THE USE OF COPPER MILL TAILINGS AS A CEMENT REPLACEMENT, AND STABILIZED SOIL

by

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AND ENGINEERING MECHANICS
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MASTER OF SCIENCE
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1975
STATEMENT BY AUTHOR

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SIGNED: Samih Qagish

APPROVED BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

R. A. JIMENEZ
Professor of Civil Engineering

July 1, 1975
Date
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ABSTRACT

The feasibility of using copper mill tailings as a cement replacement or as a stabilized material was investigated in this study. Details of materials, laboratory procedure and tests using different testing equipment are also given. It was found that the use of cement with copper mill tailings as a stabilized soil gives satisfactory results. The use of copper mill tailings as a cement replacement does not meet the physical requirements of cement.
It cannot be disputed that the widespread use of portland cement has made an important contribution in shaping our modern civilization. It has become accepted as one of the most essential of the structural elements used in building our towns, roads and public works.

Portland cement is an artificially produced mixture of minerals of very complicated structure. Portland cement is manufactured essentially from silica and calcium, two of the most common minerals. In the presence of water, these minerals change to a complex colloidal product which is responsible for the phenomenon of hydraulic cement [Czernin, 1962]. Portland cement and asphalt cement have come to occupy such positions of prominence on the list of Civil Engineering materials, that no engineers can avoid consideration of them.

Now days the high cost of material construction due to either the shortage of these materials or the great demand for them, especially the cement, directs one's attention to produce a mixture of cement with an available cheap material having the same properties as cement, where the properties of a material determines the purposes it can usefully serve.

Here we study the probability of using copper mill tailings as a cement replacement so as to reduce the cost of portland cement, at the
same time the use of copper mill tailings converts it to a useful product instead of being a wasteful one.

Pozzolans are one of the successful materials which were used with cement. Pozzolans are a mixture of silicons or silicons and aluminous materials which possess no cementitious action but in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to give compounds having cementitious properties.

Arizona is the third district of the United States and the fourth in the world in point of productive capacity of copper [Stevens, 1906]. The current annual production of copper is 125 million tons in the United States, and the major portion of this is produced from the mines in Arizona. So it is easy to imagine the huge quantities of mill tailings discarded by mines and the problems associated with this, such as stabilization, air pollution and the large area of land occupied in this state.

Soil stabilization is concerned with the modification of physical properties of soils, the processes used are compaction, drainage, treatment of the soil with admixtures and thermal or electrical treatment. The results are usually increased strength and durability and decreased volume change and permeability compared with the natural soil. Zakhour [1973] presented the stabilization techniques of copper mill tailings and the results were satisfied, but it would be better if these studies included also using copper mill tailings as a profitable and competitive industry which helps at the same time to release large areas of land occupied by this material, especially in a country as
America which also depends on the agriculture as an important source of its developed civilization and to reduce the air pollution which this country suffers from.

**Purpose and Scope**

In this study, different levels of copper mill tailings will be mixed with cement in order to evaluate the feasibility of using it as a cement replacement, the following tests will be performed:

A. Pastes of cement and five levels (0, 1, 2, 4, 8%) of copper mill tailings will be mixed to find:
   1. Normal consistency of the mixture.
   2. Time of setting of the mixture
   3. Autoclave expansion of the mixture.

B. Mixing of mortars with four levels (0, 2, 4, 8, 12%) of copper mill tailings so as to find out:
   1. Compressive strength of the mixture.
   2. Tensile strength of the mixture.

C. Mixing concretes with three levels of copper mill tailings (0, 4, 8%). Testing of the specimen will be at two ages (7 days and 28 days). The purposes of this test are:
   1. Determining the compressive strength of the mixture.
   2. Determining the tensile strength of the mixture.

D. Mixing copper mill tailings with four levels of portland cement (0, 4, 8, 12%) to produce cement stabilized soil, the specimens will be tested at 7 days. The purposes of the test are:
1. Determining the compressive strength.

2. Determining the tensile strength.

Test procedures will be according to ASTM [1970] except for the tensile strength (double punch) of the stabilized copper mill tailings.
CHAPTER 2

MATERIALS AND SAMPLES PREPARATIONS

Materials

Cement

Five types of cement are generally manufactured, their uses are as follows:

I. In general concrete construction.

II. In general concrete construction which is exposed to moderate sulfate action.

III. When high early strength is needed.

IV. When low heat of hydration is needed.

V. When high sulfate resistance is required.

Each of the five types has to satisfy the following chemical and physical requirements as indicated in Tables 1 and 2 according to ASTM specifications [1970, Part 9].

Soil

The soil used was copper mill tailings, it was classified as silty sand, this soil had a grain size distribution as shown in Figure 1. The textural composition of the soil is outlined in Table 3.

