Compressive Strength and Water Absorption of Mortar Incorporating Silica Fume

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Abstract

Cement is a non-renewable resource and the continuous exploration in achieving development agenda cause the high demand worldwide. This may cause the natural resources facing depletion problems without replacement and brought to the critical environmental issue in future. Due to this concerned, the alternative construction materials resources must be explored for replacement purposes. The high demand of cement in construction field has turned the cement industry into a second largest producer of greenhouse gas that leads to global warming as cement mortar is an important material in masonry construction. The use of by-product of cementitious materials such as silica fume as mineral admixture is introduced as the partial replacement of cement for construction field. Therefore, this paper aims to present the finding of water absorption and compressive strength of mortar incorporating silica fume. Silica fume was used as partial replacement of cement based on cement weight percentage in five mortar mixtures consist of 0%, 5%, 10%, 15% and 20% of silica fume. The total of 100 mortar cubes was prepared which 20 samples mortar mixtures each series. All the specimens are subjected to air curing. Each series 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 highest compressive strength and lowest water absorption. The silica fume as 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

1. INTRODUCTION

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

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

Therefore, the by-product mineral such as silica fume become one of the most popular mineral admixtures used in Ordinary Portland cement for many years. Silica fume is referred as microsilica or condensed silica fume produced from high-purify quartz and coal in submerged electric furnace in manufacturing the silicon and ferrosilicon alloys [5]. It is finely ground solid materials that has 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 possesses the potential to improve the compressive strength as well as reduce the water absorption of mortar based on some previous researcher’s findings. This is due to the packing effect of silica fume which act as the filler to fill the spaces between the hardened microstructure of the concrete [7]. The used of silica fume can also improve the concrete strength and enhanced the concrete durability for long term as the result from the less water absorption [8].
The additional used of silica fume into 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 that required for the mixture as well as the cost of the concrete or mortar can be reduced [9].

Therefore, this study is aimed to investigate the water absorption and compressive strength of mortar incorporating silica fume as well as the relationship between water absorption and compressive strength of mortar that containing silica fume. The results obtained are expected to beneficial to the cement industries towards more sustainable construction materials.

II. EXPERIMENTAL DESIGN

A. Materials

The raw materials such as cement, sand, silica fume, water and superplasticizer were prepared in this study. The ordinary Portland Cement (OPC) complies with ASTM C150 [10] is used 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 is 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 were based on water-cementitious ratio. The cementitious admixtures such as superplasticizers supracoat SP1000 was used for workability purposes.

B. Mortar Mix Design

The mortar mixture consists of Ordinary Portland Cement, sand, water, silica fume and superplasticizer based on 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 in order to determine the ideal ratio of the replacement of cement with silica fume. The 20% silica fume taken as optimum percentage of partial replacement to cement based on the previous researches on pozzolanic material blended in cement mixture [13]. The water cement ratio is based on trial mix to make sure the mortar is achieved an acceptable workability to enable minimum compaction. In addition, there is 1% to 2% of supracoat SP1000 is used for every specimen [14] and the mix ratios are tabulated in Table 1.

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Cement (kg)</th>
<th>Sand (kg)</th>
<th>Silica Fume (kg)</th>
<th>Water / Cement Ratio</th>
<th>Supra-coat SP1000 (% of Cement)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0.43</td>
<td>1.59</td>
<td>Control</td>
</tr>
<tr>
<td>M5</td>
<td>0.95</td>
<td>3</td>
<td>0.05</td>
<td>0.45</td>
<td>1.67</td>
<td>5% SF</td>
</tr>
<tr>
<td>M10</td>
<td>0.9</td>
<td>3</td>
<td>0.10</td>
<td>0.50</td>
<td>1.76</td>
<td>10% SF</td>
</tr>
<tr>
<td>M15</td>
<td>0.85</td>
<td>3</td>
<td>0.15</td>
<td>0.54</td>
<td>1.87</td>
<td>15% SF</td>
</tr>
<tr>
<td>M20</td>
<td>0.8</td>
<td>3</td>
<td>0.20</td>
<td>0.61</td>
<td>1.98</td>
<td>20% SF</td>
</tr>
</tbody>
</table>

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 are average of two sample cubes for water absorption test and three samples for compressive strength test. The test is conducted at four different ages which were 14, 28, 56 and 90 days.

