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Influence of Low and High Organic Wastewater Sludge on Physical and Mechanical Properties of Concrete Mixes

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ABSTRACT

The present study is aimed at obtaining the influence of low and high organic wastewater sludge on physical mechanical properties of concrete mixes. A laboratory-testing program was carried out on concrete mixes having several ratios of low and high organic sludge with respect to cement content, including no sludge mix as reference mix. The low organic sludge represents the exposed sludge to the sun for a long period of time, while the high organic sludge simulates the fresh sludge taken from the secondary pond surface. Due to the high sand content, the low organic sludge was utilized as an additive and as a sand replacement, while the high organic sludge was used only as an additive material. In all cases, four sludge contents of 0, 2.5, 5 and 10% by weight of cement were introduced to the concrete mixes. The effect of sludge particle size was also investigated in this study. Slump values, densities and compressive strengths were obtained for the non sludge and sludge concrete mixes. The high organic sludge was also utilized to produce interlock bricks as an example of non-structural elements. The densities, absorption capacities and compressive strengths of the sludge interlock bricks were presented. The results showed that a percentage of 5% low organic and high sludge by cement content could be used as an additive or as sand replacement (in case of low organic sludge) to concrete mix without causing a significant reduction in compressive strength. Adding high organic sludge to concrete mixes had a slight to moderate adverse effect on concrete compressive strength and mix workability.

Key words: Concrete mixes, waste water, low organic sludge, high organic sludge, interlock bricks, concrete compressive strength

INTRODUCTION

Gaza strip has a rapidly increasing population, compared to its limited land area, which generates larger quantities of waste in the society resulting in an adverse effect to environment and human. One of the waste aspects in the Gaza Strip is the wastewater sludge. The large volume of sludge produced and limited land area of Gaza strip sludge encourages finding new methods to dispose and/or use such high quantities of sludge (Nasser and Afifi, 2006; Shomar, 2005).

Recent studies explore the possibility of using sewage sludge as construction materials in order to identify new horizons to solve such problem (Al-Malack *et al.*, 2002; Yague *et al.*, 2005; Valls *et al.*, 2004; Monzo *et al.*, 2004; Mun, 2007; Malliou *et al.*, 2007; Chen and Lin, 2009). Yague *et al.* (2002) used dry sludge from waste water treatment plants as an additive to produce prefabricated concrete bricks. Non sludge concrete bricks and bricks containing 2% of dry sludge by cement weight were prepared. The results of density, porosity, absorption coefficient and compressive strength of the non sludge and sludge were obtained. They also suggested increasing the proportion of added sludge to reach values of the order of 4 or 5% and to study how the properties vary.

Valls *et al*. (2004) studied the physical and mechanical properties of concrete containing different percentages of dry sewage treatment plant sludge. They concluded that dry sludge could be used as an addition to concrete without the need for large changes in its preparation process. It is found that 10% sludge content is maximum content, which can be used in concrete, where lower contents gave better results.

Yague *et al*. (2005) evaluated the use of dry sludge as an additive for concrete. The concrete specimens were subjected to different types of accelerated attack in order to evaluate long-term performance and compare them with the reference concrete (not containing sludge). The performance of the concrete containing sludge was acceptable and comparable to the results obtained for the reference concrete not containing sludge.

Mun (2007) evaluated the feasibility of using large quantity of sewage sludge to make lightweight aggregates. Sintered lightweight aggregate from sewage sludge is experimentally manufactured with various mass ratios of clay to sewage sludge by a rotary kiln. He found out that the experimentally manufactured lightweight aggregate with a recommendable sewage sludge content is similar or superior in physical properties to the commercial sintered lightweight aggregate. In particular, the water absorption of the recommended lightweight aggregate is about half or less than that of the commercial sintered lightweight aggregate.

Malliou *et al*. (2007) used sludge from urban wastewater treatment plants to prepare several mixtures of sludge-cement-calcium chloride and calcium hydroxide. The results of this study showed that the use of wastewater sludge into construction material can be achievable. However, long term experiments of durability should be carried out before any final conclusions.