The standard AASHO compaction curve for copper mill tailings is shown in Figure 2 with a maximum dry density 116.3 pcf occurring at an optimum moisture content of 14.0 percent.
Table 1. Chemical Requirements of Cement by ASTM

<table>
<thead>
<tr>
<th></th>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
<th>Type IV</th>
<th>Type V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon dioxide ($S_2O_3$), min. percent</td>
<td>....</td>
<td>21.0</td>
<td>....</td>
<td>....</td>
<td>....</td>
</tr>
<tr>
<td>Aluminum oxide ($Al_2O_3$), max. percent</td>
<td>....</td>
<td>6.0</td>
<td>....</td>
<td>....</td>
<td>....</td>
</tr>
<tr>
<td>Ferric oxide ($Fe_2O_3$), max. percent</td>
<td>....</td>
<td>6.0</td>
<td>....</td>
<td>6.5</td>
<td>....</td>
</tr>
<tr>
<td>Magnesium oxide ($MgO$), max. percent</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Sulfur trioxide ($SO_3$) when $36.0 Al_2O_3$ is 8 percent or less, max. percent</td>
<td>2.5</td>
<td>2.5</td>
<td>3.0</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Sulfur trioxide ($SO_3$) when $36.0 Al_2O_3$ is more than 8 percent, max percent</td>
<td>3.0</td>
<td>....</td>
<td>3.0</td>
<td>....</td>
<td>....</td>
</tr>
<tr>
<td>Loss of ignition, max. percent</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Insoluble residue, max. percent</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Tricalcium silicate ($36.0 S_2O_3$), max. percent</td>
<td>....</td>
<td>50.0</td>
<td>....</td>
<td>35.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Dicalcium silicate ($26.0 S_2O_3$), min. percent</td>
<td>....</td>
<td>....</td>
<td>....</td>
<td>40.0</td>
<td>....</td>
</tr>
<tr>
<td>Tricalcium aluminate ($36.0 Al_2O_3$), max. percent</td>
<td>....</td>
<td>8.0</td>
<td>15.0</td>
<td>7.0</td>
<td>5.0</td>
</tr>
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</table>
Table 2. Physical Requirements of Cement by ASTM

<table>
<thead>
<tr>
<th></th>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
<th>Type IV</th>
<th>Type V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness specific surface, sg cm per g (alternate methods) Turbidimeter test:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average value, min.</td>
<td>1600</td>
<td>1600</td>
<td>....</td>
<td>1600</td>
<td>1600</td>
</tr>
<tr>
<td>Minimum value, any one sample</td>
<td>1500</td>
<td>1500</td>
<td>....</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>Air permeability test:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average value, min.</td>
<td>2800</td>
<td>2800</td>
<td>....</td>
<td>2800</td>
<td>2800</td>
</tr>
<tr>
<td>Minimum value, any one sample</td>
<td>2600</td>
<td>2600</td>
<td>....</td>
<td>2600</td>
<td>2600</td>
</tr>
<tr>
<td>Soundness:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autoclave expansion, max. percent</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Time of setting (alternate methods) Gillmore test:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial set, min. not less than</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Final set, hr. not more than</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Vicat test:</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Set, min. not less than</td>
<td></td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Air content of mortar, max. percent of volume, less than</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Compressive strength, psi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The compressive strength of mortar cubes, composed of 1 part cement to 2.75 parts graded standard sand, by weight, shall be equal to or higher than the values specified for the ages indicated below:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 day in moist air</td>
<td>....</td>
<td>....</td>
<td>1700</td>
<td>....</td>
<td>....</td>
</tr>
<tr>
<td>1 day in moist air, 2 days in water</td>
<td>1200</td>
<td>1000</td>
<td>3000</td>
<td>....</td>
<td>....</td>
</tr>
</tbody>
</table>
Table 2.—Continued

<table>
<thead>
<tr>
<th>Condition</th>
<th>Tensile Strength, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 day in moist air, 6 days in water</td>
<td>2100 1800 .... 800 1500</td>
</tr>
<tr>
<td>1 day in moist air, 27 days in water</td>
<td>3500 3500 .... 2000 3000</td>
</tr>
</tbody>
</table>

Tensile strength, psi

The tensile strength of mortar briquets composed of 1 part cement and 3 parts standard sand, by weight, shall be equal to or higher than the values specified for the ages indicated below:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Tensile Strength, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 day in moist air</td>
<td>.... .... 275 .... ....</td>
</tr>
<tr>
<td>1 day in moist air, 2 days in water</td>
<td>150 125 375 .... ....</td>
</tr>
<tr>
<td>1 day in moist air, 6 days in water</td>
<td>275 250 .... 175 250</td>
</tr>
<tr>
<td>1 day in moist air, 27 days in water</td>
<td>350 325 .... 300 325</td>
</tr>
</tbody>
</table>

Table 3. Soil Textural Composition

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>---</td>
</tr>
<tr>
<td>Sand</td>
<td>61%</td>
</tr>
<tr>
<td>Silt</td>
<td>33%</td>
</tr>
<tr>
<td>Clay</td>
<td>6%</td>
</tr>
</tbody>
</table>
Figure 1. Grain size distribution curve.
Figure 2. Dry density - moisture content relationship for the copper mill tailings. [Zakhour, 1973, p. 30.]
Sand

