissolving different concentrations of (CB) in water then adding to cement. The water to cement ratio (w/c) is 0.5. The percentages of (CB) used range from 1 to 8 % by weight of cement, the cement to a sand ratio (c/s) 0.43.

The mixing is carried out under continuous and vigorous stirring for about three minutes. After complete mixing, the resulted pastes is poured into (10 ×10 ×10 cm3) molds. The molds are kept at about 100% relative humidity at room temperature for one day. The hardened mortar is then removed from the molds after they attained the final setting and cured underwater for the rest of the hydration ages (up to 28 days).

Compressive Strength

Three specimens of each mix at different hydration times (3, 7, and 28 days) are used for examining the compressive strength of the pastes. The mean value of the three specimens at each hydration age is considered as the determined compressive strength. The strength test machine used is of point load taster (20063 cemasco S/N-Controls) type, Milano-Italy.

Bulk density and air content of the mortar

The bulk density is determined by measuring the weight of the sample in air and under water. The density and air content are then calculated as mentioned in (ASTM Standard C 138-08 – 2008).

Thermal conductivity

The thermal conductivity coefficient was tested using the steady-state guarded hot plate method (ASTM C 177). Ten discs, measured 130 mm in its diameter and the height was 30 mm, were used for this purpose, two for each mix. The thermal conductivity (k) was calculated using the following equation:

$$K_T = \frac{q_x x}{\Delta T}$$

Where: thermal conductivity constant (K_T) in W/(m*K), heat transfer rate or flux (qx) in W/m^2, distance or length (x) in meter and temperature differential (ΔT) in Celcius.

RESULTS AND DISCUSSION

Effect of the presence of air entraining agent on the on the bulk density of the mortar:

Air content is an important factor, which affects other aspects of the foam mortar (i.e. density, compressive strength, thermal conductivity, and workability). By adding an air-entraining agent to mortar, its molecules are inserted between adjacent molecules at the water surface; the mutual attraction between the separated water molecules is reduced. Reducing the surface tension stabilizes the bubbles against the deformation, thus facilitating the formation of bubbles.

The values of the air entrained in mortar hydrated for 28 days in presence of different percentages of (CB) are determined and given in Table (4). The results show a progressive increase in the air content by increasing an air entraining agent concentration and reaches its maximum value at the concentration of 8 %.

Table 4. Composition and properties of foam mortar mixes.

Mixture	Cement/ sand ratio	Water/ cement ratio	C B %	Density g/cm^3	Air percent	Thermal conductivity W/m.k	CS (N/mm^2)		
							3 days	7days	28 days
M0	0.43	0.50	0.0	1.93	0.00	0.76	79.14	95.30	115.20
M1	0.43	0.50	1.0	1.15	38.1	0.28	51.36	61.90	85.50
M2	0.43	0.50	2.0	0.93	48.9	0.22	20.19	24.05	35.65
M3	0.43	0.50	4.0	0.87	51.7	0.19	19.96	22.60	28.60
M4	0.43	0.50	5.0	0.77	56.6	0.17	17.01	20.51	27.42
M5	0.43	0.50	6.0	0.75	58.1	0.15	16.50	19.93	26.07
M6	0.43	0.50	8.0	0.72	61.2	0.12	15.10	18.21	24.11

The density of mortar is directly affected by the air content; they are inversely proportional to each other. The determined density of the hardened control specimen (zero air entraining agent concentration) and those of the specimens containing the air entraining agent after 28 days of hydration are shown in Table (2). The results showed that density decrease with increasing concentration, which refers to the increase in air content. It is found that the density decreases by about 0.3g/cm^3 when the air content is increased by about 14% (figure 1). (Qaraman et al., 2016).

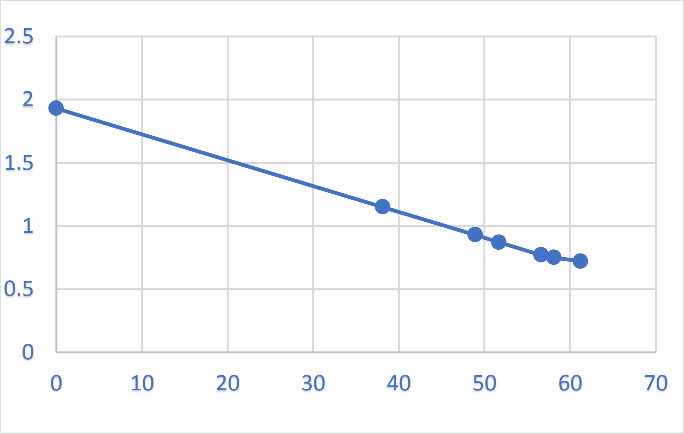

Figure 1: The relationship between the density and the percent of entrained air

Figure 1 (a & b) shows the photographs of the hardened foam mortar in the absence (M0) and presence of (CB) (M6) after 28 days of hydration. It can be noticed that the structure of mortar with the addition of (CB) produces consistent bubble structure with a uniform small air voids system these voids increase by increasing the concentration of (CB). These findings may indicate that a uniform air void system effects on the physical properties (i.e. density, compressive, and thermal conductivity) of the mortar, these results are great confirmed with previous findings **(qaraman, 2016, Ramamurthy, 2009, Neville, 1995 and Hassan, 2016)**.

