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

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***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 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 recourses, 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, faiences 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

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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/m^3 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 process. The proposed procedure includes recycling the slurry sludge and using it as a source of water in concert 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 m^3/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 50m^3 of sludge is produced weekly. There are 10 sludge storage basins with average volume of 8 m^3 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-Akadir 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 (SiO_2), calcium oxide (CaO), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), magnesium oxide (MgO), chloride (Cl), potassium oxide (K_2O), phosphorus oxide (SO_3), 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/cm^2). 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 m^3 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 I
MIXTURE PROPORTIONS OF DESIGN MIX.

Component	Coarse Gravel	Medium	Fine	Silica	Cement	Water	Admixture chemicals	Total kg
Weight kg/m^3	510	510	195	710	260	190	7	2382
Weight (kg/trial mix) (0.03m^3)	15.3	15.3	5.85	21.3	7.8	5.7	0.21	71.46
Ratio (%)	21.4	21.4	8.2	29.8	10.9	7.9	0.3	100

TABLE II
Slurry sludge proportions IN THE TESTED SAMPLES

Sample Label	Amount used in the trial mix, (kg)			Slurry sludge/ total water Ratio of, (%)	Number of samples
	clean water	slurry sludge	Total water		
T_1	0	5.7	5.7	100	24
T_2	1.425	4.275	5.7	75	24
T_3	2.85	2.85	5.7	50	24
T_4	4.275	1.425	5.7	25	24
T_R	5.7	0	5.7	0	24

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 T_1, T_2, T_3, and T_4 which refer to the ratio of slurry sludge to the total amount of water (100%, 75%, 50%, 25% respectively), while T_R 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 quality or 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
SPECIFICATION OF THE MODIFIED SAMPLES

Sample Lable	M_1	M_2	M_3	M_4	M_R
Settling time, (min.)	0	30	60	90	0
Concentration of suspended ,(mg/l)	21000	205	170	135	20
Reduction in solids concentration,%	0	99	99.2	99.4	0
Weight of suspended solid in the mix (kg/m3)*	3.99	0.039	0.032	0.025	0.004
Ratio of suspended solid in the mix (%)**	$1.7*10^{-3}$	$1.6*10^{-5}$	$1.3*10^{-5}$	$1.0*10^{-5}$	$1.6*10^{-6}$

*= (concentration *190 liters of water /mix)
**= (concentration *190 liters of water /mix)/total weight of 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 M_1. After 30 min., a sample was taken from the supernatant water of the first basin and used in the production of concrete samples labeled M_2. After 60 and 90 min., samples were taken from the second and the third basin and used in the production of concrete samples of M_3 and M_4 respectively. Samples of M_R 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 K_2O, 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].

TABLE IV
CHEMICAL AND PHYSICAL PROPERTIES OF THE STONE CUTTING SLUDGE

Parameter	Unit	*Current work*	Torres, *,et. al.* (2004) (Granite sludge)	Turgut, *,et. al.* (2007 (Limestone dust)	Ferreira, *,et. al.* (2004) (Granite sludge)
Water content (slurry)	% by wt	97.3	*	*	*
TS (slurry)	Mg/l	17000	*	*	*
TDS (slurry)	Mg/l	950	*	*	*
TVS (slurry)	Mg/l	0.3	*	*	*
SiO_2	% wt	0.83	71.65	0.26	61.2
CaO	% wt	54.22	1.83	56.19	6.6
Al_2O_3	% wt	0.21	14.25	0.25	12.4
Fe_2O_3	% wt	0.11	2.86	0.3	12.4
MgO	% wt	0.91	0.86	0	0.9
K_2O	% wt	0	4.43	0	4.1
Cl	% wt	0	*	*	*
SO_3	% wt	0.11	*	0	*
LSF	---	2064.34	*	*	*
SR	---	2.53	*	*	*
AR	---	1.88	*	*	*
LOI (%)		43.6	*	42.56	0.68

* Not detected

2) 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, D_{50}, was about 9.06 µm, while D_{10}, D_{16}, D_{84} and D_{90} 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/m^3, which is far below the amount of fine sand which has the same size of sludge particles (4.38% =104kg).