The sand used for the compressive strength determination of hydraulic cement mortars was natural silica sand from Ottawa, Illinois, graded as follows:

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Percentage Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 100</td>
<td>98 ± 2</td>
</tr>
<tr>
<td>No. 50</td>
<td>72 ± 5</td>
</tr>
<tr>
<td>No. 30</td>
<td>2 ± 2</td>
</tr>
<tr>
<td>No. 16</td>
<td>None</td>
</tr>
</tbody>
</table>

Segregation of graded sand was prevented since it would cause variations in the normal consistency of the mortar which finally affected its strength.

The sands used for tensile strength of hydraulic cement mortars was natural silica sand from Ottawa, Illinois, graded to pass No. 20 sieve and retained on a No. 30. The amount of sand retained on sieve No. 20 was not more than 15 gm and passed No. 30 not more than 5 gm after five minutes of continuous sieving of a 100 gm sample.

Aggregates

The quality and strength of concrete is directly related to the characteristic and properties of the mineral aggregates. So as to determine these properties the following tests as described in the following paragraphs are usually run:
Moisture Content in the Natural State. For determining the natural moisture content, weighing samples of the fine and coarse aggregates are taken from the bins, oven-drying for 24 hours, then reweighing them. The natural moisture content is determined from this formula:

\[
\text{Natural Moisture Content} = \frac{\text{Natural Weight} - \text{Oven-Dry Weight}}{\text{Oven-Dry Weight}} \times 100
\]

Free Moisture Content. A sample is taken from the fine aggregate, drying it at a temperature of 110°C until a constant weight is obtained. Allow it to cool to the ordinary temperature, cover with water, and let it soak for 15 hours. Then spread it on a flat surface exposed to a current of warm air, place the dried fine aggregate into the mold, tamp the surface 25 times with the tamper. SSD is obtained when the tamped fine aggregate slumps slightly after the removal of the mold, if not this indicates that it is above the SSD condition.

Absorption of Water Aggregates. Samples of aggregates are soaked in water for 24 hours air-drying them to SSD, weighing at SSD, oven-drying for 1 to 3 hours, then reweighing. The absorption percentage is determined from this formula:

\[
\text{Absorption} = \frac{\text{SSD Weight} - \text{Oven-Dry Weight}}{\text{Oven-Dry Weight}}
\]

Specific Gravity. It is very necessary to know the specific gravity of the aggregates in order to calculate the weight-volume relationships for the mix.
For the fine aggregates, SSD samples are weighed in a graduated cylinder of known weight, filling it with water to a given level, reweighing, then dropping the contents, and reweighing the cylinder filled with water to the same level. Then the specific gravity is determined from this formula:

\[
\text{Bulk Specific Gravity of Fines} = \frac{w_s}{w_s + w_1 - w_2}
\]

where

\(w_s\) = SSD weight

\(w_1\) = weight of bottle, water and sample, and

\(w_2\) = weight of bottle and water.

For the coarse aggregate, a SSD weighing sample is taken in a copper bucket of known weight, then it is submerged in water to know its weight. The specific gravity of coarse aggregate can be determined from this formula:

\[
\text{Bulk Specif Gravity of Coarse Aggregate} = \frac{\text{SSD Weight}}{\text{SSD Weight} - \text{Weight in Water}}
\]

**Maximum Unit Weight.** Figure 3 shows the maximum unit weight for a series of trials that were run using a fixed volume and varying percentages of fine and coarse aggregates by weights. The samples were placed in three layers, each layer being compacked 25 times with a bullet-pointed rod to achieve the greatest density. All the information about the aggregates is shown in Table 4.
Figure 3. Maximum unit weight of aggregates.
Table 4. Aggregate Data

<table>
<thead>
<tr>
<th></th>
<th>Fines</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent natural moisture</td>
<td>0.36</td>
<td>0.1</td>
</tr>
<tr>
<td>Percent absorption</td>
<td>1.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>2.62</td>
<td>2.65</td>
</tr>
</tbody>
</table>

Maximum unit weight of aggregate (pcf) 122 - percentage of fines in aggregates 46%

Sample Preparation, Curing and Molding

Sample preparation, molding and curing of the normal consistency, time of setting, autoclave expansion, compressive strength and tensile strength were performed according to ASTM designation: C 187-68, C 266-65, C 151-66, C 109-64 and C 190-63.

