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Influence of a new type of additive on the performance of polymer-lightweight mortar composites

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Abstract

This paper shows how a new powder polymer additive (PPA), containing a waterproofing agent, a rheology control agent and air-entrainers, affects the workability, mechanical properties and setting times of polymer-lightweight mortar composites (PLMC). The waterproofing agent was a mixture of redispersible polyethylene vinyl acetate and redispersible silane based polymer powder. The rheology control agent was a redispersible hydroxypropyl carboxymethyl ether of patato starch based polymer powder. Air-entraining agent was a redispersible and an unmodified sodium laurly sulphate based polymer powder. Pumice fine aggregate at 0–3 mm size fraction was used as lightweight aggregate throughout the research work. In order to examine the effects of powder polymer additive on flowability and the performance when the additive is mixed in a mortar, the mixture proportions were set in four trial batches. The volume proportions of cement and pumice lightweight fine aggregate were fixed at 1:9, 1:8, 1:7 and 1:6, respectively, defining the mixture of mortar for measuring the compressive strength and workability of lightweight mortar. In this research study, PLMC mortars with 28 different mixture proportions (M1–M28) by weight of cement contents of 0.2%, 0.4%, 0.6%, 0.8%, 1.0% and 1.2% were adopted for the mortar mixture batches, respectively. Flow value of mortar was measured using a flow table method in accordance with the regulation in ASTM C230, ‘‘flow table for use in tests of hydraulic cement’’. The target flow was fixed at 130 mm for each mixture proportion, which is regarded as the most suitable fluidity to secure workability at a site. For each mixture, 12 fresh plastic mortar samples were prepared according to the method specified in ASTM C305 and cured in a humidified atmosphere for 24 h, removed from the mould after 24 h, cured in water for 7 days, and then cured in air. The compressive strength test results were evaluated in accordance with ASTM C270.

The suitability of using a new powder polymer additive in terms of workability and required compressive strength in PLMC mortar applications is also presented in this paper. It is observed that PLMC mortars have adequate strength and more convenient workability for their use in general masonry construction applications.

Keywords: Composite; Powder polymer; Pumice; Mortar; Lightweight

1. Introduction

Mortar is a bonding agent that integrates block or brick into a masonry assembly. Centuries ago, combinations of sand and lime were used as mortar. These combinations took months and even years to harden as the lime slowly combined with carbon dioxide from the air to form calcium carbonate. Because it took so long for these mortars to harden and gain strength, it was necessary to use very thin joints [1,2]. The use of industrial made mortars has been mostly implemented to masonry building, but several other applications were also successfully tried, such as concrete repairing, construction renovation, tile fixing, anchoring of bolts, amongst others [3,4]. Floor screed mortars and external thermal insulation or moisture controlling composite systems are examples of growing markets [5]. Mortars can also be defined as powder, paste or liquid balanced mixtures of three types of components, namely aggregates and fillers, binders, and additives and admixtures [6].

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Masonry mortar is composed of one or more cementitious materials, clean, well-graded masonry sand, and sufficient water to produce a plastic, workable mixture. Modern specifications call for proportions by volume ranging from one part of cementitious material to 2–1/4 to 3–1/2 parts of damp, loose mortar sand. The choice of cementitious material, masonry cement, a Portland cement combination, is largely a matter of economics and convenience. Any of these combinations will produce mortar with acceptable properties as long as the specifications are met [1].

The use of lightweight masonry mortars is in most countries for an improving schedule in masonry construction applications. The majority of lightweight masonry mortars today are produced in modern highly automated and closely controlled foundations like as ready mix concrete productions. This production has to match strict standards that describe properties specified for the products. These may include denotations on aggregate type, size, strength, flow value, water retention, insulating properties and fire resistance. Some natural lightweight materials such as pumice, scoria, vermiculite, perlite etc., can be used as aggregates in masonry mortar that meets all these requirements.

Lightweight masonry mortars are made of lightweight aggregates, cement, water and admixtures which are used in construction of non-load bearing infill walls and partitions in exterior or interior building applications. One of the most effective ways to reduce the dead load in multi storey buildings is to lighten the weight of the structure. Lightweight masonry mortars can be produced from a density range of 750–1300 kg/m^3 with an average reduction in weight of 45–65% as compared to conventional masonry mortars.

Lightweight masonry mortars have two distinct important sets of properties; those in the plastic state and those in the hardened state. The plastic properties help to determine the mortar's compatibility with masonry and its construction suitability. Properties of hardened mortars help determine the performance of the finished masonry [7]. Lightweight masonry mortars need to meet the following requirements:

- creamy consistency,
- good trowel standing strength,
- high water retention,
- high compressive strength,
- high adhesive shear strength,
- good pumpability.

Admixtures are used in lightweight masonry mortar to increase workability, decrease setting time and to retard freezing. Although some admixtures are harmless, some are detrimental to mortar and the resulting masonry work. Since the properties of both plastic and hardened mortars depend so largely upon mortar ingredients, the use of admixtures should not be considered unless their effect on the mortar is known. The use of admixtures should also be examined for their effect on the masonry, masonry units and items embedded in the masonry work. ASTM C1384, standard specification for admixtures for masonry mortars, provides methods to evaluate the effect of admixture on mortar properties [7].

