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Original article

The effect of partial replacement of cement with diatomaceous earth (DE) on the compressive strength and absorption of mortar

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ABSTRACT

The purpose of this study was to determine the effect of partial replacement of cement with diatomaceous earth (DE) on the compressive strength and absorption of mortar. The cement volume was replaced by different contents of replacement levels of 0%, 10%, 20%, 30% and 40% DE. Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC) were used while the binder and sand were mixed at 1: 2 and 1: 4 vol ratios. Moreover, $5 \times 5 \times 5$ cm^3 cubes were used as the test specimens and their compressive strength was determined at 1, 3, 7, and 28 days while the absorption was evaluated at the curing age of 28 days. The results showed that the compressive strength of mortar with OPC for both 1: 2 and 1: 4 ratios decreased with the increment in the content of the DE. However, at 40% cement replacement, the mortar with OPC was categorized as type M according to SNI 6882:2014 or ASTM C270-10 with 28 days compressive strength observed to be greater than 17.2 MPa. Meanwhile, the mortar with PCC for 1: 2 was observed to have the highest compressive strength of 36.63 MPa at 20% cement replacement and 25.39 MPa at 10% cement replacement for 1:4. Furthermore, the absorption of mortar with DE was observed to be greater than for mortar with cement only.

1. Introduction

Mortar is a homogenous mixture of cement, fine aggregate, and water which is widely applied in plastering, masonry work, repairing damaged concrete, floor leveling, rendering, and development of a precast product such as bricks, masonry block, cone block, and roof tiles (Bunganaen et al., 2006; Ramakrishna and Sundararajan, 2019) as well as in both structural and non-structural constructions. The structural aspect includes a masonry of split stones for the foundation while the non-structural part involves a brick masonry. However, mortar with a cement to sand ratio of 1: 2 is often used for adhesives and plastering of trasram bricks, bathroom walls, and masonry in the ground to ensure impermeability while those with 1: 4 are mostly used as brick masonry adhesive and in plastering ordinary walls.

Due to the importance of mortar in bearing the load of construction, its use in Indonesia is expected to be in accordance with the SNI 6882:2014 specification adopted from the ASTM C270-10 (2010) standard, especially with the focus on the ability to sustain compressive loads based on its compressive strength. This is, however, influenced by several factors including density, type and amount of cement, aggregate properties, and the age of the mortar.

Cement is increasingly being used due to the increase in constructions and has also been reported to be one of the major contributors to the production of greenhouse gas emissions, especially CO_2 (Hanle et al., 2006). A total of 5–7% of global CO_2 emissions is caused by cement plants with each ton produced reported to be emitting 900 kg into the atmosphere (Benhelal et al., 2013). The CO_2 emissions further lead to global warming and more disastrous consequences if not controlled and reduced (Mahlia, 2002; Zhang et al., 2012). Indonesia is, however, committed to deal with this problem through the implementation of the Action Plan for Reducing Greenhouse Gas (RAN-GRK) in several sectors (Damayanti & Lestari, 2013). One of the measures to achieve this is to find more environmentally-friendly materials such as diatomaceous earth to partially replace cement as a binder.

Diatomaceous earth (DE) with the chemical formula (SiO, nH2O) is a siliceous sedimentary rock consisting of fossilized skeletal remains of aquatic plants or single-celled algae. Its main

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constituent, silica, makes it possible to use the material as a binder and has also be found to be an alternative to the selection of good pozzolanic material (Hasan et al., 2020a). Moreover, DE is easy to obtain at a relatively inexpensive price and this is associated with its quite high deposits in Aceh Besar Regency, Indonesia with an estimation of 40,353,700 tons. This makes the use of the material in construction one of the efforts to utilize natural resources in the area and, according to ASTM C618-15 (2015), DE is classified as Class N natural pozzolan which is suitable as a cement replacement.

Several studies have been conducted on the use of pozzolanic material as a partial replacement for cement in mortars (Al-Kutti et al., 2019; Amin, 2012; El-Sayed and El-Samni, 2006; Hossain et al., 2016; Khan et al., 2017; Reddy et al., 2013; Shah et al., 2020; Shahnaz et al., 2016) as well as on the utilization of activated geopolymer materials to totally replace cement in mortar production (Luukkonen et al., 2018; Gomaa et al., 2017). However, no research has been conducted on the potentials of DE to perform this same function with most of the previous research focusing on its application in the production of composite cement (Stamatakis et al., 2003; Fragoulis et al., 2005; Kastis et al., 2006; Pokorny et al., 2016, 2017; Hasan & Saidi, 2020), high-performance concrete (Tagnit-Hamou et al., 2003; Hasan et al., 2020b; Hasan et al., 2020c), and ultra-high-performance concrete (Saidi et al., 2020).

The ability of mortar to absorb plays important role in its durability with the ingress of several aggressive ions, liquids, and gases from the environment reported to be responsible for its degradation as observed in the acids, alkalies, and sulfates causing its chemical corrosion (Sicakova et al., 2017). It has been discovered that mortar is more durable when it absorbs less content. This research was, therefore, conducted to determine the compressive strength and absorption capacity of mortar using diatomaceous earth to partially replace cement.

2. Classification of mortars

Based on SNI 6882:2014 and ASTM C270-10 (2010), cement mortars are classified into 4 types according to their strength and the material specification requirements consisting of cement, aggregate, and water. They are as follow:

Type M is a mixture with high compressive strength and a minimum strength of 17.2 MPa recommended for both reinforced and non-reinforced masonries to bear a large compressive load.

Type S has a minimum strength of 12.4 MPa and recommended for structures to bear normal compressive loads but with the flexural strength required to withstand large lateral loads originating from earth pressure, wind, and earthquake loads. It is also recommended for structures underground and those in contact with the soil such as foundations, retaining walls, pavement, and drainage channels due to its high durability.

Type N has a minimum strength of 5.2 MPa and commonly used for above-ground masonry construction. It is recommended for interior and exterior load-bearing walls. Moreover, its medium strength provides the best fit between compressive and flexural strength, workability, and economically useful in general masonry construction.

Type O has a minimum strength of 2.4 MPa and contains high lime content. It is recommended for interior and exterior walls that do not withstand structural loads. This means it is mostly applied in local work because of its good workability and affordability.

