IOSR Journal of Engineering (IOSRJEN) www.iosrjen.org
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 08, Issue 9 (September. 2018), ||V (I) || PP 50-55

Production of Low-Cost Concrete Using Powder from Demolition Concrete

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Abstract: Recycling or recovering of concrete is a very important issue because it reduces both the use of new virgin aggregates and the unnecessary landfill of valuable materials that can be recovered and redeployed. In this study, concrete was crushed and sieved, then the fine recycled concrete powder (less than 90 μm diameter) was added to cement with different percentages (from 10 to 30 wt.%) to prepare mortar samples. Increasing the amount of recycled concrete powder was found to decrease the consistency which is related to the high content of limestone in the powder. The addition of recycled concrete powder decreased slightly the initial setting time and it did not affect the final setting of mortar samples, while the compressive strength of mortar samples decreased from 52.20±2.18 MPa to 50.91±0.57 MPa when 10 wt.% recycled concrete powder was added. Then recycled concrete powder was used to prepare concrete samples. The slump of concrete decreased with the increasing of powder content; it has a value between 6.0-7.0 cm. It was found that the recycled concrete powder can be added to concrete samples with a percentage up to 10 wt.% without significantly decreasing the compressive strength of the produced samples. The compressive strength of concrete samples decreased from 35.18±0.29 MPa to 33.67±0.12 MPa. The use of the recycled concrete powder was found to save approximately 8% of the cost of the used cement.

Keywords: Recycled concrete powder, Compressive strength, Consistency, Setting time.

Date of Submission: 26-08-2018 Date of acceptance: 07-09-2018

I. INTRODUCTION

Concrete is the most important material in building construction because it has many advantages such as strength, durability, heat storage capability and chemical inertia. Unfortunately, cement production, which is the main constituent in concrete, has huge bad effects on the global environment. Cement production is one of the most energy-intensive of all industrial manufacturing processes. Including direct fuel use for mining and transporting raw materials, cement production takes about 1,758 KWh for every ton of cement [1]. Approximately 1.25 ton of carbon dioxide could relate into the atmosphere during cement production, other air pollutants such as sulfur dioxide, nitrous oxides, and dust can also result in water pollution and solid waste [2].

In these days, scientists and researchers show an exponential interest towards recycling and reusing of concrete to produce high-quality concrete. They do that by using appropriate percentages from recycled concrete with some additives to the mixture of concrete [3-8]. The effects of the addition of recycled concrete on concrete properties, such as wear resistance, water absorption, and mechanical properties, were investigated [4,6,8].

C. Nenoa*et al*. studied the performance of mortar by replacing the natural sand by recycled fine aggregate with same particle size distribution; it was found that the flexural and compressive strength were improved up to 35% and 45%, respectively [4]. Utilization of crushed clay brick in the concrete industry was investigated; it was found that the using crushed clay brick, as alternative aggregates, has negative effects on concrete porosity and its mechanical properties. On the other hand, a decrease in its density and an increase in its thermal resistance were observed [6].

Construction waste management was one of the requirements to be considered in the construction buildings as green buildings [9]. The Palestinian Central Bureau of Statistics (PCBS) estimated that the solid waste produced quantities in West Bank were about 700000 tons in 2009 and it is expected to increase in the future [10]. Gaza Strip, which is a very small area, suffers from a huge volume of construction and demolition wastes, and the lack of natural aggregates. According to the United Nations Development Programme (UNDP), around 600,000 and 2,000,000 tons of rubble was generated in 2008 and 2014, respectively [9, 11]. The solid waste sector in Palestine, including construction waste, is still suffering from mismanagement, as the Palestinian Environmental Law should focus on adding some regulations that force workers in the construction field to get

rid rubble and debris that results from the construction sector in a properly manner. Without such regulations the accumulations of construction waste will be thrown in random dumps and on roadsides as it already happens [9]. However, construction waste management became an important topic, especially after the global trend of interest in green buildings. The Engineers association in Palestine founded the Palestine Higher Green Building Council in 2010, which was drawn up the main points for the conditions of green buildings.

In this work, concrete wastes which cause harms to the environment especially when thrown into lands were crushed to prepare recycled concrete powder. After sieving, the powder was used with different percentages to produce concrete (from 10 to 30 wt.%).The effects of powder content on the compressive strength of the produced concrete were investigated.

II. MATERIALS AND METHODS

2.1. Materials

Concrete waste mass was collected from different construction sites and solid waste dumps. The coarse aggregate, sand, cement type OPC 42.5 and chemical admixture type G according to ASTM C-494, were brought from Al-Nabali concrete batch plant in Birzeit city. The physical and mechanical properties of the used aggregate are shown in Table1.

Table1: Physical and Mechanical Properties of Aggregate Used in Concrete Mixtures.

