CHAPTER 7

THE STUDY OF USED OF CERAMIC INDUSTRIAL WASTE AS REPLACEMENT MATERIAL OF FINE AGGREGATE IN CONCRETE MIX

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7.1 INTRODUCTION

Concrete is a global material that underwrites commercial well-being and social development. These days, there two commonly used structural materials: concrete and steel [1]. Concrete which contains waste products as aggregate is called ‘Green’ concrete. Use of hazardous waste in concrete-making will lead to green environment and sustainable concrete technology and so such concrete can also be called as ‘Green’ concrete. Concrete are mostly used in construction engineering field because the used of the material are economics and have higher strength, durability and availability of raw materials. For this research, the concrete have been modified by replaced the fine aggregate with Ceramic Industrial Waste (CIW) in concrete mix.

Construction and Demolition (C&D) wastes contribute the highest percentage of wastes worldwide (75%) [2]. Ceramic industry produces 30% - 40% of waste from the manufacturing of the ceramic such as ceramic powder, sludge, and the rejected ceramic tiles. Most of the waste are discarded into landfill and this may cause contaminate the soil and the air. Today landfills were designed to minimize the contact with air and water required for degradation, thereby practically eliminating the degradation of waste. Ceramic industrial waste consider hazardous waste because of the dust created can cause health affect and environment degradation.

Ceramic industrial waste was chosen due to its beneficial properties into concrete technology which is have good thermal insulator, refractory (material that retains its strength at high temperatures), hard and brittle. The ceramic wastes properties show that it give many advantages in concrete technology which can increase the use of ceramic industrial waste in concrete mix. To protect the environment, the usage of the ceramic industrial waste will give many advantages such as reduce the use of other raw materials. Reuses of the waste give benefits in terms of energy, for the ceramic industry the waste have highly endothermic decomposition reaction (reaction process that requires absorption of heat). This project is about a method to produce ceramic industrial waste as
replacement material of fine aggregate in concrete mix.

7.2 OBJECTIVE AND SCOPE OF STUDY

The main objectives of this project were:

- To determine the compressive strength of concrete mix that contains Ceramic Industrial Waste.
- To determine the percentage of water absorption, density of concrete and optimum content of Ceramic Industrial Waste to be replace in concrete mix.
- To differentiate and compare the concrete mix that contains Ceramic Industrial Waste with conventional concrete.

For this final year project focuses on ceramic industrial waste (CIW) as fine aggregate as replacement material in concrete mix. The CIW were crushed using Milling Jaw Crusher Machine for smooth particle of the waste as fine as the fine aggregate. The crushing CIW mixed with coarse aggregate, natural fine aggregate, cement and water to produce the concrete mix. Design of concrete mix was calculated using Concrete Mix Design (DOE Method). The percentage of concrete that contain CIW was set 0% for control sample while 10%, 20%, and 30%. Each percentage has 3 sample cubes for cube test. So that, the total of the cube test at age 7 and 28 days were 48 concrete cubes. The tests include slump test for fresh concrete mix and cube test for compressive strength, water absorption and density test of concrete. The dimension of the cube test used is 150mm x 150mm x 150mm.

7.3 LITERATURE REVIEW

CONCRETE

As we all know, concrete is materials that are widely used in construction field. 80% of the buildings are using concrete for the construction work. Nowadays, there are precast concrete or Industrial Building System (IBS) concrete type that use for make the work effective, easier and reduce time. Every year, concrete technology increasing with many creative ideas that follow the specifications of the conventional concrete. History of the concrete technology, concrete is widely used during Roman Empire. It is known as Roman Concrete or opus caementicium is made from quicklime, pozzolana and aggregate of pumice. The tests show that Roman Concrete had as much compressive strength as modern Portland-cement concrete with 20 MPa or 2,800psi [3].

Concrete is a composite material in which a binding material mixed in water on solidification binds the inert particles of well graded fine and coarse aggregate. Cement known as binding materials because of the high viscosity characteristics that can mix the materials perfectly. For normal concrete mix, sand used as fine aggregates while crushed stones and gravel used as coarse aggregate. When correctly proportioned, concrete is at first a plastic mass that can be cast or molded into nearly any size or shape. Upon hydration of the cement by the water, concrete becomes stone like in strength, durability, and hardness [4].