Although many admixtures are to be suitable for use in lightweight masonry mortars, inclusion of powder polymer of organic materials as a percentage of cement content in the mixture is not a widespread for use in applications in the literature. In this respect, a new research work was carried out to optimise the polymer-lightweight mortar composites according to the related standards with using a new powder polymer as a percentage of cement use in mortar batches. Basic ingredients of the polymer-lightweight mortar composite are ordinary Portland cement as a binding agent, fine pumice aggregate as a lightweight material, a new type of powder polymer additive to sprinkle as a polymer and water. This research work presents the technical results of a comprehensive experimental study on optimising the lightweight masonry mortars for building applications.

Lightweight aggregate characteristics have significant effects on lightweight mortar workability and other properties. However, limited work has been conducted for studying the effects in systematically and quantitatively. Using the ASTM standard flow table test, this study provides a systematic study for the effect of pumice aggregate on mortar flowability. The research results will provide engineer with an insight on mortar selection and mix design.

The workability of a pumice lightweight aggregate–cement mix can be improved by additions of powder polymer materials without using any hydrated builder's lime. Powder polymer material on its own does not have cementing properties and should be used as an addition to, not as replacement of ordinary cement. Masonry mortars could contain workability improvers such as hydrated lime, fly ash, air-entraining agents and powder polymer materials.

2. Experimental work

2.1. Purpose of assessment

The experimental work was carried out in order to determine the influence of a new type of additive (PPA) on the performance of polymer-lightweight mortar composites for use in masonry wall constructions. It was aimed in this study to evaluate the effects of redispersible polymer powder on the physical properties of fresh and hardened polymer lightweight mortar composites at various cement/aggregate ratios.

2.2. Materials

Polymer-lightweight mortar composite samples were obtained by the use of cement as a binding agent, fine pumice aggregate as a lightweight material and a new type

Table 1
Chemical composition of materials

Chemical content	Cement (%)	IPA (%)
SiO_2	20.65	59.00
Al_2O_3	5.60	16.60
Fe_2O_3	4.13	4.80
CaO	61.87	1.80
Na_2O	0.14	5.20
K_2O	0.83	5.40
MgO	2.60	1.80
LOI	1.39	1.60

Table 2
Physical properties of the cement

Specific gravity (g/cm^3)	3.10
Blaine specific surface (cm^2/g)	3245
Initial setting time (min)	250
Final setting time (min)	306
Volume expansion (mm)	3
Compressive strength (MPa)	
2 days	14.7
7 days	26.9
28 days	43.0

of mortar powder additive to sprinkle as a polymer and water.

Ordinary Portland cement (OPC) which is comparable to ASTM Type I (42.5 N/mm^2) was used for all mortar samples. The chemical composition and physical properties of the cement used in this research are given in Tables 1 and 2.

The pumice aggregate samples were taken from a pumice quarry in Gölcük region of Isparta, Turkey. Isparta pumice aggregate (IPA) samples were first crushed by a primer crusher and then they were screened into 0–3 mm as fine pumice aggregate to produce mortar samples in different mixes. Only 0–3 mm size fraction of pumice aggregates were used in the mixture batches. Pumice is not a trade name but a type of glassy volcanic rock originating from lava of strictly determined chemical composition. The chemical contents of the pumice aggregates were given in Table 1. Pumice is a well known lightweight concrete aggregate, although its use has mainly been restricted to dry mixes such as for block making and masonry use. There are both advantages and drawbacks connected with the material as an aggregate [8–10]. Dry bulk unit weight and water absorption of IPA, as received from the quarry, were determined as 1030 ± 25 kg/m^3 and $24 \pm 2\%$, respectively. The compressive strength of IPA is about to 27.6 ± 1.7 MPa in accordance with DIN 1604.

The new type of admixture was used as an additive which is in powder form, containing waterproofing agent, controlling rheology agent and air-entrainers. Water proofing agent was a mixture combination of redispersible polyethylene vinyl acetate and redispersible silane based polymer powder. Controlling rheology agent was a redispersible hydroxypropyl carboxymethyl ether of patato starch based polymer powder. Air-entraining agent was a redispersible and an unmodified sodium laurly sulphate based polymer powder. The PPA was developed with the mixture of these three agents.

The PPA was specially designed for use in mineral dry mortars such as cement based rendering/plastering mortars, masonry construction mortars, joint and crack fillers, skim coats or repair mortars. The product improves the workability, reduces the tendency of mortars to shrink and crack and provides better plasticity. The pH value of PPA was 9.0 and its specific gravity was 1.1 gr/cm^3. When a sufficient PPA is used, no lime is necessary in mortar mixture. It could also be used to speed up the set time and greatly enhances the plaster spreadibility. It contains no nitrates, and is therefore not hazardous to workers It requires no environmental reporting.

Mixing water was general drinking water liquid.

