CHAPTER 5

A Review Performance of the Effective Microorganism (EM) Incorporation in Cement Based Material

Noorli Ismail¹, ², Hamidah Mohd. Saman³, Hasniza Abu Bakar², Hanita Yusof², Mohammad Hassim Sulaiman² and Mohd Faizal Md. Jaafar⁴

¹ Jamilus Research Center and Sustainable Construction, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), 86400, Batu Pahat, Malaysia
² Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), 86400, Batu Pahat, Malaysia
³ Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Malaysia.
⁴Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang (UMP), 26300 Gambang, Kuantan, Pahang, Malaysia.

*noorli@uthm.edu.my

Abstract

Up to the present, the incorporation of Effective Microorganism (EM) in cement paste showed the huge potential as an additives in enhancing the compressive strength associated with low total porosity, pore volume and pore diameters measured using Mercury Intrusion Porosimetry (MIP). The findings showed the mercury intruded at small pore diameter for microbed cement paste while control cement paste without EM, mercury was intruded largely. Subsequently, the results obtained was corroborated with denser and lesser voids of internal microstructure in cement matrix. Furthermore, full inclusion of EM in cement paste was not encouraging due to the low compressive strength recorded. This result was supported with decrement peaks of cristobalite detected by X-Ray Diffraction (XRD) analysis which was influenced the strength development. Moreover, potential study in incorporating EM in concrete need to perform extensively due to high compressive strength and tensile splitting strength recorded in previous study.

Keywords—microbed cement paste, microbed concrete, Effective Microorganism (EM), Mercury Intrusion Porosimetry (MIP)

1. INTRODUCTION

This chapter presents a literature from previous researches related to the influence of incorporating Effective Microorganism (EM) into the cement based material. Originally, EM is a beneficial bacteria developed by Dr.Teruo Higa from University of Ryukus in Okinawa, Japan [1]. EM was consists of bacteria combination of lactic
acid, phototropic, yeast and actinomycetes [1], which was known as excellent plant
growth by improving the soil quality [2-7].

Recently, few studies had been investigated by previous researchers regarding the
influence of EM to the cement hydration, its chemical phases, internal
microstructure and pore distribution of cement based material [8-15]. Generally, the
inclusion of EM showed the significant finding in enhancing the compressive
the X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) to determine the
chemical constituent, element composition and identify phases formed during the
hydration of cement. While combination of Scanning Electron Microscopy (SEM)
with instruments of Electron Disperse X-Ray (EDX) to determine the chemical
consituents on the selected spectrum on image of SEM was also performed. The
smaller pore size and volume of microbed cement paste was associated to the
increment of compressive strength [15]. The following section describes the
contents of EM and extensive studies which had been performed by incorporating
EM to the cement paste and concrete.

2. CONTENTS OF EFFECTIVE MICROORGANISM (EM)

The following four (4) main bacteria are completely harmless toward the living since
it came from category beneficial bacteria.

2.1 Lactic Acid Bacteria

Widtastuti et al. [20] and Wang et al. [21] emphasized lactic acid could easily be
found in our daily life beverage and food such as milk, yogurt and pickle, those three
example of food that had been made with rapidly decaying process with the used
of lactic acid bacteria. Lactic acid bacteria also help the composition of material by
fermenting those materials to remove the undecomposed properties of material
such as lignin and cellulose. Morphology of lactic acid bacteria are gram-positive
and a non-sporeforming cocci. The combination of photosysthetic bacteria and
yeast help the creation of sugars and other carbohydrates that promote the
production of lactic acid. Figure 1(a) shows the microscopic image of lactic acid
bacteria.

2.2 Photosynthetic Bacteria

Photosynthetic bacteria also known as Purple Non-sulphur Photosynthetic Bacteria
is an independent self-supporting microbes. Absence of sunlight and soil heat as
sources of energy, the bacteria synthesize substances form discharges of roots,
organic matter and harmful gases [22-23]. The useful substances developed are
amino acids, nucleic acids, bioactive substances and sugars, all of this substance
could help with the increase of plant growth and development and also breeding of
yeast and lactic acid bacteria. Figure 1(b) shows the microscopic image of photosynthetic bacteria.

2.3 Yeast

Wolejko et al. [24] described yeast are a type of fungi that act as leavening agent, with this yeast also like the lactic acid bacteria are easily found been used to create food in our daily life just like bread and cake. Yeast is asexually reproduced where it could reproduce even by a single parent cell. From the amino acids and sugars that were secreted by photosynthetic bacteria, yeast will synthesizes an antimicrobial and other substances that are required for plant growth. Bioactive substances such as enzymes and hormones produced by yeast help to promote active cell and root division. For effective microbes, yeast is useful substrates for fermentation just as lactic acid. Figure 1(c) shows microscopic image of yeast.

