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PORTLAND CEMENT CONTAINING FLY ASH, EXPANDED PERLITE, AND PLASTICIZER FOR MASONRY AND PLASTERING MORTARS

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ABSTRACT: Cracking of masonry and plastering mortars of clay brick wall was a major problem in the hot climate area. The problem was the worst for the wall made of lightweight blocks. In this research, masonry and plastering mortars made from Portland cement, fly ash, expanded perlite, mortar plasticizer, and sand were tested. The testing program included the determination of water demand, setting time, water retention, compressive strength, splitting tensile strength, density, and elastic modulus. For the masonry mortar, the mixes with high calcium fly ash with or without plasticizer could be used with required properties and reduced cost. The mix of expanded perlite gave water retention over the required 70%. The mix containing fly ash and 0.2% plasticizer gave water retention slightly less than 70%. It was recommended that the mix with expanded perlite should be used for indoor plastering and the mix with fly ash and plasticizer should be used for outdoor plastering.

Keywords: Portland cement; fly ash; expanded perlite; plasticizer; masonry mortar; plastering mortar.

1. INTRODUCTION

The buildings in Thailand and the neighboring countries are based on masonry wall with plastering on both sides. Most walls are masonry walls made of traditional burnt clay bricks. With advanced in construction technology, lighter weight mortar blocks containing foam (cellular lightweight concrete block), and autoclaved aerated concrete blocks with better performances in terms of temperature insulation and lighter weight are preferred. The plastering of this lightweight block wall required a special plastering mortar as tradition mortar for traditional wall usually cracks under the high absorption.

For indoor plastering, the plaster usually shows less stress due to less exposure to direct sunlight and wind. To fully utilize this plastering internally, expanded perlite is usually incorporated to improve the acoustic and insulation properties [1, 2]. Fly ash (FA) is a good pozzolanic material and has been used successfully as partial replacement of cement for making plastering mortar [3]. As FA has a small spherical particle, therefore, FA can improve the workability of fresh mortar. The pozzolanic reaction is slow and hence delay in setting time which is an important factor for the hot climate. Moreover, use of FA has also improved the cohesiveness of the mortar [4].

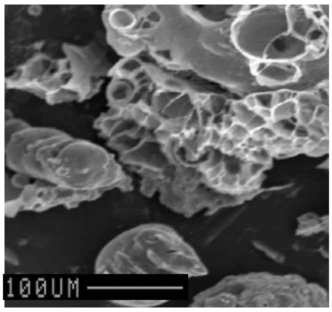
Properties of masonry mortar can be divided into two groups, viz. fresh mortar and hardened mortar [5]. Fresh mortar properties are very important as the mortar needs to have good workability which includes plasticity, consistency and cohesiveness. The workability of mortar is often determined by a mason using his technical skill by observing and feeling of behavior and response of mortar to the trowel. The fresh mortar properties viz., water demand, flow, and water retention can be properly tested in accordance with specified standards. For hardened mortar, compressive strength, flexural strength, and elastic modulus are important properties. Over the past few years, geopolymer binders have been developed for masonry units because it has a high performance similar to commercial masonry mortar. For example, geopolymer binders made from fly ash and water treatment sludge [6] and geopolymer binders produced from fly ash based geopolymer incorporating recycled glass [7].

Therefore, this research aims to investigate the use of Portland cement-fly ash-perlite-plasticizer blends for use as masonry and plastering mortars. The data should provide a good guideline for masonry and plastering mortars of lightweight wall panel both internal and external exposures.