2.3. Mixture proportions and scope

In order to analyse the effects of powder polymer additive (PPA) on workability and mortar performance on strength, four trial batches were organised in different mixture proportions. These proportions are presented in Table 3. Throughout the experimental research, volume proportions of cement and pumice lightweight fine aggregates were used

Table 3
Mixture proportions for testing mortar

Mix	OPC (% by volume)	IPA (% by volume)	PPA (% by weight of cement)	w/c
M-1	1	9	0.0	1.5366
M-2	1	9	0.2	1.2296
M-3	1	9	0.4	1.2300
M-4	1	9	0.6	1.2303
M-5	1	9	0.8	1.2306
M-6	1	9	1.0	1.2309
M-7	1	9	1.2	1.2312
M-8	1	8	0.0	1.3191
M-9	1	8	0.2	1.1806
M-10	1	8	0.4	1.1809
M-11	1	8	0.6	1.1813
M-12	1	8	0.8	1.1816
M-13	1	8	1.0	1.1819
M-14	1	8	1.2	1.1823
M-15	1	7	0.0	1.1776
M-16	1	7	0.2	1.1160
M-17	1	7	0.4	1.1164
M-18	1	7	0.6	1.1167
M-19	1	7	0.8	1.1171
M-20	1	7	1.0	1.1175
M-21	1	7	1.2	1.1178
M-22	1	6	0.0	1.0363
M-23	1	6	0.2	1.0367
M-24	1	6	0.4	1.0371
M-25	1	6	0.6	1.0374
M-26	1	6	0.8	1.0378
M-27	1	6	1.0	1.0382
M-28	1	6	1.2	1.0386

as constant mixture rates of 1:9, 1:8, 1:7 and 1:6, respectively. These rates were used in examining the compressive strength and workability of polymer lightweight mortar composites. In America, in most of the Europe, and in Turkey, the mixture proportions of cement by volume for lightweight mortars of masonry wall construction purposes are ranged between 1:6 and 1:12. As can be seen from Table 3 that to examine the influence of a new type of additive on the performance of polymer-lightweight mortar composites for use in masonry walls constructions, initial 28 different mixture proportions (M1–M28) by weight of cement contents of 0.2%, 0.4%, 0.6%, 0.8%, 1.0% and 1.2% were adopted for the mortar mixture batches, respectively.

A series of PLMC mortar samples were produced with different proportions of pumice lightweight aggregate, cement and powder polymer additive (PPA). The results of a comprehensive experimental research work carried out on evaluating the main properties of mortar samples are presented in Table 4.

Twelve mortar specimens $5 \times 5 \times 5$ cm in size for each mixture batches were prepared, and experiments were carried out according to the preparation mixture table as shown in Table 3. The fresh plastic mortar was mixed and manufactured according to the method specified in ASTM C305 "Standard practice for mechanical mixing of hydraulic cement paste and mortars of plastic consistency". The specimens were prepared in a mould of $5 \times 5 \times 5$ cm, in accordance with ASTM C305, cured in a humidified atmosphere for 24 h, removed from the mould after 24 h, cured in water for 7 days, and then cured in air.

The target flow was fixed at 130 mm for each mixture proportion, which is regarded as the most suitable fluidity to secure workability at a site.

2.4. Test method

Particle shape and surface texture of lightweight aggregates were characterised with an angularity test based on ASTM C1252 "Standard test methods for uncompacted void content of fine aggregate (as influenced by particle shape, surface texture, and grading)". Fine aggregate angularity was defined as the percentage of air voids in a loosely compacted fine aggregate. High void content indicates that the aggregate contains a large amount of fractured and irregular particles.

Flow value of mortar was measured using a flow table method in accordance with the regulation in ASTM C230, "flow table for use in tests of hydraulic cement". This ASTM test was originally designed to determine the water content needed for a cement paste sample obtaining a given flow spread of 110 ± 5 mm. The upper part of the flow table was first carefully and cleanly wiped, and the plate was placed in the centre of the flow table. About 2.5-cm-thick layers of mortar prepared were then placed in the plate, followed by tamping 20 times with a hammer. After filling the flow mould with mortar and tamping it as

Table 4
Main properties of a mortar with PPA

Mix	Initial setting (min) [not less than the value]	Final setting (h) [not more than the value]	Standard consistence (mm)	Plastic set density (kg/m^3)	Dry set density (kg/m^3)	Compressive strength (MPa)
M-1	90	3.30	185	1587	1290	3.772
M-2	120	3.45	167	1483	1226	3.652
M-3	135	3.55	175	1399	1119	2.344
M-4	150	5.30	170	1375	1100	1.927
M-5	180	6.00	172	1367	1085	1.673
M-6	230	6.30	171	1250	1016	1.372
M-7	240	7.00	170	1194	1012	1.303
M-8	110	3.45	157	1587	1302	4.147
M-9	135	3.52	172	1601	1177	3.211
M-10	140	4.30	166	1424	1119	2.743
M-11	190	6.45	161	1399	1065	1.876
M-12	225	6.54	175	1331	1043	2.34
M-13	250	7.15	174	1314	1038	1.725
M-14	255	7.22	164	1277	982	2.981
M-15	110	3.45	157	1632	1327	5.220
M-16	115	4.15	165	1498	1238	5.310
M-17	150	5.00	168	1414	1131	3.730
M-18	170	5.45	178	1356	1085	2.672
M-19	190	7.15	178	1347	1069	2.756
M-20	245	7.45	178	1236	1005	2.198
M-21	252	7.48	181	1113	943	1.732
M-22	135	4.30	162	1657	1347	7.821
M-23	165	6.00	168	1506	1186	4.308
M-24	180	6.00	171	1459	1167	5.116
M-25	225	6.00	167	1341	1073	3.203
M-26	210	6.30	169	1331	1056	2.927
M-27	230	6.30	171	1319	1072	3.433
M-28	250	6.30	176	1239	1050	3.701

