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Compressive Strength and Water Absorption of Mortar Incorporating Silica Fume

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Abstract

Cement is a non-renewable resource, and continuous exploration in achieving the development agenda cause the high demand worldwide. This may cause the natural resources to face depletion problems without replacement and brought to the future's critical environmental issue. Due to this concern, the alternative construction materials resources must be explored for replacement purposes. The high demand for cement in the construction field has turned the cement industry into the second-largest greenhouse gas producer, leading to global warming as cement mortar is an important material in masonry construction. A by-product of cementitious materials such as silica fume as a mineral admixture is introduced as the partial replacement of cement for the construction field. Therefore, this paper aims to present the water absorption and compressive strength of mortar incorporating silica fume. Silica fume was used as partial replacement of cement-based cement weight percentage in five mortar mixtures consist of 0%, 5%, 10%, 15%, and 20% of silica fume. A total of 100 mortar cubes was prepared, which 20 samples of mortar mixtures for each series. All the specimens are subjected to air curing. Each series of mortar mixtures consists of two samples for water absorption test and three for compressive strength test at the ages of 14, 28, 56, and 90 days. The results obtained indicated that 20% partial replacement of cement with silica fume produced the highest compressive strength and lowest water absorption. The silica fume as a partial replacement for cement in producing mortar presented the opposite relationship between compressive strength and water absorption, and this development possesses the potential used as sustainable construction materials.

Keywords — *silica fume, water absorption, compressive strength, renewable, construction material*

I. INTRODUCTION

The current global environmental challenges may refer to the sustainability of human activity and development against depletion of natural resources by changing to a sustainable engineering approach [1]. Current global issues related to environmental sustainability for concrete in construction emphasize material resources in producing concrete. To ensure the future sustainability of concrete in construction, alternative ingredient materials for concrete such as cement need to be sourced.

The consumption of concrete in the world is estimated at 10 to 15 billion metric tonnes per year, where annual production of concrete is estimated to be 7 billion cubic meters worldwide [2, 3]. The high demand for cement in the construction field, which resulted in the cement industry turned into the second-largest greenhouse gas producer and led to global warming. Industrial wastes such as Fly Ash, Slags, Rice Husk Ash, Silica fumes, etc., pose a huge threat when released into the environment[4]. The disposal solutions must be carried out for future sustainability.

Therefore, the by-product mineral such as silica fume has become one of the most popular mineral admixtures used in Ordinary Portland cement for many years. Silica fume is referred to as a microsilica or condensed silica fume produced from high-purity quartz and coal in a submerged electric furnace manufacturing the silicon and ferrosilicon alloys [5]. It is finely ground solid materials that have been used as the partial replacement for cement, somehow as an additive based on the preferable special properties [6].

The partial replacement of silica fume with cement can improve the compressive strength and reduce the water absorption of mortar based on some previous researcher's findings. This is due to the packing effect of silica fume, which acts as the filler to fill the spaces between the concrete's hardened microstructure [7]. The use of silica fume can also improve the concrete strength and enhance the concrete durability for the long term due to less water absorption [8].

The additional use of silica fume into the concrete mixture will increase the concrete strength by strengthening the aggregate-matrix transition zone [9]. Besides, the availability and low cost of the silica fume become one of the alternatives to improve the strength of mortar mixing. As silica fume is one of the famous mineral admixtures from the by-product of other countries, it can be used to reduce the amount of cement required for the mixture, and the cost of the concrete or mortar can be reduced [9].

Therefore, this study investigates the water absorption and compressive strength of mortar incorporating silica fume and the relationship between water absorption and compressive strength of mortar containing silica fume. The results obtained are expected to benefit the cement industries towards more sustainable construction materials.

II. EXPERIMENTAL DESIGN

A. Materials

The raw materials such as cement, sand, silica fume, water, and super plasticizer were prepared in this study. The ordinary Portland Cement (OPC) complies with ASTM C150 [10] to produce mortar mixtures incorporating silica fume. The fine aggregate passing through the 4.75mm sieve size was used in the mortar mixture based on ASTM C144 [11]. The silica fume used in this study has complied with the BS EN 197-1[12], where it contains at least 85% by mass of amorphous silicon dioxide. It was used as the partial replacement of the cement in mortar mixtures. The water consumption used in mortar mixtures was based on a water-cementitious ratio. The cementitious admixtures such as superplasticizer supra coat SP1000 was used for workability purposes.

