Effect of Using Stone Cutting Waste on the Compression Strength and Slump Characteristics of Concrete

Kamel K. Alzboon and Khalid N. Mahasneh

Abstract—The aim of this work is to study the possible use of stone cutting sludge waste in concrete production, which would reduce both the environmental impact and the production cost. Slurry sludge was used as a source of water in concrete production, which was obtained from Samara factory/Jordan. The physico-chemical and mineralogical characterization of the sludge was carried out to identify the major components and to compare it with the typical sand used to produce concrete. Samples analysis showed that 96% of slurry sludge volume is water, so it should be considered as an important source of water. Results indicated that the use of slurry sludge as water source in concrete production has insignificant effect on compression strength, while it has a sharp effect on the slump values. Using slurry sludge with a percentage of 25% of the total water content obtained successful concrete samples regarding slump and compression tests. To clarify slurry sludge, settling process can be used to remove the suspended solid. A settling period of 30 min. obtained 99% removal efficiency. The clarified water is suitable for using in concrete mixes, which reduce water consumption, conserve water resources, increase the profit, reduce operation cost and save the environment. Additionally, the dry sludge could be used in the mix design instead of the fine materials with sizes < 160 μm. This application could conserve the natural materials and solve the environmental and economical problem caused by sludge accumulation.

Keywords—Concrete, recycle, sludge, slurry waste, stone cutting waste, waste.

I. INTRODUCTION

The high consumption of raw materials by the construction sector, results in chronic shortage of building materials and the associated environmental damage. Concrete industry is particularly important as it is not only responsible for consuming natural resources and energy but also for its capacity of absorbing other industries waste and by-products [1]. For this reason, the civil and environmental engineers have been challenged to convert the industrial wastes to useful building and construction materials [2]. In recent years the construction industry has shown considerable interest in the utilization of waste [3].

To create products made of stone, the shape of the stone must be decorated through cutting, shaping, and finishing, which can release dust and slurry sludge. The generated sludge from cutting stones factories is prohibited from being discharged to the public sanitary system [4]. Currently, these factories hold the generated sludge in open or closed basins for two or three weeks based on the quantity of sludge and the volume of basins. During the holding period, the sludge losses significant amount of water by evaporation especially during hot season. At the same time, the suspended particles will settle and condense at the bottom of the basin, which increases its density. The contents of settling basins eventually have to be transported by trucks and disposed off in a sanitary landfill.

The sludge produced through the cutting and working of stone is still considered an inert waste product. Once it has satisfied the required criteria for acceptance, it is given to authorized waste dump [5]. This sludge causes many economical and environmental problems such as increase cost of waste storage, and transportation, disposal and production cost. In addition, sludge affects the aesthetic and cause conflict with environmental authorities and pressure groups.

The high cost of water and the environmental problems associated with slurry disposal has motivated the studies and researches to reduce economic losses as well as environmental impact.

As a result of environmental and economical parameters, recycling sludge is the focus point of several ongoing researches.

Reference [6] used textile effluent treatment plant sludge in many building materials such as hollow bricks, solid bricks, cement concrete flooring tiles and pavement blocks.

Reference [7] investigated the possibility of producing bricks from dried sludge and they found that the sludge proportion and the firing temperature were the two key factors determining the brick quality.

When the wastes are employed in addition to cement and in partial substitution of aggregates, up to 30% can be used to provide mortars of higher physical and mechanical properties than the reference ones [8].

Reference [9] found that waste sludge up to 9% could effectively be used as an additive material in cement. Stone slurry was used for production of clinker, mosaic tiles, faïences and in asphalt mixtures as a commercial filler substitute [1], [7], [8], [10]. Reference [11] studied the change in concrete properties when dry sludge from a sewage treatment plant was added, and they found that up to 10% of treatment plant sludge can be added to concrete for use in certain very specific applications.

Other researchers studied the possibility of using sludge generated from municipal wastewater treatment plant for producing clay bricks. They obtained good results concerning strength and water absorption but the main problem was the...
presence of biodegradable material in the sludge, which may cause voids, and weight loss in bricks [12]-[15].

Reference [16] has shown that the physico-chemical characteristics of granite sludge match well the requirements needed in brick and roof tile formulations. Thus, their incorporation results in negligible changes in the properties of the final products [17]. Menezes et al. have extensively reported the production of bricks and tiles using granite sludge [ Cited in 17].