in the first layer, the plate was lifted smoothly and immediately allowed to fall down the table 25 times for 15 s at a height of 1.27 cm. Then the spread diameter of the mortar sample was measured in the lower part four times at the same interval. The flow value of the mortar was expressed as an average of this measurement.

3. Results and discussion

Mortars have two distinct, important sets of properties; those in the plastic state and those in the hardened state. The plastic properties help to determine the mortar's compatibility in masonry construction. Properties of plastic mortars are evaluated as workability, water retention, initial flow and flow after suction. Properties of hardened mortars also help to determine the performance of finished masonry. Hardened properties are usually bond strength, durability, extensibility and compressive strength. Plastic mortar properties are more important for masonry wall construction applications. On the other hand, properties of hardened mortar are of more importance to the designer and owner. Therefore, the research investigations were especially focussed on workability, water retention, and initial flow as plastic mortar properties and compressive strength, setting time and dry set density as hardened mortar properties. The followings are the brief discussion of the research findings on these properties.

3.1. The influence of PPA contents for initial flow and water retention

Pumice lightweight aggregate–cement mixtures should have good workability, but low drying shrinkage. The balance between these two conflicting needs depends on the requirements of the application, and the challenge is to find the optimum balance through the correct choice of materials and proportions. Probably the most important quality of plastic masonry mortar is workability, because of its influence on other important mortar properties in both the plastic and hardened states. Although experienced masonry wall construction applications are good judges of the workability of the mortars [7], there is no direct measurement of the workability of pumice lightweight aggregate–cement mixes, only a subjective assessment. Initial flow, water retention and resistance to segregation affect workability. In turn, these are affected by properties of the mortar ingredients [7].

Initial flow value of PLMC was essentially measured for each mixture batches to analyse the mortar's water content. Fig. 1 shows the initial flow values of test results examined in accordance with the requirements of the ASTM standard testing. The research showed that initial flow values for all mixtures were found to be between 157 and 185 mm flow value. Lee et al. [11] stated that it is difficult to obtain an acceptable workability for cement mortars by inorganic pigments under initial flow value of 152 mm. With comparing the approach of this research work, PLMC mixtures are in the range of acceptable workability. As can be seen in Fig. 1 is that initial flow values of mortars with PPA are all higher than control mortar without using PPA except for the batch of 1:9 C/P ratios. The research results also showed that the initial flow values increase with increase of PPA content especially for 1:7 and 1:6 C/P batches. However, similar fact was not recorded for the 1:9 and 1:8 C/P batches. Initial flow of control mortar mixture for 1:9 C/P batch is found to be higher than all the other mixture's initial flow values for the same batch. According to the research findings, it can be emphasised that workability of the PLMC is much better in a mixture of low content of pumice aggregate and in high amount of PPA. Increasing the pumice aggregate content affects the increase of total air void in a mixture due to its high porosity; therefore more water content should be required. In order to reach to a better workability for PLMC mixtures in high C/P batches, water content of the mixture should be increased.

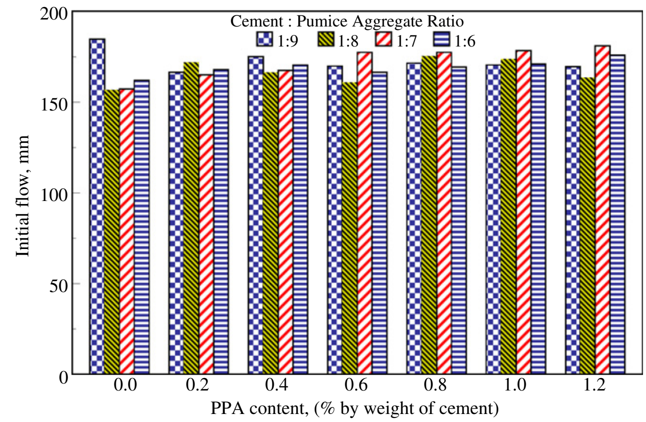

Fig. 1. Initial flow value of mixture proportions.

An increase in the flow of lightweight mortar at the time of use is very beneficial because it can satisfy the suction of the masonry and can allow greater control of the mortar for the masonry layer in a wall construction. Mortar having this property resists the rapid loss for mixing water (prevents loss of plasticity) to the air on a dry day or to an absorptive masonry unit. Rapid loss of water causes the mortar to stiffen quickly, making it practically impossible to obtain good bond and weather-tight joints [1,7].