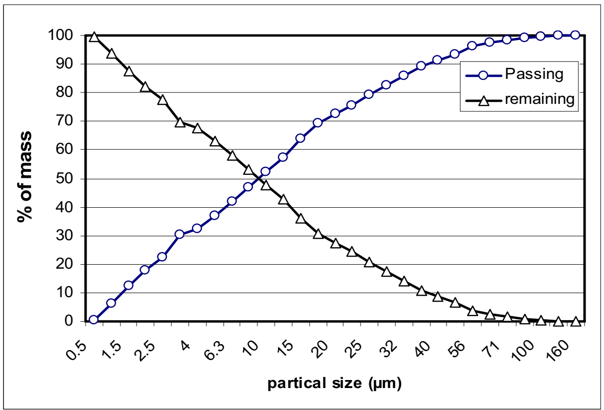

Fig. 1 Particle size distribution of the sludge

B. *Specifications of the Fabricated Concrete Samples*

1) Slump test

The goal of the slump test is to measure the consistency of concrete. Concrete should be sufficiently workable so that it can be compacted to the maximum density. The main factors affecting the workability are water and additives contents of the mix. Water in concrete mix lubricates the surface of aggregates and thus reduces the internal friction resulting in improved workability [9].

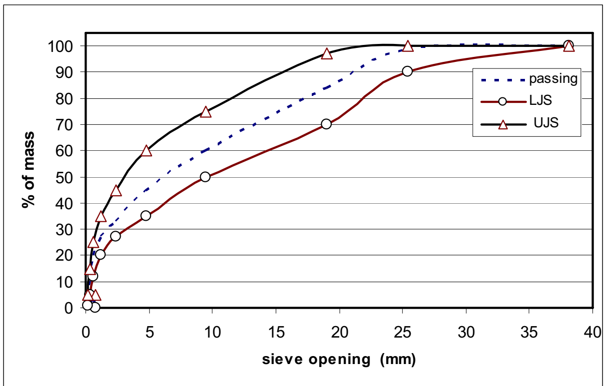

Fig. 2 Particle size distribution of the aggregate in the mix design,: Js : LJS, UJS lower and upper limit of Jordanian standards

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 V
RESULT OF CONCRETE SLUMP TESTS

Sample Label	Slump after 10 min. (cm)	Slump after 30 min. (cm)	reduction in slump (cm)	% of reduction
T1	19.5	8	11.5	59
T2	20	10	10	50
T3	21	12	9	43
T4	22	16	6	27
TR	22	16.5	5.5	25

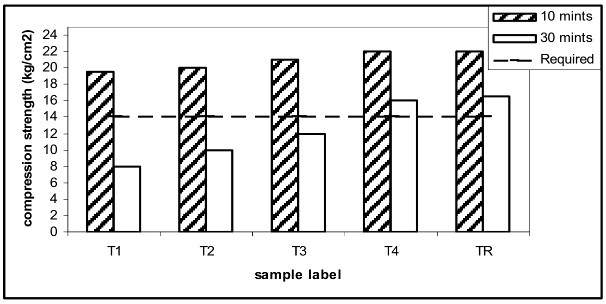

Fig. 3. Slump test result

2) Compression Strength Test

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/mm^2).

Results show that the compression strengths of all samples were complying with the standard. In comparison with the reference sample (T_R), 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 sludge) were added to the mixes of samples labeled as T_1, T_2 T_3 and T_4 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.

TABLE VI
COMPRESSION FOR THE FABRICATED CONCRETE SAMPLES

Sample Label	Ratio of slurry sludge to the total water content (%)	Result after 7 days (kg/m^3)		Result after 28 days (kg/m^3)		Relative strength to T_R (28 days)
		compression	density	compression	density	
T_1	100	245	2400	270.6	2380	98%
T_2	75	244	2390	273.7	2376	99%
T_3	50	241	2380	279.2	2380	101%
T_4	25	234.	2385	301.8	2380	109%
T_R	0	234	2380	276.9	2377	100%

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/m^3), 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.