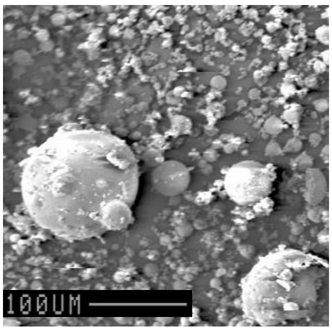
2. MATERIALS AND EXPERIMENTAL DETAILS

2.1 Materials

Ordinary Portland cement (PC), fly ash (FA), expanded perlite (EP) and river sand are the main ingredients. FA is collected from Mae Moh power station in northern Thailand. The PC and EP are commercially available. The scanning electron micrographs (SEM) of EP and FA are shown in Fig. 1. The particle shapes of EP are very variable containing spherical, angular and very irregular particles. The particles are porous which give the light density. FA particles are mostly spherical. The surface of the large particles appeared to be rougher than those of the smaller particles. The chemical compositions and physical properties of PC, FA and EP are given in Table 1 and 2, respectively. The CaO content of this FA was high at 16.55% which was normal for the lignite coal ash. EP contained 71.32% of SiO_2 and 8.35% of K_2O. It is relatively light and fine with a specific gravity of 0.93 and Blaine fineness of 4200 g/cm^2. Local river sand with a specific gravity of 2.62 and fineness modulus of 1.75 is used. The gradation of the sand was in accordance with the requirements given in specified standard of ASTM C144 [5]. A commercial air-entraining mortar plasticizer (MP) was also used.



a) EP



b) FA

Fig. 1 SEM photos of EP and FA

2.2 Mortar compositions

All the mortars were prepared with 1:3 binder-to-sand ratios. The PC:FA ratios of 100:0, 80:20 and 60:40, whereas EP:sand ratios of 0.0:3.0, 0.1:2.9, and 0.2:2.8 were used. The mortar mixes were divided into three series such as series A, Series B, and Series C with MP at dosages of 0.0, 0.1 and 0.2% by weight of the binder, respectively. The workability of mortar is very important to the rendering work. Thus, the flows of mortars were controlled to be within 95±5% by adjusting the amount of water. The mix proportions of the mortar are given in Table 3

Table 1 Chemical compositions of PC, FA and EP

Chemical compositions	PC	FA	EP
SiO_2	20.54	38.72	71.32
Al_2O_3	5.46	20.76	10.73
Fe_2O_3	3.00	15.28	2.58
CaO	64.62	16.55	1.86
MgO	0.78	1.49	-
Na_2O	0.21	1.19	-
K_2O	0.32	2.69	8.35
SO_3	2.80	0.78	-
LOI	1.15	0.10	1.25

Table 2 Physical properties of PC, FA and EP

Binder	Blaine fineness (cm^2/g)	Average particle size (μm)	Retained on sieve No. 325 (%)	Specific gravity
PC	3650	15	NA	3.15
FA	2500	65	67	2.21
EP	4200	29	40	0.93

Table 3 Mix proportions of plastering mortars

Mix	Ratios by mass				Series A		Series B		Series C	
	PC	FA	EP	Sand	MP	W/B	MP	W/B	MP	W/B
Control	1.0	0.0	0.0	3.0	0.0	0.65	0.1	0.55	0.2	0.54
F2P0	0.8	0.2	0.0	3.0	0.0	0.64	0.1	0.54	0.2	0.53
F2P1	0.8	0.2	0.1	2.9	0.0	0.84	0.1	0.77	0.2	0.76
F2P2	0.8	0.2	0.2	2.8	0.0	1.04	0.1	0.99	0.2	0.98
F4P0	0.6	0.4	0.0	3.0	0.0	0.63	0.1	0.53	0.2	0.52
F4P1	0.6	0.4	0.1	2.9	0.0	0.83	0.1	0.80	0.2	0.75
F4P2	0.6	0.4	0.2	2.8	0.0	1.00	0.1	0.96	0.2	0.93

Note: MP=Percentage of MP by weight of binder

2.3 Testing methods and regimes

For the testing of fresh mortars, the flow [8], and setting time [9] were determined right after the mixing. The determination of the water retention [10] was done using the apparatus. The test was done by applying a vacuum of 51 mm as indicated by a mercury manometer to the funnel to create suction to the mortar bed for 60 seconds. The water retention was calculated from the flows of the mortar before and after suction.