Water retentivity is an important property and is related to workability. A mortar that has good water retentivity remains soft and plastic long enough for the masonry units to be carefully aligned, levelled, plumbed, and adjusted to proper line without danger of breaking the intimate contact or bond between the mortar and the units. When low-absorption units such as split block are in contact with a mortar having too much water retentivity, they may float. Consequently, the water retentivity of a mortar should be within tolerable limits [1,7].

Mortars are not generally used immediately after mixing; some of its water may evaporate while it is on the mortar board. In actual site applications, most of the craftsmen add water to mortar in order to replace water lost by evaporation. This causes the some casualties for workmanship. Therefore, the long time use of fresh mortar is preferred without retempering. To analyse the ability of fresh mortar in its plastic condition for a workable state, the change of flow values for all mixture batches was periodically measured up to final setting time and the reduction of flow rates was evaluated. Figs. 2–5 show the relationship between flow value and the time after mixing without adding any water for the mixture batches. Although compressive strength may be slightly reduced and mortar colour

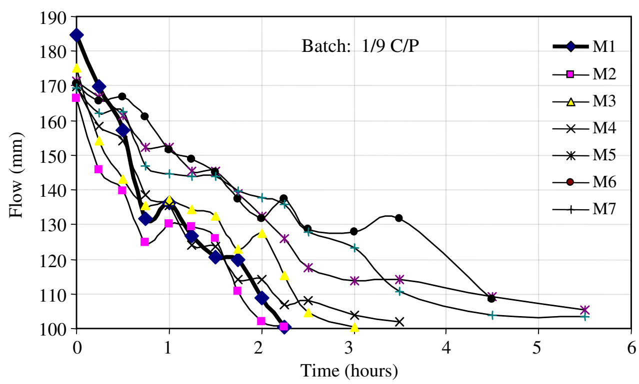

Fig. 2. Flow value versus time for 1:9 C/P batch.

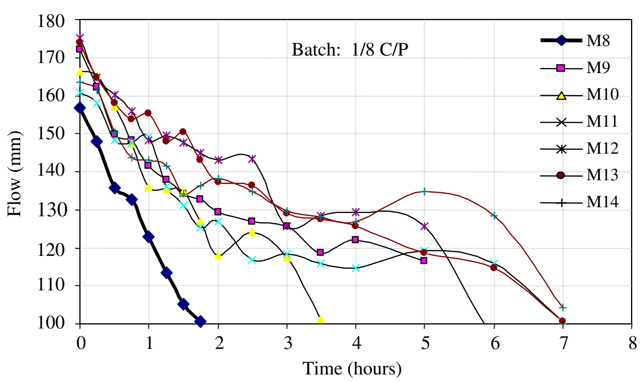

Fig. 3. Flow value versus time for 1:8 C/P batch.

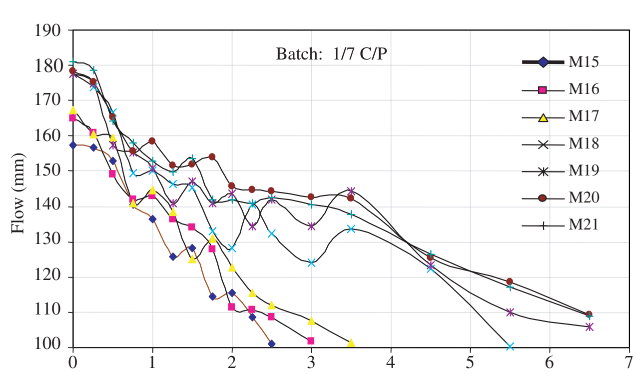

Fig. 4. Flow value versus time for 1:7 C/P batch.

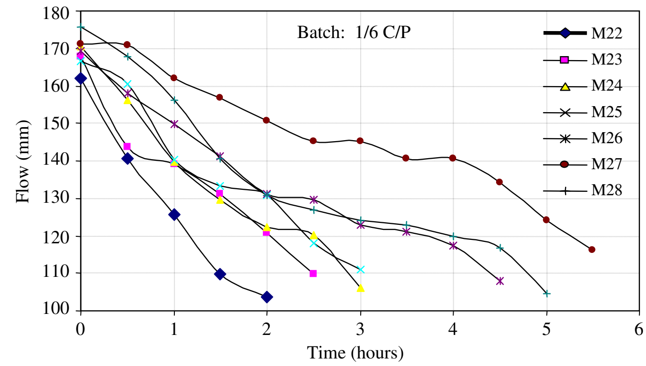

Fig. 5. Flow value versus time for 1:6 C/P batch.

lightened if mortar is retempered, bond strength may be lowered if it is not. All mortar should be used within 2 1/2 h after mixing since the mortar will begin to set [7].

Making a good workable mortar mixture composition could be examined by measuring the flow changes of mortar at time of use. In this research work, the flow value of 130 mm at 2 1/2 h after mixing was set as a target flow for each mixture proportion, which is regarded as the most suitable fluidity to secure workability at a site. This was at the same time used as a control parameter of water retentivity (Fig. 6).