B. Mortar Mix Design

The mortar mixture consists of Ordinary Portland Cement, sand, water, silica fume, and superplasticizer. The ratio of 1:3 of cement to sand by weight is used as the control mix for this study. The percentage of 5%, 10%, 15%, and 20% of silica fume is used as partial cement replacement to determine the ideal ratio of cement replacement with silica fume. The 20% silica fume was taken as optimum partial replacement to cement-based on previous research on pozzolanic material blended in cement mixture [13]. The water-cement ratio is based on the trial mix to ensure the mortar is achieved acceptable workability to enable minimum compaction. In addition, there is 1% to 2% of supra cost SP1000 is used for every specimen [14], and the mix ratios are tabulated in Table 1.

TABLE I
Mortar mix design

Mix ID	Ce-ment (kg)	San d (kg)	Silica Fume (kg)	Water / Cement Ratio	Supra -coat SP100 0 (% of Ce-ment)	Re-marks
M0	1	3	0	0.43	1.59	Contr ol
M5	0.95	3	0.05	0.45	1.67	5% SF
M10	0.9	3	0.10	0.50	1.76	10% SF
M15	0.85	3	0.15	0.54	1.87	15% SF
M20	0.8	3	0.20	0.61	1.98	20% SF

C. Specimens casting and test method

The specimen's cube size of 100 mm x 100 mm x 100 mm was prepared as tabulated in Table 2. There is an average of two sample cubes for the water absorption test and three samples for the compressive strength test. The test is conducted at four different ages, 14, 28, 56, and 90 days.

TABLE 2
Number of Specimens

Mi x ID	Number of Specimens		Curing Ages				Total Speci mens
	Water Absorp tion Test	Compre ssive Strengt h Test	14 days	28 days	56 day s	90 days	
M 0	2	3	5	5	5	5	20
M 5	2	3	5	5	5	5	20
M 10	2	3	5	5	5	5	20
M 15	2	3	5	5	5	5	20
M 20	2	3	5	5	5	5	20
Total Specimens			25	25	25	25	100

D. Testing Procedure

The tests are conducted at four different ages, 14, 28, 56, and 90 days, where there are 2 cube specimens used for the water absorption test and 3 cubes for the compressive strength test. The water absorption testis conducted based on BS 1881-122 [15]. The water absorption test procedure begins with the mortar specimens that under air curing are dried in an oven for 24 hours at temperatures that vary between 100°C to 105°C, as shown in Fig. 1. The mass of dried mortar specimens is weighted.

After that, the dried mortar specimens are immersed in water for 10 minutes, 20 minutes, 30 minutes, 60 minutes, 120 minutes, 180 minutes, and

240 minutes as shown in Fig. 1. Currently, the mass of wet mortar specimens is weighted based on the testing period, and the percentage of water absorption is determined.

(a) Drying of mortar cube in oven (b) Immersion of mortar cube in water

Fig 1:Oven dried and immersion of mortar cube process

The mortar compressive strength test is conducted according to BS EN 12390-3 [16]. The compression strength test is carried out based on four curing ages where the compressive strength test of the mortar cube is tested on 14th, 28th, 56th, and 90th. The specimen is placed in the machine so that the load shall be applied to the opposite sides of the cube cast, as shown in Fig. 2. Then, the specimen is aligned centrally on the base plate of the machine. The load is applied gradually until the specimen failed. Lastly, the maximum load applied to the specimen was recorded.

Fig 2: Mortar cube specimen under compressive axial load

III. RESULT AND DISCUSSION

A. Dry Density

The dry density results for five mortar mixes were presented in Fig. 3 as mass per unit volume. It is essential to determine the dry density of mortar cubes due to the different proportions of mixtures, which resulted in different mass for every specimen. The results indicated that the M20 has the highest dry density, 1955kg/m3, compared to others. This means that the density of the mortar cube is proportional to the silica fume partial replacement volume. This is due to the silica fume presence that acted as filler to fill up the pore spaces, which resulted in a more compactable mortar cube [17].

