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UTILIZING INDUSTRIAL WASTEWATER IN PRODUCTION OF CONCRETE: EXPERIMENTAL & FEASIBILITY STUDY

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Abstract: Concrete is the most widely used construction material in the world and is considered one of the largest water consuming industries as approximately 150 liters of water is required per cubic meter of concrete mixture. Recently, population explosion coupled with urbanization has raised the demand for water resulting in its scarcity making water a critical environmental issue that is limiting water supplies and water quality worldwide. On the other hand, with industrialization, the quantity of wastewater generated has soared up warranting appropriate measures for utilization and disposal. This work addresses potential utilization of industrial wastewater in ordinary performance concrete. This study was conducted to investigate the possibility of saving water used in concrete mixtures and make use of produced wastewater domestically and industrially. Mixing water was utilized from wastewater from 7 different industrial plants: ceramic, marble, halva, jam and nestle factories. Non-treated effluents have been used as mixing water in preparing mortar cubes. Hardened concrete properties were assessed through compressive strength testing. The outcome uncovers that the utilization of wastewater from certain sources can produce mixes of comparable strength and durability when compared to control specimens created by tap water. Experimental work is backed up with a feasibility study, incorporating water savings to better judge the potential of the utilization of wastewater in concrete mixing.

Keywords: (Industrial Wastewater, Mixing Water, Mortar, Concrete)

1 INTRODUCTION

In an age of increasing human population and dwindling resources, coupled with the need to curb expenditure in various sectors of the government's budget, attention has been brought to the re-use of resources wherever possible. Perhaps one of the most valuable resources in Egypt and the Middle East in general is water. Therefore, efforts towards wastewater re-use have lately gained worldwide consideration and attention in both the agricultural and industrial fields. Second to water, concrete is of the most widely consumed materials worldwide, with three tons used per person per year (Metcalf and Eddy, 1991). Twice as much concrete is used in construction as all other building materials combined. Concrete is also one of the highest water consuming materials as it requires about 150 liters of water per cubic meter. As demand increases for this fundamental building material, concrete industries have the environmental and societal responsibility to contribute to sustainable development. Accordingly, studies such as the one presented here are carried out in the hope of optimizing the characteristics and properties, ensuring that concrete remains environmentally friendly and affordable. The need of a sustainably developed and environmental friendly concrete industry is aggravated by population growth and scarcity of water (Borger et al., 1994). The world population doubled from 1959 to 1999, increasing from three billion to six billion. According to the United States Census Bureau, the world population is projected to reach nine billion by 2043; or, an increase of 50% relative to 1999. Thus, it is expected that the water demand will have an increasing trend; leading to water scarcity making water reusing, recycling and conservation a necessity. The practice of reuse involves processing used materials into reusable products in order to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, and reduce air pollution and water pollution by reducing the need for conventional waste disposal. Reuse is one of the key components of modern waste management and is an effective method to be applied for the reuse of wastewater in both the agricultural and industrial fields (Sandrolini et al., 2001).

2 RESEARCH MOTIVATION

The main objectives of this study are to examine the potential use of concrete produced through mixing with different wastewaters. This study is of crucial importance particularly in countries of economical rise up. The need for infrastructure will increase the need for high productivity and high performing structures without compromising strength or durability. In addition to many countries scarcity of water resources, makes it very important to use resources wisely. Two main aspects have the major contribution behind this research: (1) The need for durable structures for strategic projects, and (2) Feasibility and Environmental aspects that should be carefully studied and adapted.

3 METHODOLOGY

In the construction industry, potable water is usually used since it is recommended by most specifications and its chemical composition is known and well regulated. A popular criterion of the suitability of water for mixing concrete is the expression that if water is fit to drink it is suitable for making concrete. Other criteria attempting to ensure the suitability of water for batching fresh concrete require that the water be clean and free from deleterious materials. However, these specifications may not be the best basis for evaluation of the suitability of water as mixing water. Some waters, which do not meet these criteria, have been found to produce concretes of satisfactory quality. Currently there are no special tests developed to determine the suitability of mixing water except comparative tests. Generally, comparative tests require that, if the quality of water is not known, the strength of the concrete made with water in question should be compared with the strength of concrete made with water of known suitability (Muniandy, 2009). Both concretes should be made with cement proposed to be used in the construction works. In the design codes, it is recommended that the compressive strength of concrete cubes made of untried water not to be less than 90% of cubes made with tap water. In this study, mortar cubes were chosen to be used for the comparative tests instead of concrete cubes as this eliminates the risk of aggregates' sizes and strength variability from one cube to another so as not to skew the results. Mortar cubes of dimensions (50mmx50mmx50mm) were prepared according to ASTM (C 109/C 109M – 07ε1) using different industrial wastewater effluents. The cubes were then tested and compared to their corresponding control cubes (mortar cubes made by using tap water).