Fig. 6 shows that only nine of PLMC mixtures proved the target flow at the set time. These are M12, M13, M14, M18, M19, M20, M21, M26 and M27, respectively. The PPA was found to be non-effective in all the mixtures of 1:9 C/P batch to satisfy the required workability condition. Also, control mortar mixtures were in same state. All the flow values of mixture proportions in this batch are lower than 100 mm, even some of than lower than the 100 mm value. This means that the mortar has already being hardened. Therefore, this mortar position could not be used to run the wall construction. Similar positions were also obtained for the mixture of both 0.2 and 0.4 PPA contents of all batches. In addition, the required workability condition was only reached for the mixture of 1:7 C/P with 0.6% PPA. The research showed that it is seems to be

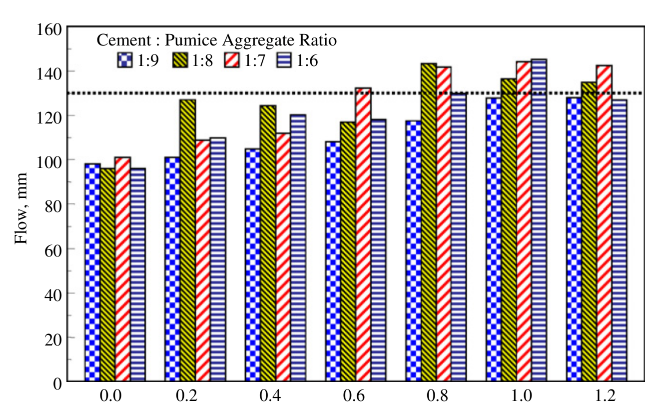

Fig. 6. Flow value of mixture proportions at 2 1/2 h time after mixing.

increasing the PPA content increases the water retention of mortar. However, the most effective use of PPA content is over the 0.8% rate for batches ranged between 1:7 and 1:8 C/P. Increasing the pumice aggregate content in mixtures lowers the workability. Because, the porosity of the pumice aggregates is very high, and therefore water absorption capacity of the mortar is higher. Thus, water loss in a mixture is rapid especially in low amount of cement as a binding agent. The PPA prevents the water loss in mortar mixture in certain duration.

3.2. Compressive strength properties of mortar samples

As with concrete, the compressive strength of mortar primarily depends upon the cement content, water content, water/cement ratio, aggregate and admixture content. Masonry mortars are classified into four types: M, S, N and O [7]. Type N mortar is general all-purpose mortar with good bonding capabilities and workability. Type S is for high flexural bond strength. Type M is also for high compressive strength mortar but not very workable. In addition, Type O is a low strength mortar which is mostly used for interior applications [1,7]. Although these mortar types have basic characteristics, they can be used in a variety of applications. No single mortar is best for all purposes. These four different types of mortar can be made with a variety of cementitious materials, such as masonry cement, mortar cement or Portland cement:lime. These mortars can be provided as preblended mortars, site-mixed or as extended life mortars.

Figs. 7–10 show the compressive strength of PLMC mortar samples having PPA in different proportions of cement by weight at curing of 7, 14 and 28 days, respectively. Fig. 7 indicates that with the increase of PPA content above 0.2% of cement by weight, compressive strength of PLMC mortar samples at 1:9 C/P ratio decreases. In the present investigation, the tests were performed on 28 days cured specimens, but it can be anticipated that these mortars may gain more strength at a later age. For economy, the PPA content of PLMC mortars should be kept as low as possible. The minimum average crushing strength prescribed in ASTM C270 is 2.4 N/mm^2 for O type mortar and is 5.2 N/mm^2 for N type mortar. Table 5 provides a basic guide to mortar selection [7], and Table 6 also specifies the compressive strength of cube samples for mortar types according to regulation of ASTM C 270. None of the mortar samples with batches of 1:9 C/P ratios can supply the strength requirement of N type mortar. But, only two mixtures of M1 and M2 provide the strength requirement of O type mortar. Strengths of the samples at 28 days are 3.772 and 3.652 N/mm^2, respectively. Although these mortars can easily be used

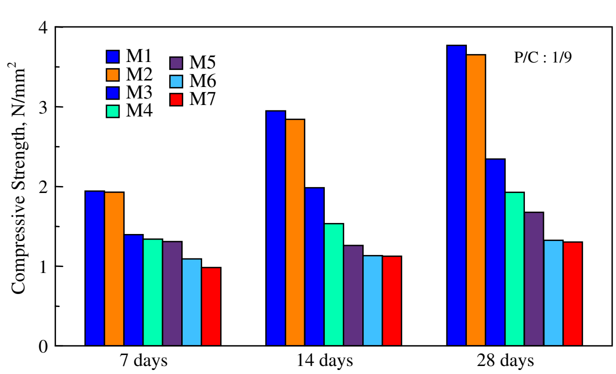

Fig. 7. Compressive strength values of PLMC mortar samples (1:9 C/P batch).