2.4 Actinomycetes

Generally, actinomycetes was found in soil having similar features with fungi. The major function helps the growth of plant pathogens in the rhizosphere to decompose together with dead plant, animal and fungal to produce benefit enzyme for crop production. Actinomycetes are aerobic and can be cultivated easily on simple growing media and are a gram positive [25].

Figure 1: Image of (a) lactic acid bacteria [16], (b) phototropic bacteria [17], (c) yeast [18] and (d) actinomycetes [19] taken under light microscope.
3. COMPRESSIVE STRENGTH OF MICROBED CEMENT PASTE AND CONCRETE

Nobuyuki et al. [11], Jamaludin et al. [10], Andrew et al. [8], Noorli et al. [12-14], Isa et al. [9] and Noorli et al. [15] investigated the influence EM incorporated in cement paste and concrete by enhancing their compressive strength. Significant findings in EM incorporation showed high increment of compressive strength up to hundred percent (100%) in microbed cement paste [12-14]. Overall, EM contents added between 5% and 30% was able to increase the compressive strength corresponding the control cement paste. However, the fully inclusion of EM in cement paste was not recommended due to the adverse contribute of the former. Nobuyuki et al. [11] added 5, 10 and 15 percent of EM. No. 1, EM. No. 3, EM-X, and EM-ceramics from the total of water and cement contents. Air entraining agent was added into the concrete mix to improve the workability of the microbed concrete. The testing of compressive strength was conducted at 3 days, 7 days and 28 days on control and microbed concrete specimens. Table 1 shows the resulted compressive strength at age of 28 days. The inclusion of 15% EM-ceramics records increment of compressive strength more than half corresponding to control concrete without EM. While inclusion 5% of other EM types also increased the compressive strength of concrete with increment between 6% and 30%.

Table 1: Increment of compressive strength for microbed concrete specimens at age of 28 days [11]

<table>
<thead>
<tr>
<th>Types Of EM</th>
<th>Content (%)</th>
<th>Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM.No.-1</td>
<td>5%</td>
<td>25% &gt; control</td>
</tr>
<tr>
<td>EM No.-3</td>
<td>5%</td>
<td>6.5% &gt; control</td>
</tr>
<tr>
<td>EM-X</td>
<td>5%</td>
<td>30% &gt; control</td>
</tr>
<tr>
<td>EM-Ceramic</td>
<td>15%</td>
<td>52% &gt; control</td>
</tr>
</tbody>
</table>

Table 2 lists seven (7) prescribed environments of acidic, clay soil, wastewater, marine, alkaline, and outdoor was performed by Jamaludin et al. [10] in order to investigate the EM influence to compressive strength in different curing regimes at age of 28 days and 91 days. Portion of EM was mixed with five percent (5%) of molasses. All of the concrete specimens were left exposed to the environment till its aging days. The increment and decrement of compressive strength under six (6) different curing regimes as shown in Table 3 illustrates that microbed concrete specimens exposed to outdoor and HCL environment achieved high compressive strength at age of 28 days and 91 days, respectively. The increment of compressive strength might be due to reaction between the acidic EM and alkaline cement paste to produce a new and unidentified substance where the substance is assume to
have property and behaviour similar to pozzolanic materials which will later fill up the voids in the concrete and strengthen the internal bonding. However, no testing was conducted to prove their assumption. While, the microbed concrete specimens which was immersed in seawater recorded low compressive strength at age of 91 days may be due to reaction of seawater to concrete specimens. The comparison was made corresponding to control specimens which was cured in the closed room.

**Table 2**: The description of seven prescribed environments [10]

<table>
<thead>
<tr>
<th>Environment</th>
<th>Abbreviation</th>
<th>Full Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidic</td>
<td>HCL</td>
<td>Hydrochloric acid</td>
<td>Fully immersed in hydrochloric acid solution</td>
</tr>
<tr>
<td>Soil</td>
<td>SOIL</td>
<td>Clay soil</td>
<td>Buried 300mm underground</td>
</tr>
<tr>
<td>Wastewater</td>
<td>WWTR</td>
<td>Wastewater</td>
<td>Fully immersed in wastewater</td>
</tr>
<tr>
<td>Marine</td>
<td>SWTR</td>
<td>Seawater</td>
<td>Fully immersed in seawater</td>
</tr>
<tr>
<td>Alkaline</td>
<td>NaOH</td>
<td>Sodium hydroxide</td>
<td>Fully immersed in sodium hydroxide solution</td>
</tr>
<tr>
<td>Outdoor</td>
<td>OUTDR</td>
<td>Outdoor</td>
<td>Placed and exposed to the open area</td>
</tr>
<tr>
<td>Indoor</td>
<td>INDR</td>
<td>Indoor</td>
<td>Kept undisturbed inside a closed room</td>
</tr>
</tbody>
</table>