3.1 Materials

Below is the list of materials used in the experimental program and the corresponding standard:

i. Cement: Portland Ordinary Cement was used (ASTM C150)
ii. Sand: Graded standard sand was used which is made of natural silica and conforming to the requirements for graded standard sand in Specification C 778.
iii. Water: Eight different types of water were used for the mixing process of the mortar cubes, which were:
    a. Tap Water (Control)
    b. Waste Water from a Potato Factory (Starch)
    c. Waste Water from a Jam Production Factory (Jam)
    d. Waste Water from a Halva Production Factory (Halva)
    e. Waste Water from a Stone-Pit (Stone-Pit)
    f. Waste Water from a Ceramic Factory (Ceramic)
    g. Waste Water from a Marble Factory (Marble)
    h. Waste Water from an Ice-Cream and Dairy Products Factory (Ice-Cream)

To simulate the effect of varying concentrations of sugar and starch in the mixing water on the concrete compressive strength, two other waters were prepared.

i. Water containing dissolved sugar with different concentrations:
   a. 15 g of sugar in 120 g of water (12.5%)
   b. 35 g of sugar in 120 g of water (29.2%)
   c. 50 g of sugar in 120 g of water (41.7%)
   d. 75 g of sugar in 120 g of water (62.5%)
ii. Water containing dissolved starch with different concentrations:
   a. 15 g of starch in 120 g of water (12.5%)
   b. 25 g of starch in 120 g of water (20.8%)
   c. 35 g of starch in 120 g of water (29.2%)
   d. 50 g of starch in 120 g of water (41.7%)

3.2 Mold

The mold was designed according to the following requirements:

- Its inner dimensions should be 50mmx50mmx50mm.
- Its edges should be tight enough not to escape any mortar or water.
- Unlocking the bars that separate the cubes from each other should be an easy process
- Its base plate should be stiff to hold all parts of the mold together, and smooth to provide a flat surface for the cubes.
- The connection between the separating bars and the base plate should be stiff and firm no to escape mortar or water from the bottom.

First, a sample mold of three cubes was produced so that the design could be tested. After proving its efficiency, the sample mold was up scaled into a mold of twelve cubes. Three molds were produced with the same design and dimensions, having twelve cube partitions each. All molds were produced in the German University in Cairo’s workshop.

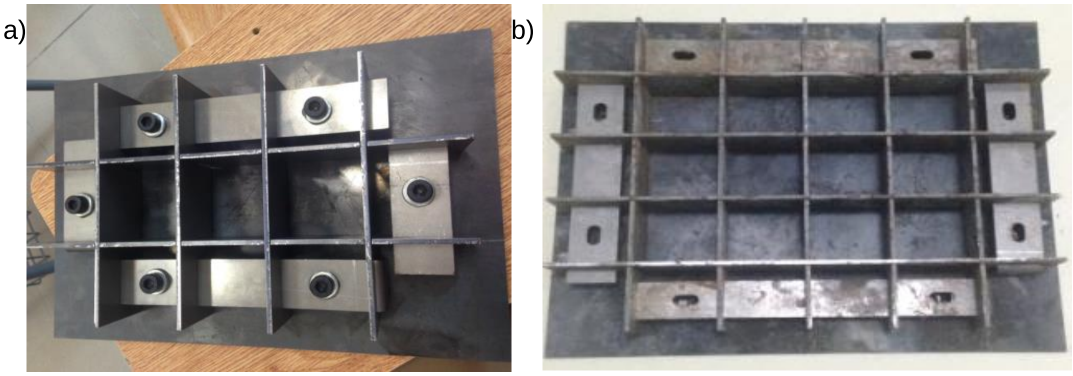

Figure 1: Sample of the molds used; a) 3-Cube mold and b) 12-Cube mold.

