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REUSE OF WATER TREATMENT PLANT SLUDGE AND RICE HUSK ASH IN CONCRETE PRODUCTION

Sherif H. Al-Tersawy*, Faten A. El Sergany
* Associate Professor of Properties and Testing of Materials Engineering, HTI, 10th of Ramadan City, Egypt
Associate Professor of Sanitary & Environmental Engineering, HTI, 10th of Ramadan City, Egypt

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ABSTRACT

The problem of Egyptian agricultural land is the production of Rice Husk Ash (RHA) with a huge amount and nothing made to reuse of it that made a lot of environmental problems. The average quantity of RHA produced in Egypt annually ~6 million ton and only 17% of it reused and the rest burnt causing a significant environmental problem. On the other hand, a lot of new water treatments plants (WTP) came into work producing many sludge quantities. The reuse of the sludge will reduce the burden on the environment. The competence of using the sludge generated from WTP and the RHA produced from agricultural waste was investigated in the production of concrete. Several mixes were created to check application suitability for RHA and sludge and to determine the product best application. Concrete mixes were produced with different mixing ratios of burnt RHA and sludge ash between 0 % and 30% as a cement replacement. 10% RHA cement replacement gave a very near 28 days compressive and tensile strength values to control concrete specimens. The 20% RHA replacement using dolomite as coarse aggregate attained the minimum limit for structural concrete. 10% of sludge ash replacement for the higher grades of concrete (400 kg/m3 cement content) and by using the dolomite as coarse aggregate gave suitable properties to use as structural concrete. More than 10% sludge ash replacement ratios may be suitable to use in other types of architectural concrete. Increasing cement replacement ratio slightly decreases the water absorption of RHA specimens while for sludge ash specimens, as the percentage of sludge ash increases, water absorption values of concrete samples steadily increases.

KEYWORDS: Water treatment Sludge ash Reuse, Agricultural wastes reuse, Construction Materials.

INTRODUCTION

The problem of Egyptian agricultural land is the production of RHA with the huge amount of minimal reuse of it that made a lot of environmental problems especially the farmers burn it causing many air pollution emissions. The average quantity of rice husk produced in Egypt annually is about 6 million ton, only 17% of it reused and the rest burned in the fields causing the significant air pollution problem called black cloud which became a big environmental issue during the last ten years. The measurements done by observations plants succeeding EEAA through the portable laboratory show the percent of increase of black cloud in the air in the zones surrounding the governorates works with rice farming in the harvesting season. On the other hand, solid wastes produced from water treatment plants are considered as secondary products known as sludge. It is used since 30th from the twenty century in sand and desert reclamation, but due to the increase in waste and industrial treatment projects in Cairo, the quantity of the produced sludge highly increased ≈ 30000 m3/day which can not be afforded in land reclamation only. That is why it is necessary to find different methods to reuse the produced sludge. In this research, an experimental study was done to benefit from the produced water treatment sludge and rice husk properties to provide safe environmental materials, useful for the society and have economic income.

LITERATURE REVIEW

Researchers in recent years developed many uses for the sludge, solving its disposal problem without any adverse effects on the environment with economic income too. Sludge considered from the most essential elements for feeding lands in its liquid state before dewatering specially with loose, poor soil as it approved great success in certain zones as Abu Rawash, El Nubareiyah, North Damieta, El Husseinyah, Wadi El Molak, North West Coast,

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East Suez Canal and North Sinai. Also sludge produced from septic tank, vault and farmer vault was used in producing thermal energy after drying it under sun rays in the form of disk mixed with the rest of plants & land wastes (called Gila Disks) to be fuel for ovens due to its high thermal energy. Most of the researchers found that sludge used in land reclamation is limited by time not exceeding 10 years for best assumption & not less than 2 years, on condition that it not include radiant or heavy metals and to be used for a period from half to twice the period of the used sludge produced from clean irrigation water with chemical fertilizers, and the sludge may be used after that for the same soil for an interval equal to half the previous interval, thus using sludge in these cases will be limited in period. Researchers on "Improved Digested sludge" approved its high quality as organic fertilization for plants especially fruitful and citrus trees as orange, mandarins& lemon. Also its ability to be used for extended interval exceeding 20 years without any adverse effects or problems on the trees. [1-5]. There are no complete researches done in Egypt concerning this field except a study had been done in one of the projects, comparing between certain materials used as a substance in retaining sand or earth bank side slopes for stabilization bonds and it is ended with difficulties to rely on sludge only for that purpose while success probability for mixing it with cement or Bentonite exist. [6]. It was approved that digested sludge is useful as a safe and natural organic fertilizer which don't affect human and animals health also it increase plant growth rate by quarter percent and help in accelerating crops ripening by a percent not less than 10%. [7]. Recently, sludge is used with a large success in electric generating in many countries as America and Britain through two different methods. First way depend on producing methane gas only by digestion or with organic solid waste, which in turn is used in handling electrical generator turbines and is called the clean method as it don't cause any residues harm the environment in case of incineration. Second method depends on mixing it with organic wastes, papers and burning to produce gases which handle electrical generator turbines. The first method is the most economic and the best for the environment where fine organic fertilizer is produced as a secondary product which cause additional income and don't generate polluted gases as carbon oxide (as the second method) [8]. Indian and American scientist succeeded in reusing the sludge after partial drying mixed with silt or clay by ratios range from 1:1,1:3 in fixing agriculture roads and non-paved roads, as it achieved well fixation for the soil under high traffic roads. The sludge pavement thickness range from 10→30 cm according to the road level, where it is compacted by a masher then flooded with water and finally left to dry producing hard layer not causing any dust. [9]. Sludge generated from industrial wastewater treatment plant for constructional materials, chemicals and papers succeeded in tiles production after mixing it with clay. [10], [11]. A combinations of sewage sludge ash with marble dust, fly ash and RHA as 30% replacement in Portland cement pastes increased the compressive strength up to 9% [12]. TAI and WEB [13] discussed the ability of using the sludge ash produced from wastewater treatment plants for a moderate city in producing light aggregate for concrete mixed with clay with different ratios and burning it, using the produced ash in producing light concrete of good characteristics and high resistance for raising and internal decoration works. Benlalla et al., [14] incorporated sludge from water treatment plant with clay, alumina sludge (5-30%) in the manufacturing of ceramic bricks. The specimens made of theses mixtures were fired at 800, 900, and 1000 □C. The results of both mechanical and physical tests showed that the ceramic bricks samples were dense and with high mechanical resistance. No deformations or cracks were detected. Chiang et al., [15] produced lightweight bricks by sintering mixes of dried water treatment sludge and RHA. The addition of RHA increased the porosity of samples. They found that mixes containing 15 % RHA and sintered at 1100 ◦C produced relatively high strength materials and low bulk density which were compliant with relevant local standards for use as lightweight bricks. El Sergany et al.,[16] produced a concrete brick using sludge ash partially replacing cement with ratio 25% or sand with 35% suitable for filling walls, decoration needs and raising buildings above normal permissible due to its less in weight by 40% and less in price by 35%. Hassan et al., [17] realized the similarity of water treatment sludge to clay and hence investigated it in the making of bricks. They used replacement ratios of 3%, 6%, 9%, and 12% of the total weight of sludge and clay mixtures. Physical, mechanical, and chemical tests were made to the produced bricks. It was found that both sludge % and firing temperature were the main parameters affecting bricks properties. It was found that the optimum sludge ratio to give good bonding of clay and sludge was 6%. Francisco et al., [18] produced concrete blocks using sewage sludge ash (5, 10, 15, and 20 %) as a cement and sand replacement and with the addition of an inert material such as marble dust. The resulted concrete blocks provided resistances and densities similar to the control samples and reduced water absorption significantly. El Nadi & El Sergany [19] applied sludge ash and cement dust to produce light concrete mix. This concrete achieved average compression resistance 60 % compared to normal cement concrete; also it achieved fine result in abrasion test with ratio 20 % better than the cement concrete. It also has high acid resistance as well as its weight range from (1/4→1/5) cement concrete. In another study [20], sludge from water treatment plants and construction demolition waste were evaluated for recycling in concretes and mortars. The two joined materials proved to be an excellent recycling alternative from the axial compression, tensile strength, modulus of elasticity, and water absorption points of view.