MODIFIED CONCRETE

Modified concrete known as a normal concrete that have been modified in terms of the material used.
In concrete technology, many types of modified concrete that have been created to compared the strength and durability of the modified concrete with normal concrete. Terms “modified concrete” is not modified 100% of the normal concrete, it just 20%-70% of the normal concrete will be modified. Usually for cementations material used for normal concrete is Ordinary Portland Cement (OPC) but for modified concrete it may use other type of material that have same properties with cement such as fly ash or easy cement. Gravel and crushed aggregate are widely used as coarse aggregate while river sand used in fine aggregate for normal concrete. For modified concrete, ceramic waste, fly ash, disc and others can be used as replacement material for aggregate in concrete mix. The most important thing that needed in modified concrete mix is the material can give some differences and have higher quality in strength and durability of the concrete.

CERAMIC INDUSTRIAL WASTE

Ceramic can be defined as the art that deals with the design and fabrication of objects made from fired clay. All type of earthenware (urn), stoneware and porcelain included the term of “ceramics” [5]. Ceramic Industrial Waste (CIW) is a waste that made during the manufacturing of this ceramics such as ceramic powders, ceramic sludge and the excessive clay. Ceramic waste powder is settled by sedimentation and then dumped away which results in environmental pollution [6].

To increase the sustainability in concrete technology, CIW are used as replacement materials for fine aggregates, coarse aggregates and cementations materials. In ceramic industry, about 15%-30% production goes as waste. Generally, ceramic materials contribute the highest percentage of waste within the Construction and Demolition wastes which is 54% [2]. Ceramic products are made from natural materials which contain a high proportion of clay minerals. These, through a process of dehydration followed by controlled firing at temperatures of between 700ºC and 1000ºC, acquire the characteristic properties of “fired clay” [18].

The selected ceramic industrial waste (sludge) are from the crushing process of gneiss, sludge from the cutting and polishing process of varvite, sludge from the process of filtration/clarification of potable water, and an iron-containing residual clay. The composition of the ceramic solid waste used will give positive effects with respect to environmental, economic issues and the sustainability of the concrete when it mixes together [7].

PROPERTIES OF CERAMIC INDUSTRIAL WASTE (CIW)

To reduce the usage of raw materials in concrete mix such as cement and gravel or sand as aggregates, CIW are widely used because of the common properties it have with the raw materials. Generally, CIW have common properties with the ceramic itself but it depend on what materials used in manufacturing the ceramics. Ceramics are high durability, strength and brittleness, high electrical and thermal resistance and have the ability to withstand the damaging effects of acids, oxygen, and other chemical because of their inertness properties. This shown that the usages of CIW in concrete mix is economical and reduces environmental pollution.

The physical properties include in ceramic industrial wastes are high fracture toughness, anti-static, non-magnetic and low thermal conductivity. Table 7.1 shows the comparison of properties between three types of materials: ceramics, metal and polymer. Ceramic Industrial Waste are chosen as substitution materials of fine aggregate in concrete mix which is replace sand as fine aggregate. Bulky sludge from CIW are used and crushed into fine aggregate. The sludge is produced from the
manufacturing process. Disposal of this sludge will increase environmental problems.

According to past results, addition of CIW in concrete mix decreases the strength characteristic of the concrete. The compressive strength increase with the increase of the CIW content till 20% replacement of fine aggregate and after that decrease in its strength. In conclusion, to increase the sustainability of the concrete technology, it is necessary to use the ceramic industrial waste as replacement material in concrete mix because of the production of this waste have been increase from day to day.

Table 7.1: Comparisons of Properties between Three Types of Materials

<table>
<thead>
<tr>
<th>Property</th>
<th>Ceramic</th>
<th>Metal</th>
<th>Polymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>Very High</td>
<td>Low</td>
<td>Very Low</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>Very high</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Density</td>
<td>Low</td>
<td>High</td>
<td>Very Low</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Thermal Expansion</td>
<td>High</td>
<td>Low</td>
<td>Very Low</td>
</tr>
<tr>
<td>Ductility</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Source: (American Ceramic Society, 2014)

CONCRETE TEST

Concrete cube test can be divided into two types which are for the fresh concrete and hardened concrete test. For fresh concrete the slump test were conducted to determine the workability of fresh concrete for 7 and 28 days. Meanwhile, for hardened concrete 3 type of test were conducted which are the compressive strength test, water absorption test and density of the concrete test after curing for 7 and 28 days. The experiment was done to determine the compressive strength test of concrete cube. The percentage of water absorption was calculated by using the equation below:

\[
\text{Compressive strength (N/mm}^2\text{)} = \frac{\text{Maximum load (kN)} \times 1000}{\text{Area of cube mould (mm}^2\text{)}}
\]

For water absorption of concrete test were done to determine the percentage of water absorption of concrete. The calculation for water absorption test was measured by using calculation below:

\[
\text{Percentage of water absorption (\%)} = \frac{\text{Wet mass (kg)} - \text{Dry mass (kg)}}{\text{Dry mass (kg)}} \times 100
\]

Meanwhile for density test were done to determine the relative density of concrete cube. The density was calculated by using calculation below:

\[
\text{Density of hardened concrete} = \frac{\text{Weight of concrete block (kg)}}{\text{Volume of concrete block (m}^3\text{)}}
\]

7.4 METHODOLOGY

Figure 7.1 shows the flowchart of methodology. The preparation and test was done by following the
process of the flowchart.