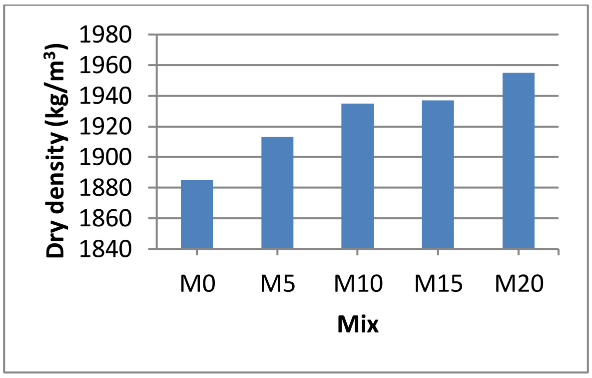

Fig 3: Dry density of mortar cube

B. Water Absorption

The relationship between the water absorption of mortar cube with different silica fume proportions over the curing days was shown in Fig 4. The results obtained show that the water absorption of the cubes increases gradually until the 28th curing days. After that, the water absorption rate dropped after 28th and remained constant from 56th to 90th. M0 has the highest percentage of water absorption, while M15 remains constant for a percentage of water absorption throughout the 90 days. M10 has a higher percentage of water absorption than M20, which has the lowest water absorption percentage among all the 5 mixes throughout the 90 days.

The results indicated a significant drop of water absorption for the small dosage of silica fume replacement, such as the control mix, while the mix that contained a higher dosage of silica fume was almost constant for water absorption. M0 is the control mix that does not contain any silica fume, while M20 contains the highest percentage of cement replacement with silica fume. It proves that the high content of silica fume can reduce the pores between particles as silica fume can act as the mortar's filler.

The fewer particle pores in mortar cube that due to the high content of silica fume able to form the packing effect in the mortar cube. The water absorption decreases with the increasing of percentage replacement of silica fume in the mix.

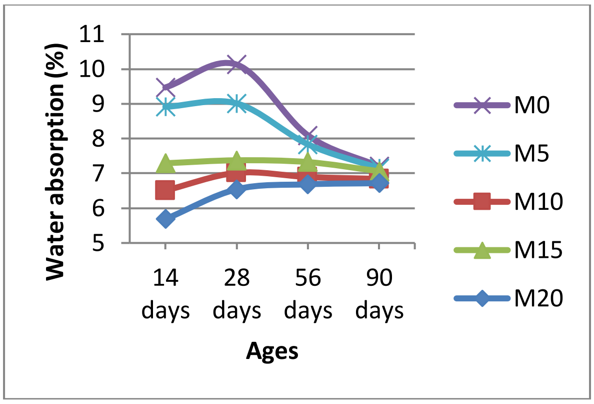

Fig 4: Water absorption rate at 240 minutes

C. Compressive Strength

The compressive strength of mortar cube containing silica fume was showed in Fig. 5. The results obtained show a significant increment of compressive strength for all mortar cubes from 14th to 90 days. However, the development of compressive strength for M0 after 56th days to 90 days showed a static strength compared to another four- series mixes of mortar strength. M20 had the highest compressive strength development, 65.2 MPa at the age of 90th day, followed by mix M15, M10, and M5. M20 has the highest compressive strength is due to the high percentage of partial replacement of cement with silica fume. This happened due to the pozzolanic effect of silica fume and cement that resulted in forming condensed concrete.

The silica fume as pozzolanics materials blended in cement types will also perform better results with the longer curing periods [13]. In addition, the presence of silica fume that acted as filler in the cube can be fixed into the mortar pores where the cube becomes less porosity. Therefore, the compressive strength of the mortar cube increases with the increment of silica fume's partial replacement as cement for the mix.