On the other hand, Agricultural wastes especially rice straw or husks had been used in several purposes for producing reused materials as artificial wood plates, heat isolation materials, animal food, additions with clay or loamy bricks to improve their properties and also in wastewater treatment [21-23]. Ganesan et al., [24] studied the effect of the RHA partial cement replacement on concrete properties. These properties included mechanical properties, water absorption, sorptivity, total charge-passed, and rate of chloride ion penetration. The results indicated that replacing of cement with RHA up to 30% of cement has no adverse effect on the prementioned concrete properties. Givi et al., [25] studied the Effect of RHA particle size on strength, water permeability and workability of binary blended concrete. They used 5 microns and 95 microns average particle size of RHA as a partial replacement of cement (5%, 10%, 15% and 20% by weight). Replacement, 10% of cement by ultra fine rice husk ash particles, gave the ultimate concrete strength. It was concluded that decreasing RHA average particle size provides a positive effect on the compressive strength and water permeability of hardened concrete. However, as particle size decreased, workability of fresh concrete decreases. Chindaprasirt and Rukzon [26] studied the strength, porosity and corrosion resistance of mortars made with ternary blends of ordinary Portland cement (OPC), RHA and fine fly ash (FA). The ternary blends of OPC, RHA and FA produced mortars with higher strengths at the low replacement percentage with RHA and FA at the later age compared to control OPC mortar. Up to 20% replacement of RHA and FA, The porosity of mortars reduces but increases with the 40% replacement level. It was found that chloride induced corrosion resistance of mortars containing single RHA, or FA, as well as the ternary blend OPC, RHA and FA are significantly improved, however, the corrosion resistance of ternary blend mortar is higher than that of mortar containing single RHA or FA. Sakr [27] studied the effect of using SF or RHA as a partial replacement for cement on the Properties of Heavy Weight Concrete. It was found that mixes containing ilmenite as coarse aggregate and mixed with 15% SF had the highest compressive, tensile, flexural, and bond strengths; density; modulus of elasticity; and attenuation coefficient values. SF mixes gave a better resistance to sulfate attack than mixes with RHA. Results showed that the concrete with RHA had higher physical and mechanical properties than samples without any additives but had lower properties than that mixed with SF. Ismail and Waliuddin [28] studied the effect of rice husk ash on high strength concrete. They used RHA passed from #200 and #325 sieves with a cement replacement ratio (10-30%). They proved that fine grinding of RHA improves concrete strength and that the optimum RHA ratios are 10% to 20 %. De Sensale [29] used RHA for making normal concrete in two forms, residual RHA and RHA produced by controlled incineration. He used two RHA cement replacement ratios (10% and 20%) and three water cement ratios. He noted that the compressive strength at early ages for mixes with RHA was less than control specimen while it exceeded the compressive strength of control specimens at 91 days age. Also, it was found that in the long term, the behavior of concrete with RHA produced by controlled incitation was more significant than concrete with residual RHA. He concluded that the increase in compressive strength of concrete made using residual RHA is due to filler effect (physical) while the increase in compressive strength of concrete made using controlled incineration RHA was due to pozzolanic (chemical/physical) effect.