For the testing of hardened mortar, compressive strength [11] was tested by using 50x50x50 mm^3

cube specimens. The specimens were cured in water until the test age of 28 days. Elastic modulus [10] and splitting tensile strength [13] were also tested.

3. RESULTS AND DISCUSSIONS

3.1 Water requirement

The replacement of PC with FA shows a reduction in the water requirement of the mortar mixes as shown the decreasing of W/B in Table 3. This is due to the spherical particles of FA could improve the workability of the mixes with [14]. On the other hand, the inclusion of EP significantly increased the water requirement of the mixes. For the mortar without MP (Series A), the water to binder (W/B) of the Control mortar is 0.65 and those of F2P1 and F2P2 mortar with 0.1 and 0.2 of EP are 0.84 and 1.04. The EP has very light, porous and very variable in the particle shape, therefore, it substantially increased the water demand of the mixes [15]. The addition of MP tends to slightly reduce the water demand through the aid of air void in improving the workability [16].

Table 4 Setting time and water retention of plastering mortars

Mix	Series A			Series B			Series C		
	Setting time (min)		Water retention (%)	Setting time (min)		Water retention (%)	Setting time (min)		Water retentio (%)
	Initial	Final		Initial	Final		Initial	Final	
Control	130	205	40	170	240	52	190	250	64
F2P0	135	205	43	200	295	55	215	330	66
F2P1	168	205	78	235	295	85	235	340	84
F2P2	150	190	85	260	340	87	250	340	90
F4P0	130	200	44	200	330	56	215	340	65
F4P1	140	220	84	245	340	89	230	370	91
F4P2	150	200	86	235	340	90	305	390	92

3.2 Setting time of mortars

The results of setting time of mortars are shown in Table 4. The addition of FA has little effect on the setting time of mortars. A slight increase in the setting time was reported with the use of FA [17]. The addition of EP, however, increased the initial setting time due to increase in the water content of the mixes. For the mixes with MP, the initial and final setting times of Control mortar of Series B are 170 and 240 minutes and slightly longer than those of Control mortar of Series A of 130 and 205 minutes However, the mixes with FA and EP with 0.1% MP show significant increase in initial and final setting times of between 200-260 and 295-340 minutes. For the incorporation of 2% MP, the setting time tends to increase. The mixes with FA and EP with 2% MP show a significant increase in initial and final setting times of between 215-305 and 250-390 minutes. The use of MP has a retarding effect on the mortars. The increase in setting time especially the initial setting time can be beneficial in hot tropical climate. Early stiffening of mortar in hot condition can lead to cracking delimitation of mortar from lightweight block panel.

3.3 Water retention of mortars

The results of the water retention tests on mortars are shown in Table 4. The incorporation of only FA has slightly increased the water retention of the mixes. Water retentions of Series A in F2P0 and F4P0 mortars without EP are 43 and 44% as compared to the corresponding values of 40% of the Control mortar. The incorporation of EP and MP results in significant increases in water retention characteristics of the mortars. For example, the F2P1 and F2P2 mortars without MP show water retention of 78 and 85%, and the F2P2 mortars with 0.1% and 0.2% MP show water retention of 87 and 90%. For the mixes with only MP, the water retentions are also quite high. The F2P0 mortars with 0.1% and 0.2% MP show water retentions of 55 and 66%, and the F4P0 mortars with 0.1% and 0.2% MP show water retentions of 56 and 65%. As per ASTM C91 [18], the minimum water retention requirement for mortar mix is 70%. According to Table 4. It can be suggested that the use of MP and/or EP could improve the water retention characteristics of the mixes to the required level.