The aim of this study, which conducted at the department of civil Engineering, IU-Gaza in 2009, is to obtain the influence of low and high organic municipal wastewater sludge on physical an mechanical properties of concrete Mixes, which available in the Gaza Strip Waste water treatment plants. The low organic sludge contains also high sand content, while the high organic material has a low sand content. The low organic sludge was utilized as an additive and as a sand replacement, while the high organic sludge was used as an additive material only. The effect of sludge particle size was also investigated in this study. Slump values, densities and compressive strengths were obtained for the non sludge and sludge concrete mixes. The high organic sludge was also utilized to produce interlock bricks as an example of non-structural concrete elements. The densities, absorption capacities and compressive strengths of the sludge interlock bricks were presented.

MATERIALS AND METHODS

The current experimental program was conducted at the Materials and Soil Laboratory, Department of Civil Engineering at The Islamic University of Gaza from February to September 2009. All sludge samples (Type I and II) were passed through drying process at temperature 105±5°C before using in concrete mixes. The drying process facilitates the sludge handling and gives them a granulometry. In this study, the produced mixes represent the concrete produced by the Gaza Strip ready mixed concrete plants.

Characterization of gaza sewage sludge: The sludge samples, which used in all experiments, were obtained from Gaza wastewater treatment plants in the region of Gaza City, the Gaza Strip. The sludge produced in this plant is exposed to sun for a long period of time and then transferred to dumping sites (Nasser and Afifi, 2006; Shomar, 2005). The long period, which the sludge stayed in an aerobic condition, reduces the organic content due to decomposition of organic material (Howard *et al.*, 1984). The obtained samples were classified into two main Characterizations as shown in Table 1.

Type I is obtained from the sludge exposed to the sun for a long period of time and then accumulated and transferred to dumping sites. The organic material content (weight loss at 550°C) varied between 11 to 13%. The moisture content of sludge (weight loss at 105°C) ranges from 20 to 25%. ASTM C136 (2006) procedure was used to determine the sieve analysis of the applied wastewater sludge. Type II sludge samples were taken from the top surfaces of the secondary ponds where high organic content and low sand content are presented. The solid content of this type ranges from 25 to 30%, organic content varied between 51-53% and density of sludge particles was around 1 g cm^3. Figure 1 presents the grain size distribution of the sludge of Type I and II.

In the present study, Type I and II sludge were utilized as an additive to the concrete mix and while Type I sludge was used a sand replacement. According to sludge particles size, two forms of sludge particles were prepared; namely, (1) Sludge pellets having size larger than Gaza strip natural sand, which ranges from 600 to 850 μm. The pellets size ranges between 1.18 mm to 850 μm and (2) Sand-size sludge similar to the Gaza natural sand, passing sieve 850 μm.

Concrete mixing process: The ingredients of the non-sludge concrete mix (reference mix) and their proportions are given in Table 2. The reference mix is designed for a targeted compressive strength of 300 kg cm^{-2}. The mixing process of all concrete samples (with or without sludge) is carried out in a conventional blade-type mixer according to ASTM C192 (2007).

Table 1: Characterization of Gaza city wastewater sludge

Constituents	Type I	Type II
Solid content (%)	85-90	25-30
Organic content (%)	11-13	51-53
Moisture content (%)	20-25	
Sludge characterizations	Low organic with high sand materials	High organic with low sand materials