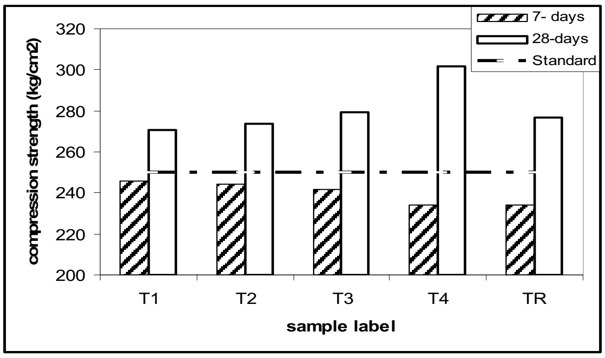

Fig. 4. Compression values of the tested samples

C. Specifications of the Modified Concrete Samples

1) A. Slump Test

Modified concrete samples were fabricated in order to improve the components of mixture by excluding the fine materials in the slurry sludge.

All fabricated samples have good slump values and comply with the company requirement for ready mix concrete as illustrated in Table 7. Result indicated that the 30 min. slump values for all modified samples (M_2, M_3, M_4) were >14cm, which maintains a good workability when the vehicles arrives the pouring sites. In contrast, the slump value of samples M_1 (without settling) decreased to 8 cm which is far blew the required workability level. There was insignificant variation in slump values for all modified samples and the reference one as shown in Figure 5. Due to the advantage of settling process, concentrations of suspended particles in water, which used in theses samples, were very low (<205 mg/l). Based on this result it is recommended to use slurry sludge after settling period of 30 min. as a source of water in concrete production.

TABLE VII
RESULT OF SLUMP TESTS FOR THE MODIFIED SAMPLES

Sample Lapel	Slump after 10 min. (cm)	Slump after 30 min. (cm)	reduction in slump (cm)	% of reduction
M_1	19	9	11.5	53
M_2	22	16.5	5.5	25
M_3	22.5	17	5.5	24
M_4	23.5	18	5.5	23
M_R	23.5	18	5.5	23

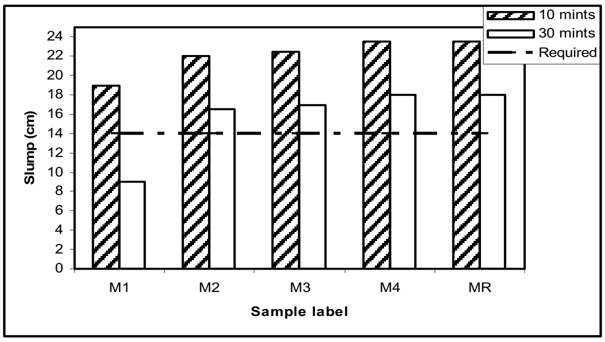

Fig. 5 Slump Test result for the modified samples.

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.

TABLE VIII
COMPRESSION AND DENSITY OF THE MODIFIED CONCRETE SAMPLES

Sample Label	Result after 3 days		Result after 28** days (kg/m^3)		Relative strength compare with M_R (28 days)
	Comp-ression	Density	Comp-ression	Density	
M_1	238	2362	268	2354	96.7%
M_2	228	2371	279	2364	100.3%
M_3	226	2379	276	2372	98.5%
M_4	230	2365	276	2360	98.7%
M_R	231	2370	280	2367	100

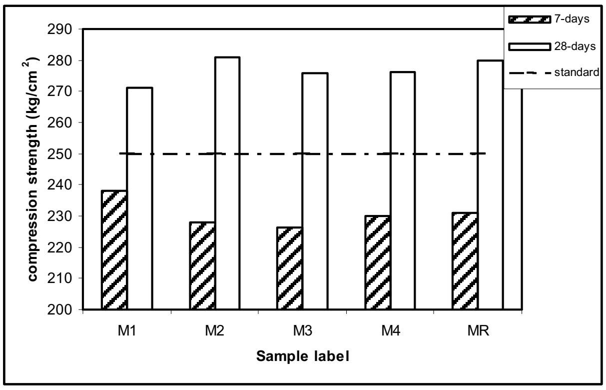

Fig. 6 Compression strength of the modified samples Jordanian standard for 28-days compression strength

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

[1] Almeida Nuno, Branco Fernando, Santos José Roberto, 2007, Recycling of stone slurry in industrial activities: Application to concrete mixtures, Building and Environment, 42(2): 810-819.