STATEMENT OF THE PROBLEM AND STUDY METHODOLOGY

The burning of waste rice straw and husk in Egypt in September and October of each year is a considerable burden on the national economy in Egypt, as well as on public health. This uncontrolled disposal of agricultural waste by the farmers created what is known as the black cloud. These kinds of pollutants are responsible for sensitivity and shortness of breath illnesses also it is an intermediary for the infection of seasonal diseases that arises at this time of the year. Although the Egyptian government already produced controlled burning machines with filtering devices to control the burning of rice husk and rice straw, still the reuse of the burning ash is a major concern. On the other hand, many new water treatments plants came into work producing many sludge quantities. The reuse of the sludge will reduce the burden on the environment. On the other side, the findings of partial replacements of cement in the concrete industry are of a significant economic impact on the fast growing civil business in Egypt and other countries. In this study, each type of the recycled materials; WTP sludge ash and RHA are mixed with concrete ingredients as a partial replacement of cement. Burnt Sludge from water treatment plant as well as burnt RHA from rice production was used in several concrete mixes as a partial cement replacement (10-30%). Two types of coarse aggregates are examined (dolomite and gravel) to understand the effect of each type. Two grades of concrete were used for each recycled material. Several Tests had been applied on the produced concrete according to construction standard methods [30-32]. The tests covered the compression strength, the tensile strength, water absorption of the produced concrete mixes. Also scanning electron microscope (SEM), and X-ray diffraction images (XRD) were taken.

EXPERIMENTAL STUDY

Materials

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One of the targets of this study is to produce concrete of normal quality like that used in conventional concrete applications. Materials used are commercially available in local markets for normal production of concrete.

Cement

The cement used in this investigation is an ordinary Portland cement. The type of OPC used is (CEM I 42.5 N) which complies with the Egyptian standard specification (ESS No.4756-1/2007). A laboratory physical and chemical tests were made to the cement (as per ESS No.2421/2005) to investigate its suitability for concrete work. The properties of the cement used in this investigation are shown in Table (1).

Table (1): Properties of Cement Type (CEM I 42.5 N)

Properties		**Measured Values**
Fineness (cm^2/gm)		3280
Specific Gravity		3.15
Expansion (mm)		1.2
Initial Setting Time (min)		180
Final Setting Time (min)		230
Compressive strength (N/mm^2)	2 days	22.8
	7 days	33.2
	28 days	56.0
Chemical Compositions	SiO_2	20.32 %
	Al_2O_3	5.16 %
	Fe_2O_3	3.60 %
	CaO	63.43 %
	MgO	1.02 %
	SO_3	2.22 %
	Loss ignition %	1.3 %

Fine Aggregate

Natural siliceous sand was used in this work as fine aggregate. The sand is clean free from impurities. Physical and chemical tests of fine aggregate were carried out according to the Egyptian standard specifications ESS No.1109/2002. The physical and chemical properties of the sand are shown in Tables (2).

Table (2): Physical and Chemical Properties of the used Sand

Test	**Results**	**Specification Limit***
Specific Gravity	2.64	-
Unit Weight	1.70	-
Materials Finer than no 200 Sieve	1.46	Less than 3 %
Chloride content (CL^{-1} %)	0.045	Less than 0.06 %
Sulfate content (SO_3 %)	0.070	Less than 0.40 %

* ESS No.1109/2002

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Coarse Aggregate

Both Gravel and Dolomite from natural sources with nominal maximum size of 10 mm is used in the experimental work. The properties of gravel are complying with ESS No.1109/2002. The physical and chemical properties are presented in Table (3).

Table (3): Physical and chemical Properties of the used gravel

Test	Results	Specification Limit*
Specific gravity	2.61	-
Unit Weight	1.65	-
Materials Finer than no 200 Sieve	1.38	Less than 4 %
Absorption %	2.15	-
Abrasion (Los Anglos)	14.84	Less than 25 %
Crushing Value	17.55	Less than 30 %**
Impact Value	9.20	Less than 30 %
Chloride content (CL^{-1} %)	0.009	Less than 0.04 %
Sulfate content (SO_3 %)	0.031	Less than 0.40 %

* ESS No.1109/2002

A crushed coarse aggregate (Dolomite) brought from (Dahshoor source), was used throughout this work and its max size was (10 mm). The physical and chemical properties are presented in Table (4).

Table (4): Properties of Dolomite Used in the Experimental Work

Test	Results	Specification Limit*
Specific gravity	2.7	-
Unit weight and voids	1.62	-
Materials finer than no 200 sieve	1.12	Less than 2 %
Absorption	1.23	-
Abrasion (Los Anglos)	14.62	Less than 25 %
Crushing Value	20.5	Less than % 45**
Impact Value	11.6	Less than 30 %
Sulfate content	0.05%	≤0.1%
Bulk Density (kg/m^3)	1565	

* ESS No.1109/2002

Sludge ash

The sludge ash used in this research work was brought from Berka water treatment plant located at eastern Cairo. WTP sludge; Figure (1-a); was heated in an oven; Figure (1-b); for two hours at 600 degrees then it was grounded in the mill; Figure (2-c). The properties of the sludge without burning and with burning at different stages are shown in Table (5).

Table (5) Chemical Composition of Water Treatment Planet Sludge (Berka WTP, Eastern Cairo)

Raw Material	Quantity (mg/l)				
	w/t burn	150°- 4 hr	150°- 6 hr	150°- 8 hr	250°- 4 hr
PH	6.45	6.30	6.0	6.0	6.1
Chromium	20	-	-	-	-

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Aluminum	160	20	20	18	20
Iron	1170	350	293	250	234
Copper	900	780	650	560	400
Manganese	1000	700	600	460	400
Silicates	14300	124.4	11360	10950	10730
Chlorides	8650	7500	7345	5795	5570
Sulfates	1925	230	190	109	98
Phosphates	2540	1060	910	767	512
Nitrates	35000	642	390	212	165
Biochemical Oxygen	1005	573	460	352	322
Chemical Oxygen	1515	980	787	612	546