**Table 3**: Increment and decrement of compressive strength for microbed concrete specimens with six (6) different curing regimes [10]

<table>
<thead>
<tr>
<th>Curing Regimes</th>
<th>Compressive strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28 days</td>
</tr>
<tr>
<td>HCL</td>
<td>5% &gt; control</td>
</tr>
<tr>
<td>Soil</td>
<td>2% &gt; control</td>
</tr>
<tr>
<td>WWTR</td>
<td>13% &gt; control</td>
</tr>
<tr>
<td>SWTR</td>
<td>3% &gt; control</td>
</tr>
<tr>
<td>NaOH</td>
<td>No increment</td>
</tr>
<tr>
<td>OUTDR</td>
<td>15% &gt; control</td>
</tr>
<tr>
<td>INDR</td>
<td>16% &gt; control</td>
</tr>
</tbody>
</table>

Andrew et al. [8] added EM proportion started from 5% to 50% which was measured from total water contents. Mix designation for volume 0.09m³ of concrete grade 30 for control and microbed concrete specimens as shown in Table 4 tabulates that 5% EM was calculated by multiplying 5% from 18.45 liter of water contents. Therefore, 920ml of EM was added in the concrete to prepare twelve (12) concrete specimens. The incorporation of 5% EM dilution recorded 30% increment of compressive strength associated with 5.5% increment of flexural strength. While
30% EM dilution contributes 67% increment of splitting tensile strength corresponding to control concrete specimens without EM. All concrete specimens were immersed in EM solution till the testing’s day. Isa et al. [9] added four (4) different EM contents which was locally produced by themselves in concrete specimens. Inclusion of 5%, 10% and 15% EM recorded lower compressive strength than control concrete specimens without EM as shown in Figure 2. However, 3% inclusion of EM recorded high compressive strength with increment of 13% at age of 28 days.

Table 4: Mix design of control and microbed concrete with Grade 30 in weight (kg) [8]

<table>
<thead>
<tr>
<th>Cement</th>
<th>Water (l)</th>
<th>EM (l)</th>
<th>Fine Aggregates</th>
<th>Coarse Aggregates</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.75</td>
<td>18.45</td>
<td>-</td>
<td>90.9</td>
<td>70.65</td>
</tr>
<tr>
<td>33.75</td>
<td>17.53</td>
<td>0.92</td>
<td>90.9</td>
<td>70.65</td>
</tr>
</tbody>
</table>

Table 5: Strength increment of microbed concrete at the age of 28 days [8]

<table>
<thead>
<tr>
<th>Strength Types</th>
<th>EM dilution</th>
<th>Strength increment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive</td>
<td>5%</td>
<td>30% &gt; control</td>
</tr>
<tr>
<td>Splitting Tensile</td>
<td>30%</td>
<td>67% &gt; control</td>
</tr>
<tr>
<td>Flexural</td>
<td>5%</td>
<td>5.5% &gt; control</td>
</tr>
</tbody>
</table>

Figure 2: Compressive strength of concrete specimens containing EM [9]
4. MICROSTRUCTURE EXAMINATION SUBSTANTIATED WITH ELEMENT COMPOSITION OF MICROBED CEMENT PASTE

Due to the limited findings regarding the microstructure and element composition of concrete specimens, this section describes the literature published in cement paste. Noorli et al. [14] conducted the testing of X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) on the crushed specimens of control and microbed cement paste containing EM. The predominance of portlandite and calcite in the diffractograms of the control and microbed specimens taken at the age of 7 days and 28 days is shown in Figure 3. The amorphous XRD patterns of the control and microbed cement specimen were obviously produced. The peaks of calcite and portlandite became smaller with the increase of curing days in the control specimen. On the other hand, the peak of vaterite becomes higher in the microbed cement. More number of vaterite peaks produced in the microbed cement specimen as compared to the cement specimen without microbes at the age of 28 days. Meanwhile, the peaks of cristobalite for microbed cement which is responsible to the strength development showed the decrement peaks at age of 7 days and increased at age of 28 days corresponding to cement paste without EM. The decrement peaks of cristobalite was correlated to the lowest compressive strength recorded in the cement paste containing 100% EM.