Compressive and Tensile Strength of Concrete

The trial method for determining the proportion of concrete mix is followed, the final calculated results for the mix are:

- Cement = 59.1 lbs
- Water = 30.6 lbs
- Gravel = 127.1 lbs
- Sand = 108.1 lbs
- Final mix weight = 147.7 pcf

The calculations for the concrete mix are shown in the appendix.
The previous weights of cement, water, aggregates and sand are fed into a revolving drum in which there are blades that handle the ingredients so as to mix them thoroughly. After one minute of mixing the batch is discharged by tilting the drum. The molds used for both compression and tension are the same, 6 inches in diameter by 12 inches in height. Sample preparation, molding and curing is as specified in ASTM Designation: C 192-66 (American Society for Testing and Materials). Check of the consistency is performed and a slump of about 3 inches is required as in Table 5 [Baker and Degroot, 1931, p. 18].

Table 5. Slumps for Various Kinds of Concrete

<table>
<thead>
<tr>
<th>Type of Structure</th>
<th>Slump in Inches</th>
<th>Consistency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive sections, pavements, and floors laid on the ground</td>
<td>1 4</td>
<td>Stiff</td>
</tr>
<tr>
<td>Heavy walls, slabs, beams</td>
<td>3 7</td>
<td>Medium</td>
</tr>
<tr>
<td>Thin walls, columns, etc.</td>
<td>4 8</td>
<td>Wet</td>
</tr>
<tr>
<td>Mortar for floor finish</td>
<td>1 2</td>
<td>Stiff</td>
</tr>
</tbody>
</table>
Tensile Strength of Stabilized Copper Mill Tailings

**Flexural Test.** The dimensions of the flexural test specimens are 3x3x11-1/4 inches. According to ASTM specifications, the length is greater than three times the depth. The required amount of copper mill tailings is mixed with a limited amount of water to give the maximum dry density of 116.3 pcf. Sample preparation, curing and molding is performed according to ASTM designation: D 1635-63. The static compaction was done at a slow rate by means of 60k capacity Tinius Olson Testing Machine until the required thickness is obtained.

**Double Punch.** The dimensions of the double punch test specimens are 4 inches in diameter and 4.6 inches high.

The same procedure as the flexural test is used for the preparation, curing and molding the specimen.
CHAPTER 3

EQUIPMENT AND TEST PROCEDURES

Equipment and test procedures of the normal consistency, time of setting, autoclave expansion, compressive strength of mortar and compressive strength of concrete are performed according to ASTM Designation: C 187-68, C 266-65, C 151-66, C 109-64 and C 192-66 respectively.

Figures 4, 5, 6 and 7 illustrate the apparatuses which were used in the normal consistency, time of setting, autoclave expansion and compressive strength of cement mortar tests.

Tensile Strength of Cement Mortars

The test ages of the specimens are 7 and 28 days. Figure 8 shows the tensile strength test of cement mortar. The type of machine used depends on applying the stress by a stream of shot which runs from a chamber of the machine into a vessel. When the briquette breaks, the stream of shot is automatically stopped and the stress is determined by the weight of shot inside the vessel. The maximum capacities of the machines which are usually used for tensile-testing vary from 1000 to 2000 pounds. The following requirements have to be achieved in a satisfactory machine: the clips for supporting the briquets are provided with roller bearings whose faces are 1-1/4 inches apart, the briquets
Figure 4. Vicant needle apparatus.
Figure 5. Gillmore needle apparatus.
Figure 6. Autoclave expansion apparatus.
Figure 7. Compressive strength test of cement mortar.
Figure 8. Tensile strength test of cement mortar.
are centered accurately in the clips and the rate of loading is applied continuously at a rate of 600 pounds per minute.

**Tensile Strength of Concrete**

The same machine was used for both tension and compression test. The indirect tensile test was performed in this study. This method was suggested by Brazil in 1947 [Elevery, 1963]. In this test the specimen was placed horizontally in the machine and the load applied as shown below:

![Cylinder Splitting Test Diagram]

**Cylinder Splitting Test**

The stress is calculated by this formula:

\[ \text{Tensile stress} = \frac{2P}{\pi DL} \]

- \( P \) = the load at failure lb.
- \( D \) = the diameter of the cylinder, and
- \( L \) = the length of the cylinder
**Tensile Strength of Stabilized Copper Mill Tailings**

**Flexural Strength**

The third-point loading method was used according to ASTM Designation: D 1635-63. The molds used were 3x3x11-1/4 inches. Figure 9 shows the apparatus used in the flexural test. All fracture occurred within the middle third of the length, therefore the modulus of reputeure was calculated by the formula:

\[ R = \frac{PL}{bd^2} \]

where:

- \( R \) = modulus of reputeure, in pounds per square inch
- \( P \) = maximum applied load, in pounds
- \( b \) = average width of specimen, in inches, and
- \( d \) = average depth of specimen, in inches

The load was applied at a constant rate of 0.05 inch per minute. Figure 10 shows the flexural test of stabilized copper mill tailings.