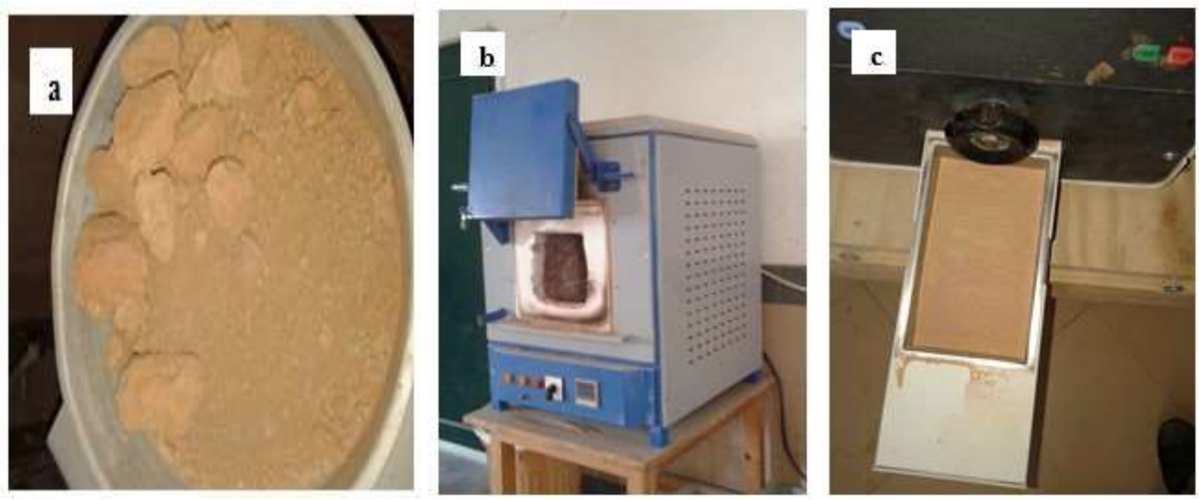

Fig. (1) a: Raw sludge material from Berka WTP, b: Oven used in the temperature treating process, c: Grounding mill.

RHA

The RHA utilized in this study was obtained from the burning process; open air burning process; of rice husk resulted from the planting of white rice in an agricultural rice field in Belbees city, Sharqia Governorate, Egypt. Like the sludge ash, RHA was grounded in the same apparatus; Figure (1-c). The RHA was analyzed to obtain its properties. Chemical analysis of the used RHA is shown in Table (6).

Table (6) Chemical Composition of RHA

Chemical composition	Weight %
SiO_2	90
AL_2O_3	0.2
Fe_2O_3	1.70
K_2O	1.63
CaO	0.30
C	17

Preparation of Test Specimens

A total of 28 mixes were made, four control mixes, twelve mixes include sludge ash, and twelve mixes include RHA. Either sludge ash or RHA mixes were divided into two mixes according to the grade of concrete; G1 and G2. In each grade of concrete, two types of coarse aggregate were used; Dolomite (D) and Gravel (G). Table (7) and Figure (2) show the identification of concrete mixes and a description of mixes names abbreviations. The mixes proportions (Kg/m3 of concrete) are shown in Table (8).

Table (7) Identification of Concrete Mixes

D-G1-10S	Dolomite concrete, grade1 (350kg/m3), 10% replacement of sludge ash
D-G1-20S	Dolomite concrete, grade1 (350kg/m3), 20% replacement of sludge ash

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D-G1-30S	Dolomite concrete, grade1 (350kg/m3), 30% replacement of sludge ash
G-G1-10S	Gravel concrete, grade1 (350kg/m3), 10% replacement of sludge ash
G-G1-20S	Gravel concrete, grade1 (350kg/m3), 20% replacement of sludge ash
G-G1-30S	Gravel concrete, grade1 (350kg/m3), 30% replacement of sludge ash
D-G2-10S	Dolomite concrete, grade2 (400kg/m3), 10% replacement of sludge ash
D-G2-20S	Dolomite concrete, grade2 (400kg/m3), 20% replacement of sludge ash
D-G2-30S	Dolomite concrete, grade2 (400kg/m3), 30% replacement of sludge ash
G-G2-10S	Gravel concrete, grade2 (400kg/m3), 10% replacement of sludge ash
G-G2-20S	Gravel concrete, grade2 (400kg/m3), 20% replacement of sludge ash
G-G2-30S	Gravel concrete, grade2 (400kg/m3), 30% replacement of sludge ash
D-G1-10RH	Dolomite concrete, grade1 (350kg/m3), 10% replacement of RHA
D-G1-20RH	Dolomite concrete, grade1 (350kg/m3), 20% replacement of RHA
D-G1-30RH	Dolomite concrete, grade1 (350kg/m3), 30% replacement of RHA
G-G1-10RH	Gravel concrete, grade1 (350kg/m3), 10% replacement of RHA
G-G1-20RH	Gravel concrete, grade1 (350kg/m3), 20% replacement of RHA
G-G1-30RH	Gravel concrete, grade1 (350kg/m3), 30% replacement of RHA
D-G2-10RH	Dolomite concrete, grade2 (400kg/m3), 10% replacement of RHA
D-G2-20RH	Dolomite concrete, grade2 (400kg/m3), 20% replacement of RHA
D-G2-30RH	Dolomite concrete, grade2 (400kg/m3), 30% replacement of RHA
G-G2-10RH	Gravel concrete, grade2 (400kg/m3), 10% replacement of RHA
G-G2-20RH	Gravel concrete, grade2 (400kg/m3), 20% replacement of RHA
G-G2-30RH	Gravel concrete, grade2 (400kg/m3), 30% replacement of RHA

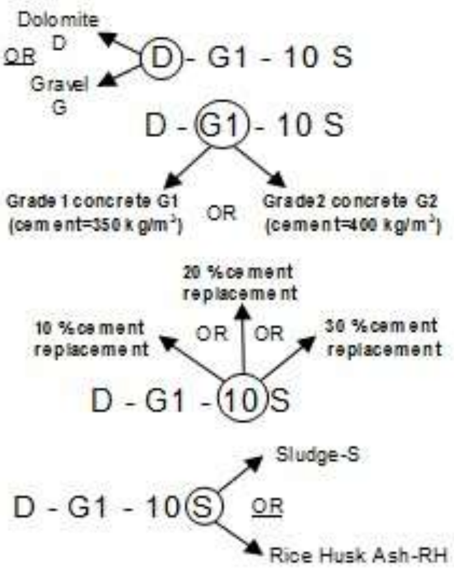

Fig. (2) Diagram showing the meaning of mixes abbreviations.