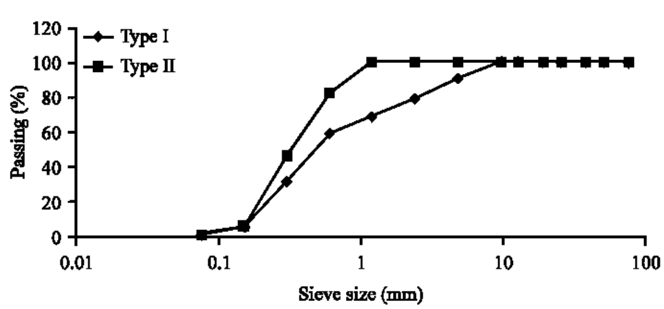

Fig. 1: Grain size distribution of Type I and II sludge

Table 2: Reference concrete mix proportions

Material description	Size/Type	Condition	Weight (kg m^3)	Volume (m^3)	Material source
Cement	Type I	Dry	310	0.0984	Nisher Type I, Silos
Coarse aggregate	25 mm	Dry	580	0.2164	Crushed Limestone
Coarse aggregate	19 mm	Dry	260	0.1004	Crushed Limestone
Coarse aggregate	10 mm	Dry	390	0.1548	Crushed Limestone
Fine sand	0.1-0.8 mm	Dry	650	0.2444	Gaza Dune sand
Free water	Tap	Liquid	167	0.167	Tab water
Additives	-	-	-	-	-
Air content	Air	Air		0.0186	-
Total			2357	1.00	-

The mixing process of the concrete mixes was carried out according to ASTM C 192 (2007). Coarse aggregate and some of the mixing water, which may involve admixture if required, was first added to the mixer. Fine aggregate, sludge (if present), cement and the remaining mixing water are then added to the operating mixer. With all ingredients in the mixer, mixing is last for about 3 min. The mixer is then stopped for 3 min and re-mixing is continued for another 2 min. Having done that, the concrete mix is ready for the subsequent steps (Kosmatka *et al*., 2002).

Testing program: The testing program comprises obtaining fresh properties by applying the slump test according to ASTM C143 (2010) and the compressive strength of all samples at 7, 28 and 90 days according to ASTM C192 (2007). The 90 days curing period was used as indication for long behavior of concrete strength. The 10×10×10 cm mould cubes were used to obtain the samples for compression testing and at least 3 cubes were considered for each test result. The density and absorption of non-sludge and sludge concrete samples were determined according to ASTEM C642 (2006).

When utilizing Type I and Type II sludge as an additive, concrete mixes having 0, 2.5, 5 and 10% of cement weight as dry sludge were prepared. Also, concrete mixes using Type I dry sludge to replace 0, 2.5, 5, 10 and 20% of the sand content were performed. The effect of sludge particle size on concrete properties was examined. The high organic sludge was also utilized to produce interlock bricks as an example of non-structural elements. The densities, absorption capacities and compressive strengths of the sludge interlock bricks were studied.

RESULTS AND DISCUSSION

Type I sludge (low organic materials and high sand content): Type I sludge was added to concrete mixes in two different ways. It was first applied as an additive to concrete mixes in four percentages; namely, 0, 2.5, 5 and 10% of total cement content. It was also used to partially replace sand content in five percentages 0, 2.5, 5, 10 and 20%. The influence of these sludge percentages on the slump value, concrete density and compressive strength are explained in Table 3-4 and Fig. 2-3, respectively.

Slump value: When sludge content in concrete is 5% or less, no significant change in slump was observed when the dry sludge is applied an additive or replacement of sand, while the slump was slightly enhanced in case of 2.5% sludge content. When the sludge content increased to 10% as an additive, the slump reduced to 2.0 cm. A reduction in slump was also observed when the replacement percents were more than 5%. The slump reached zero at replacement amount of 20%

Table 3: Slump value of concrete mixes with sludge as an additive and as sand replacement

Sludge as additive (%)	Slump (cm)	Sludge as sand replacement (%)	Slump (cm)
0	4	0	4
2.5	4.5	2.5	5
5	4.5	5	4
10	2.0	10	3.5
		20	0