**Double Punch**

The molds used were 4 inches in diameter and 4.6 inches in height. Figure 11 shows the double punch test of stabilized copper mill tailings. The apparatus consists of two steel discs with 1 inch in diameter applied on both top and bottom surfaces of the cylinder specimen. A slow rate of loading was applied 0.05 inch per minute. The maximum load the specimen can withstand was recorded. The tensile stress was calculated from the formula which was developed by Fang [1970]:
Figure 9. Elevation shows the apparatus used in the flexural test.
Figure 10. Flexural test of stabilized copper mill tailings.
Figure 11. Double punch test of stabilized copper mill tailings.
\[ \sigma_t = \frac{P}{\pi (1.0bH - a^2)} \]

where

\( \sigma_t \) = simple tensile strength, psi

P = load applied, lb.

b = radius of the specimen, inch

H = height of the specimen, inch, and

a = radius of the steel disc.

The previous formula can be written as:

\[ \sigma_t = \frac{P}{28.12} \]

if the specimen is 4 inches in diameter, 4.6 inches in height and the steel discs are 1 inch in diameter.
CHAPTER 4

DATA PRESENTATION AND ANALYSIS

Normal Consistency

Different levels of copper mill tailings (0, 1, 2, 4, 8%) were mixed with different amounts of cement to give 500 gm of mixture. Variable amounts of water was added to the mixture and the penetration for each case is recorded. The normal consistency of the mixture will occur when a penetration of 10 mm takes place. Plot between the penetration (mm) and the water content are shown for the different levels of copper mill tailings in Figures 12 and 13, the results are shown in Table 6.

Table 6. The Normal Consistency of Cement with Different Levels of Copper Mill Tailings

<table>
<thead>
<tr>
<th>Level of Copper Mill Tailing</th>
<th>Weight of Cement gm</th>
<th>Weight of Copper Mill Tailing gm</th>
<th>Penetration mm</th>
<th>Normal Consistency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>500</td>
<td>0</td>
<td>10</td>
<td>27</td>
</tr>
<tr>
<td>1</td>
<td>495</td>
<td>5</td>
<td>10</td>
<td>26.5</td>
</tr>
<tr>
<td>2</td>
<td>490</td>
<td>10</td>
<td>10</td>
<td>26</td>
</tr>
<tr>
<td>4</td>
<td>480</td>
<td>20</td>
<td>10</td>
<td>25.5</td>
</tr>
<tr>
<td>8</td>
<td>460</td>
<td>40</td>
<td>10</td>
<td>26</td>
</tr>
</tbody>
</table>
Figure 12. Consistency of portland cement with 0% level of copper mill tailings.
Figure 13. Normal consistency of portland cement with 8% level of copper mill tailings.
It is clear from the above data and Figure 14 that as the percentage of copper mill tailings in the mixture increases the normal consistency decreases until 4% and begins to increase at 8% level of copper mill tailings. The decrease of the normal consistency up to 4% is due to the decrease of the porosity and the surface area of the mixture. The increase of the normal consistency at 8% is caused by the increase of the skin friction of the needle and also to the relative changing of the density of the mixture at this level.

Time of Setting

A sufficient period of the time of setting is required so that the crystallization of particles will form after the concrete is thoroughly tamped so good concrete is obtained. For different levels of copper mill tailings we notice from Table 7 that the initial and final setting decreases as the percentage of copper mill tailing increases until 4% level then the initial and final setting become to increase as the percentage of copper mill tailing increases. At 2 and 4% levels of copper mill tailing the initial set does not meet the requirements of cement which is not less than one hour.

Autoclave Expansion of the Mixture

The expansion of the cement specimens mixed with different percentages of copper mill tailings increased as the percentage of copper mill tailings increased, this result can easily be seen by noticing Figure 15 and Table 8. This increase in the expansion is caused by the effect of copper mill tailing on the hydration of lime which takes place
Figure 14. Normal consistency of portland cement with different percentages of copper mill tailings.
Table 7. Initial and Final Setting of Cement with Different Levels of Copper Mill Tailings.

<table>
<thead>
<tr>
<th>Level of Copper Mill Tailings</th>
<th>Initial Set Minutes</th>
<th>Final Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>70</td>
<td>9 hours and 50 minutes</td>
</tr>
<tr>
<td>1%</td>
<td>65</td>
<td>9 hours and 10 minutes</td>
</tr>
<tr>
<td>2%</td>
<td>55</td>
<td>8 hours and 55 minutes</td>
</tr>
<tr>
<td>4%</td>
<td>50</td>
<td>8 hours and 45 minutes</td>
</tr>
<tr>
<td>8%</td>
<td>65</td>
<td>9 hours and 20 minutes</td>
</tr>
</tbody>
</table>

Table 8. The Expansion of Cement with Different Levels of Copper Mill Tailings.