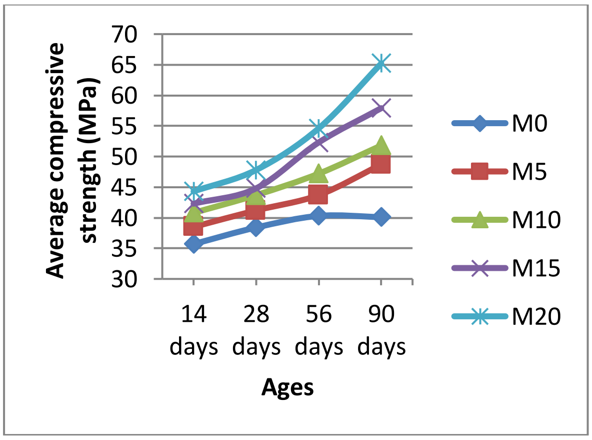

Fig 5: Average compressive strength of mortar cube versus ages

IV. COMPRESSIVE STRENGTH AND WATER ABSORPTION

A. Compressive Strength and Water Absorption over the type of mix

The relationship of the percentage of water absorption and compressive strength of sample cube over a percentage of silica fume partial replacement was taken at the mature curing ages of 28th days, as showed in Fig. 6. The results indicated that the compressive strength development is the opposite of the water absorption percentage for all mortar mixes. This means the higher silica fume content will increase the compressive strength while the water absorption percentage will decrease. The high content of silica fume in the mortar cube can increase the compactness of mortar as the finer particles size of silica fume can act as the pore filler for the mixtures. In addition, the pozzolanic effect of silica fume can form a strong bond between the mixtures, which resulted in increasing the compressive strength of the mortar.

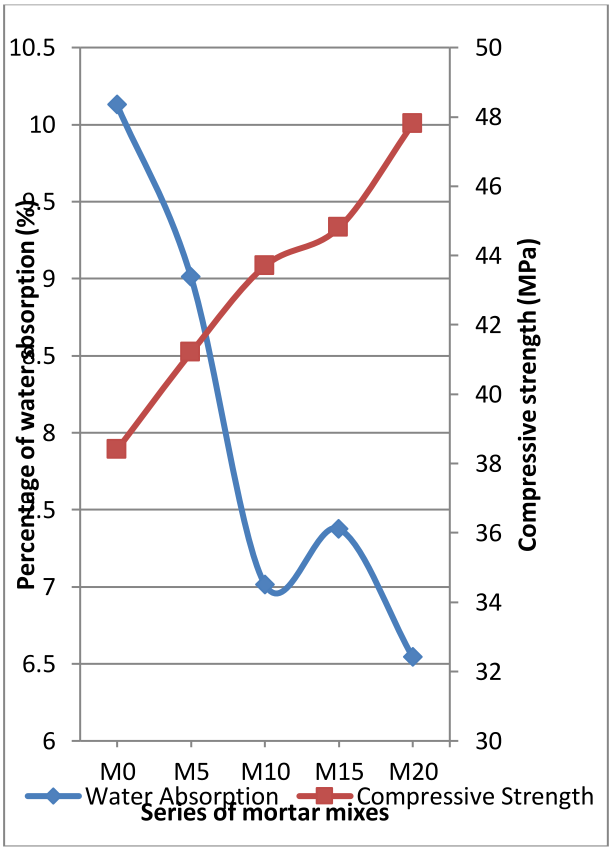

Fig 6: Water absorption and compressive strength for series of mortar mixes

B. The Relationship of Compressive Strength and Water Absorption of Mortar

The relationship between the compressive strength over the percentage of water absorption for all mixes at 28th days curing was showed in Fig 7. The result shows that the lower the percentage of specimens' water absorption, the higher the compressive strength. This is due to decreasing the spaces between pores size where there is less water being absorbed throughout the 240 minutes test period.

The low percentage of water absorption resulting in high compressive strength is due to the compactness effect of silica fume. This is due to the presence of silica fume in the mixture. The silica fume reacts as the filler to fill the pore spaces between the mix, and the pozzolanic effect from silica fume produced a stronger bond behavior for the mix. Besides, the results also indicated the opposite relationship between water absorption and compressive strength of the samples.

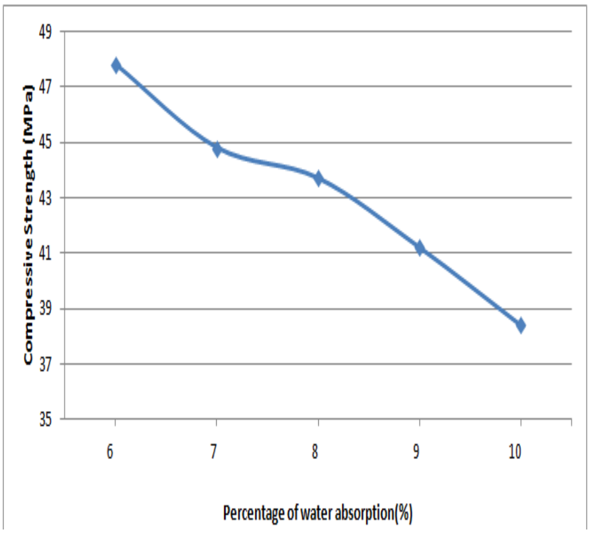

Fig 7: Average compressive strength versus water absorption for mortar

V. CONCLUSIONS

This study has investigated the water absorption and compressive strength of mortar incorporating silica fume. The result obtained showed that water absorption rate has an opposite relationship with the compressive strength. This means the higher the silica fume dosage will decrease the water absorption rate but will increase the mortar compressive strength. This is because the silica fume reacts as pore filler in the mortar mix and possesses a strong bond characteristic due to the pozzolanic effect.