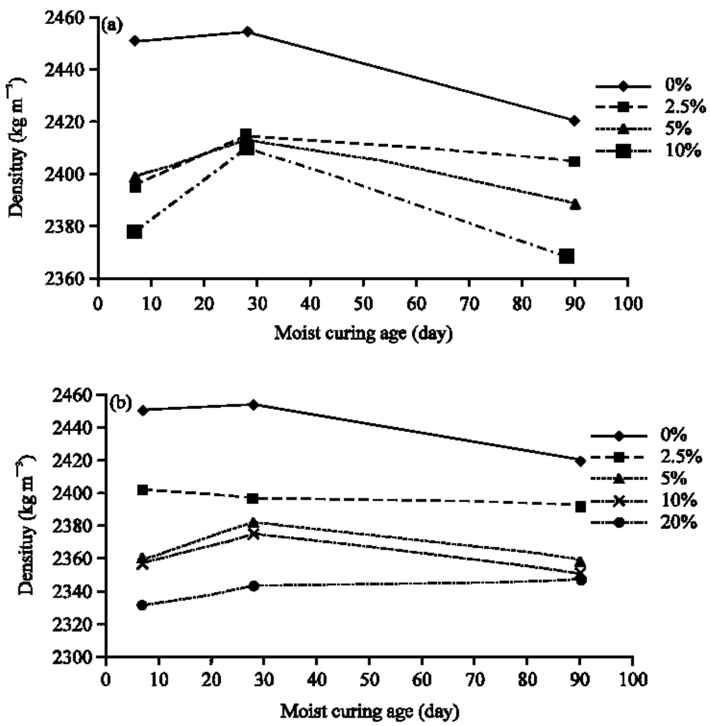

Fig. 2: Relation between density and curing age for sludge content as: (a) As an additive and (b) As a sand replacement

(Table 3). The reduction in slump as sludge content increased may be explained by the spongy surface of sludge particles with high absorption ability.

Density: The density of the tested mixes decreased as sludge content increased. This means that the weight of samples as the volume is constant decreases as sludge increases, whether used as an additive or sand replacement. The density decreases because dry sludge has a lower density than the solid ingredients of concrete (Fig. 2a, b).

Compressive strength: The results of compression testing of cubes (Fig. 3a, b) reveals that using Type I dry sludge in concrete mixes as an additive or as sand replacement has no significant adverse effect on compressive strength at low sludge contents. When using Type I sludge as a sand replacement at higher sludge contents (10% and above), the compressive strength showed significant reduction.

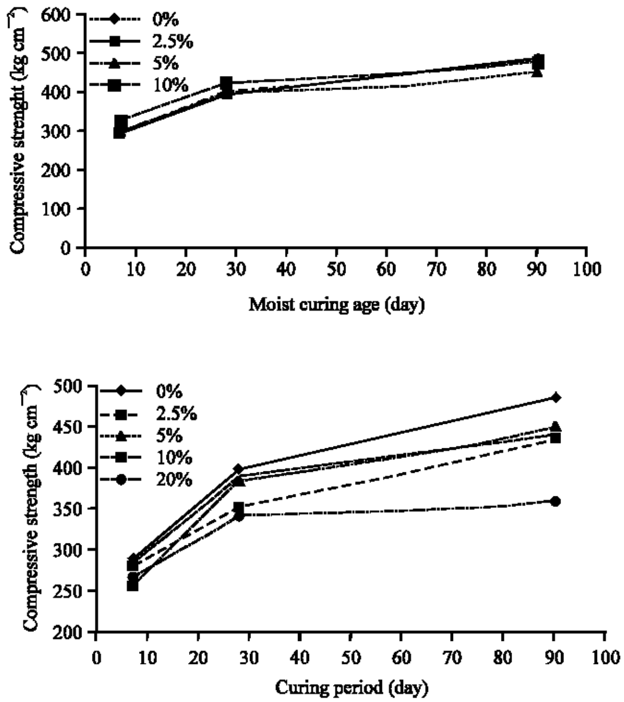

Fig. 3: Relation between compressive strength and curing age for sludge content as: (a) As an additive and (b) As a sand replacement

The compressive strength results can also be expressed as a relative strength ratio (R_s). The relative strength ratio, R_s is defined as the ratio of the compressive strength of sludge concrete to that of the reference mix. Table 4 presents the relative compressive strength ratio of concrete mixes containing sludge as additive material and as sand replacement at curing age of 28 and 90-day.

Figure 3 and Table 4 indicates that when Type I sludge was applied, as an additive there was no significant effect on the compressive strength. While, when using this type as a replacement of sand, the compressive strength decreases as sludge content increases. Table 4 shows that in general the reduction in compressive strength of concrete containing sludge as sand replacement at 90-day age was higher than that at 28-day age. The reduction in compressive strength after 90 days curing period reached about 10% for replacement percent 2.5, 5 and 10%. The compressive strength decreased to about 26% at replacement content of 20%. It can be concluded that using Type I sludge (low organic material and high sand content) as an additive or to as sand replacement up to 10% by cement content will have cause very slight adverse influence on the compressive strength.