<table>
<thead>
<tr>
<th>Level of Copper Mill Tailings</th>
<th>Weight of Cement gm</th>
<th>Weight of Copper Mill Tailing gm</th>
<th>Weight of Water gm</th>
<th>Average Expansion of 3 Specimens inches</th>
<th>Percentage of Expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>500</td>
<td>0</td>
<td>135</td>
<td>0.016&quot;</td>
<td>.16</td>
</tr>
<tr>
<td>1</td>
<td>495</td>
<td>5</td>
<td>132.5</td>
<td>0.017&quot;</td>
<td>.17</td>
</tr>
<tr>
<td>2</td>
<td>490</td>
<td>10</td>
<td>130</td>
<td>0.018&quot;</td>
<td>.18</td>
</tr>
<tr>
<td>4</td>
<td>480</td>
<td>20</td>
<td>127.5</td>
<td>0.20&quot;</td>
<td>.2</td>
</tr>
<tr>
<td>8</td>
<td>460</td>
<td>40</td>
<td>130</td>
<td>0.22&quot;</td>
<td>.22</td>
</tr>
</tbody>
</table>
Figure 15. Autoclave expansion of portland cement with different percentages of copper mill tailings.
at high temperature and also due to the difference of the specific heat of the copper mill tailing and cement. The coefficient of thermal expansion for copper mill tailing is higher than the cement.

Compressive Strength of Hydraulic Cement Mortars with Different Levels of Copper Mill Tailings

The compressive strength of the cement mortars treated with different percentages of copper mill tailings increased as the percentage of copper mill tailings increased until 8% then it began to decrease. The increase in strength is caused by the improvement of the gradation of the mixture which is associated with more carrying load due to less void ratio and more contact points. This can easily be seen from Table 9, and also from Figure 16. The use of copper mill tailings up to 8% with cement will be accepted in the concrete construction provided that these members are exposed to compression stresses.

Tensile Strength of Hydraulic Cement Mortars with Different Percentages of Copper Mill Tailings

From Table 10 and also from Figure 17 it is easy to see that the tensile strength of cement mortars decreases as the percentage of copper mill tailings increases. This decrease in strength is due to the reduction of the amount of cement which reflects on the adhesion of the particles. This adhesion is directly proportional to the maximum load the specimens can withstand. It is recommended that only 1% of copper mill tailings be used with cement which gives tensile stress more than 275 and 350 lb/in² at 7 and 28 days testing which are required according to the American Society for Testing Materials. For the small and not important construction it can be increased up to 2%.
Table 9. Compressive Strength of Hydraulic Cement Mortars with Different Levels of Copper Mill Tailings.

<table>
<thead>
<tr>
<th>Level of Copper Mill Tailings</th>
<th>Weight of Cement gm</th>
<th>Weight of Sand gm</th>
<th>The Amount of Water gm</th>
<th>Flow Table cm</th>
<th>Average Compressive Strength of 3 Specimens lb/in²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>500</td>
<td>1375</td>
<td>290</td>
<td>22</td>
<td>2710 3730</td>
</tr>
<tr>
<td>1</td>
<td>495</td>
<td>1375</td>
<td>280</td>
<td>21.5</td>
<td>3030 4000</td>
</tr>
<tr>
<td>2</td>
<td>490</td>
<td>1375</td>
<td>280</td>
<td>22</td>
<td>3200 4160</td>
</tr>
<tr>
<td>4</td>
<td>480</td>
<td>1375</td>
<td>275</td>
<td>21.5</td>
<td>3420 4280</td>
</tr>
<tr>
<td>8</td>
<td>460</td>
<td>1375</td>
<td>275</td>
<td>22.5</td>
<td>3600 4360</td>
</tr>
</tbody>
</table>
Figure 16. Compressive strength at 7 and 28 days of hydraulic cement mortars with different levels of copper mill tailings.
Table 10. Tensile Strength of Hydraulic Cement Mortars with Different Levels of Copper Mill Tailings.

<table>
<thead>
<tr>
<th>Level of Copper Mill Tailing %</th>
<th>Weight of Cement gm</th>
<th>Weight of C.M.T. gm</th>
<th>Weight of Water gm</th>
<th>Weight of Sand gm</th>
<th>Average Tensile Strength of 3 Specimens lb/in² 7 days</th>
<th>28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>300</td>
<td>0</td>
<td>132</td>
<td>900</td>
<td>315</td>
<td>395</td>
</tr>
<tr>
<td>1</td>
<td>297</td>
<td>3</td>
<td>130.8</td>
<td>900</td>
<td>295</td>
<td>365</td>
</tr>
<tr>
<td>2</td>
<td>294</td>
<td>6</td>
<td>129.6</td>
<td>900</td>
<td>265</td>
<td>345</td>
</tr>
<tr>
<td>4</td>
<td>288</td>
<td>12</td>
<td>129</td>
<td>900</td>
<td>225</td>
<td>300</td>
</tr>
<tr>
<td>8</td>
<td>276</td>
<td>24</td>
<td>129.6</td>
<td>900</td>
<td>200</td>
<td>260</td>
</tr>
</tbody>
</table>
Figure 17. Tensile strength at 7 and 28 days of hydraulic cement mortar with different levels of copper mill tailings.
Compressive and Tensile Strength of Concrete

The effect of copper mill tailings on concrete, is the same as on cement mortars. The compressive strength increases as the percentage of copper mill tailing increases up to 8% and then tensile strength decreases as rapidly as the percentage of copper mill tailing increases. According to Fuller and Thompson [1907] the increase in compressive strength is caused by the improvement of the gradation of the concrete mixture. The decrease in tensile strength is due to the reduction of the amount of cement which is directly proportional to the adhesion. This is shown very clearly in Table 11 and also in Figures 18 and 19.