Water represents about 8% of the total volume of the concrete mix, so water is considered as one of the major components of the production. This water is supplied by private tanks with an average cost of $ 6/m³ in Jordan. Due to the high inflation rate and the increase in fuel price, the cost of water increased which reflected on the operation cost and decreased the profit. For this reason, this study aims to evaluate an alternative final destination for the growing production of sludge from stone cutting production. The proposed procedure includes recycling the slurry sludge and using it as a source of water in concrete production. The slurry sludge contain high quantity of water, so reuse process will reduce cost of production, clean the environment, and reduce water demand.

II. METHODOLOGY

A. Sampling

Sludge samples were taken from the slurry stream in Samara factory located in Irbid governorate/Jordan. This factory uses water for stones and marbles cutting, marble finishing and for public uses. The average water consumption is about 80 m³/week. The cost is in continuous increase and it is estimated about $ 480 /week.

Sludge is produced from stones cutting and granite, and polishing of marbles. The amount of the generated sludge is variable and depends on the active operations. In average, about 50m³ of sludge is produced weekly. There are 10 sludge storage basins with average volume of 8 m³ of each one. Some of these basins are useless as a result of accumulation and consolidation of sludge for a long time. Sludge is stored in these basins for many days and then it is transported to the disposal site at Al-Akadira area. The cost of sludge transport is estimated to be about $400 /week. Samples of slurry sludge were taken and used a source of water in concrete production. Concrete mixes were designed and fabricated in Irbid ready mix concrete company/Jordan.

B. Sludge Characteristics

In order to clarify the influence of the incorporation of stone cutting sludge as a raw material for concrete production, samples of sludge were collected and analyzed to determine sludge characteristics. Theses include: water content, size distribution, density, total suspended solid (TSS), total volatile solid (TVS), silica oxide (SiO₂), calcium oxide (CaO), aluminum oxide (Al₂O₃), ferric oxide (Fe₂O₃), magnesium oxide (MgO), chloride (Cl), potassium oxide (K₂O), phosphorus oxide (PO₃), sodium ratio (SR), aluminum ratio (AR), lime saturation factor and lost on ignition (LOI).

Standard method was used to determine water content, total solid, density of sludge and the total volatile solid [18]. Other chemical components have been determined by X-ray diffraction method. Analyses of chemical compositions of the sludge were repeated three times at three different laboratories. The other characteristics were conducted for 8 samples.

C. Fabrication of Concrete Samples

In order to exclude the effect of used materials on the results, proportions of aggregate, sand, cement and admixture (additives) were taken as a constant. Theses proportions were examined according to the Jordanian standards and recommended as a successful mix design for concrete class 25 (250kg/cm²). The proportions of the mix design constituents are illustrated in Table I.

To determine the best sludge - water ratio, the slurry sludge was mixed with clean water with different ratios as illustrated in Table II. The mixture of clean water and slurry sludge was gradually added to the dry components of the mix. Mechanical mixer ith capacity of 0.03 m³ was used to produceomogenous mixture, which can be achieved after seven min. of mixing process.

After completion of mixing, slump test was carried out for each mixing ratio at two different times (10 and 30 min.). The concrete producer is responsible for the concrete slump as specified for a period of 30 min. after the requested time or the time the truck arrives at the placement site which ever is later [19]. For this reason, the slump test was conducted after 30 min. Slump cone have a height of 30cm, a bottom diameter of 20cm and an upper diameter of 10cm was used. The standards also state, that when the cone is removed, it should be lifted up vertically, without any rotational movement at all and sure that the concrete sample does not move [19]. Wait for the

<table>
<thead>
<tr>
<th>Component</th>
<th>Coarse Gravel</th>
<th>Medium</th>
<th>Fine</th>
<th>Silica</th>
<th>Cement</th>
<th>Water</th>
<th>Admixture Chemicals</th>
<th>Total kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight kg/m³</td>
<td>510</td>
<td>510</td>
<td>195</td>
<td>710</td>
<td>260</td>
<td>190</td>
<td>7</td>
<td>2382</td>
</tr>
<tr>
<td>Weight (kg/trial mix) (0.03m³)</td>
<td>15.3</td>
<td>15.3</td>
<td>5.85</td>
<td>21.3</td>
<td>7.8</td>
<td>5.7</td>
<td>0.21</td>
<td>71.46</td>
</tr>
<tr>
<td>Ratio (%)</td>
<td>21.4</td>
<td>21.4</td>
<td>8.2</td>
<td>29.8</td>
<td>10.9</td>
<td>7.9</td>
<td>0.3</td>
<td>100</td>
</tr>
</tbody>
</table>