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Table (8) Mixes Proportions

Mix	cement (kg)	Water (L)	W/C	Aggregate (Kg)			Sludge ash or RHA (Kg)
				Sand	Dolomite	Gravel	
D-G1	350	175	0.5	615	1230	-	MT
G-G1	350	175	0.5	602	-	1204	MT
D-G2	400	200	0.5	601	1202	-	MT
G-G2	400	200	0.5	588	-	1176	MT

MT: according to mix type; as % of cement weight.

Concrete specimens were cast for compressive strength, tensile strength, absorption test, Scan Electron Microscope test (SEM), and X-ray diffraction test (XRD). For each mix, the corresponding specimens, respectively, are six cube specimens with 15 cm side length (3 cubes for seven days age and three cubes for 28 days age). For absorption test, three cubes with 10 cm side length were cast. Three cylinders (15 cm diameter and 30 cm height) for the tensile strength test. Six small mortar cubes with 1 cm side length were cast from each mix for the SEM and XRD test. All specimens were cured in clean tap water at room temperature until the testing date.

STUDY RESULTS & DISCUSSIONS

The mechanical and physical properties of concrete mixes were investigated. Test results and discussions are presented in the following sections.

Compressive Strength

Table (9) and Figures (3-10) show the test results of concrete strength for all mixes. The standard deviation and variance of results were included to verify the quality control of concrete of tested samples.

It can be noted that all control specimens had given compressive strength values between 25 N/mm^2 and 37 N/mm^2 after 28 days. Compressive strength values of grade#2 mix (G2) were higher than G1 values by 18%, 21% for concrete with Dolomite (D), Gravel (G) as a coarse aggregate respectively. Dolomite samples were higher than gravel samples with 9% and 6% for G1 and G2 respectively. The increase in compressive strength in dolomite samples is attributed to the interlocking and friction effect of the angular and rough surface of dolomite particles compared to gravel (interfacial bond between coarse aggregate and mortar). In such normal strength concrete, the strength of the coarse aggregate particles is not dominant as cracks occur in the weaker chain (mortar). Obviously, adding sludge ash decreases the strength of pilot concrete which may be attributed to low physical and chemical contribution of the sludge ash ingredients to hydration and cement reaction. Moreover, the higher the percentages of sludge ash in concrete are the lower cement quantity and hence lower hydration products. The compressive strengths of all sludge ash concrete specimens were less than those of control concrete specimens considering seven days age and 28 days age.

The percentage decrease at 28 days was 30%, 43%, and 48% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 1 concrete with dolomite and it was 32%, 46%, and 50% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 1 concrete with gravel. The percentage decrease at 28 days was 33%, 44%, and 49% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 2 concrete with dolomite and it was 34%, 46%, and 51% for sludge ash replacement of 10%, 20%,

Table (9) Results of the Experimental Work

Mix	Cubes Comp. Strength (N/mm2)						Tensile Strength (N/mm2)	Absorption (%)		
	7 days			28 days						
	avg.	S.D.	Var.	avg.	S.D.	Var.	avg.	avg.	S.D.	Var.
D-G1-control	20.7	1.2	5.8	31.5	1.3	4.2	3.6	2.15	0.1	3.3
D-G1-10S	16.4	1.1	6.5	22.0	2.6	12.0	2.2	2.30	0.2	6.5
D-G1-20S	14.9	0.9	6.3	17.9	0.2	1.3	1.5	2.80	0.1	5.1

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D-G1-30S	12.0	1.3	10.7	16.3	0.3	1.8	1.6	3.60	0.1	3.9
G-G1-control	18.4	0.4	2.0	29.0	1.0	3.4	3.3	1.85	0.1	3.8
G-G1-10S	14.0	0.4	2.6	19.7	0.4	1.8	1.7	2.20	0.1	5.0
G-G1-20S	11.3	1.5	13.6	15.7	2.0	12.7	1.4	2.55	0.3	10.2
G-G1-30S	9.4	1.0	10.6	14.4	2.0	14.1	1.3	3.10	0.4	11.3
D-G2-control	24.4	1.0	4.2	37.0	2.0	5.5	4.0	1.70	0.1	7.6
D-G2-10S	19.0	2.1	10.8	24.8	1.4	5.7	2.3	2.05	0.1	3.4
D-G2-20S	17.2	0.8	4.4	20.7	1.3	6.1	1.9	2.40	0.2	8.8
D-G2-30S	13.7	1.3	9.7	18.8	1.6	8.7	1.7	3.05	0.2	7.0
G-G2-control	22.0	1.6	7.3	35.0	2.0	5.6	3.9	1.50	0.1	6.7
G-G2-10S	16.5	1.3	7.9	23.2	1.0	4.3	2.1	1.90	0.1	7.4
G-G2-20S	13.2	1.0	7.2	18.8	1.6	8.5	1.8	2.25	0.2	9.4
G-G2-30S	11.1	0.8	7.4	17.0	0.9	5.3	1.5	3.00	0.2	5.3
D-G1-control	20.7	1.2	5.8	31.5	1.3	4.2	3.6	2.15	0.1	3.3
D-G1-10RH	17.0	0.7	4.2	32.7	1.9	5.8	3.6	2.07	0.1	5.5
D-G1-20RH	13.0	1.1	8.6	25.4	1.5	5.9	2.9	2.05	0.1	5.5
D-G1-30RH	9.9	1.2	12.6	19.7	1.5	7.8	2.1	2.00	0.1	6.0
G-G1-control	18.4	0.4	2.0	29.0	1.0	3.4	3.3	1.85	0.1	3.8
G-G1-10RH	13.4	0.9	6.4	27.6	2.0	7.4	2.8	1.76	0.2	8.8
G-G1-20RH	9.1	0.8	8.4	19.2	1.4	7.1	2.0	1.70	0.1	8.3
G-G1-30RH	7.3	0.9	12.0	15.0	1.5	10.0	1.7	1.63	0.1	4.3
D-G2-control	24.4	1.0	4.2	37.0	2.0	5.5	4.3	1.70	0.1	8.3
D-G2-10RH	18.7	1.0	5.6	37.4	2.0	5.4	4.1	1.65	0.1	6.1
D-G2-20RH	15.7	1.0	6.5	30.8	2.1	6.7	3.1	1.63	0.1	8.7
D-G2-30RH	11.2	1.1	9.5	21.5	1.5	7.0	2.4	1.58	0.1	6.3
G-G2-control	22.0	1.6	7.3	35.0	2.0	5.6	4.0	1.50	0.1	6.7
G-G2-10RH	15.5	0.8	4.9	32.2	1.6	4.9	3.6	1.44	0.1	5.9
G-G2-20RH	11.6	1.2	10.3	23.6	1.9	8.0	2.5	1.41	0.1	8.0
G-G2-30RH	9.0	1.0	11.1	19.1	1.5	8.1	2.1	1.37	0.1	9.3