Stabilized Copper Mill Tailings

Different percentages of cement (0, 4, 8, 12%) are mixed with copper mill tailing so as to see the increase in it's compressive and tensile strength. The results are satisfied, the increase in tensile and compressive stresses are significant and it can be noticed from Table 12 and Figures 20, 21 and 22. The tensile strength was determined by two methods; flexural test and double punch. Flexural tests gives values which are about twice as high as the double punch method. This difference in values depend on the way of testing and also on the densities of the specimens. Zakhour [1973] did a study on the stabilized techniques of copper mill tailing bricks. His values are about twice as high as the values which are obtained in this study.
Table 11. Compressive and Tensile Strength of Concrete with Different Levels of Copper Mill Tailings.

<table>
<thead>
<tr>
<th>Level of Copper Mill Tailings %</th>
<th>Weight of Cement lb</th>
<th>Weight of Copper Mill Tailings lb</th>
<th>Weight of Aggregates lb</th>
<th>Weight of Sand lb</th>
<th>Weight of Water lb</th>
<th>Slump Test inch</th>
<th>Average Compressive Stress of 3 Specimens lb/in² 7 days</th>
<th>28 days</th>
<th>Average Tensile Stress of 3 Specimens lb/in² 7 days</th>
<th>28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>59.1</td>
<td>0</td>
<td>127.1</td>
<td>108.1</td>
<td>30.6</td>
<td>3.1</td>
<td>3041</td>
<td>4090</td>
<td>470</td>
<td>620</td>
</tr>
<tr>
<td>4</td>
<td>56.8</td>
<td>2.4</td>
<td>127.1</td>
<td>108.1</td>
<td>30.6</td>
<td>3.1</td>
<td>3250</td>
<td>4440</td>
<td>400</td>
<td>540</td>
</tr>
<tr>
<td>8</td>
<td>54.4</td>
<td>4.7</td>
<td>127.1</td>
<td>108.1</td>
<td>30.6</td>
<td>3.1</td>
<td>3400</td>
<td>4600</td>
<td>355</td>
<td>475</td>
</tr>
</tbody>
</table>
Figure 18. Compressive strength at 7 and 28 days of concrete with different levels of copper mill tailings.
Figure 19. Tensile strength at 7 and 28 days of concrete with different levels of copper mill tailings.
Table 12. Tensile and Compressive Strength of Stabilized Copper Mill Tailings with Different Percentages of Cement.

<table>
<thead>
<tr>
<th>Level of Cement</th>
<th>Weight of C.M.T. gm.</th>
<th>Weight of Cement gm.</th>
<th>Weight of Water Required for Cement Hydration</th>
<th>Total Amount of Water Reqd. gm.</th>
<th>Flexural Strength R lb/in²</th>
<th>Compressive Strength lb/in²</th>
<th>Weight of C.M.T. gm</th>
<th>Weight of Cement gm</th>
<th>Weight of Water Required for Cement Hydration</th>
<th>Total Amount of Water gm</th>
<th>Double Punch σt lb/in²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>2094.8</td>
<td>0</td>
<td>0</td>
<td>425.0</td>
<td>3</td>
<td>15</td>
<td>1766.7</td>
<td>0</td>
<td>0</td>
<td>242.6</td>
<td>1</td>
</tr>
<tr>
<td>4%</td>
<td>2971.0</td>
<td>123.8</td>
<td>32.1</td>
<td>440.2</td>
<td>32</td>
<td>215</td>
<td>1696.1</td>
<td>70.7</td>
<td>19.3</td>
<td>252.2</td>
<td>12</td>
</tr>
<tr>
<td>8%</td>
<td>2847.2</td>
<td>247.6</td>
<td>64.3</td>
<td>445.4</td>
<td>56</td>
<td>360</td>
<td>1625.1</td>
<td>141.4</td>
<td>38.6</td>
<td>261.9</td>
<td>22</td>
</tr>
<tr>
<td>12%</td>
<td>2723.4</td>
<td>371.4</td>
<td>96.5</td>
<td>470.6</td>
<td>75</td>
<td>460</td>
<td>1554.4</td>
<td>212.0</td>
<td>271.4</td>
<td>271.4</td>
<td>33</td>
</tr>
</tbody>
</table>

Note: 0.26 lb of water is required for the hydration of 1 lb of cement.
Figure 20. Flexural strength at 7 days of copper mill tailing with different levels of cement.
Figure 21. Compressive strength at 7 days of copper mill tailing with different levels of cement.
Figure 22. Tensile strength at 7 days by double punch of copper mill tailing with different levels of cement.
CHAPTER 5

CONCLUSIONS

The main purpose of this research was to investigated the probability of using copper mill tailings as a cement replacement. A better understanding of this will be made by adjustments and verification from the field investigation to laboratory study which it depends on right now.