TABLE II

<table>
<thead>
<tr>
<th>Sample Label</th>
<th>Amount used in the trial mix, (kg)</th>
<th>Slurry sludge/total water ratio of, (%)</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁</td>
<td>0</td>
<td>5.7</td>
<td>5.7</td>
</tr>
<tr>
<td>T₂</td>
<td>1.425</td>
<td>4.275</td>
<td>5.7</td>
</tr>
<tr>
<td>T₃</td>
<td>2.85</td>
<td>2.85</td>
<td>5.7</td>
</tr>
<tr>
<td>T₄</td>
<td>4.275</td>
<td>1.425</td>
<td>5.7</td>
</tr>
<tr>
<td>T₅</td>
<td>5.7</td>
<td>0</td>
<td>5.7</td>
</tr>
</tbody>
</table>
concrete mixture as it slowly slumps. After the concrete stabilizes, the slump-height of the slumped cone of concrete was measured by using a ruler.

For compression test, samples were taken in a steel mould with internal dimensions of 150*150*150mm. The mould was filled in three approximately equal layers (50 mm deep). A bar was provided to compact the concrete. About 25 strokes per layer were applied to produce the required compaction. After the top layer has been compacted, a trowel was used to finish off the surface level with the top of the mould, and the outside of the mould was wiped clean.

Samples were labeled as T1, T2, T3, and T4 which refer to the ratio of slurry sludge to the total amount of water (100%, 75%, 50%, 25% respectively), while T8 refers to the reference sample (clean water). Samples were left for 24 hours for drying and then they put in the storage tank and merged by water for 28 days. This production and curing procedure comply with Jordanian standards JS96/87 [19]. Twenty four samples of concrete were taken for each mixing ratio. After incurring period, the samples were sent to the material laboratory and tested for compression strength. The 7 –days test may help in detect potential problems with concrete mixing. The 7 –days test may help in detect potential problems with concrete mixing and testing procedure at the lab, but is not a basis for rejection concrete samples. A 28 days test is the main that use a basis of rejection or acceptance [19].

The dry compressive strength of samples was determined by using a calibrated compression test machine (Matest®) with a maximum capacity of 2000 kN and loading it at a uniform slow rate.

### Table III

<table>
<thead>
<tr>
<th>Sample Lable</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Settling time, (min.)</td>
<td>0</td>
<td>30</td>
<td>60</td>
<td>90</td>
<td>0</td>
</tr>
<tr>
<td>Concentration of suspended (mg/l)</td>
<td>21000</td>
<td>205</td>
<td>170</td>
<td>135</td>
<td>20</td>
</tr>
<tr>
<td>Reduction in solids concentration,%</td>
<td>0</td>
<td>99</td>
<td>99.2</td>
<td>99.4</td>
<td>0</td>
</tr>
<tr>
<td>Weight of suspended solid in the mix (kg/m3)**</td>
<td>3.99</td>
<td>0.039</td>
<td>0.032</td>
<td>0.025</td>
<td>0.004</td>
</tr>
<tr>
<td>Ratio of suspended solid in the mix (%)*</td>
<td>1.7*</td>
<td>10^3</td>
<td>1.6*</td>
<td>10^3</td>
<td>1.3*</td>
</tr>
</tbody>
</table>

** (concentration *190 liters of water /mix)

### D. Improvement of Sludge Quality

In order to decrease the concentration of suspended solid in the slurry sludge, the slurry sample was taken and put in three settling basins for 90 min. The primary function of the sedimentation process is the removal of settleable suspended solid to produce clarified water (supernatant). During settling period, the suspended particles flocculate, settle and accumulate in the bottom of the basin. Before settling, initial sample was taken, and used in the production of concrete samples labeled as M1. After 30 min., a sample was taken from the supernatant water of the first basin and used in the production of concrete samples labeled M2. After 60 and 90 min., samples were taken from the second and the third basin and used in the production of concrete samples of M3 and M4 respectively. Samples of M8 refer to the reference sample (clean water) as illustrated in Table III. This experiment aims to find the effect of settling process on the concentration of suspended particles and subsequently on concrete characteristics. These samples were produced, incurred and tested similarly as the conventional samples.