(a) M0 **(b) M6**

Figure 1: (a & b) The hardened mortar in absence (a) and presense (b) of (CB) after 28 days.

Microstructure and Morphology Investigations (SEM Analysis)

The scanning electron microscope (SEM) is a powerful tool for imaging and chemical analysis in cement research. With a high resolution and a large depth of focus, it enables a detailed study of the surface topography of the rough surfaces of e.g. the formed calcium silicate hydrate (CSH) and calcium hydroxide (CH).

Scanning electron microscope (SEM) is used to examine the surface structure of hardened cement pastes, in the absence and in presence of 8% (CB) at the two hydration ages 7 and 28 days.

Microscopic photos for the 7 days hydration age are illustrated in Figure (3). Figure (3-a) shows the hydration products formed in absence of (CB). Calcium hydroxide appears as hexagonal plates beside the fibrous CSH phase. Figure (3-b) shows the micrographs of the hardened Portland cement pastes in presence of (CB), Large calcium hydroxide hexagonal plates beside CSH phase can be noticed.

Figure4 (a & b) shows the micrographs of the hardened Portland cement pastes in absence of (CB) and in presence of 8% (CB) after 28 days hydration. It can be noticed that the hydration products have a more compact structure composed of calcium silicate hydrates which explain the improvement in the strength after year for all mixes.

On another hand, the structure of cement paste with the addition of (CB) produces consistent bubble structure with a uniform and homogenous bubble structure with air voids system (85.7 µm).

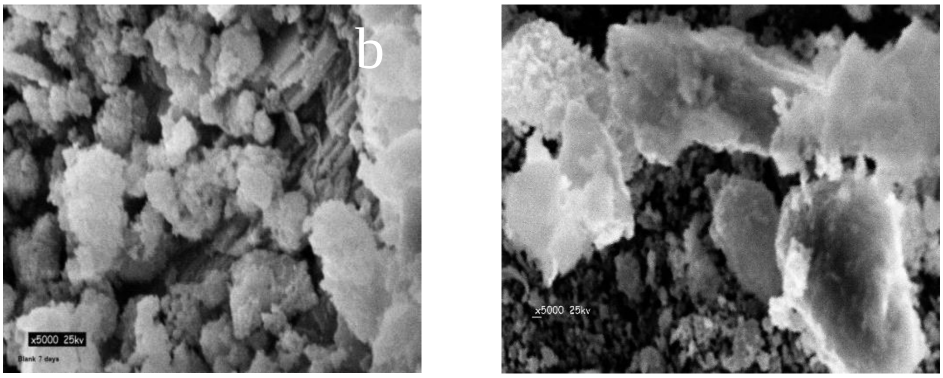

Figure 3: SEM of hardened cement pastes after 7 days hydration (X = 5000).

a) Without (CB) b) 8 % (CB)

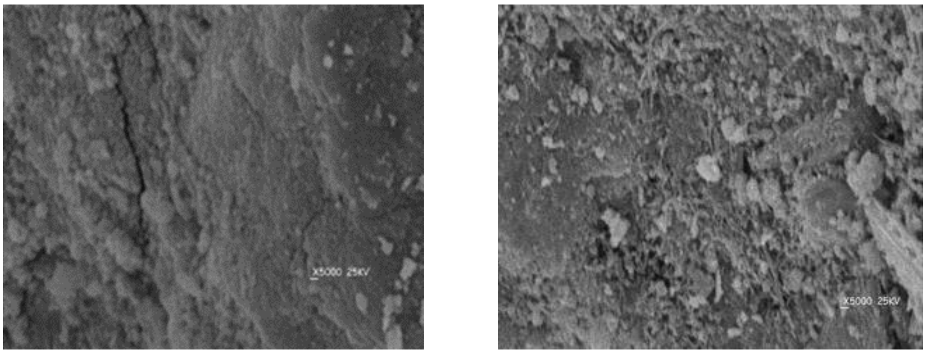

Figure 4: SEM of hardened cement pastes after 28 days hydration (X = 5000).
a) Without (CB) b) With 8% (CB)

Effect of Air entraining agent on the Compressive Strength of the Hardened mortar

Compressive strength is an important criterion specified in the design of foam mortar and should be considered equally important as density. The properties of hardened mortar are time-dependent, therefore, any test method performed on the mortar should be done at a certain hydration age.

The values of the compressive strength of hardened mortar without and with (CB) at optimum concentrations and different hydration ages (3, 7 and 28 days) have been determined.Three specimens of each mix at each hydration time are used for examining the compressive strength of the mortar. The mean value of the compressive strength of the three specimens at each hydration age is considered.

The results are given in Table (4) and represented graphically in Figures (5). All mixes show an increase in the values of the compressive strength with increasing hydration time. This is believed to be due to the progress of the cement hydration. The highest compressive strength is achieved, after 28 days.