3. Materials and method

3.1. Materials

The materials used in this study were Ordinary Portland Cement (OPC), Portland Composite Cement (PCC), diatomaceous earth (DE), fine aggregates, and water. The OPC and PCC were produced by PT. Semen Andalas Indonesia while the diatomaceous earth (DE) was obtained from Lambeurenut Village, Lampanah Leungah Sub-district, Aceh Besar Regency. The DE sample was ground and sieved using sieve #200 after which the DE powder was dried at 100 °C in the oven for 24 h. The oven-dry DE powder was calcined at 500 °C for 5 h in a laboratory furnace and was recorded to have a bulk density of 770 kg/m^3, a saturated surface dry specific gravity of 2.00, oven-dry specific gravity of 1.89, and absorption of 6.54%. The chemical composition of OPC, PCC, and DE was analyzed by conducting an X-ray fluorescence (XRF) test using an XRF Analyzer of TORONTOTECH TT-EDXPRT.XRF and the results are shown in Table 1 together with the mineralogical composition of OPC and PCC which was determined based on SNI 15-(2049)2004. Moreover, the particle-size distributions of OPC, PCC, and DE were analyzed through particle size analyzer (PSA) test using MicroBrook 2000 L PSA test device, and the results are shown in Fig. 1 while the specific surface area was 539.8 m^2/kg, 613.5 m^2/kg, and 675.6 m^2/kg, respectively. The surface texture and morphology of DE before and after grinding were analyzed through scanning electron microscopy (SEM) microphotograph using a Hitachi SU-3500 device and the results are shown in Figs. 2 and 3. The morphology of DE particles before and after grinding and calcining was almost the same which have cellular structures with a lot of nanopores distributed on their surfaces.

The water used was PDAM water (Local Water Company) while the fine aggregate was the sand obtained from the Krueng Aceh river and with a bulk density of 1630 kg/m^3, a saturated surface dry specific gravity of 2.67, oven-dry specific gravity of 2.62, absorption of 1.81%, and fineness modulus of 3.13. Meanwhile, the result of the sieve analysis is shown in Fig. 4. It is, however, important to note that these physical properties and size distribution values fulfilled the ASTM C33/C33M-18 (2018) requirements.

3.2. Mix proportion and preparation of specimens

For each type of cement, both OPC and PCC, the mortar specimens were produced by mixing cement and sand at the volume ratio of 1: 2 and 1: 4 (hereinafter referred to as mortar 1: 2 and mortar 1: 4). The volume of cement in each ratio was replaced with 0%, 10%, 20%, 30%, and 40% DE. Therefore, 20 mixtures were obtained including 5 each for mortar 1: 2 using OPC, mortar 1: 2 using PCC, mortar 1: 4 using OPC, and mortar 1: 4 using PCC as shown in Table 2**.** The mix proportion for all mixtures is presented

Table 1
Chemical and mineralogical composition of OPC, PCC, and DE.

Chemical analysis	OPC (%)	PCC (%)	DE (%)
SiO_2	17.25	20.95	78.73
Al_2O_3	2.32	2.31	0.39
Fe_2O_3	4.67	7.87	2.89
MgO	2.13	4.87	1.11
SO_3	2.56	2.23	0.39
CaO	70.34	61.08	16.34
K_2O	0.73	0.69	0.15
Mineralogical composition	(%)	(%)	NA
C_3S	68.72	62.25	NA
C_2S	17.34	17.78	NA
C_3A	6.45	6.32	NA
C_4AF	7.44	13.15	NA

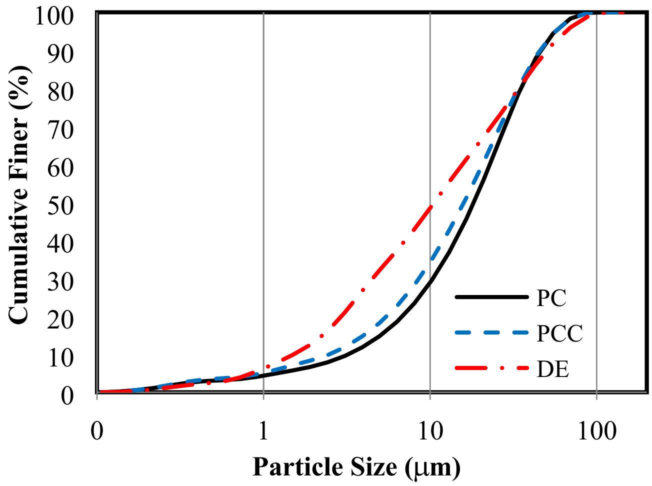

Fig. 1. Particle- size distribution of PC, PCC, and DE.

in Table 3. Meanwhile, due to the fact that the replacement of cement by DE is based on volume and the lower specific gravity of DE compared to cement, the weight of the DE added was lower than cement replaced. Therefore, the water to binder ratio (W/(C + DE)) increases with the increase in DE content as shown in Table 3.

The specimens were produced by placing all the materials into a 10 L mixer and stirred for approximately 15 min after which the homogenous mixture was poured into the cube mold twice with each of the layers compacted by round steel and tapped using a rubber hammer. This was followed by the leveling of the surface using the appropriate spoon to produce specimen cubes with 50 mm sides in accordance with ASTM C109/109M-16a (2016). It is important to note that 25 specimens were cast for each mixture, 5 of which were for absorption tests and the remaining 20 specimens for the compression tests. After the specimens were 24 h old, they were removed from the mold and labeled with a name or code for identification. They were later cured in a protected fresh water bath and removed a day before the compression and absorption tests were conducted to clean and dry their surface water.

3.3. Compression and absorption tests

The compressive strength was determined using the methods recommended by ASTM C109/109M-16a (2016) after the specimens were 1, 3, 7, and 28 days old using 5 specimens for each mixture. The process involved placing the specimen between two loading plates after which a vertical direction load was applied on it and increased slowly until it was destroyed using a universal testing machine.

Absorption was tested when the specimens were 28 days old with reference to ASTM C642-13 (2013). This involved drying the specimens at 105 °C for 24 h in the oven after which they were weighed and subsequently immersed in water. The change in weight was measured every 5 min for the first 90 min to determine the quantity of water absorbed by the mortar. Furthermore, the change in weight was also measured after 10, 15, and 24 h of immersion. However, a constant weight means no more absorption, and the value at this point was recorded as the absorption capacity of the specimen. Therefore, the absorption was calculated by comparing the weight of water absorbed with those in the oven-dry state, and the results are expressed as a percentage.