### III. RESULTS AND DISCUSSIONS

#### A. Characteristics of Sludge

1) Physical and Chemical Characteristics

Table IV illustrates the average physical and chemical characteristics of sludge samples generated from the stone cutting process. The result of analyses was compared with other studies’ results. It was found that there was a great compositional difference in sludge derived from different cutting processes. This variation in the mineralogical and chemical composition of the sludge was attributed to the variation in the type and origin of rocks [5].

Water contents in the slurry samples ranges from 95.1-99.4%, so that sludge is considered as a significant source of water. Sludge contains high quantity of calcium oxide (54.22%) while undetectable limit of K2O, Cl were found. In addition, small amount of silica, ferric oxide, aluminum oxide and volatile solid were detected. The high content of CaO confirmed that the original stones were marble and limestone [1].

#### B. Size distribution of Sludge

In order to determine the sludge particles distribution, 32 sieves with diameter ranges from 0.5 μm to 300 μm were used. Fig. 1 shows the sieve analysis of the dried sludge and the differential particle size distribution. The average particle size, D50, was about 9.06 μm, while D10, D16, D84 and D90 were about 1.31μm, 1.8 μm, 30 μm and 37.69 μm, respectively. The largest measured particle size is approximately 160 μm. Reference [10], found that the maximum size was 363.1 μm.
in contrast to [2], found that 99.76%, of limestone dust has a particle size less than 1.18mm.

In order to select the best gradation of aggregates, the company evaluated the result of many trial mixes, and the best gradation was chosen as shown in Fig. 2.

Results of particle size analysis indicated that around 4.38% of the aggregate volume has a particle size less than the maximum size of sludge particles (160µm). From the point view of material distribution, the sludge is suitable as a fine material for being directly incorporated into concrete production. If the slurry sludge is used instead of water, the total amount of sludge solid particles in the mix is 5.7 kg/m³, which is far below the amount of fine sand which has the same size of sludge particles (4.38% =104kg).

Concrete producers prefer to produce concrete with slump value >14 cm after 30 min. to avoid concrete hardening during transportation and waiting at site. Results indicated that the 30 min. slump values decreased as the sludge ratio in the mix increased. In addition, the reduction in slump value (between 10 and 30 min.) increased as the sludge ratio increased as shown in Table V, and Fig. 3. Regarding higher contents of stone slurry (substitution of more than 25% of water), the decrease of slump values was significant. For this reason the trial samples of T1, T2 and T3 were considered as failed samples because the final slump value (after 30 min.) was very low and additional reduction during transportation and waiting is expected. T4 samples have a good 30 min. slump and could be recommended for use in the ready mix concrete. The failure of samplesT1, T2 and T3 in achieving the required slump value was attributed to the presence of fine material in these samples which increases the surface area, increase the contact area between cement and these materials, so additional water amount is required to lubricate the components and lead in decreasing the slump values.

Table VI shows the results of the compression strength values for all samples. The obtained results were compared with Jordanian standards for concrete class 25 (25N/mm²).

Results show that the compression strengths of all samples were complying with the standard. In comparison with the reference sample (TR), there was insignificant variation in compression strength values of all samples as shown in Figure 4. This result was attributed to the fact that the suspended particles represent less than 3% of the slurry sludge volume. Based on component proportions listed in Table 2, only 5.7, 4.27, 2.85, 1.42 liters of suspended solid (in a form of slurry) were added to the mixes of samples labeled as T1, T2, T3 and T4 respectively, so limited change in components proportions occurs. Reference [1] found a similar result where the using of low contents of stone slurry (substitution of less than 20% of sand), result in insignificant reduction of compressive strength values. Samples with higher slurry proportions obtained higher 7 days compression strength compared with the reference sample, while T4 obtained the higher value at 28 days.
The fine materials of sludge fill the voids between aggregates, and due their high surface area, it could enhance the chemical reaction between cement and other components. Furthermore, by acting as micro-filler, the stone slurry promoted an accelerated formation of hydrated compounds, thus resulting in a significant improvement of compressive strength especially at 7 days results [1]. Moreover, the slurry particles completed the matrix interstices (transition zone and capillary pores) and reduced space for free water [1]. The combination of these reasons may resulted in a better bonding among the concrete components and explain the high strength of these samples [1]. The density of slurry sludge is slightly higher than the water density (1044 kg/m³), so there was insignificant variation in concert density for different samples where the measured values ranged from 2350-2380 kg/m³. In addition to the effect of used materials, density is affected by degree of compaction.