3.4 Compressive and splitting tensile strength of mortars

The compressive and splitting tensile strengths at 28 days of mortars are given in Table 5. For the compressive strength of the incorporation of FA, it has a small reduction in strength of the mixes. For the 0, 20, and 40% fly ash mixes of Series A (Control, F2P0, and F4P0), the 28-days compressive strengths are 26.0, 23.5, and 17.7 MPa. The reduction in strength is due mainly to slow pozzolanic reaction of the rather coarse FA with a median particle size of 65 microns. In addition, it is generally accepted that the reaction between SiO_2 from FA and $Ca(OH)_2$ forms C-S-H gel becomes dominant at the ages after 28 days as reported by previous studies [19, 20]. Furthermore, the inclusions of EP and MP reduce the strength of mortars due to the increase in the air voids. This is increased the water requirement of the mixes with EP and hence low in the strength of EP [21, 22]. The 28-day compressive strength of F2P1 and F2P2 mortars with 0.1%MP and 0.2% MP are 12.8 and 6.4 MPa, respectively. However, the minimum requirement compressive strength at 28 days of type N, S, and M mortars as per ASTM C91 (2003) are 6.2, 14.5, and 20.0 MPa, respectively. Only the F4P2 mortar with 0.2% MP gives lower than the requirement. According to Table 5, Series A; (F2P2, F4P1, F4P2), Series B; (F2P1, F2P2, F4P1, F4P2), and Series C; (F2P1, F2P2, F4P1) mortars would satisfy the compressive strength and water retention requirement of Type N. While, F2P1 mortar of Series A would satisfy the requirement of Type S.

Table 5 Compressive strength and splitting tensile strength of mortars at 28 days

Mix	Compressive strength (MPa)			Splitting tensile strength(MPa)		
	Series A	Series B	Series C	Series A	Series B	Series C
Control	26.0	19.9	16.2	2.5	2.0	1.5
F2P0	23.5	18.6	14.2	2.3	1.8	1.3
F2P1	16.5	12.8	9.3	1.4	1.0	0.8
F2P2	11.3	8.8	6.4	0.8	0.8	0.5
F4P0	17.7	14.7	10.8	1.5	1.3	0.8
F4P1	12.8	9.5	7.2	1.0	0.8	0.6
F4P2	8.8	7.3	4.6	0.7	0.5	0.4

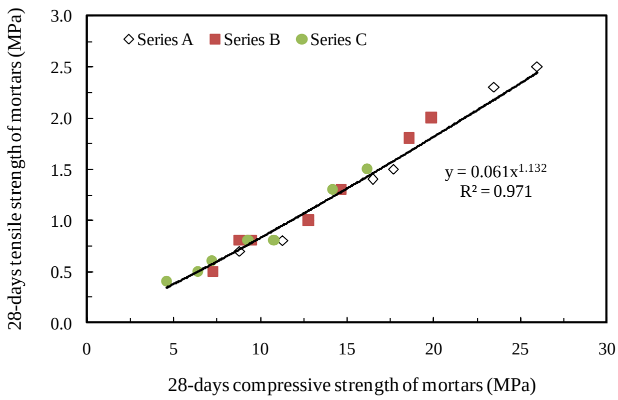


Fig. 2 Relationship between splitting tensile and compressive strengths at 28 days of mortars

The splitting tensile strength of the mortar follows the same trend of compressive strength results. The use of FA has also reduced the tensile strength of mortar. The tensile strengths were reduced with the increase in the addition of or replacement with MP and EP. The ratio of the compressive strength to the splitting tensile strength is between 7 to 15% and can be estimated as a nonlinear function as shown in Fig. 2. The relationship could be presented in the form as shown in Eq. (1).

$$ft = 0.061 f_c'^{\,1.132} \quad (1)$$

Where ft is splitting tensile strength of mortars at 28 days (MPa), and f'_c is the compressive strength of mortars at 28 days (MPa).