3.3 Equipment

The compressive strength-testing machine used for the tests conducted in this thesis is a Zwick/Roell equipment of the model Z100. It was used for the compression testing in room temperature (25°C) as well as in increased temperatures (50°C, 100°C and 150°C).

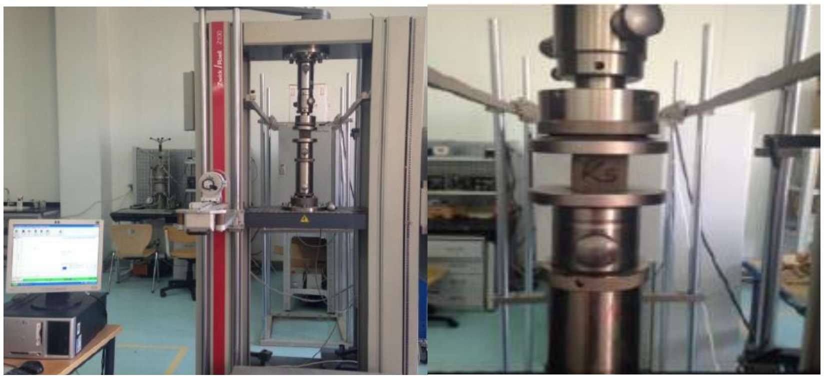

Figure 2: The equipment used for the compressive strength testing under room and higher temperatures

4 RESULTS AND INTERPRETATIONS

Visual examination of cube specimens indicated uniformity and suggested that they were satisfactory. This includes cubes made by using tap water, starch wastewater, stone-pit wastewater, marble wastewater, ice-cream wastewater and ceramic wastewater. On the contrary, cubes made by using jam and halva wastewaters experienced serious problems. The halva-made cubes had cracks in them before testing, and a few even split into two parts. Moreover, jam wastewater had a negative effect on the cubes, even worse than halva. Jam made most of the cubes crack and crumble as soon as they're picked out of the curing tub. This resulted in an insufficient study of the heat effect on the cubes made by using the halva and jam wastewaters.

4.1 3-Day Compressive Strength:

The compressive strength test after 3 days of curing showed that samples made by using tap water have the highest load sustainability (F_{max}= 22919.4 N). Second to tap water were the stone-pit cubes that sustained a maximum force of 20662.65 N. After that came the starch cubes (F_{max}= 15940.05 N) and the ceramic cubes (F_{max}=11633.31 N). The cubes that sustained the least loads were those mixed with jam and halva wastewaters. They sustained a maximum force of 110.31 N and 369.1015 N respectively, which were far beyond all other samples made by other wastewaters. The marble factory cubes had an F_{max} of 23051.4 N, which exceeds the F_{max} of tap water. While the ice-cream factory cubes sustained a maximum force of 13337.27 N. This suggested that the marble factory's wastewater is the only one so far that can be used for concrete mixing, and that jam and halva wastewater contained a sugar content that acted as a strength reducer, an this drew a preliminary conclusion that those two waters shouldn't be used in the concrete industry.

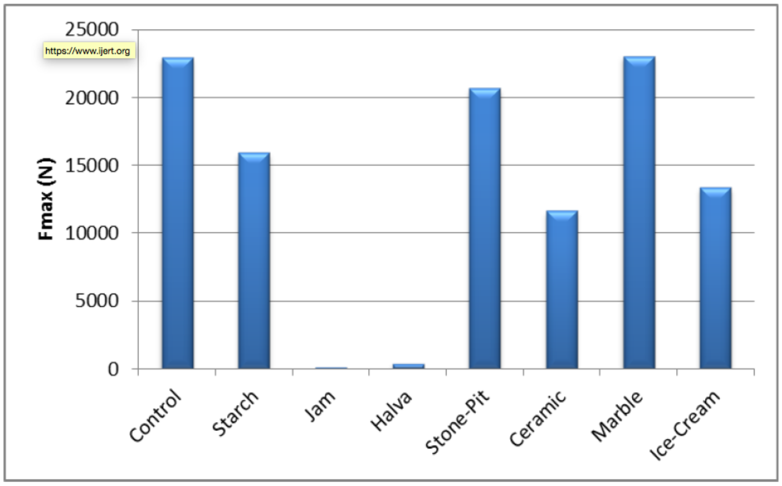

Figure 3: Comparison of 3-day compressive strength of different mixing waters.