[2] Turgut, P. and Algin, H.M., 2007. Limestone dust and wood sawdust as brick material. Building and Environment Journal, 42 (9): 3399-3403.

[3] Connan, H., Klimesch, D., Rayt, A., and Thomas, P., 2005, Autoclaved opc-quartz blends incorporating clay-brick waste. part i: factorial design effects on strength development, Advances in Cement Research, 17(4):133-141.

[4] Ammary, B., 2007. Clean cutting stone industry. International Journal of Environment and Waste Management, 1 (2/3): 106-112.

[5] Colombo A. , Tunesi A., Barberini V., Galimberti L., Cavallo A., chemical and mineralogical characterization of cutting process sludge , exploitation of sludge from stone working synthesis of the research., accessed 2008,http://www.aigt.ch/ download/ rapporto_INTERREG-en.pdf .

[6] Balasubramanian J., Sabumon C., john U. Lazar ,And ilangovan R.,1995, Reuse of textile effluent treatment plant sludge in building materials, journal of materials processing technology 48 (1-4) : 379–384.

[7] Weng, C., Lin, D. and Chiang, P., 2003. Utilization of sludge as brick materials. Advances in Environmental Research, 7 (3): 679-685

[8] Colangelo F., Marroccoli M., and Cioffi R., Properties of self-leveling concrete made with industrial wastes. Conference on use of building materials in building structures, November,2004, Barcelona , Spain

[9] Arslan E. I Il , Aslan Sibel, Ipek Ubeyde, Altun Samet, Yazicio lu Salih, 2005, Physico-chemical treatment of marble processing wastewater and the recycling of its sludge, Waste Management & Research, 23(6): 550-559.

[10] Misra A., Gupta R., Gupta R.C., Utilization of marble slurry in construction materials, Workshop on gainful utilization of marble slurry and other stone waste, Indian School of Mines, accessed 2008, http://www.cdosindia.com/papers/marble_slurry_ workshop/anurag_ mishra _-_utilisation_of _marble_slurry _in_ construction .doc.

[11] Valls, S., Yagüe, A., Vázquez, E. and Mariscal, C.,2004. Physical and mechanical properties of concrete with added dry sludge from a sewage treatment plant. Cement and Concrete Research, 34 (12): 2203-2208.

[12] Abdul, G. L., Azni, I., Abdul, A. S., Calvin, H.K.W., Mohd, S. J. and Aminuddin M. B., 2004. Reusability of sewage sludge in clay bricks. Journal of Material Cycles and Waste Management, 6(1):141-47.

[13] Lin, D. and Weng, C., 2001. Use of sewage sludge ash as brick material. Journal Env. Eng., 127 (10): 922-927.

[14] Slim, J.A., Wakefield, R.W., 1991. The utilization of sewage sludge in the manufacture of clay bricks. Water SA WA SA DV, 17 (3): 197-202.

[15] Tay, Jh., 1986. Potential use of sludge ash as construction material. Resources and Conservation, 13(1): 53-58.

[16] Ferreira, J.M.F., Torres, P.M.C., Silva, M.S. and Labrincha J.A., 2004. Recycling of granite sludge in brick-type and floor tile-type ceramic formulation. Journal of the European Ceramic Society, 24 (10-11): 3177-3185.

[17] Torres, P., Fernandes, H.R., Agathopoulos, S., Tulyaganov, D.U. and Ferreira, J. M. F., 2004. Incorporation of granite cutting sludge in industrial porcelain tile formulations, Journal of the European Ceramic Society, 24 (10-11):3177-3185.

[18] APHA, 1998, Standard Methods for the Examination of Water and Wastewater, 20th ed. Washington, D.C: American Public Health Ass., WPCF, and AWWA.

[19] MPWH, Ministry of Public Works and Housing of Jordan, 1985, Specifications of the architectural and civil works, 1st edition, Amman, Jordan.