Figure 3: XRD analysis for specimens of control and microbed cement paste for (a) 7 days and (b) 28 days [14]
While, Figure 4 and Figure 5 which was produced by Noorli et al. [14] shows the SEM micrograph of cement paste specimens containing with and without EM. The internal structures of microbed cement specimens are denser as compared to control cement paste without EM at the age of 7 days of curing. The similar SEM image was also reported in the study of Noorli et al. [12]. Meanwhile, the microstructure of cement matrix between microbed and control cement paste at the age of 28 days does not show significant differences in its internal structure. However, it is clearly seen that the microstructure of microbed cement paste contains smaller voids corresponding to control cement paste without EM.

![Figure 4: SEM micrograph of control cement specimen at age of (a) 7 day and (b) 28 days [14]](image1)

![Figure 5: SEM micrograph of microbed cement specimen in (a) 7 day and (b) 28 days after curing [14]](image2)

The combination of Scanning Electron Microscopy (SEM) substantiated with instruments of Electron Disperse X-Ray (EDX) was performed by Noorli et al.[14] which was tested on the cement paste specimens containing EM at age of three (3) days. The image of SEM and EDX spectrum for control and microbed cement paste specimen is shown in Figure 6 and Figure 7, respectively with magnification of 3000. The dense and less void of microbed cement matrix shows the chemical composition of the microbed cement paste specimen is featuring high concentration in calcium (Ca) ions and low concentration ions in aluminium (Al), sulfur (S),
magnesium (Mg) and silica (Si). Meanwhile, Ca concentration ions of the control were doubled than microbed cement paste. Generally, the amount of Ca in control cement paste was higher than microbed cement. Furthermore, the amount of silica (Si) was detected in microbed cement with seven (7) percent.

Figure 6: SEM micrograph substantiated with representative EDX spectrum spotted on control cement specimen at age of three (3) days [12]

Figure 7: SEM micrograph substantiated with representative EDX spectrum spotted on microbed cement specimen at age of three (3) days [12]

5. PORE DISTRIBUTION PROFILES OF MICROBED CEMENT PASTE

This section describes the literature published in cement paste due to the limited findings of pore distribution in concrete specimens. The pore volume (mL/g) against pore size of control and microbed cement paste is referred to the Figure 8 which was obtained from Mercury Intrusion Porosimetry (MIP) tests. Generally, the curves of both specimens was located at the larger pores region due to pore diameters positioned at size more than 1µm. The pore volume of microbed cement paste slightly lower compared to the cement paste without EM. In control and microbed cement paste, the larger mercury intrusion presented at pore diameter between 40µm and 50µm and started from 20µm to 40µm, respectively. The
incorporation of EM in cement paste contributes the smaller of pore size and lower pore volume. Table 6 presents the microbed cement paste having the reduction of the total porosity (16.5%) than the control cement paste (20.3%) while median diameter represents the point that located 50% of pore size distribution curve. In microstructure examination found the densification matrix of microbed cement paste was denser and less voids with respect to the control paste without EM [12-13]. The micrograph image captured was consistent with the result of porosity and median pore diameter. The microbed cement paste presents smaller value of median pore diameter corresponding to control cement paste. The maximum and minimum pore diameter do not show significance effect to the setting time of cement. Rationally, these two (2) data do not correlate to the pore volume of cement paste unless the graph of logarithm was constructed.

![Figure 8: Pore size distribution profile of control and microbed cement paste at age of 28 days](image)

<table>
<thead>
<tr>
<th>Total porosity (%)</th>
<th>Control</th>
<th>Microbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average pore diameter (µm)</td>
<td>0.0539</td>
<td>0.0206</td>
</tr>
<tr>
<td>Median pore diameter (µm)</td>
<td>0.2424</td>
<td>0.0154</td>
</tr>
<tr>
<td>Maximum pore diameter (µm)</td>
<td>319.057</td>
<td>319.163</td>
</tr>
<tr>
<td>Minimum pore diameter (µm)</td>
<td>0.00301702</td>
<td>0.003017</td>
</tr>
</tbody>
</table>

6. CONCLUSION

Overall, significant findings showed the increment of compressive strength due to EM incorporation in cement paste and concrete. Limited finding in EM incorporation into the mortar specimens described the potential of future studies in this matter.
Furthermore, the extensive studies is required to be evaluated in incorporating of EM in concrete specimens. Meanwhile, the capability of SEM substantiated with EDX system was proven to describe the SEM micrograph with the chemical composition on the point interest. However, it is still need to support the result by providing the XRD test. SEM micrograph showed that the microstructure of microbed cement paste was less voids and denser at the early strength and achieved full hydration at age of 28 days. The increment of compressive strength of cement paste was associated to decrement of total porosity which was recorded by MIP test. Less value of total porosity was consistent with the image of micrograph which was captured by SEM. Dense and less void observed from SEM image proven that the testing of MIP was able to conduct to relate the increment of compressive strength.

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