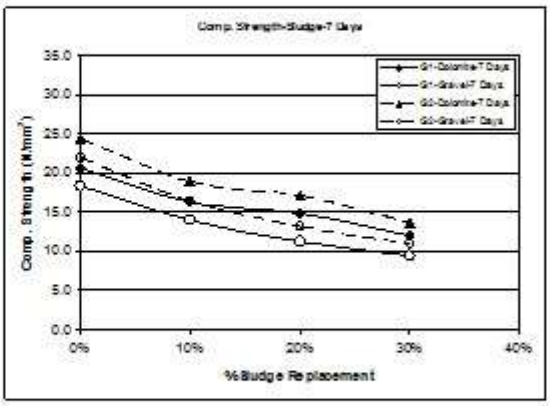

Fig. (3) Comp. Strength results at seven days for sludge ash samples

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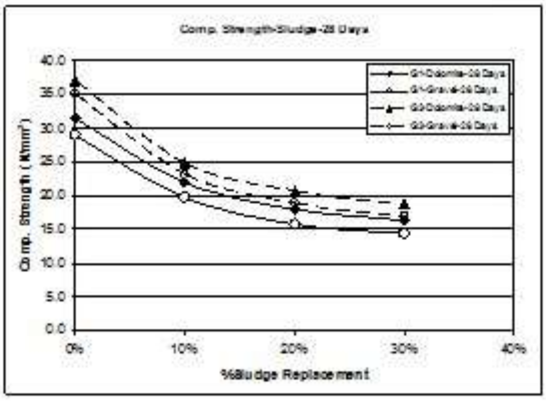

Fig. (4) Comp. Strength results at 28 days for sludge ash samples

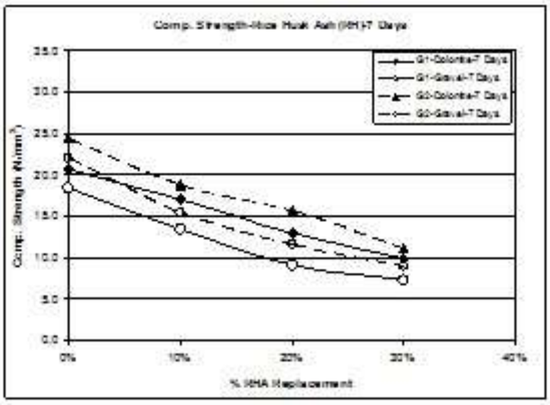

Fig. (5) Comp. Strength results at seven days for RHA samples

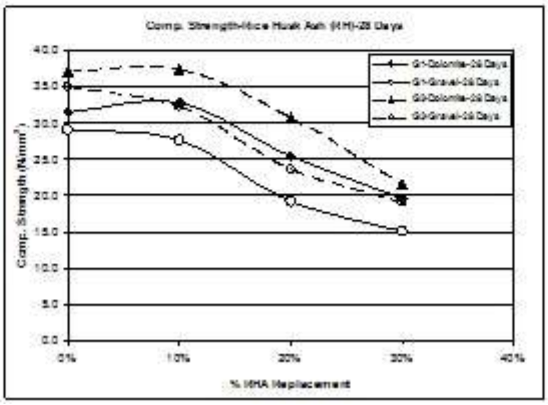

Fig. (6) Comp. Strength results at 28 days for RHA samples

and 30% respectively for grade 2 concrete with gravel. This steep decrease might be because by replacing 10 % and more of cement with sludge ash powder, the cement reaction was lower in the concrete mass due to the drop of the CaO ratio as a result of higher replacement of sludge ash. The compressive strengths of RHA concrete specimens showed a different behavior. The compressive strength values for 10% RHA replacement were slightly greater than the control specimens for the dolomite specimens in the two grades of concrete G1 and G2; 104% and 102% respectively. While the compressive strength values were slightly lower than the control specimens for the gravel specimens in the two grades of concrete G1 and G2; 95% and 92% respectively from control samples. For 20% RHA replacement ratio; the compressive strength values were 81%, 83% from the control specimens considering grade 1 and grade 2 dolomite concrete specimens respectively while the compressive strength values were 66%, 67% from the control specimens considering grade 1 and grade 2 gravel concrete specimens respectively. For 30% RHA replacement ratio; the compressive strength values were 63%, 58% from the control specimens considering grade 1 and grade 2 dolomite concrete specimens respectively while the compressive strength values were 52%, 55% from the control specimens considering grade 1 and grade 2 gravel concrete specimens respectively. It can be seen that the optimum amount of silica leached out from RHA is at 10% cement replacement. At this ratio, the silica amount is capable to efficiently react with the lime resulted from hydration process leading to almost equal strength. Higher than this ratio, the silica leached from RHA replaces a part of the cementitious materials without any contribution to the strength.