Type II Sludge (high in organic material and low in sand content): This type of sludge was currently used only as an additive in pellets form with size 1.18 mm to 850 μm in four contents of 0, 2.5, 5 and 10%. The effect of sludge particles size was also considered by using fine sludge particles of size less than 0.85 mm. The obtained results of the testing program of Type II sludge are presented in Table 5-7 and Fig. 4 and 5.

Table 4: R_s of mixes with sludge contents as an additive and as sand replacement

	R_s at			
	Sludge as additive (%)		Sludge as sand replacement	
% of Sludge	28 days	90 days	28 days	90 days
0	1	1	1	1
2.5	1.06	0.99	0.89	0.89
5	1	0.93	0.97	0.93
10	1.06	0.98	0.98	0.91
20	--	--	0.86	0.74

Table 5: Slump values of mixes having sludge pellets contents as an additive

Sludge content (%)	Slump value (cm)
0	4
2.5	5
5	3.9
10	2.3

Table 6: Relative strength R_s of mixes with sludge pellets at different slumps

	R_s at 4cm slump		R_s at 10.5 cm slump	
Sludge content (%)	28 day	90 day	28 day	90 day
0	1	1	1	1
2.5	1.06	0.95	0.89	0.89
5	0.9	0.91	0.81	0.85

Table 7: Relative strength of mixes with different sludge pellets amounts as an additive

Additive sludge (%)	R_s (28 day)	R_s (90 day)
0	1	1
2.5	1.14	1.02
5	0.96	0.87
10	0.88	0.83

Slump value: The slump values of concrete mixes having Type II sludge pellets of 0, 2.5, 5 and 10% contents were obtained as shown in Table 5.

The results shown in Table 5 indicated that the slump was slightly improved at sludge content 2.5%. However, for 5% sludge content, the slump was very close to that of the reference mix. When the sludge content increased to 10%, the slump significantly decreased. It can be said that the sludge particles can maintain or even improve workability only at low sludge contents (not more than 5%). For higher sludge contents the workability decreases due to the fact that the sludge particles absorb considerable amount of mixing water and hence depraving the mix from its free water which work as a lubricant. It can be concluded that a modification of mix proportion is needed when applying sludge contents more than 5% by cement weight in order to compensate the reduction of slump.

To further study the effect of sludge pellets on slump and compressive strength, 2.5 and 5% sludge pellets contents having 4 and 10.5 cm slump mixes were examined. Table 6 showed that

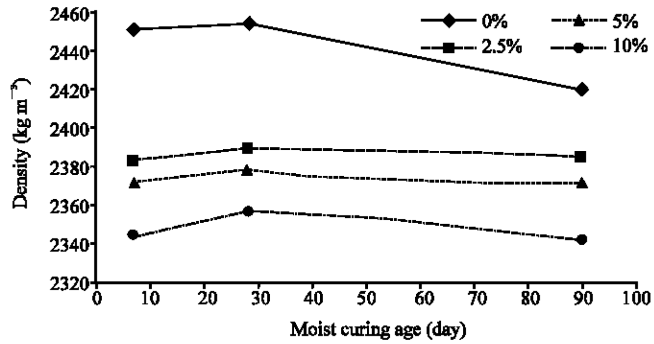

Fig. 4: Influence of sludge contents on concrete density

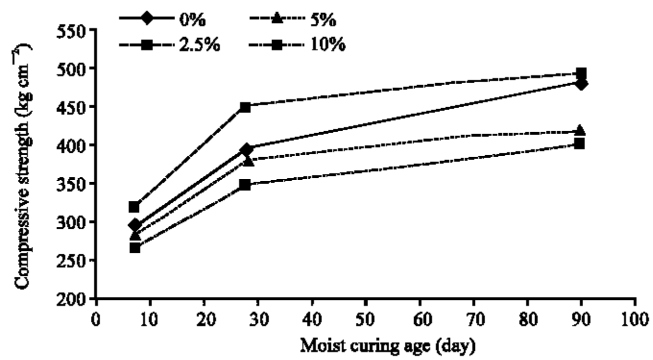

Fig. 5: Influence of Type II sludge contents on compressive strength

compressive strength of 2.5 and 5% sludge mixes with 4 cm slump and at 90 days curing age reached 95 and 91% of the reference compressive strength, respectively. Also, the compressive strength of the 2.5 and 5% sludge mixes with 10.5 cm slump at 90 days curing age reached 89 and 85% of the corresponding reference value, respectively. This finding can be explained through the fact that organic matters which present in sludge entrain more air and consequently voids, into concrete mass resulting in lowering the compressive strength.