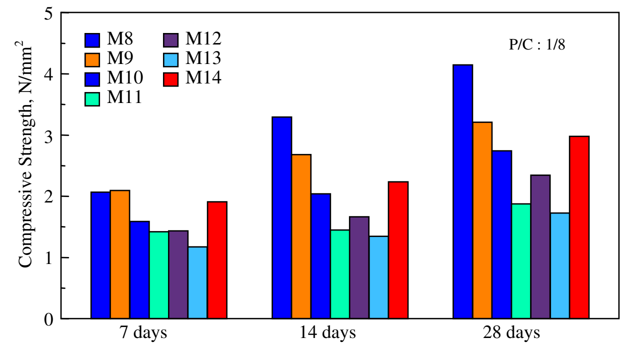

Fig. 8. Compressive strength values of PLMC mortar samples (1:8 C/P batch).

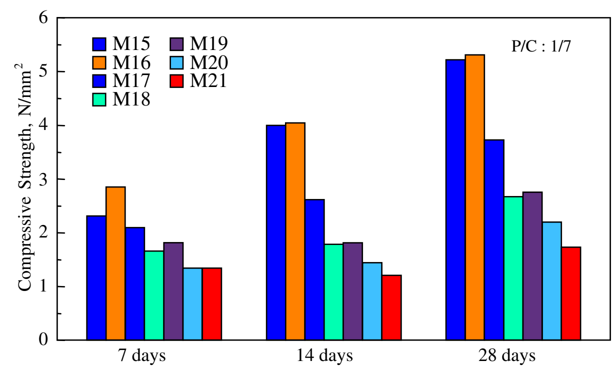

Fig. 9. Compressive strength values of PLMC mortar samples (1:7 C/P batch).

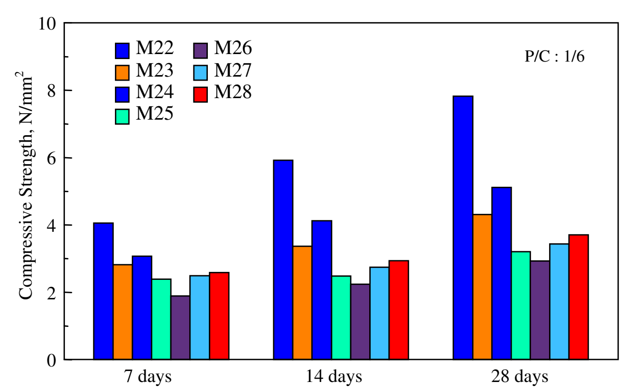

Fig. 10. Compressive strength values of PLMC mortar samples (1:6 C/P batch).

Table 5
Basic mortar selection guide [7]

Locations	Building segment	Mortar type	
		Recommended	Alternative
Exterior, above grade	Reinforced or loadbearing walls Veneer or non-loadbearing walls parapets, chimneys	S N N	N S S
Exterior, at or below grade	Foundation walls, retaining walls, sewers, manholes, paving	M	S
Interior	Loadbearing walls partitions	N O	S N

Table 6
Compressive strength of mortar types [1,7]

Mortar type	Average compressive strength at 28 days (N/mm^2)
M	17.2
S	12.4
N	5.2
O	2.4

with 0.2% PPA content by weight of cement for the purpose of non-load bearing building applications according to the strength requirement for O type mortar, they could not be used in similar applications due to their insufficient fluidity to secure workability. Therefore, the research work with 1:9 C/P ratios showed that it could not be obtained N and O type mortar with the high content of pumice lightweight aggregate and of PPA.

Fig. 8 also shows compressive strength values of PLMC mortar samples at 1:8 C/P ratios. Similar fact with 1:8 C/P ratio batches was observed on the compressive strength specification. Increasing PPA content in the mixture lowers the compressive strength of the mortar samples up to 1.2% PPA content by weight of cement at 1:8 C/P ratios. At this mixture batch, the crushing strength of mortar sample with no any PPA content at 28 days was 4.147 N/mm^2. However, addition of only 0.2% PPA by weight of cement in this mixture lowers the strength value as 3.211 N/mm^2. Therefore, no effect was gained with addition of PPA into the mixture for strength. At the same time, the flow value of the mixture was already under the target flow value of 130 mm at 2 1/2 h after mixing, which is unsuitable for secure workability. Although the mixtures of M12, M13 and M14 with 0.8%, 1.0% and 1.2% PPA by weight of cement, respectively satisfy the target flow, their strengths were tested as low values than the minimum strength requirement for O type mortars. The results indicate that PLMC mortars with high proportion of PPA content have less strength compared to mortars without using PPA.

Decreasing the pumice aggregate content of mortar increases the strength. This condition can be seen in Figs. 9 and 10. The mixtures of M15 and M16 at 1:7 C/P ratio were supplied the N type mortar strength requirement. Their strengths at 28 days are higher than 5.2 N/mm^2. In addition, M17, M18 and M19 mixture batches with PPA content of 0.4, 0.6 and 0.8, respectively were also supplied only O type mortar strength requirement. Their strengths at 28 days are higher than 2.4 N/mm^2 and lower than 5.2 N/mm^2. The research for this batch of C/P ratio showed that increasing the PPA content lowers the strength of the mortar samples. However, the target flow of these mixtures was in acceptable values. Therefore, as specifying the required strength requirement for a mortar type, only the mortar batch for 0.2% PPA by weight of cement at 1:7 C/P ratio can be used at 2 h set time as N type mortar for reinforced or loadbearing wall exterior applications and the partitions in interior applications of a building. In addition, the mortar batches for 0.6% and 0.8% PPA by weight of cement at 1:7 C/P ratio can only be used in an acceptable secure workability as just O type mortar for the partitions in interior applications of building construction.