The following conclusions can be taken from this study:

1. The use of copper mill tailings as a cement replacement does not give adequate results.

2. The change of normal consistency and time of setting of cement with different levels of C.M.T. up to 4% is negligible.

3. The use of copper mill tailings up to 8% with cement give satisfactory results when it's subjected to a compressive stress.

4. When more than 8% of copper mill tailing is used with cement, precautions have to be taken to reduce cracking as a result of high expansion of the mixture.

5. In small jobs where a low stress, especially in tension is required, up to 4% in general of copper mill tailing can be used.
6. Cement is a very effective additive to copper mill tailing and the stabilized copper mill tailing and by using different percentages of cement gives a satisfactory result.

**Recommendations for Further Research**

1. More laboratory experiments have to be run to evaluate the effect of copper mill tailing as a cement replacement.

2. Chemical analysis is required to see the effect of its compositions on cement.

3. The laboratory experiments have to simulate the field conditions, so a further research is needed to give a good idea about the behavior of this material in the field.
APPENDIX

CONCRETE MIX

Water/cement ratio = .47
Specific gravity of sand = 2.62
Specific gravity of gravel = 2.65
Specific gravity of cement = 3.15
Workability factor = .15
Maximum aggregate density = 122pcf

Volume of solids/ft$^3$ = Max. Aggregate Density \((S.G. \ of \ Aggregate) \times \gamma_w\)

Volume of voids = 1 $V_S$

$V_S$ = volume of solids

Volume of paste = W.F. $\times V_V$

$V_V$ = volume of voids

Weight of cement = $\frac{\text{volume of paste} \times \gamma_w}{w/c + \text{specific gravity of cement}}$

Considering one cubic foot of maximum density of aggregate.

Volume of solids = .75 ft$^3$
Volume of voids = .25 ft$^3$
Volume of paste = $1.5 \times (.25) = .38 \text{ ft}^3$
Weight of cement: \[ \frac{(0.38)(62.4)}{0.47 + \frac{1}{3.15}} = 30.31 \text{ lbs} \]

Weight of water: \[ (w/c) \times 3 = (0.47) \times (30.31) = 14.24 \text{ lbs} \]

Weight of aggregate:
- Gravel correction: \[ (\% \text{ gravel}) \times (\text{max. unit density}) \]
  \[ (0.46) \times (122) = 56.12 \text{ lbs} \]
- Sand correction: \[ (\% \text{ sand}) \times (\text{max. unit density}) \]
  \[ (0.47) \times (30.31) = 14.24 \text{ lbs} \]

Volume of mix:
\[ \text{volume of solids} + \text{volume of paste} = 0.75 + 0.38 = 1.3 \text{ ft}^3 \]

Adjusted to a volume of 2.2 cubic feet.

Cement: \[ \frac{2.2}{1.13} \times (30.31) = 59.1 \text{ lbs} \]

Water: \[ \frac{2.2}{1.13} \times (14.24) = 27.80 \text{ lbs} \]

Gravel: \[ \frac{2.2}{1.13} \times (65.88) = 128.55 \text{ lbs} \]

Sand: \[ \frac{2.2}{1.13} \times (56.12) = 109.50 \text{ lbs} \]

Moisture Corrections

Gravel correction: \[ \text{gravel} \times [1 - (\% \text{ absorption} - \% \text{ contained moisture 6})] \]

Gravel: \[ 128.55 \times [1 - (0.02 - 1)] \]
\[ = 127.1 \text{ lbs} \]

Sand Correction: \[ \text{sand} \times [1 - (\% \text{ absorption} - \% \text{ contained moisture 5})] \]
<table>
<thead>
<tr>
<th>Material</th>
<th>Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>109.5 [1 - (0.02 - 0.0036)] = 108.1 lbs</td>
</tr>
<tr>
<td>Additional water needed to achieve SSD condition in the aggregates</td>
<td>((128.55 - 127.1) + (109.5 - 108.1)) = 2.8 lbs</td>
</tr>
<tr>
<td>Cement</td>
<td>59.1 lbs</td>
</tr>
<tr>
<td>Water</td>
<td>30.6 lbs</td>
</tr>
<tr>
<td>Gravel</td>
<td>127.1 lbs</td>
</tr>
<tr>
<td>Sand</td>
<td>108.1 lbs</td>
</tr>
<tr>
<td>Final mix weight/ft^3</td>
<td>147.7 lbs</td>
</tr>
</tbody>
</table>
SELECTED BIBLIOGRAPHY


ASTM, American Society for Testing Materials, Parts 9, 10, 11, 1970.


Czernin, W. *Cement Chemistry and Physics for Civil Engineers*, Britain, Grosly, 1962.