The compressive strength decreases dramatically from M0 to M2 by increment the (CB) concentration then decrease slowly from M2 to M6, The lowest value recorded after 28 days for the compressive strength (24.11 N/mm^2) corresponds to 8 % concentration of (CB).

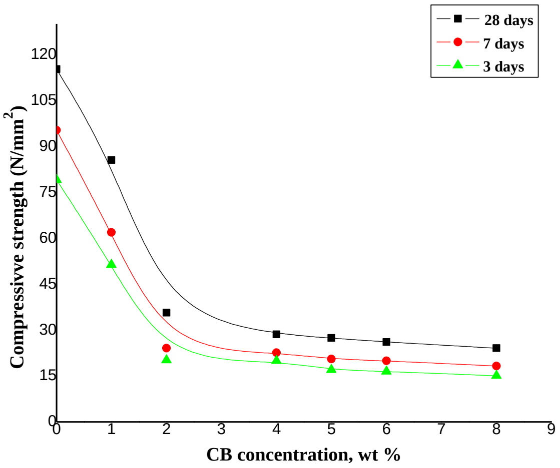

Figure 5: The compressive strength of (CB) specimens at 3 ,7 and 28 days

It is noticed that compressive strength decreases by increasing the entrained air where lower strength is caused if more voids exist in the cement paste.

Although a high air content in mixes (M2 – M6) which range from 48.9% and 61.2% but they have maintained an acceptable level of compressive strength which may refer to a well-distributed small air bubble (Qaraman, 2016) and (Narayanan and Ramamurthy,2000).

Effect of density on thermal conductivity of foam mortar

Thermal Conductivity is the main criteria of lightweight mortar and insulation blocks, its better insulation properties refer to its low thermal conductivity. This is due to cellular structure. Foam mortar, with a density of 400kg/m3, having approximately the same excellent heat insulation value as a 25 mm thickness of cork. **(Chen, et al.,2013)**
The results show that the thermal conductivity of all foam mortar samples is positively proportionate with the density (Fig. 6)

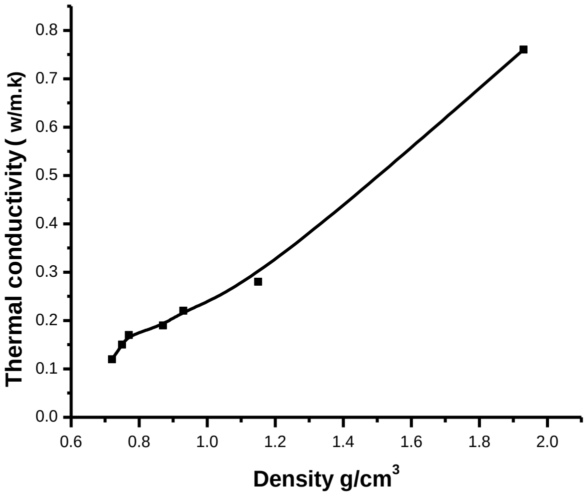

Figure (6): the relationship between Thermal Conductivity and Density

The thermal conductivity for foam mortar reduced from 0.76 to 0.12 W/mK for corresponding densities ranged from 1.93g/cm3 to 0.72g/cm3, respectively. The results have confirmed that lowering the density leads to lower thermal conductivity, which is corroborative with the findings from other researchers (Meletse,2005 and Bumanis, 2013). The lowering of conductivity by minimizing the density of foam mortar is controlled by its porosity. Low-density foam mortar will have high air content and high porosity value compared to the high density. Thus, it will be more effective as thermal insulation material. Therefore, it can be concluded that insulation was in approximately inverse proportion to the density of foam mortar (Wang, et al., 2015).

CONCLUSION

Cocamidopropyl Betaine plays a significant role in the air stabilization in foam mortar. The addition of Cocamidopropyl Betaine in the mortar paste produce a Low-density mortar with high air content and high porosity value compared to the high density, the addition. The addition of 8% of the Cocamidopropyl Betaine to mortar paste during the mixing reduce the density of hardened mortar from 2 gm/cm3 to 0.72 gm/cm3 with air content up to 62%. The SEM Analysis illustrate that the addition of Cocamidopropyl Betaine produces consistent bubble structure with a uniform and homogenous bubble structure with air voids system (85.7 µm). The thermal conductivity of all foam mortar samples is positively proportionate with the density. The thermal conductivity of foam mortar reduced from 0.76 to 0.15 W/mK for corresponding densities ranged from 1.93g/cm3 to 0.72g/cm3, respectively. Thus, the foundations of formation and evolution of the structure of foam mortar in the presence of Cocamidopropyl Betaine will enhance the thermal and physical properties of foam mortar**.**

ACKNOWLEDGMENTS

The authors greatly thank the services and facilities provided by Dr. Mohammed Al-Asqalani, the laboratories of Al-Israa University and the soil and materials laboratories at the Islamic University of Gaza.

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