![Flowchart of Methodology](image)

**PREPARATION OF MATERIAL**

For this final year project, it is important to identify desirable properties and components and to be able to use factors involved in producing concrete and the methods employed in concrete production. The materials to produce concrete are basic materials which is cement, fine aggregate, coarse aggregate and water. Two types of fine aggregate are used for this project which is natural fine aggregate and crushed Ceramic Industrial Waste (CIW). These materials are prepared to ensure the experiment and laboratory test can carry out smoothly to achieve the objective studies.

**Preparations of Replacement Material (Ceramic Industrial Waste)**

Ceramic Industrial Waste (CIW) is needed as replacement material of fine aggregate on concrete. The percentage of sludge that will use in this experiment is 10%, 20%, and 30%. The sludge of industrial ceramic wastes were collected from the production and manufacturing of ceramic industry at MML Kluang known as sludge cake of ceramic. The waste product is made from clay material under high
temperature during the manufacturing process. The Ceramic Industrial Waste (CIW) was crushed using milling jaw crusher.

**SIEVE ANALYSIS TEST**

Sieve analysis test is used in grading the aggregates to get the suitable size of the coarse and fine aggregates that will be used in this experiment. Sieve analysis test was done to identify the distribution size of an aggregate and it was done according to British Standard BS410:2000 (Specification for Test Sieve)

**DESIGN OF NORMAL CONCRETE MIX (DOE METHOD)**

The material of concrete mix are prepare based on quantities from DOE Method. Table 7.2 below shows the quantities material needed using British Standard Method for Concrete Mix Design (DOE Method) and Table 7.3 shows the total weight of CIW as replacement material for fine aggregate in concrete mix for per trial mix of 0.036 m³.

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Cement (kg)</th>
<th>Water (kg or L)</th>
<th>Fine Aggregate (kg)</th>
<th>Coarse Aggregate (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mm 20mm 40mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per m³ to nearest 5kg</td>
<td>396</td>
<td>210</td>
<td>664</td>
<td>- 1130 - -</td>
</tr>
<tr>
<td>Per trial mix of 0.036m³</td>
<td>14.26</td>
<td>7.56</td>
<td>23.90</td>
<td>- 40.68 - -</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percentage of Industrial Ceramic Waste (sludge) (%)</th>
<th>Total Weight of Industrial Ceramic Waste (sludge) (kg)</th>
<th>Total Weight of Natural Fine Aggregate (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>23.90</td>
</tr>
<tr>
<td>10</td>
<td>2.39</td>
<td>21.51</td>
</tr>
<tr>
<td>20</td>
<td>4.78</td>
<td>19.12</td>
</tr>
<tr>
<td>30</td>
<td>7.17</td>
<td>16.73</td>
</tr>
</tbody>
</table>

**PREPARATION OF SAMPLE**

The total sample of concrete cube that used for this project is 48 cubes. Therefore, there were 24 cubes for Compression Test and 24 cubes for Water Absorption Test and Density Test. For water absorption test and density test used the same concrete cube. The concrete were immersed in curing tank for 7 and 28 days for curing process after the preparation of the sample.

**LABORATORY TEST**

For this project, there are two tests that will be held in laboratory. Figure 7.2 shows the flow of laboratory that will be done.
7.5 RESULTS AND DISCUSSIONS

SLUMP TEST

Slump test was done based on the procedures provided in BS EN12350-2:2009 (Testing fresh concrete: Slump Test) which is to test the workability of the fresh concrete. Table 7.4 shows the result of slump test obtained.