4. Results

4.1. Compressive strength

4.1.1. Mortar 1:2

The average compressive strength of the mortar 1: 2 for OPC is shown in Fig. 5 and a reduction is observed in the value as the quantity of cement replaced by DE was increasing. However, the compressive strength at 28 days for all the mixtures is above the 17.2 MPa required for type M mortar by SNI 6882:2014 and ASTM C270-10 (2010). Moreover, the compressive strength obtained for 10, 20, 30, and 40% cement replacement was 37.85, 33.91, 30.39, and 25.59 MPa, respectively, while the value for OPC cement only was 38.58 MPa.

The average compressive strength of mortar 1: 2 with PCC is shown in Fig. 6 and the value at 10% cement replacement is observed to be slightly lower than at 0% while 20% was higher but 30% and 40% were also lower than the use of cement only. The highest compressive strength was achieved at 20% cement replacement for all test ages with the 36.63 MPa recorded on the 28th day found to be more than 35.33 MPa for control mortar. However, the lowest compressive strength of 24.59 MPa was obtained at 40% cement replacement but this is still higher than the required 17.2 MPa for type M mortar by SNI 6882:2014 and ASTM C270-10 (2010).

The development in compressive strength of mortars 1: 2 from 1 day to 28 days for all mixtures with OPC and PCC are shown in Figs. 7 and 8, respectively. A similarity in the development rate

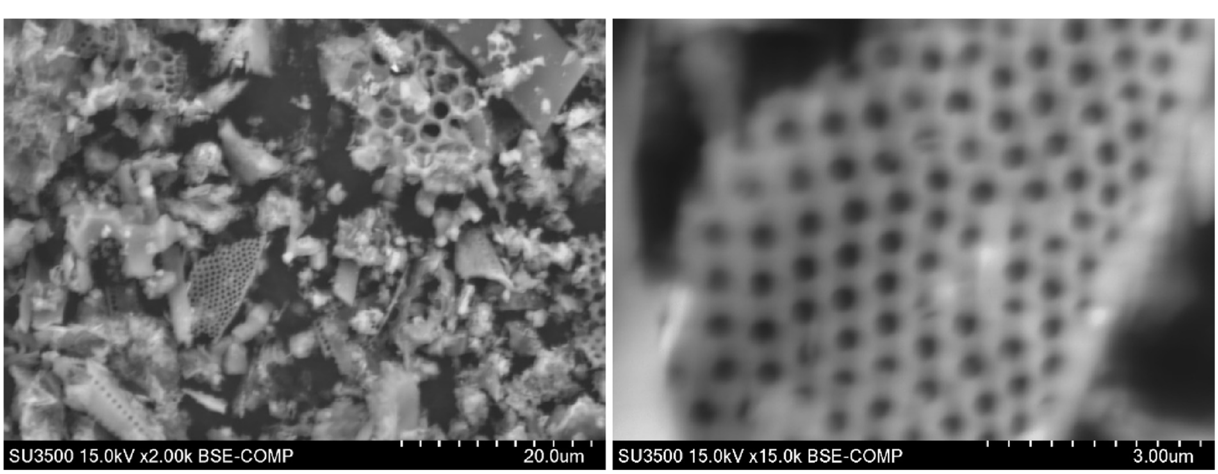

Fig. 2. SEM microphotograph of DE before grinding.

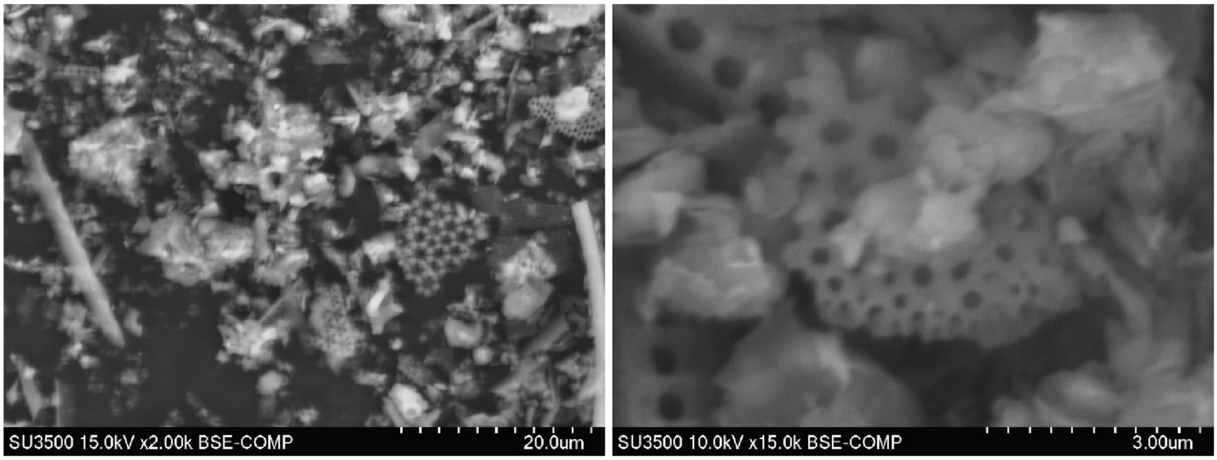

Fig. 3. SEM microphotograph of DE after grinding and calcining.

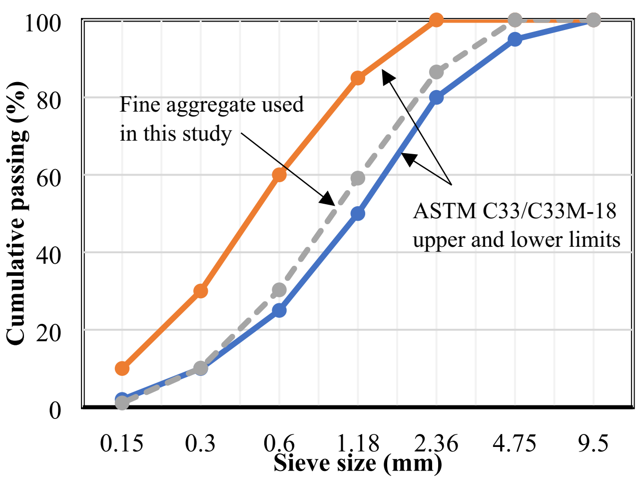

Fig. 4. Sieve analysis result for the fine aggregates.

was observed for the two types of cement, except for 10% cement replacement for OPC which showed a higher trend from 7 days to 28 days than other mixtures. The 28 days compressive strength of the OPC mortar with 10% cement replacement was almost close to the control mortar.