Tensile Strength

Table (9), Figure (7), and Figure (8) show the results of tensile strength test made using splitting test.

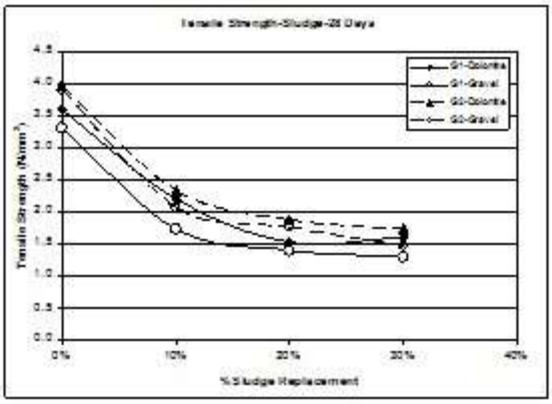

Fig. (7) Tensile Strength results at 28 days for sludge ash samples

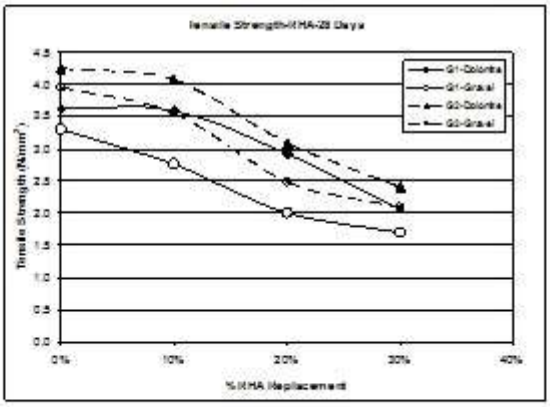

Fig. (8) Comp. Strength results at 28 days for RHA samples

For sludge ash specimens, it is observed that the tensile strength decreases as the percentage of RHA increases. Results show that tensile strength was decreased by 39%, 58% and 56% for grade 1- dolomite specimens, by 48%, 58% and 61% for grade 1- gravel specimens, by 43%, 53% and 58% for grade 2- dolomite specimens, and by 46%, 54% and 62% for grade 2- gravel specimens when using sludge ash percentage by 10%, 20%, and 30 % respectively. This pattern and the pattern of RHA tensile strength specimens are consistent with that of the compressive strength results and confirm its accuracy. Considering RHA tensile strength specimens, the values were 100%, 81%, and 58% for grade 1- dolomite, 85%, 61%, and 52% for grade 1- gravel, 95%, 72%, and 56% for grade 2-dolomite, and 90%, 63%, and 53% for grade 2- gravel. As compressive strength test results, the tensile strength test results at 10% RHA replacement were almost the same or slightly less than the control test results.

Water absorption

Table (9), Figure (9), and Figure (10) show the results of water absorption tests for sludge ash and RHA specimens.

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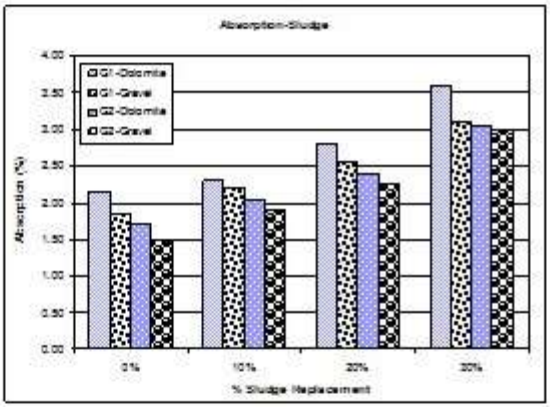

Fig. (9) Water absorption results for samples containing sludge ash

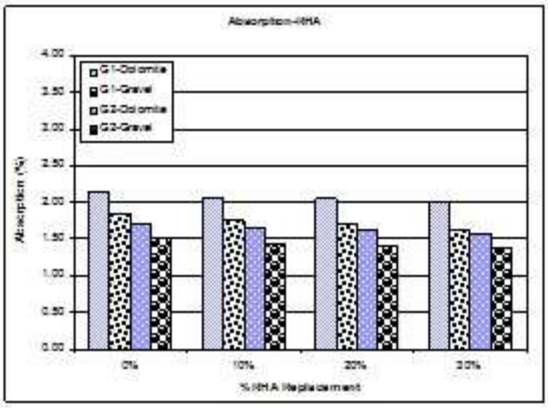

Fig. (10) Water absorption results for samples containing RHA

It can be seen that increasing percentage of sludge ash lead to an increase in water absorption values and that considering each sludge ash or RHA percentages, grade 2 concrete and dolomite concrete samples gives the least absorption values among other concrete samples. This is attributed to the denser cement paste in grade 2 concrete and the physical non-porous properties of gravel particles compared to dolomite particles. The percentage increase in water absorption compared to control mixes at 28 days were 107 %, 130%, and 167% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 1 concrete with dolomite. And it were 119%, 138%, and 168% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 1 concrete with gravel. It were 121%, 141%, and 179% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 2 concrete with dolomite and it were 127%, 150%, and 200% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 2 concrete with gravel. These results are attributed to the reduced amount of cement as the percentage of sludge ash increases in the mix and as this sludge ash is a water-permeable material, the particles distributed in the concrete pores would allow a more water absorption in the concrete particles. On the other hand, the percentage of water absorption values slightly decreases with the increase in RHA content. In each percentage, the type of coarse aggregate and grade of concrete affected the absorption value as seen in Figures (9 and 10). This is attributed to the pozzolanic action of RHA and filler effect provided by RHA. The percentage of water absorption values compared to control mixes at 28 days were 96 %, 95%, and 93% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 1 concrete with dolomite. And it were 95%, 92%, and 88% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 1 concrete with gravel. It were 97%, 96%, and 93% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 2 concrete with dolomite and it were 96%, 94%, and 91% for sludge ash replacement of 10%, 20%, and 30% respectively for grade 2 concrete with gravel.