3.5 Density and elastic modulus of mortars

The results of density and elastic modulus are shown in Table 6. The density and elastic modulus were affected by the inclusion of FA, MP, and EP in a similar manner. The incorporation of FA, MP, and EP are slightly reduced both the density and elastic modulus of mortars. The density and elastic modulus of normal mortar without FA, EP, and MP are 2100 kg/m^3 and 23.00 GPa. The density of Control mortars with 0.1% MP and 0.2% MP are 1980 and 1860 kg/m^3 with an elastic modulus of 17.20 and 12.20 GPa, respectively. In general, mortar modified with additives that increased the air-content higher than the control mortar [23] subject to lower in density and elastic modulus. The incorporation of FA and EP in PC and sand drastically reduced both the density and elastic modulus of mortars. This is due to the low specific gravity of FA and EP of 2.21 and 0.93 as compared to 3.15 and 2.65 of PC and sand, respectively. For example, the density and elastic modulus of F4P0 mortar of series A is low at 1900 kg/m^3 and 19.20 GPa, while the F4P2 mortar of Series A shows the lowest density and elastic modulus of 1580 kg/m^3 and 5.90 MPa.

Table 6 Density and elastic modulus of mortars at 28 days

Mix	Density (kg/m^3)			Elastic modulus (GPa)		
	Series A	Series B	Series C	Series A	Series B	Series C
Control	2100	1980	1860	23.00	17.20	12.20
F2P0	2020	1860	1720	21.80	16.70	10.80
F2P1	1750	1700	1650	13.80	8.80	4.60
F2P2	1530	1500	1470	7.25	4.90	3.00
F4P0	1900	1820	1750	19.20	12.30	9.80
F4P1	1630	1600	1570	12.80	6.80	4.20
F4P2	1580	1530	1490	5.90	4.20	1.90

The relationship between density and elastic modulus of mortars could be estimated as a linear function as shown in Fig. 3 and the relationship as shown in Eq. (2). Moreover, the relationship between compressive strength and elastic modulus of mortars are presented in Fig. 4 and Eq. (3).

$$E = 0.032D - 44.05 \quad (2)$$

$$E = 7.785\sqrt{f'_c} - 17.10 \quad (3)$$

Where E is the elastic modulus of mortars at 28 days (GPa), f'_c is the compressive strength of mortars at 28 days (MPa), and D is the density of mortars at 28 days (kg/m^3).

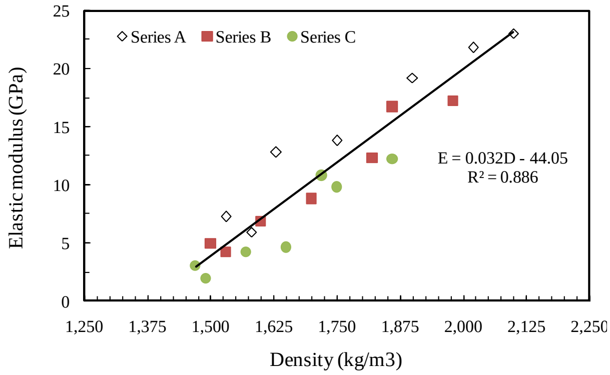


Fig. 3 The relationship between elastic modulus and density at 28 days of mortars

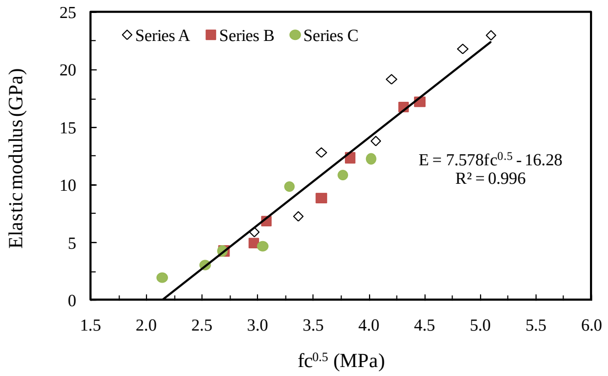


Fig. 4 Relationship between elastic modulus and compressive strength at 28 days of mortars