On the other hand, increase of pumice lightweight aggregate content with increasing the PPA amount in mixtures improved the strength conditions of the mortar comparing situation due to higher content of cement. This impact was clearly observed in the batch of 1:6 C/P ratios (Fig. 10). All the mixtures in this batch were supplied the required minimum strength of O type mortar. However, improving the strength of PLMC mortar does not mean that it is in a very good workability condition. To consent a positive application, the mortar must have at least an acceptable flow at certain duration and supply a minimum O type mortar strength requirement. Therefore, the mortar batches for 0.8% and 1.0% PPA by weight of cement at 1:6 C/P ratio can only be used as O type mortar for the partitions in interior applications of building construction. Although the other mixtures of this batch have been supplied the required strength, they are not be used in mortar application due to insufficient workability conditions.

3.3. Density properties of mortar samples

The difference in dry set densities of PLMC mortars made with various proportions of PPA when cured in air environment condition is also presented in Table 4. The results indicate that PLMC mortars with high proportion of PPA have less density compared to mortars without using PPA. It is evident from Table 4 that, the loss in dry mortar density at 1.2% PPA by weight of cement batch was found to be as 21.49% for 1:9 C/P ratio, 24.46% for 1:8 C/P ratio, 28.94% for 1:7 C/P ratio, and 22.05% for 1:6 C/P ratio, respectively. It is also observed that reduce in W/C ratio with using PPA in mixtures results in increase of the compressive strength of these PLMC mortars.

4. Conclusions

According to research findings, it can be assumed that PLMC mortars can be produced by the use of composites blends containing pumice lightweight aggregate, powder polymer additive and cement to comply with the requirements of ASTM C270.

The research findings show that higher the amount of PPA in the mixture, lesser the dry set density of PLMC mortars. Mixture batches of 1:9 C/P ratios with all additions of PPA contents could not be used in producing PLMC mortars due to their insufficient workability. In addition, mixture batches of 1:8 C/P ratios up to 0.8% PPA content could not also be used in producing PLMC mortars due to same case. Similarly, the mortar composites up to 0.6% PPA content for batch of 1:7 C/P ratio and up to 0.8% PPA content for batch of 1:6 C/P ratios are in same manner. Among the PLMC mortar compositions, only four mixture batches of M18, M19, M26 and M27, respectively can be used as O type mortar with complying the required technical specifications. The compressive strength of mortars decreases for use of PPA up to between 0.8% and 1.2% by weight of cement contents as a powder polymer admixture for different mixture batches. Use of PPA more than 0.2% of cement content causes the strength reduction for PLMC mortars due to the insufficient water amount in the mixture for hydration reaction. It was also observed that reduce in W/C ratio results in increase of the compressive strength of PLMC mortars.

Within the 1/9 to /6 range of C/P ratios, dry set densities between 943 and 1347 kg/m^3 and compressive strength values between 1.38 and 7.82 N/mm^2 can be achieved dependant on mixture proportions. Standard consistence of PLMC mortars, in the present investigation was obtained to be between 157 mm and 185 mm. The final setting of various mortar composites is found to be 3.30–7.15 h higher compared to normal aggregate mortars.

References

[1] The Northwest Masonry Guide. Masonry systems data mortar and grout mixes and specifications. USA: Masonry Institute of Washington, Washington State Conference of Mason Contractors; 2000.

[2] Sebaibi Y, Dheilly RM, Queneudec M. A Study of the viscosity of lime–cement paste: influence of the physico-chemical characteristics of lime. Constr Build Mater 2004;18:653–60.

[3] Robery P, Shaw J. Materials for the repair and protection of concrete. Constr Build Mater 1997;11(5–6):275–81.

[4] Mosquera MJ, Benitez D, Perry SH. Pore structure in mortars applied on restoration. Cement Concrete Res 2002;32:1883–8.

[5] Enevoldsen JN, Hansson CM, Hope B. The influence of internal relative humidity on the rate of corrosion of steel embedded in concrete and mortar. Cement Concrete Res 1994;24(7):1373–82.

[6] Fernandes V, Silva L, Ferreira VM, Labrincha JA. Influence of the kneading water content in the behaviour of single-coat mortars. Cement Concrete Res 2005;35:1900–8.

[7] Brick Industry Association, 2003. Technical notes on brick construction, Technical Notes 8-Mortars for Brick Masonry. Virginia, USA; Revised June 2003.

[8] Ásgeirsson H. Léttsteypur ur vikri (Lightweight pumice concrete), IBRI; 1984.

[9] Thorarinsson S. Hekla, Almenna bókafélagiO, Reykjavík, 1979.

[10] Berge O. Lätt isolerande konstruktrionsbeton med isländsk pimpsten som ballast. Västra Frölunda. nóv. 1983.

[11] Lee HS, Lee JY, Yu MY. Influence of inorganic pigments on the fluidity of cement mortars. Cement Concrete Res 2005;35:703–10.