<table>
<thead>
<tr>
<th>Percentage of CIW (%)</th>
<th>Collapse Height (mm)</th>
<th>Type of Collapse</th>
<th>Degree of Workability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>57</td>
<td>True Slump</td>
<td>Medium</td>
</tr>
<tr>
<td>10</td>
<td>31</td>
<td>True Slump</td>
<td>Medium</td>
</tr>
<tr>
<td>20</td>
<td>18</td>
<td>True Slump</td>
<td>Low</td>
</tr>
<tr>
<td>30</td>
<td>16</td>
<td>True Slump</td>
<td>Low</td>
</tr>
</tbody>
</table>

According to Table 7.4, 0% and 10% contained of CIW in concrete mix were within the range of the proposed height of slump in design concrete mix which is between the range of 30mm to 60mm. While for 20% and 30% of CIW contained in concrete mix did not achieved in the height of slump design the proposed range and the degree of workability is at low state. Based on the result from Table 7.4, the reaction of CIW towards water were very high. The concrete contained 20% and 30% of CIW in concrete mix hardened very fast compared to 0% and 10% of CIW contained in concrete mix. It can be conclude that, the higher the percentage of CIW in concrete mix, the higher the reactivity of CIW with water in concrete mix.
According to graph on Figure 7.3, the workability of concrete mix decrease with addition of Ceramic Industrial Waste (CIW). This is because the characteristic of the CIW that have been observed through the experiment are very reactive towards water. Hence, the higher the percentages of CIW replace of fine aggregate in concrete mix, the lower the workability of the concrete.

**COMPRESSIVE STRENGTH TEST**

All the data collected from the compression test for 3 samples of each percentage of CIW in concrete mix was obtained to get the average strength of concrete. Figure 7.4 shows the graph of Compressive Strength against Percentage of Ceramic Industrial Waste (CIW) at the age of 7 and 28 days.

The compressive strength of concrete at age 7 days increase when the percentage of CIW increase but up to 20% of CIW only and the compressive strength of concrete decrease at 30% of
CIW contained in concrete mix. All of the percentage of CIW contained in concrete mix except 0% of CIW contained in concrete mix achieved the minimum compressive strength at age of 7 days which is according to [14], the minimum compressive strength of concrete at 7 days for grade concrete M30 is 20N/mm².

The compressive strength of concrete at age 28 days decrease when the CIW started used in the concrete mix. 10% and 20% shows higher value of compressive strength compared to sample concrete. Meanwhile, 30% of CIW contained in concrete mix shows the lowest value of compressive strength. Hence, the highest compressive strength based on this project is 10% of CIW contained in concrete mix as replacement material of fine aggregate with 33.3N/mm².

Based on Figure 7.5, at age 7 days, 20% of CIW contained in concrete mix shows the highest difference value of compressive strength with control sample with positive value. All the percentages shows positive value of compressive strength at age 7 days which is they achieved the minimum strength of concrete because the minimum strength of concrete cube is at least 20 N/mm² at the age of 7 days [14]. While, at age 28 days, 10% and 20% are positioned at positive state of the graph. This shown that, both of the percentages 10% and 20% of CIW contained in concrete mix achieved the minimum strength of designated concrete. Thus, 10% of CIW is the optimum content to be replaced as fine aggregate in concrete mix.

**Figure 7.5:** Graph of different of compressive strength with control sample against the percentage of Ceramic Industrial Waste (CIW) at the age of 7 and 28 days

**WATER ABSORPTION TEST**

The water absorption test was done based on procedures provide in BS 1881: Part 122: 1983 (Testing Concrete: Method for determination of water absorption).

Based on Figure 7.6, it shown that the concrete that contain higher percentage of Ceramic Industrial Waste (CIW) have higher value of percentage of water absorption. This shown that, sample with more percentage of CIW have higher absorption ability. The percentage of water absorption increase as the age and the percentage of the CIW increase. This is because, the concrete was not compacted properly so that, the distance of the particles become farther and caused the water absorbed into the concrete. Water absorption is strongly affected by environmental temperature and
Concrete moisture content. So that, the result may be varied because water absorption is strongly affected by environment temperature and concrete moisture content [17] that can cause incorrect evaluation of concrete performance.

Figure 7.6: Graph of percentage water absorption test against percentage of Ceramic Industrial Waste (CIW) at the age of 7 and 28 days

According to the graph at Figure 7.7, the different percentage of water absorption test with control sample increase when the percentage of CIW increased, while it reduced when the increase of the age. the higher the percentage of CIW contained, the higher the absorption ability of the concrete. When the concrete at age 7 days, it can be seen that the percentage of water absorption is greater compared to concrete at age 28 days. This is because the presence of the CIW in concrete mix caused the particles stick together and filled the void inside the concrete mix. The durability of the concrete increase due to the lower percentage water absorption when the age increases. The less water used, the stronger the concrete will be [15].
**RELATION DENSITY OF CONCRETE CUBE WITH COMPRESSION STRENGTH TEST AND WATER ABSORPTION TEST**

According to Duggal [16], the basic density of concrete is classified as super heavy (over 2500 kg/m³), dense (1800-2500 kg/m³), light weight (500–1800 kg/m³) and extra light weight concrete (below 500 kg/m³). Based on Table 7.5, the percentage contained of Ceramic Industrial Waste (CIW) in concrete mix falls in the range of dense concrete or normal concrete which is between 1800-2500 kg/m³.