4.1.2. Mortar 1:4

The average compressive strength for different mixtures of mortar 1: 4 for OPC is shown in Fig. 9 and a tendency of the compressive strength to decrease with the increase in the cement replacement was observed. However, from 10% to 20% cement replacement, a slight increase was recorded even though it later decreased at 30% and 40% replacements. Moreover, at 28 days, the compressive strength for each mixture was above 17.2 MPa required for type M mortar according to the SNI 6882:2014 and ASTM C270-10 (2010) as recorded with the 24.97, 24.32, 24.32, and 20.31 MPa for 10, 20, 30, and 40% cement replacement, respectively, while the control mortar had 33.27 MPa.

The average compressive strength of mortar 1: 4 with PCC is shown in Fig. 10 and a slight increase was recorded at 10% after which the value decreased at other replacement levels. Moreover, at 28 days, the compressive strength for each mixture was above 17.2 MPa which is required for type M mortar, except for 40% cement replacement. Therefore, the mortar 1: 4 with PCC at 40% cement replacement cannot be classified as type M mortar but as a type S mortar. For the 10, 20, 30, and 40% specimens, the compressive strength of mortar 1: 4 with PCC at 28 days was 25.39, 23.18, 18.34, and 16.75 MPa, respectively while mortar without DE was 25.27 MPa.

The development of compressive strength of mortar 1: 4 from 1 to 28 days for all mixtures with OPC and PCC is shown in Figs. 11 and 12, respectively. The results showed the development rate is almost the same for all the mixtures except at 30% and 40% cement replacements for OPC which were found to have higher rates from 7 to 28 days while the compressive strength for 30% at 28 days was almost close to 10% and 20% cement replacements.

4.1.3. Comparison of compressive strength of OPC and PCC mortars

Figs. 13 and 14 compare the compressive strength of mortars 1: 2 and 1: 4 with OPC and PCC at the curing age of 28 days. From Fig. 13, the compressive strength of mortar 1: 2 with OPC was higher than PCC for all mixtures, except for the 20% cement replacement. Meanwhile, for mortar 1: 4 as depicted in Fig. 14, the compressive strength of the specimen with PCC was found to be higher than OPC only at 10% cement replacement.

4.2. Absorption

4.2.1. Mortar 1:2

The average absorption for mortar 1: 2 with OPC and PCC is shown in Fig. 15 and the specimens with PCC were found to have lower absorption compared to OPC. Moreover, for the specimens with OPC, the mortar with DE content has a higher absorption

Table 2
Mortar mixtures.

Cement type	Cement to sand volume ratio	Cement replacement ratio (% volume)				
OPC	1: 2	0	10	20	30	40
	1: 4	0	10	20	30	40
PCC	1: 2	0	10	20	30	40
	1: 4	0	10	20	30	40

Table 3
Mix proportion for 1 m^3 of mortar.

Mixtures	Cement replacement	Cement, C	DE	Sand	Water, W	W/(C + DE)
	(% volume)	(kg)	(kg)	(kg)	(kg)	
Mortar 1: 2	0	688	0	1165	344	0.50
	10	619	44	1165	344	0.52
	20	550	87	1165	344	0.54
	30	482	131	1165	344	0.56
	40	413	175	1165	344	0.59
Mortar 1: 4	0	479	0	1621	344	0.72
	10	431	30	1621	344	0.75
	20	383	60	1621	344	0.78
	30	335	90	1621	344	0.81
	40	287	120	1621	344	0.85

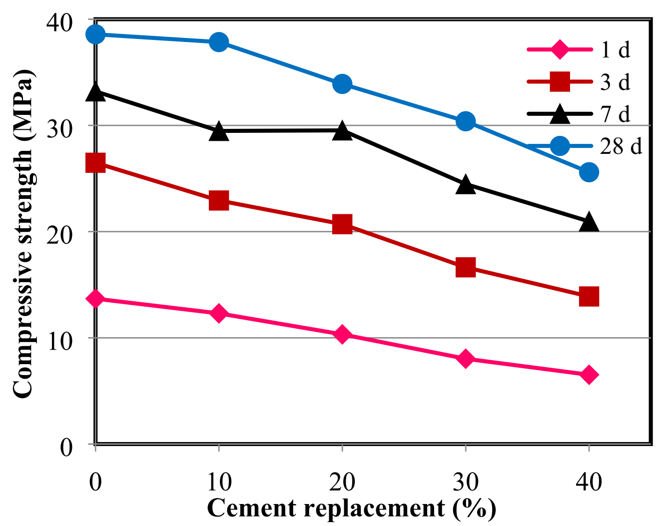

Fig. 5. Compressive strength of OPC mortar 1: 2.

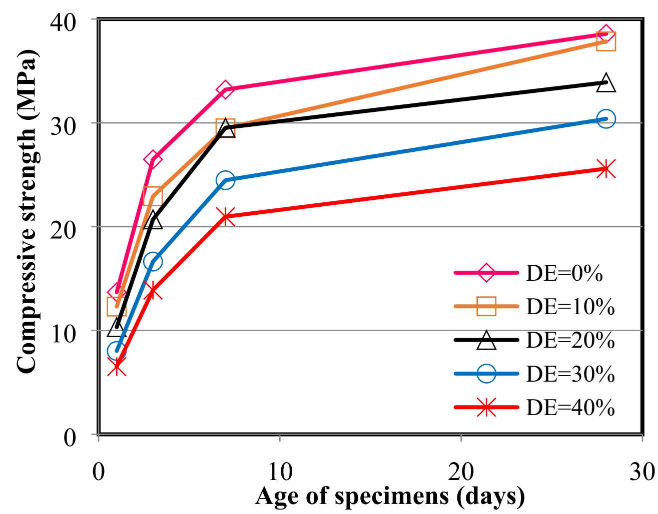

Fig. 7. Compressive strength development for OPC mortar 1:2.

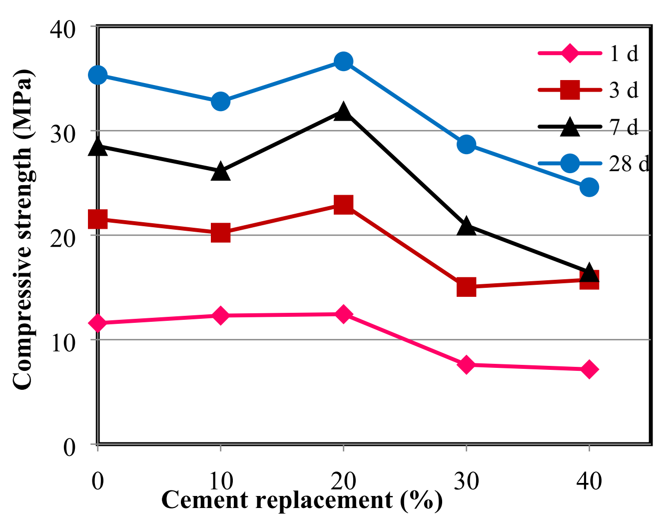

Fig. 6. Compressive strength of PCC mortar 1: 2.