Density: It is obvious in Fig. 4 that the density of concrete mixes slightly to moderately decreases as sludge content increases, which agrees to the corresponding finding of Type1 sludge. The reduction in density is higher in this type of sludge than that of Type I sludge due to the high organic material, which has low specific density. This agrees very well with that of Valls *et al.* (2004). They showed that the density of concrete decreases as sludge content increases.

Compressive strength: The results showed that the compressive strength reduces as the sludge content increases. It is thought that the high organic content in this type of sludge increases the amount of air entrained which in turn reduces the strength (Fig. 5).

Relative strength ratios shown in Table 7 indicates that after curing period of 90 days, the 2.5, 5 and 10% sludge concrete gave 100, 87 and 83% of that of the reference mix strength, respectively. This concludes that sludge can be used in concrete mixes at ratios from 2.5 to 10% without scarifying much strength (at maximum 17%).

These findings agree in general with those obtained by Valls *et al.* (2004) and Yague *et al.* (2005) who showed that the presence of sludge reduces mechanical strengths of the concrete and this reductions increase as the sludge content increases. However, the current study showed a lower reduction in compressive strength than that of Yague *et al.* (2005). It indicates that the 10% sludge concrete mixes showed the worst results, which agrees with Valls *et al.* (2004).

Influence of Sludge particle size on concrete properties: The particle size of sludge was considered as a factor in this study to obtain its effect on the fresh and hardened concrete properties. Type II Sludge (High organic sludge) was grinded obtained the required sizes. Two sizes of sludge particles were used in this study; (1) pellets size of 1.18 mm to 850 μm and (2) fine size ranging from 600 to 850 μm.

Based on concrete mix proportions shown in Table 2, pellets size and fine size sludge content of 5% by cement weight was added to produce two groups of concrete mixes.

Table 8 and Fig. 6 revealed that with 5% sludge content and at 90 days curing age, the pellets size and fine size sludge concrete showed 87 and 73% compressive strength of that of the corresponding reference mix. The reduction in compressive strength in case of fine sludge particles can be attributed to the fact that finer particles give higher surface area, thus the finer organic material become more distributed in the concrete matrix allowing in more entrained air which in turn decreases strength. The reduction in strength due to finer particles of sludge can also be attributed to the weakening bond between cement paste and aggregate.

Producing Interlock Bricks Using Sludge Concrete: The sludge concrete was also utilized in the present study to produce interlock bricks, which are widely used to pave roads, streets and pedestrian areas. 5% fine-sized (passing sieve 850 μm) Type II sludge content by cement weight was added to the interlock brick concrete mix. The dry sludge particles were first added to the natural sand and then the standard method of mixing was followed. Reference bricks (without sludge) were also produced to compare results and draw conclusions.

The interlock brick body composed of two layers; the main layer which makes up the body of brick and a thin surface layer which gives the finish of the brick. The dry fine-sized sludge was added only to the main layer, while top surface layer was made without sludge. The interlock brick

Table 8: Relative strength ratios of 5% sludge mixes with pellets and fine sizes

Curing period	R_s of pellets size sludge	R_s of fine size sludge
28 days	0.96	0.81
90 days	0.87	0.78