4.2 7-Day Compressive Strength:

The compressive strength test after 7 days showed a different pattern other than the 3 days test. After 7 days, it was shown that the cubes made by using stone-pit , marble factory, ice cream and ceramic wastewaters exceeded the compressive strength of the samples produced by using tap water by about 3% which suggested that those four wastewaters can be used in concrete mixing without having the fear that they might decrease the strength or sustainability. But this wasn't to be confirmed except after the 28 days test as they might strengthen in the early stages but experience a low development in the following stages which negates the theory of using them in concrete production. After 7 days of curing, jam and halva-made cubes remained the least load bearing cubes of all others, with a huge difference between them and other samples having an F_{max} of 673.831 and 1056.407 respectively. Starch-made cubes sustained a maximum force of 21381.3, which made it fall beyond the ceramic wastewater-made cubes sustainability. Control, stone-pit, marble, ice cream and ceramic-made cubes had an F_{max} of 32909.7, 33849.5, 33309.7, 32980.2 and 33781 respectively.

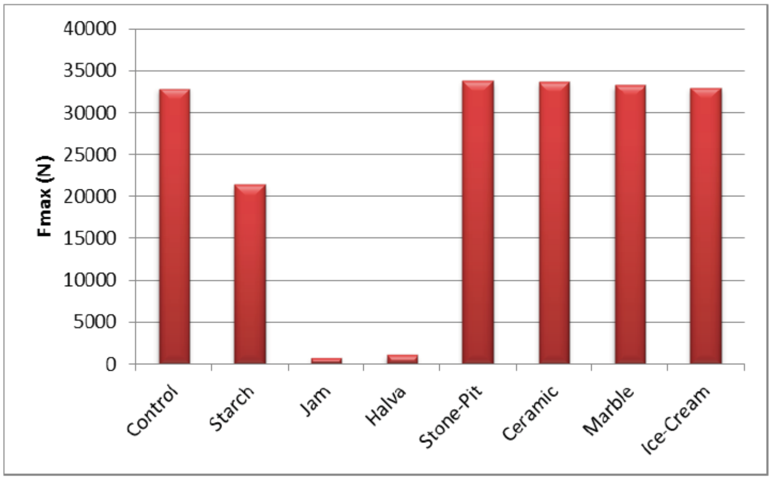

Figure 4: Comparison of 7-day compressive strength of different mixing waters.

Water with different starch concentrations was prepared to simulate the variation in compressive strength with increasing the starch content in water and was tested after 7 days of curing. The results showed that increasing the amount of starch dissolved in the water decreases the compressive strength of mortar cubes in the following trend.

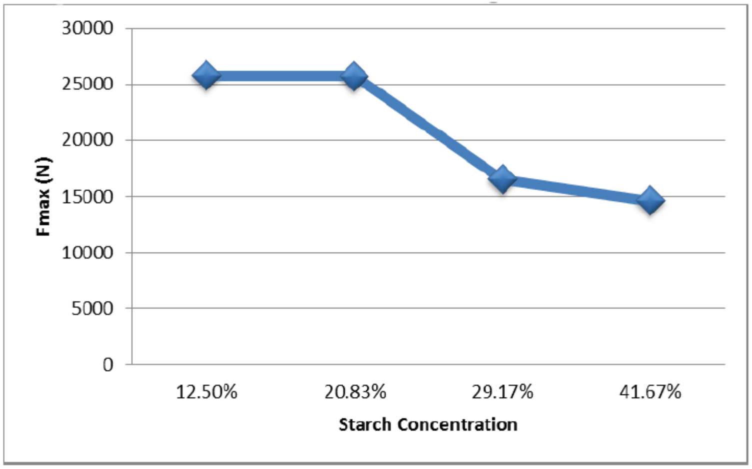

Figure 5: Trend of F_{max} Variation with different Starch Concentrations

4.3 28-Day Compressive Strength:

After 28 days of curing, ceramic wastewater based cubes had the highest ultimate strength among all other cubes. It sustained a maximum force of 51183.98 N, which exceeds the strength of control cubes that are made by using tap water by 42% which can be considered a great privilege for ceramic factories that they can now sell their wastewater to concrete producers without paying for any treatment of their wastewater. Second to ceramic were the stone-pit cubes with F_{max} of 36870.25 N. Jam and halva-based cubes remained the least load bearing waters sustaining an F_{max} of 1495.2 N and 1987.14 N respectively. Cubes mixed with starch wastewater sustained a maximum force of 33464.7 N which is a little below the strength of the tap water cubes (F_{max} 36014.65 N) but falls within the acceptable range, as according to researchers the strength of the cubes made by another water than tap water shouldn't have less than 90% percent of the strength of the tap water cubes. Moreover, in our case, starch wastewater cubes have 92.9% of the control cubes that make them satisfactory and appropriate for use in concrete production.

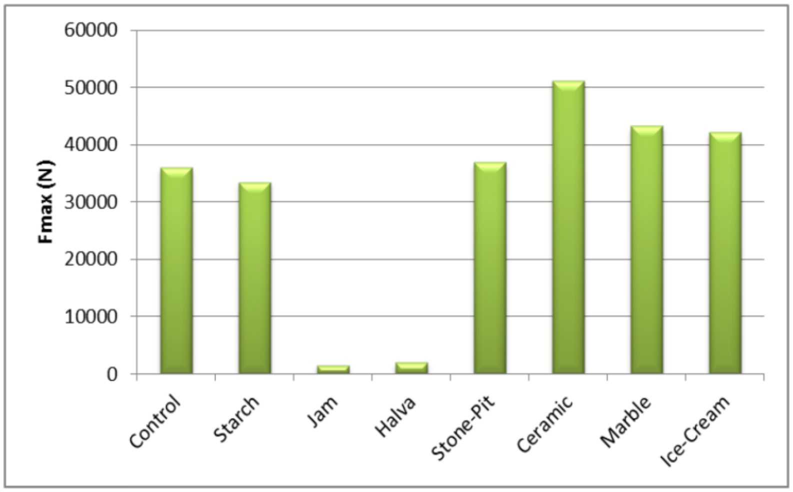

Figure 6: Comparison of 28-day compressive strength of different mixing waters.

To simulate the effect of sugar content on the compressive strength of cubes, water having variable sugar concentrations was prepared and tested for compression after 28 days of curing. The results demonstrated that the compressive strength of cubes increased with increasing the sugar concentration as shown in the following figure.