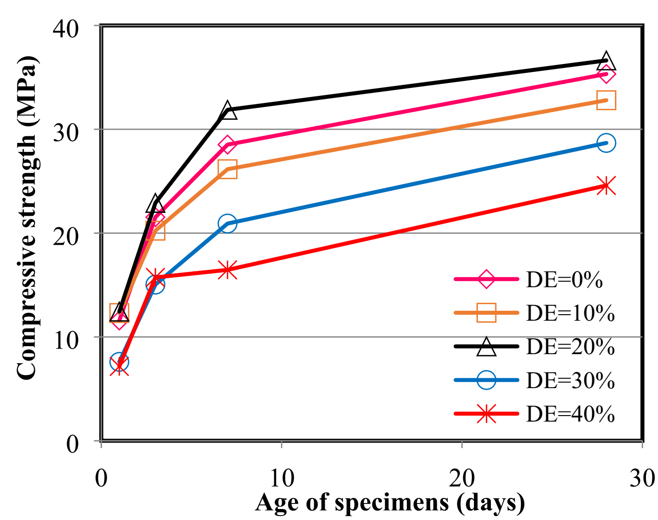

Fig. 8. Compressive strength development for PCC mortar 1:2.

compared to the mortar without the DE. Meanwhile, for PCC, the lowest absorption was recorded at 20% cement replacement while the absorption obtained at 0%, 10%, and 30% cement replacement were almost the same. The absorption became constant after the specimens have been immersed for 24 h and the values recorded are reported in Fig. 15. Moreover, the trend for mortar 1: 2 in both types of cement during 24 h immersion is shown in Figs. 16 and 17. The graph of the absorption during the first 90 min immersion is inserted in the figures to show a clear difference in the rate.

4.2.2. Mortar 1:4

The average absorption for mortar 1: 4 with OPC and PCC is shown in Fig. 18 and the specimens with PCC were found to be lower absorption than those with OPC. Meanwhile, the specimens containing DE have a slightly higher absorption compared to those

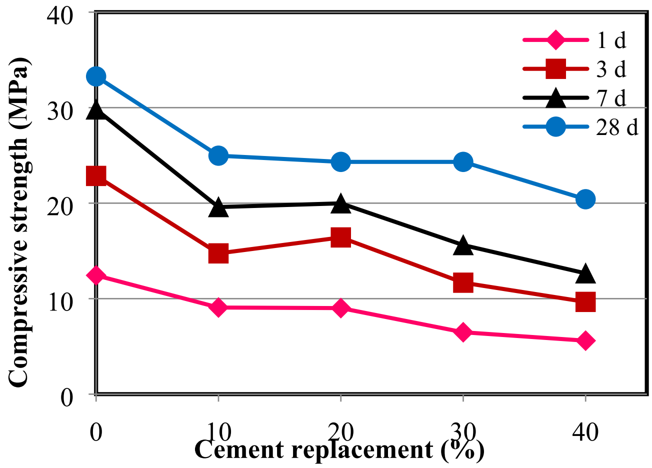

Fig. 9. Compressive strength of OPC mortar 1: 4.

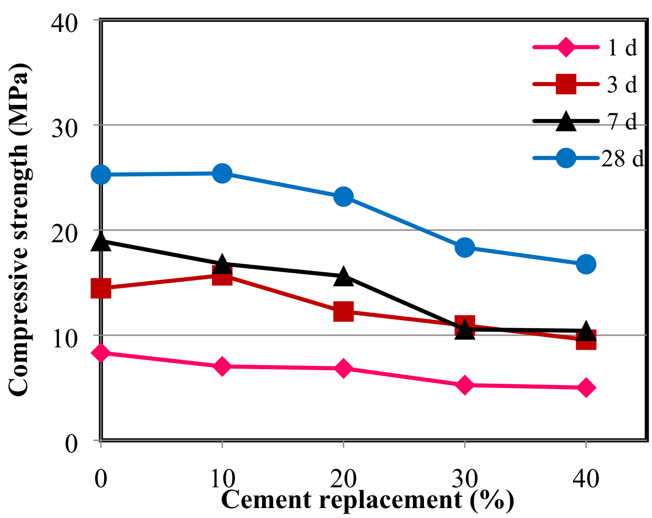

Fig. 10. Compressive strength of PCC mortar 1: 4.

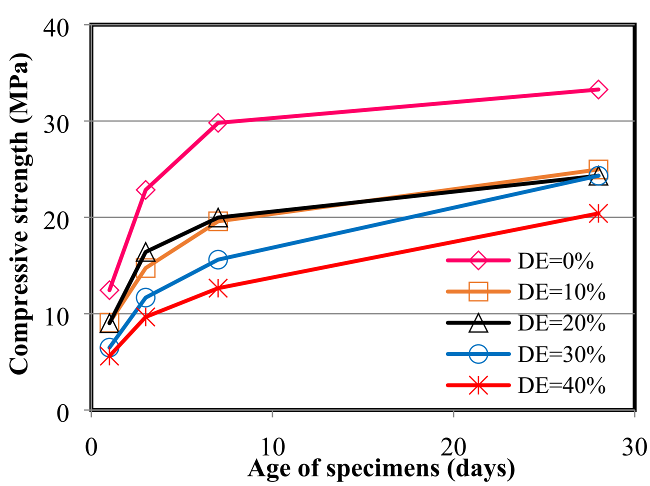

Fig. 11. Compressive strength development of OPC mortar 1:4.

without DE. The absorption was observed to become constant for OPC after 15 h of immersion while it became constant for PCC at 90 min. The increasing trend in the absorption of mortar 1: 4 for

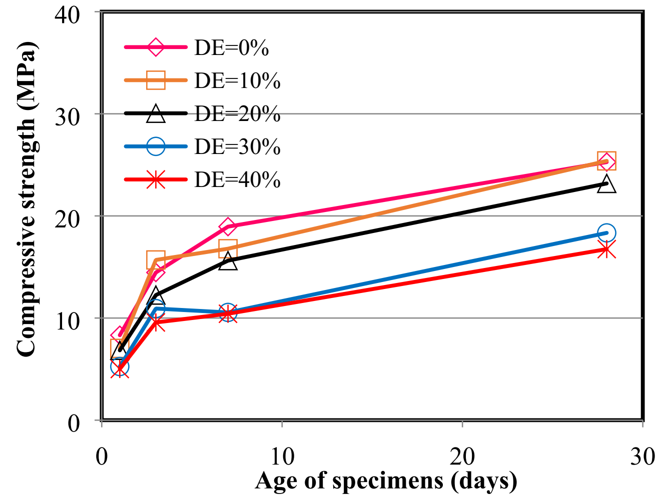

Fig. 12. Compressive strength development of PCC mortar 1:4.