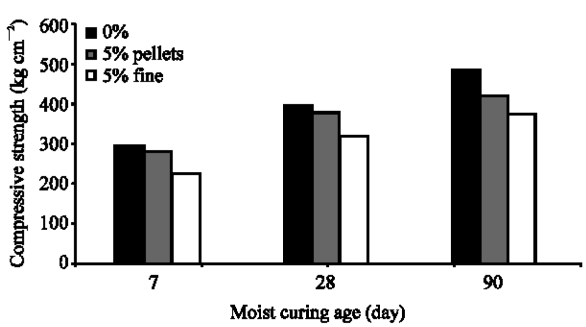

Fig. 6: Influence of sludge particle size on mix compressive strength

Table 9: Interlock brick results of density, absorption and compressive strength

Curing period	Reference bricks	Sludge bricks	% reduction
Density results			
28	2447	2442	0.2
90	2414	2402	0.5
Absorption results			
28	3.03	3.43	13.2
90	3.51	4.11	17.1
Compressive strength results			
28	615	563	8.5
90	680	596	12.4

samples were made in one of the Gaza interlock factories. About 180 bricks were produced, 90 of them were made of sludge concrete and the remaining bricks were produced as reference bricks. No difference in preparation or in appearance was noticed between the sludge brick mix and the reference brick mix. The compressive strength, density and absorption of bricks were tested at curing age of 28 and 90 days.

It is clear from Table 9 that the presence of sludge in interlock bricks reduces very slightly their densities compared with the rate of density reduction in concrete mixes. This slight reduction in density can be referred to the high compaction effort the interlock bricks are subjected to during preparation process.

The absorption test results, based on ASTM C642 (2006), of the non-sludge and sludge bricks shown in Table 9 reveals higher absorption capacities of 13.2 and 17.1% of sludge bricks than that of the non-sludge bricks at 28 and 90 days curing period, respectively. The absorption results indicated that the presence of sludge in bricks increases absorption capacity, which in turn could adversely influence durability due to higher permeability and lower water tightness. Therefore, it is recommended to add specific admixtures, which can overcome such problem.

The compressive strengths of sludge and non-sludge bricks presented in Table 9 show that a slight strength reduction of 8.5 and 12.4% in sludge bricks were observed at 28 and 90 days curing period, respectively, compared with those of the reference bricks.

Yague *et al*. (2002) manufactured prefabricated concrete bricks using 2% sludge per cement weight. Their results showed a decrease in porosity and absorption and an increase in compressive strength of the bricks. The current study showed very slight to no change in the density of the bricks and slight increase in the absorption and strength of the bricks. This can be attributed to that fact that Yague *et al*. (2002) prepared bricks using only 2% sludge per cement weight, while the tested bricks have 5% sludge content.

CONCLUSION

The aim of the current study is to obtain the influence of low and high organic municipal wastewater sludge on physical mechanical properties of concrete Mixes. The investigated properties involved workability, density, absorption and compressive strength. According to the experimental results, the usage of sewage sludge in concrete mixes as an alternative of disposal for Gaza sewage sludge is possible. The main conclusions, which can be drawn based on the experimental results, are:

- A percentage of 5% low organic sludge by cement content can be used as an additive to concrete mix without causing a significant reduction in compressive strength. Using higher sludge percentages than 5% decreases the workability of the mix and subsequently causes a reduction in slump
- Low organic sludge can also be used as a sand replacement of concrete mix due to its high sand content. The results showed that 5% of sand can be replaced by this type of sludge without changing the mix preparation and with compressive strength reached about 93% of the reference strength after 90-day age curing
- Adding high organic sludge (more than 50% of the sludge weight) to concrete mixes had a moderate adverse effect on concrete compressive strength and mix workability. The reduction in compressive strength reached 13% at 90-day curing age with 5% sludge content. The results showed that increasing the sludge content and decreasing the sludge particles size decrease the compressive strength and mix workability. For example, concrete mix with 10% sludge pellets decreased the compressive strength by 17% at 90-day curing age and significantly reduced the mix workability
- The use of high organic sludge particles in coarser sizes caused a reduction in strength. The compressive strength decreased by 13 and 22% when pellets sized and fine sized sludge particles were used, respectively
- The density of the concrete decreased in all cases with increasing sludge content. This reduction in density was higher when high organic sludge was used than low organic sludge
- It can be also concluded that the presence of sludge in bricks reduces its compressive strength by 8% at 28-day curing age and by 12% at 90-day curing age. The absorption coefficient of the sludge bricks was slightly increased

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