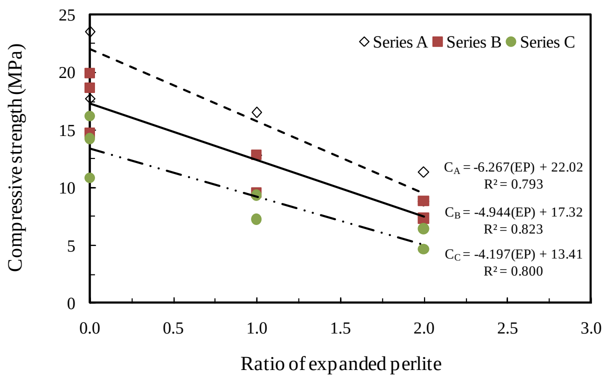


Fig. 5 Relationship between compressive strength and ratio of EP

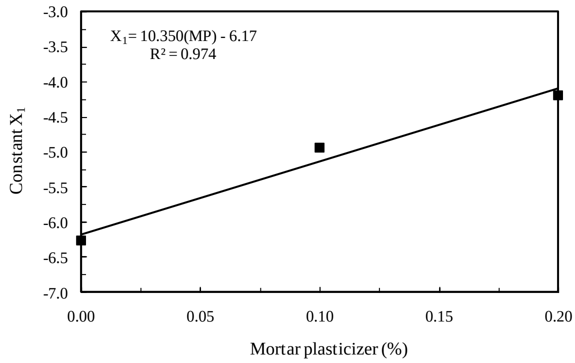
3.6 Relationship between compressive strength, density, EP, and MP

The relationship of compressive strength due to the ratio of EP and MP are shown in Fig. 5. It is found that the compressive strength tends to reduce with increasing ratio of EP at any MP level and could be estimated as a linear function as follows:

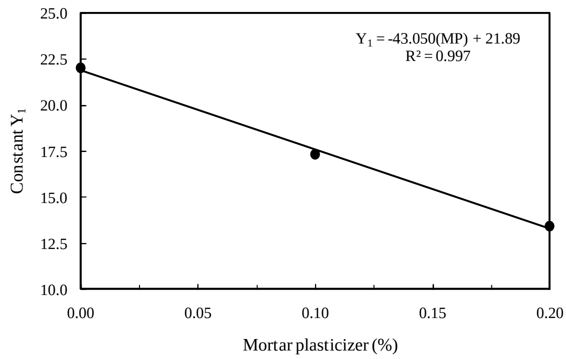
$$MP = 0\%;\ C_A = -6.251(EP) + 22.02,\ R^2 = 0.793 \quad (4)$$

$$MP = 0.1\%;\ C_A = -4.944(EP) + 17.32,\ R^2 = 0.823 \quad (5)$$

$$MP = 0.2\%;\ C_A = -4.197(EP) + 13.41,\ R^2 = 0.800 \quad (6)$$



a) Constant X_1



b) Constant Y_1

Fig. 6 Relationship between constants X_1, Y_1, and MP content

Fig. 6 shows the constants which obtained by curve fitting from Eqs. (4), (5), and (6). Thus, the empirical equations for predicting compressive strength at 28 days of mortars at any MP and ratio of EP content could be written as Eq. (7):

$$C = X_1(EP) + Y_1 \quad (7)$$

Where X_1 is $10.350(MP) - 6.17$ (R^2=0.974), Y_1 is $-43.050(MP) + 21.89$ (R^2=0.997), C is the strength of mortars at 28 days (MPa), MP is mortar plasticizer (%), and EP is the ratio of expanded perlite.