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Number of Specimens</th>
<th>Curing Ages</th>
<th>Total Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Absorption Test</td>
<td>Compressive Strength Test</td>
<td>14 days</td>
</tr>
<tr>
<td>M0</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>M5</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>M10</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>M15</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>M20</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Total Specimens</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

D. Testing Procedure

The tests are conducted at four different ages which were 14, 28, 56 and 90 days where there are 2 cube specimens had been used for water absorption test and 3 cubes for compressive strength test. The water absorption tests conducted based on BS 1881-122 [15]. The procedure for water absorption test is began with the mortar specimens that under air curing are dried in oven for 24 hours at temperatures varies between 100°C to 105°C as shown in Fig. 1. The mass of dried mortar specimens are weighted. Thereafter, 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. By the moment, the mass of wet mortar specimens are weighted based on the testing period and the percentage of water absorption is determined.

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 mortar cube are tested on 14th, 28th, 56th and 90th day. The specimen is placed in the machine in such manner 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 that applied on 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 series of mortar mixes were presented in Fig. 3 as mass per unit volume. It is essential for the determination of dry density of mortar cubes due to the different proportion of mixtures which resulted in different in mass for every specimen. The results obtained indicated that the M20 has the highest dry density which is 1955kg/m³ compared with others mix. This mean that the density of mortar cube is proportional to the silica fume partial replacement volume. This is due to the presence of silica fume that acted as filler to fill up the pore spaces which resulted in more compactable mortar cube [17].

B. Water Absorption

The relationship between water absorption of mortar cube with different silica fume proportion over the curing days was showed in Fig 4. Based on the results obtained, it shows that the water absorption of the cubes increase gradually until 28th curing days. Thereafter, the water absorption rate drop after 28th days and remain constant from 56th days to 90th days. M0 has the highest percentage of water absorption while M15 remain constant for percentage of water absorption throughout the 90 days. M10 has higher percentage of water absorption if compare to M20 which has the lowest percentage of water absorption among all the 5 mixes throughout the 90 days.

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

The less particles pores in mortar cube that due to the high content of silica fume able to form the packing effect in the mortar cube. As such, the water absorption decreases with the increasing of percentage replacement of silica fume in the mix.
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 days to 90 days. However, the development of compressive strength for M0 after 56th days to 90 days showed a static strength compared with another four series mixes of mortar strength. M20 had the highest compressive strength development which is 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 pozzolanic materials blended in cements 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 fixed into the mortar pores where the cube become less porosity. Therefore, the compressive strength of mortar cube increases with the increment of silica fumes partial replacement as cement for the mix.

The relationship of percentage of water absorption and compressive strength of sample cube over percentage of silica fume partial replacement was taken the mature curing ages of 28th days as showed in Fig. 6. The results obtained indicated that the compressive strength development is opposite relationship with the water absorption percentage for all series of mortar mixes. This mean the higher of silica fume content will increase the compressive strength while water absorption percentage will decrease. The high content of silica fume in the mortar cube able to 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.

**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 water...
absorption of specimens, the higher the compressive strength. This is due to the decreasing in the spaces between pores size where there is less water being absorbed throughout the 240 minutes test period.

In addition, the low percentage of water absorption result 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 will enable the silica fume react as the filler to fill the pore spaces between the mix and the pozzolanic effect from silica fume produced a stronger bond behaviour 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 opposite relationship with the compressive strength. This mean the higher the silica fume dosage will decrease the water absorption rate but will increased 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 pozzolanic effect.

Besides, the density of mortar 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 themix that can create the pozzolanic effect where it can increase the bond strength as well as the compressive strength for the cube.

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

REFERENCES