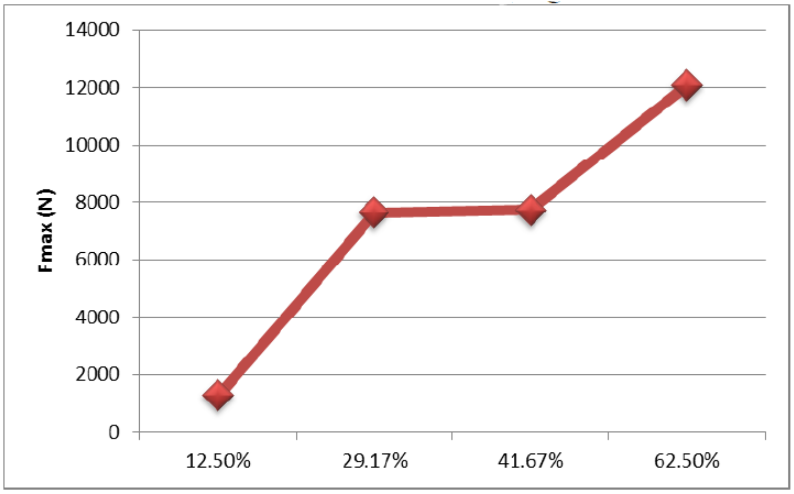

Figure 7: Trend of F_{max} Variation with different Sugar Concentrations

4.4 Strength Variation with temperature:

Cubes made with all waters were tested after 28 days of curing for compressive strength under an increasing temperature. The test was conducted using three different temperatures (50°C, 100°C, and 150°C) and comparing the strength obtained under these temperatures with the cubes tested in room temperature (25°C). Control cubes showed the best behavior under increasing heat and developed its strength in an increasing manner. All other wastewater-based cubes' compressive strength decreased as the temperature rose up. Starch wastewater-based cubes' strength decreased to 52% of their strength in room temperature when the temperature rose to 150°C. Stone-pit cubes sustained an F_{max} of 16219.5 N in 150°C, which represents only 44% of its original strength. While ceramic-based cubes decreased to 57% of its former strength before increasing the temperature. Due to the cracks and crumbling of the jam and halva cubes, there were no sufficient cubes to perform the compressive strength test under variable temperatures, but it would have been of no use as both waters can never be used in concrete production because of their very low strength and sustainability that was realized among the 3, 7 and 28 days tests.

5 FEASIBILITY ANALYSIS

Water scarcity threat has been a global center of focus for many decades in areas with no fresh water access, unlike Egypt. However, this issue has been raised in Egypt from over 30 years ago coinciding with many Nile river countries building dams to secure its share from fresh water. Grand Ethiopian renaissance dam, commonly known as Al Nahda dam, which is expected to operate by July 2017 is one of the most critical issues facing Egyptians. This dam is forecasted to decrease Egypt's share by almost 8-10 Billion cubic meters of water, and almost 40% less effect on electricity production throughout the period to fill the tanks (Elbaradei, 2016). Water saving of 192 Liters per cubic meter of concrete including mixing and curing water is estimated if approved wastewater is utilized in concrete production.

5.1 Case Study – New Capital, Egypt:

According to the plans, the city would become the new administrative and financial capital of Egypt, housing the main government departments and ministries, as well as foreign embassies. On 700 square kilometers total area, it would have a population of five million people, though it is estimated that the figure could rise to seven million (BBC News, 2015).

The study is based on the construction of the infrastructure of this gigantic development, mainly water and power plants, roads and bridges, utilities and others. Data was obtained from many sources, mainly market studies and New Capital website. This assessment is based on certain assumptions. Needless to say, the validity of these assumptions is to be questioned and perhaps modified in the light of the project nature and other prevailing parameters.

Table 1: Estimated Water Savings from utilizing wastewater in concrete of New Capital Infrastructure

Concrete Quantity for Infrastructure	7,000,000 m^3
Water Saving per m^3	0.195 m^3
Total Water Saving	1.365 Million m^3

Results listed in table 1 reveal environmental aspect of utilizing approved wastewaters in concrete production of the new capital. Almost 1.5 Million cubic meters of fresh water are estimated to be saved for the 7Mm^3 of concrete needed. The water saved is enough to supply fresh drinking water for a 1 million people for 2 years.

6 CONCLUSION AND RECOMMENDATIONS

In the light of scope, types and dosages of materials investigated as well as other experimental parameters and variability associated with this work, the following key conclusions can be warranted:

a. The mortar mixtures incorporating wastewater from marble factory, stone-pit and ceramic factory yielded higher strength than control samples with about 42% difference, which suggests that these wastewaters can be used in concrete production.

b. The mortar mixtures incorporating wastewater from jam and halva factories' effluents significantly decreased the strength of mortar cubes to the extent that they only sustained about 4% of the force that control samples sustained, indicating that these two waters can never be used in concrete production.
c. The cubes prepared with the potatoes factory wastewater sustained a maximum force of about 92% of the force sustained by the control samples, which, according to literature and previous researches, falls within permissible ranges (90% - 100%).
d. Ceramic wastewater cubes had the highest rate of strength development among all other cubes, followed by ice-cream wastewater cubes
e. With elevated temperatures, control samples hardened and sustained more load, while all cubes prepared with different wastewaters sustained less loads except for the stone-pit cubes that increased with temperature but with a slightly less rate than that of the control samples.
f. With water scarcity in Egypt and elsewhere, utilizing approved wastewater in production of concrete will contribute to efforts exerted in minimizing water consumption.

For further researches, it is recommended that the waters used in this project undergo a complete chemical analysis to be able to figure out their composition so that we can interpret why those results presented in this were achieved. Further durability experimentation shall be carried out to test concrete life expectancy and decide on limitations.

ACKNOWLEDGEMENTS

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