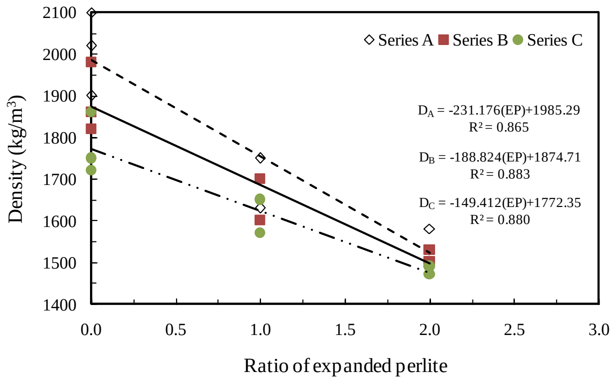
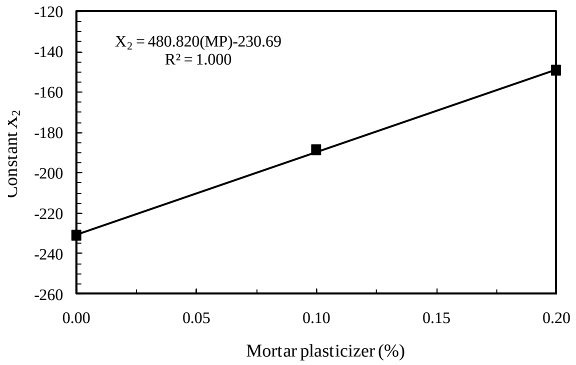
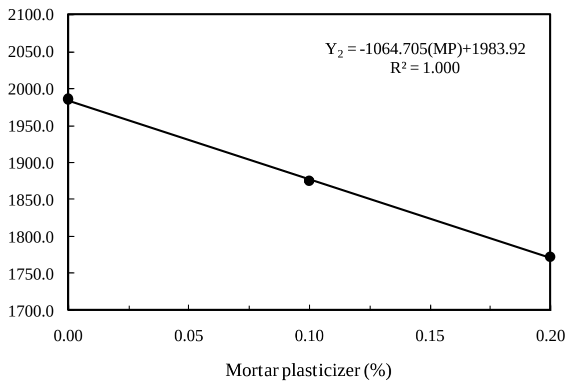


Fig. 7 The relationship between density and ratio of EP



a) Constant X_2



b) Constant Y_2

Fig. 8 Relationship between constants X_2, Y_2, and MP content

In addition, the relationship of density due to the ratio of EP and MP are shown in Fig. 7. The density of mortars decreases with increasing the ratio of EP at any MP content. These relationships could be derived as an exponential function as shown in Eqs. (8)-(11).

$$MP = 0\%;\ D_A = -231.176(EP) + 1985.29,\ R^2 = 0.865 \quad (8)$$

$$MP = 0.1\%;\ D_B = -188.824(EP) + 1874.71,\ R^2 = 0.883 \quad (9)$$

$$MP = 0.2\%;\ D_C = -149.412(EP) + 1772.35,\ R^2 = 0.880 \quad (10)$$

Thus, the empirical equations could be expressed for the density of mortars in term of MP and ratio of EP content as shown in Eq. (11). Fig. 8 shows the constants which obtained by curve fitting from Eqs. (8), (9), and (10).

$$D = X_2(EP) + Y_2 \quad (11)$$

Where X_2 is $480.820(MP) - 230.69$ (R^2=1.000), Y_2 is $-1064.705(MP) + 1983.92$ (R^2=1.000), D is the density of mortars at 28 days (kg/m^3), MP is mortar plasticizer (%), and EP is the ratio of expanded perlite.

4. CONCLUSION

The results presented in this paper indicates that the mortars containing FA, MP and EP are suitable for use as masonry and plastering work. The incorporation of FA and MP result in a slight reduction of water demand of mortar and hence workability improvement. However, the use of EP results in a drastic increase in water requirement of the mixes. The setting times of mortars were slightly increased with the use of FA and MP and were significantly increased with the use of EP due to the large increase in water content. The water retentions of mortars are increased with the use of FA, MP, and EP. The mixes containing FA and 0.2% MP give the water retention slightly less than the 70% as recommended by the ASTM C91. This mix should be suitable for use as outdoor plastering with the provision of care in moisture and evaporation control.

The mixes with EP give high water retentions in the order of between 78-92% and thus are suitable for use as masonry and plastering mortars. The compressive strength, tensile strength, density and elastic modulus were affected by the incorporation of FA, MP, and EP. The strengths, density and elastic modulus were decreased when the mixes incorporated FA and MP. The mixes with EP with high water retention, low strength, density and elastic modulus should be used in the indoor for improving their acoustic and heating properties.

5. ACKNOWLEDGEMENTS

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