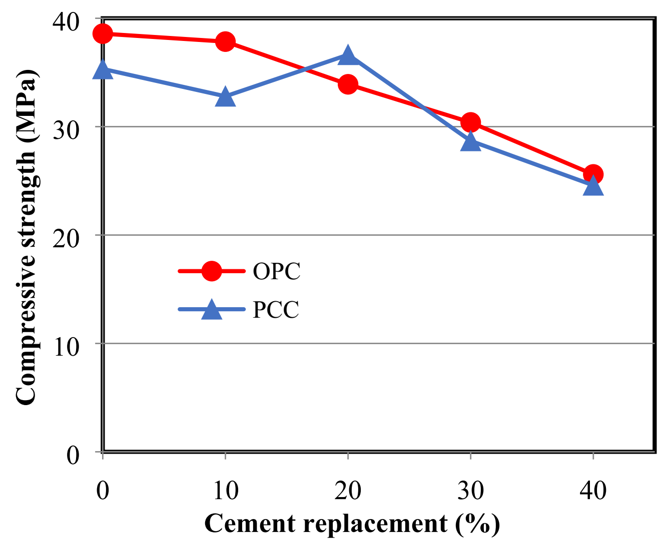

Fig. 13. Comparison of 28 days compressive strength between OPC and PCC mortar 1: 2.

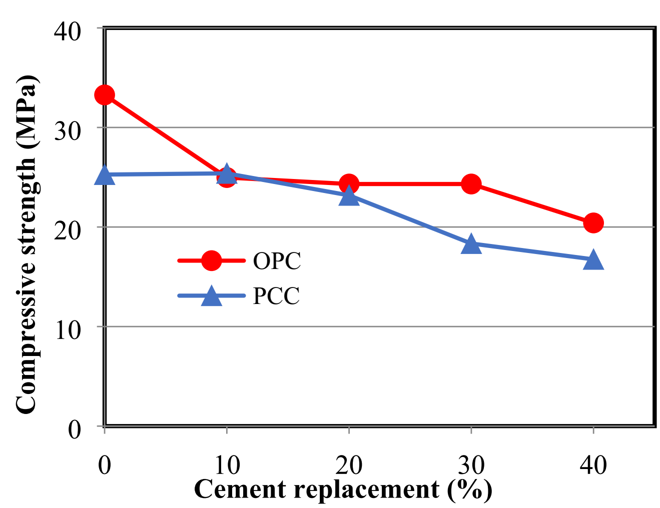

Fig. 14. Comparison of 28 days compressive strength between OPC and PCC mortar 1: 4.

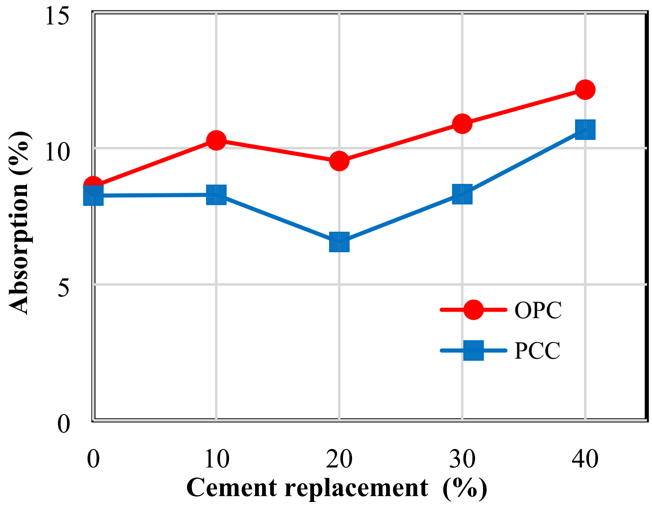

Fig. 15. Absorption of mortar 1:2.

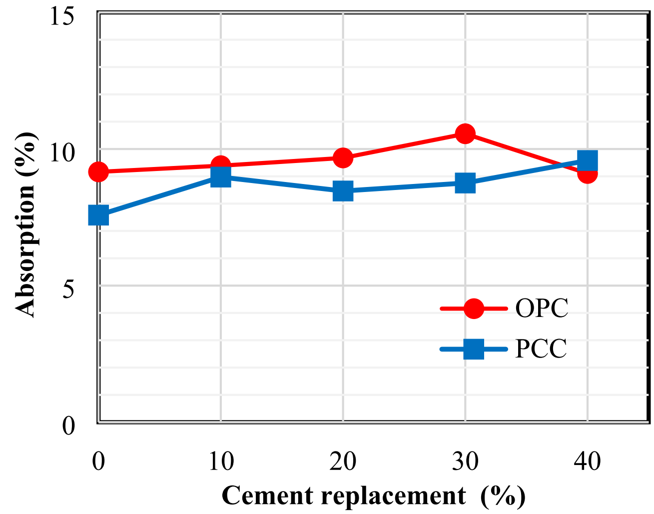

Fig. 18. Absorption of mortar 1:4.

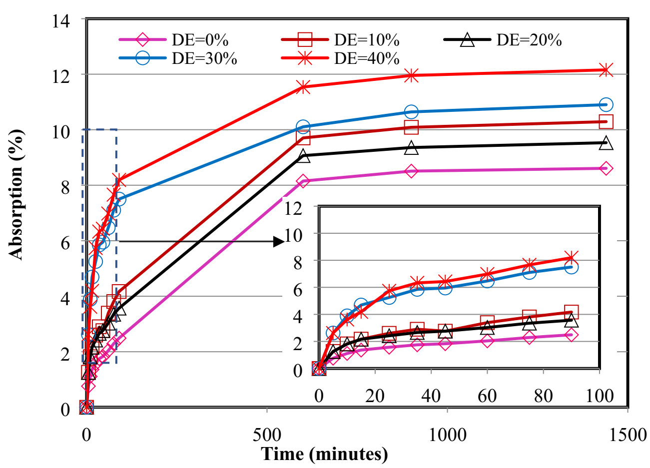

Fig. 16. Absorption of OPC mortar 1: 2 during 24 h immersion.