Table VI: Compression for the Fabricated Concrete Samples

<table>
<thead>
<tr>
<th>Sample Label</th>
<th>Ratio of Slurry Sludge to the Total Water Content (%)</th>
<th>Result after 7 days (kg/m³)</th>
<th>Result after 28 days (kg/m³)</th>
<th>Relative Strength to TR (28 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>100</td>
<td>238</td>
<td>237</td>
<td>98%</td>
</tr>
<tr>
<td>T2</td>
<td>75</td>
<td>234</td>
<td>233</td>
<td>95%</td>
</tr>
<tr>
<td>T3</td>
<td>100</td>
<td>240</td>
<td>239</td>
<td>99%</td>
</tr>
<tr>
<td>T4</td>
<td>25</td>
<td>234</td>
<td>239</td>
<td>100%</td>
</tr>
<tr>
<td>T5</td>
<td>0</td>
<td>234</td>
<td>238</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table VII: Result of Slump Tests for the Modified Samples

<table>
<thead>
<tr>
<th>Sample Label</th>
<th>Slump after 10 min. (cm)</th>
<th>Slump after 30 min. (cm)</th>
<th>Reduction in Slump (cm)</th>
<th>% of Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>238</td>
<td>236</td>
<td>25</td>
<td>53</td>
</tr>
<tr>
<td>M2</td>
<td>220</td>
<td>18</td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>M3</td>
<td>234</td>
<td>18</td>
<td>6</td>
<td>23</td>
</tr>
<tr>
<td>M4</td>
<td>238</td>
<td>18</td>
<td>6</td>
<td>23</td>
</tr>
</tbody>
</table>

2) Compression Strength

Table VIII illustrates the average compression strength for the modified samples. The compression strength of all tested samples complies with Jordanian standards for concrete class 25. There was insignificant variation in compression strength values of all samples as shown in Figure 6.

Results indicated that the slurry sludge could be added to the mix as a source of water. This method may be applied by separation of the suspended solid from the slurry sludge through settling process. In addition, the dry sludge could be used in the mix design instead of the fine materials with sizes < 160 μm. This application will conserves the natural materials and solve the environmental and economical problem caused by sludge accumulation.
products. Absorbing the stone cutting sludge and reuse it in their compression strength. Concrete companies capable in to use in concrete, and obtains adequate slump and settling process. After settling, the produced water is suitable (suspended solid) could successfully be removed by physical production of concrete. The fine materials in slurry sludge of 25% of the total volume of water be possible in the slurry sludge generating from stone cutting up to a maximum values.

Compression strength (kg/cm

This research work shows that the sludge generated from the stone cutting processes can be regarded as a source of water used in concrete mixes. Results indicated that the using of slurry sludge as a source of water in concrete production has insignificant effect on compression strength, while it has a sharp effect on the slump values.

From this study, it is possible to conclude that the use of slurry sludge generating from stone cutting up to a maximum of 25% of the total volume of water be possible in the production of concrete. The fine materials in slurry sludge (suspended solid) could successfully be removed by physical settling process. After settling, the produced water is suitable to use in concrete, and obtains adequate slump and compression strength. Concrete companies capable in absorbing the stone cutting sludge and reuse it in their products.

IV. CONCLUSIONS AND RECOMMENDATIONS

This research work shows that the sludge generated from the stone cutting processes can be regarded as a source of water used in concrete mixes. Results indicated that the using of slurry sludge as a source of water in concrete production has insignificant effect on compression strength, while it has a sharp effect on the slump values.

From this study, it is possible to conclude that the use of slurry sludge generating from stone cutting up to a maximum of 25% of the total volume of water be possible in the production of concrete. The fine materials in slurry sludge (suspended solid) could successfully be removed by physical settling process. After settling, the produced water is suitable to use in concrete, and obtains adequate slump and compression strength. Concrete companies capable in absorbing the stone cutting sludge and reuse it in their products.

REFERENCES