<table>
<thead>
<tr>
<th>Percentage of Ceramic Industrial Waste (%)</th>
<th>Average Density (kg/m³)</th>
<th>Average Strength of Concrete Cube (N/mm²)</th>
<th>Average Density (kg/m³)</th>
<th>Average Strength of Concrete Cube (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2128</td>
<td>18.6</td>
<td>2297</td>
<td>31.9</td>
</tr>
<tr>
<td>10</td>
<td>2145</td>
<td>24.9</td>
<td>2310</td>
<td>33.3</td>
</tr>
<tr>
<td>20</td>
<td>2157</td>
<td>28.8</td>
<td>2325</td>
<td>32.1</td>
</tr>
<tr>
<td>30</td>
<td>2164</td>
<td>20.3</td>
<td>2335</td>
<td>28.2</td>
</tr>
</tbody>
</table>

![Graph of relation of density concrete cube with compressive strength at age of 7 days](image)

**Figure 7.8:** Graph of relation of density concrete cube with compressive strength at age of 7 days

Based on Figure 7.8 and 7.9, the density of the concrete increase when the percentage of Ceramic Industrial Waste (CIW) contained in concrete mix increase. The compressive strength of the concrete is fluctuating and it does not affect the density. The density of the concrete depends on the weight of the concrete and the volume of the concrete. The presences of CIW affect the density of the concrete.

According to Figure 7.10 and 7.11, the density of concrete increase when the percentage of water absorption and percentage of Ceramic Industrial Waste (CIW) contained in concrete mix increase. This is because, the concrete contribute to higher weight and higher density. Thus, the concrete can decrease their percentage of water absorption when the percentage of CIW was minimizes. Based on the graph, it can be seen that, the optimum content of CIW contained in concrete...
mix for lower density is 10% of CIW. This is because it has lower density compared to 20% and 30% of CIW contained in concrete mix and lower percentage of water absorption.

Figure 7.9: Graph of relation of density concrete cube with compressive strength at age of 28 days

Figure 7.10: Graph of relation density concrete cube with percentage of water absorption at the age 7 days

Figure 7.11: Graph of relation density concrete cube with percentage of water absorption at age 28 days
7.6 CONCLUSIONS

The following conclusions were discussed from the study:

1. Slump test results gave the lowest value when increase the percentage of Ceramic Industrial Waste (CIW) replacing fine aggregate in concrete mix. This shown that, presence of CIW in the concrete mix will give poor workability to the concrete.

2. The first objective of this study is to determine the compressive strength of concrete mix that contains ceramic industrial waste. The comparison between concrete containing Ceramic Industrial Waste (CIW) with normal concrete shown that 10% of CIW contained in concrete mix is the optimum content of CIW to be replaced in concrete mix as fine aggregate. 10% of CIW achieved the optimum strength of designated concrete with grade 30.

3. The second objective of this study is to determine the percentage of water absorption, density of the concrete and the optimum content of Ceramic Industrial Waste (CIW) to be replaced in concrete mix. From the results obtained shows that 10% of the percentage containing CIW give the lowest percentage of water absorption test compared to 20% and 30% of percentage containing CIW. According to the results obtained, it can conclude that 10% of CIW contained in concrete mix have lower density compared to 20% and 30%. Based on the results of water absorption, compressive strength test and density test, it can be concluded that 10% of CIW containing in concrete mix is the optimum content to be replaced in concrete mix as fine aggregate compared with 20% and 30%. The

4. The last objective of this study is to compare the concrete containing Ceramic Industrial Waste (CIW) with conventional concrete. The comparison between concrete containing CIW with normal concrete shows that 10% of CIW it the optimum content of CIW to be replaced in concrete mix which is the most approaches to normal concrete results which is grade 30.

5. The concrete containing Ceramic Industrial Waste (CIW) is in the range of the normal concrete with the value of the density in range between 1800-2500 kg/m³. However, the lowest value of the density of the concrete that contained CIW in concrete mix is 10% of CIW for both relation with compressive strength test and water absorption test.
REFERENCES