Besides, the mortar density also increases with the increase of silica fume dosage in the mortar mix. The compressive strength development for mortar mixes containing partial replacement of silica fume indicated the increase trends even after 90th days while the mortar without silica fume content static at the ages of 56th days. This is due to the presence of silica fume in the mix that can create the pozzolanic effect where it can increase the bond strength and the compressive strength for the cube.

The pozzolanic reactions with the presence of silica fume in the mixtures cause the reduction in large pores' volume throughout the ages, resulting in the compressive strength. The pozzolanics materials blended in types of cement will perform better results with the longer curing periods. Therefore, the silica fume possesses the potential as a partial replacement for cement in producing sustainable construction materials.

REFERENCES

[1] Israel S. D., Sustainable engineering: a vital approach to innovative product development and community capacity building, 5th Inaugural Lecture Series, 5, (2016),1-40.

[2] Lee, Y. L., Karim, A. T. A., Rahman, I. A., Koh, H. B., Adnan, S. H., Nagapan, S. and Reza, F. V., Alternative Aggregates for Sustainable Construction, International Journal of Zero Waste Generation, 1, (2013),1-6.

[3] Chai, T. J., Sidek, A., Chow, T. K, and N. M. Noor., Strength Properties of 10 Millimetres Timber Clinker Aggregate Concrete, Malaysian Journal of Civil Engineering, 29,(2017), 333-344.

[4] Jyotirmoy, M., Shaswat, D., Saurabh, K. S. and Syed, M., Development of Geopolymer Concrete for the Protection of Environment: A Greener Alternative to Cement, SSRG International Journal of Civil Engineering, 6, (2019),41-47.

[5] Neville, A., Properties of Concrete, 5th Edition. England, Pearson Education Limited, (2011).

[6] Jo, B. W. Kim, C. H. Tae, G. & Park, J. B., Characteristics of cement mortar with nano-SiO_2particles, Construction and Building Materials, 21,(2007),1351–1355.

[7] Tavakoli, D. &Heidari, A., Properties of Concrete Incorporating Silica Fume and Nano-SiO_2, Indian Journal of Science and Technology, 6, (2013),3946–3950.

[8] Toutanji, H. A. & El-Korchi, T., The Influence Of Silica Fume On The Compressive Strength Of Cement Paste And Mortar, Cement and Concrete Research,25,(1995),1591–1602,

[9] Pala, M., Ozbay, E., Oztaş, A. and Yuce, M. I., Appraisal of long-term effects of fly ash and silica fume on compressive strength of concrete by neural networks, Construction and Building Materials, 21,(2007), 384–394,

[10] American Society for Testing and Materials, Standard Specification for Portland Cement. Pennsylannia: ASTM C150, (2012).

[11] American Society for Testing and Materials, Standard Specification for Aggregate for Masonry Mortar.Pennsylannia: ASTM C144, (2010).

[12] Composition, Specifications, and Conformity Criteria for Common types of cement, BS EN 197-1, (2003).

[13] Karim, M. R, Zain, M. F. M, Jamil, M, Lai, F. C., and Islam, M. N., Strength Development of Mortar and Concrete Containing Fly Ash: A Review, International Journal of the Physical Sciences. 6, (2011), 4137-4153,.

[14] Awal, A. A. S. M., and Abubakar, S. I., Properties of Concrete Containing High Volume Palm Oil Fuel Ash: A Short-term Investigation, Malaysian Journal of Civil Engineering,.23,(2011),54-66,

[15] Method for Determination of Water Absorption, BS 1881: 122, (2011).

[16] Testing hardened concrete: Compressive strength of the test specimensLondon: BS EN 12390-3, (2019).

[17] Xiao, F. C., Shang. L., G. Darwin, D. and McCabe, S. L., Role of Silica Fume in Compressive Strength of Cement Paste, Mortar and Concrete. Kansas: University of Kansas Lawrence, (1990).