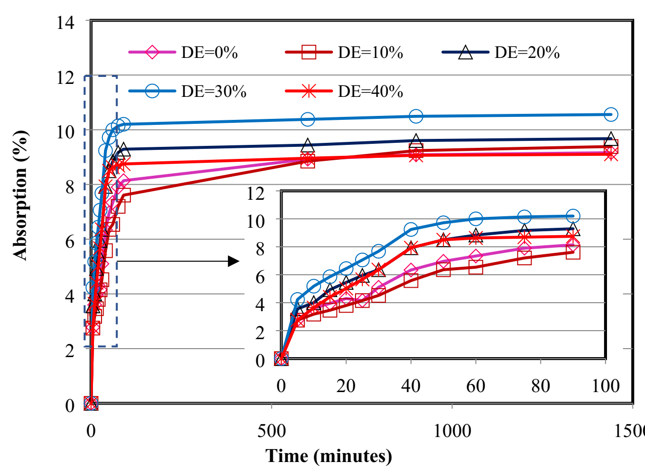

Fig. 19. Absorption of OPC mortar 1: 4 during 24 h immersion.

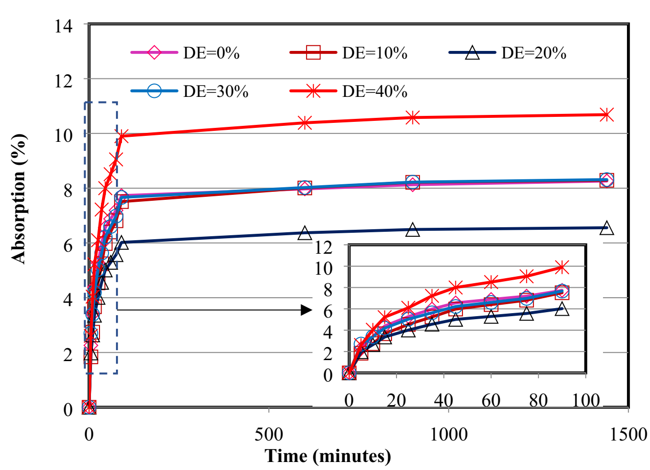

Fig. 17. Absorption of PCC mortar 1: 2 during 24 h immersion.

both OPC and PCC during 24 h immersion is shown in Figs. 19 and 20, respectively. The graph of the absorption during the first 90 min is also inserted in the figures to determine the change in rate clearly.

5. Discussion

The compressive strength of mortar is shown in Figs. 5, 6, 9, and 10 to be decreasing while the water to binder ratio presented in Table 3 is increasing with the increment in the DE content. This, therefore, means the reduction in the compressive strength based on the increase in the DE percentage is due to the increment in water to binder ratio and this is in line with the reports of several researchers (Sing et al., 2015; Nahhab and Zahra, 2018). The relationship between compressive strength and water to binder ratio based on the findings of this study is presented in Fig. 21. Furthermore, the 20% replacement level for mortar 1: 2 with PCC has a compressive strength which is higher than the control specimen and this is attributed to the active reaction of silica in DE with calcium hydroxide ($Ca(OH)_2$) released from cement hydration process to form calcium silicate hydrate which further leads to the production of a denser and stronger mortar. A lower quantity of $Ca(OH)_2$ has been reported by Amin (2012) in the mortar with pozzolanic material in comparison with the control specimen while the lowest absorption recorded in the mortar 1: 2 with PCC at 20% cement replacement as indicated in Fig. 15 shows the mortar was denser than the others.

Figs. 15 and 18 show the absorption of mortar increases with the increment in the DE content due to the nanopores structures

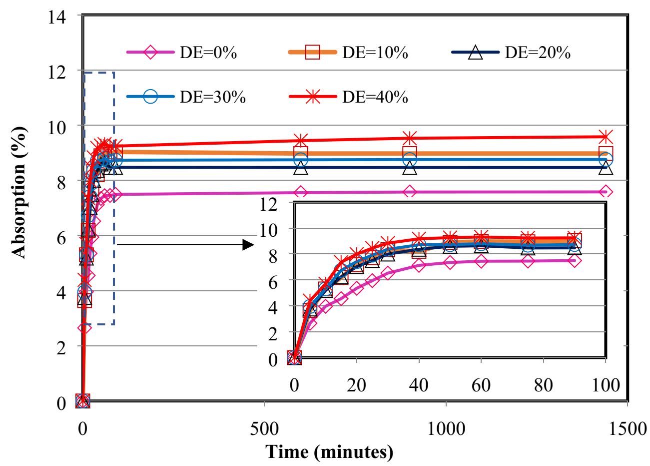

Fig. 20. Absorption of PCC mortar 1: 4 during 24 h immersion.

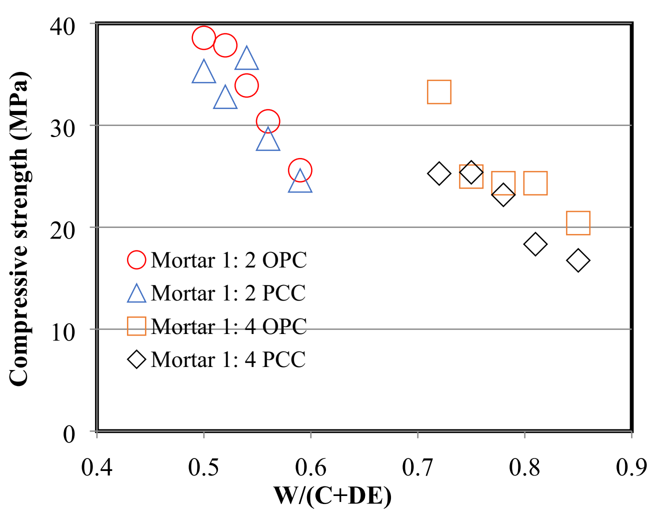

Fig. 21. The relationship between compressive strength and water to binder ratio at the 28th day.