Microstructure

Figure (11) show the results of SEM and XRD for samples of grade 1 and grade 2. The microstructure of grade2 dolomite concrete shows capillary pores that increase as the percentage of sludge ash replacement ratios increases. These pores are responsible for the permeability behavior of concrete. The SEM images clearly indicate more

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pores in the sample as the percentage of sludge ash increases; therefore, the unit weight reduces with increasing sludge ash percentage as evident in Fig.11. Also, the etching on hardened cement paste particles for 10% sludge ash replacement is obviously more dominant compared to other higher ratios as a result of a more effectiveness cement quantity than the higher cement replacement ratios. Refer to [33] for more illustrative SEM and XRD images for test samples.

CONCLUSIONS

The following can be concluded from the analysis of test results. The addition of water treatment plants sludge ash to concrete as a partial replacement of cement decreases mechanical properties of concrete i.e. compressive strength and tensile strength. However, the 10% sludge ash replacement for the higher grades of concrete (400 kg/m3 cement content) and by using dolomite as coarse aggregate gave suitable properties to use as structural concrete. More than 10% replacement ratios for both grades of concrete may be suitable to use in other types of architectural concrete

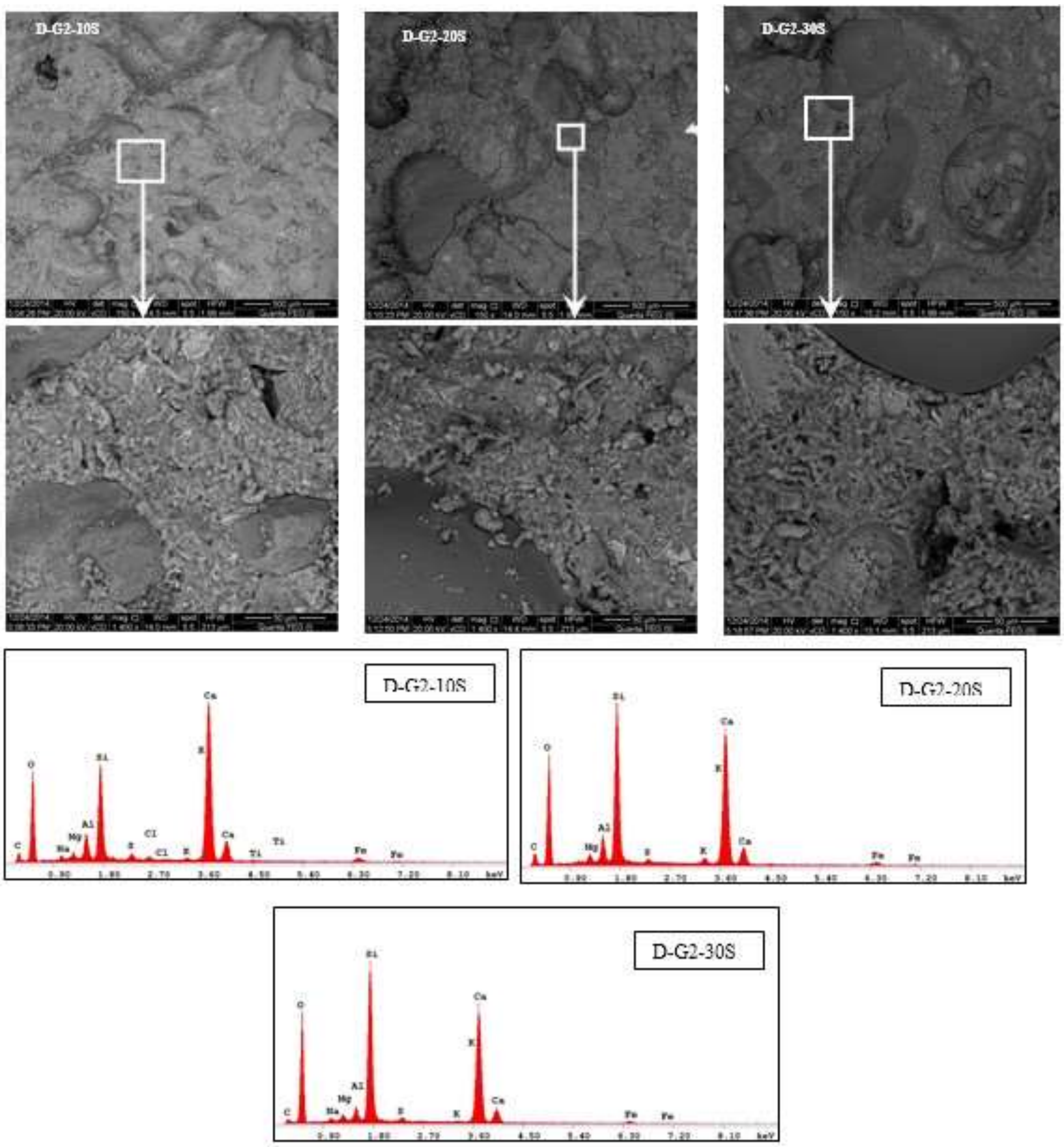

Fig. (12) SEM and XRD of grade2-dolomite samples work. It is important to highlight the 10% RHA replacement that gave a very near 28 days compressive and tensile strength values to control concrete specimens considering both grades of concrete and considering all types of coarse aggregate. The 20% replacement for both concrete grades using dolomite attained the minimum limit for structural concrete. Increasing cement replacement ratio slightly decreases the water absorption of RHA specimens while for sludge ash specimens, as the percentage of sludge ash increases, water absorption values of concrete samples steadily increases as it is a water-permeable material that is distributed in the concrete pores allowing a more water absorption in the concrete mass. While the contribution of sludge ash material is a physical filler effect, the contribution of RHA is both physical and chemical (pozzolanic) effect. The microstructure analysis showed the effect of sludge ash addition on the interfacial bond zones in concrete and on pores. Considering the results of this research work, the reuse of these materials could represent significant environmental and economic benefits.

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