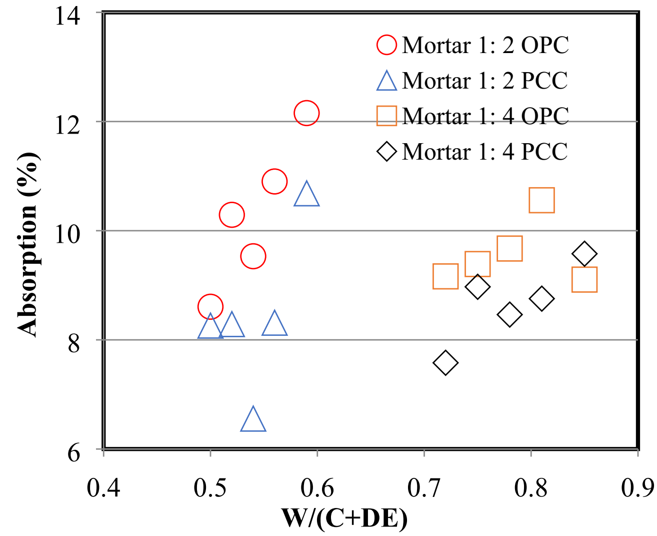

Fig. 22. Relationship between absorption and water to binder ratio.

on the DE's particle as shown in Fig. 3. The DE is also an absorbent material with an absorption capacity of 6.54%. The results showed the absorption to have increased for mortar 1: 2, especially when using OPC, until 15 h immersion and also found to remain constant afterward as presented in Figs. 16 and 17. The saturation of mortar 1: 2 was discovered to be reached only after 15 h of immersion due to its use of more cement which makes it denser with smaller pores, thereby, requiring more time to achieve saturated conditions. Meanwhile, Figs. 19 and 20 show the saturation conditions in mortar 1: 4 were reached only at 90 min immersion and this is majorly because a smaller amount of cement was used in the specimen which leads to larger pores and easy absorption of water into the pore structures thereby causing an earlier saturation. This is in line with the findings of several other studies (Achal et al., 2011; Sicakova et al., 2017; Laister et al., 2014).

Fig. 22 shows the relationship between the absorption of mortar and water to binder ratio and the absorption capacity is observed to be increasing with the water to binder ratio. Similar results have, however, been reported in several other studies (Alsayed and Amjad, 1996; Laister et al., 2014; Piasta and Zarzycky, 2017). Meanwhile, the water to cement ratio was also recorded to be increasing as the cement content in the mixture was reducing and this is possibly associated with the higher absorption observed due to the large pores created by the low cement content. The increase in water to cement ratio is also believed to have caused the total porosity of the mortar to increase even at the same cement content (Kim et al., 2014). Fig. 22 also shows the ratio between binder and sand did not affect the absorption of mortar.

There is a possibility of producing the required Type M mortar at the 1: 2 and 1: 4 mixing ratios for OPC by replacing cement up to 40% with DE and this is recommended for further use in both reinforced and non-reinforced masonries to bear a large compressive load. The same result was also observed for PCC mortar with a ratio of 1: 2. Meanwhile, for mortar 1: 4, it is possible to obtain type M mortar by replacing up to 30% of cement with DE and type S is produced at 40% replacement. This means mortar with replacement level of 40% is recommended for further use in structural masonry with normal compressive loads only. Furthermore, the lower absorption for PCC mortar means it is better for masonry and plastering work despite its low compressive strength. In fact, in the Indonesian market, its price is 25% cheaper than OPC and this is one of the reasons it is recommended for masonry and plastering works. Therefore, if the masonry work is designed to bear a normal compressive load, 40% of the cement can be replaced by DE but if it is for a large compressive load, 30% replacement is the best.

An analysis was also conducted to determine the effect of using DE as a partial replacement of cement on the emission of CO_2 into the atmosphere. It has been reported that every 1000 m^3 of brick masonry work for walls at 1: 4 requires 218 tons of cement for adhesive and plaster on both sides (SNI 6897-2008) and the replacement of 40% of the cement with DE was found to have reduced its content by $0.4 \times 218 = 87.20$ tons. Moreover, as previously mentioned by Benhelal et al. (2013) each ton of cement production releases 900 kg of CO_2 into the atmosphere and this means the quantity of the gas emitted is reduced by $0.9 \times 87.20 = 78.48$ tons for every 1000 m^3 of brick masonry work keeping other construction works constant. This also means the use of DE to partially replace cement has the ability to reduce CO_2 gas emissions into the atmosphere and, consequently, global warming.

6. Conclusions

The compressive strength and absorption of mortar using Ordinary Portland Cement (OPC) and Portland Composite Cement have been investigated. This study focused on the partial replacement of these cements with diatomaceous earth (DE) powder at different replacement levels of 0%, 10%, 20%, 30% and 40% based on volume ratio. The same volume of DE was used as replacement and a lower specific gravity was found for the DE compared to cement while the water to binder ratio increased as the quantity of the DE increases. Meanwhile, two binder to sand ratios were used and they include 1: 2 and 1: 4 thereby leading to the following conclusions:

1. The compressive strength of both mortars 1: 2 and 1: 4 using OPC was observed to decrease as the cement replacement level was increasing and this is associated with the increment in the water to binder ratio. However, the type M mortar specified in SNI 6882:2014 and ASTM C270-10 (2010) was achieved up to 40% replacement and this mortar is recommended for further use in reinforced and non-reinforced construction masonry to bear large compressive loads.
2. The highest compressive strength of mortar 1: 2 using PCC was achieved at 20% cement replacement while others were recorded to have compressive strength lower than the control specimen. However, the type M mortar specified in SNI 6882:2014 and ASTM C270-10 (2010) was achieved up to 40% replacement while at mortar 1: 4 it was at the maximum replacement of 30% for Type M and 40% for Type S. Therefore, the cement is recommended to be replaced at the maximum of 40% and 30% for mortar 1: 2 and 1: 4, respectively in reinforced and non-reinforced construction masonry to bear large compressive loads while mortar 1: 4 with PCC at 40% cement replacement is recommended for further use in structural masonry with normal compressive loads only.
3. The absorption of mortar tends to increase with the increment in the diatomaceous earth content. Meanwhile, the specimen with PCC was found to be lower absorption compared to those with OPC and this means it is better to apply mortar with PCC for masonry and plastering works.

7. Data availability

The data used to support the findings of this study are included within the supplementary information file.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data of this research is available upon request to the first author.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jksues.2020.10.003.

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