Test Name	Coarse Aggregate (25mm)	Coarse Aggregate (14mm)	Wet Crushed Sand (10 mm)	Dry Crushed Sand (5 mm)	Natural Sand
Specific gravity	2.570	2.569	2.564	2.515	2.632
Saturated surface dry (SSD)	2.602	2.600	2.617	2.562	2.646
Apparent (App)	2.653	2.666	2.708	2.639	2.668
Water absorption (%)	1.2	1.5	2.1	1.9	0.5
Abrasion (%)	27.9		-	-	-
Sand equivalent (%)	-		81	60	83
Clay lumps	0.13	0.18	0.19	0.24	-
Soundness	2.34	2.14	1.15	2.12	-
Flakiness Index	14.2	15.8	-	-	-
Elongation Index	18.9	17.9	-	-	-

2.2 Methods

The collected concrete waste mass was ground using a Jaw crusher (PEF60X100 Model), a Pan Pulverizer (Model: SK-175) and a Sealing Grinding Machine GJ100-3. A fineness test was done for the recycled concrete powder using a fineness device (Blaine surface apparatus). The test was performed in full automation, and all information related to the fineness was recorded. The fineness of the crushed recycled concrete powder was about 5600 cm^2/g. The chemical analysis test of recycled concrete powder was carried out. The first stage of the experimental program was performed by the preparation of standard mortar according to the EN 196-1 standards with the replacementof cement with 10, 20, 30 wt.% recycled concrete powder (RCP). The mixtures proportions of the produced samples are shown in Table 2. Compressive strength, fineness, consistency and setting time tests were carried out for all mortar mixtures. The compressive strength test was done according to BS EN 12390-2 using a compressive strength machine (CYBER-PLUS EVOLUTION, Italy).Consistency and setting times were carried out using a vicat device (Vicat apparatus MaTest, 24030 BrembATe DI SoprA-Italy).

Table 2: The mixture proportions of mortar samples

Material	0 wt.% RCP	10 wt.% RCP	20 wt.% RCP	30 wt.% RCP
Cement (g)	450	405	360	315
Recycled concrete powder(g)	0	45	90	145
Standard Sand (g)	1350	1350	1350	1350
Water (g)	225	225	225	225

The second stage of the experimental program was performed by the preparation of standard concrete mixtures with the replacement of cement with 10, 20, 30 wt. % of the mix. Design of the prepared samples is shown in Table 3. Slump test of the samples was carried out according to ASTM C143 while the compressive strength test was done according to BS12390-2 by using compressive strength machine (CYBER-PLUS EVOLUTION, Italy).

Table 3: Mix design of concrete samples

Material	100 wt.% Cement	90 wt.% Cement and 10 wt.% RCP	80 wt.% Cement and 20 wt.% RCP	70 wt.% Cement and 30 wt.% RCP
	(Weight (kg)			
Coarse aggregate I	7.84	7.84	7.84	7.84
crushed sand	6.44	6.44	6.44	6.44
Medium aggregate	3.99	3.99	3.99	3.99
Fine aggregate	3.71	3.71	3.71	3.71
Natural Sand	5.46	5.46	5.46	5.46
Cement	3.92	3.53	3.14	2.74
Recycled concrete powder	0.00	0.39	0.78	1.18
Water	2.70	2.60	2.52	2.45
Additive (S430)	0.31	0.31	0.31	0.31

III. RESULTS AND DISCUSSIONS

3.1. Chemical Analysis of Recycled Concrete Powder

As shown in Table 4, the chemical composition of the recycled concrete powder is similar to the chemical composition of a pozzolan material, which is a siliceous and aluminous material that possesses little or no cementitious value. But in a finely divided form and in the presence of water, it reacts chemically with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties [12]. So, the percentage of alkali substances, which later have harmful effects on concrete, is low.

Table 4: Chemical analysis for the powder

Compound	Chemical Formula	(Wt. %)
Silicone oxide	SiO_2	14.010%
Magnesium oxide	MgO	5.537%
Calcium oxide	CaO	40.270%
Iron (III) oxide	Fe_2O_3	0.862%
Potassium oxide	K_2O	0.122%
Aluminum oxide	Al_2O_3	0.815%
Titanium oxide	TiO_2	0.061%
Manganese (III) oxide	Mn_2O_3	0.071%
Phosphorous pentoxide	P_2O_5	0.087%
Sodium oxide	Na_2O	0.557%
Loss on ignition		35.470%

3.2 Consistency and Setting Time of Mortar Samples

Table 5 shows the consistency results of the prepared samples. It can be observed that increasing the amount of recycled concrete powder slightly decreases the consistency. This indicates that the water content required to produce the cement paste has decreased. The decrease in the consistency is related to the high content of limestone in concrete powder, as shown in the chemical analysis test (Table 4). Limestone has low consistency, as noted when the limestone sample was carried out in the test, it was found to be about 23%.

Table 5: Effect of recycled concrete powder content on consistency and setting time of mortar samples

Samples	Consistency	Setting time	
		Initial time	Final time
100% cement	29.50%	140 min	170 min
90% cement, 10%powder	29.50%	130 min	185 min
80% cement, 20% powder	28.50%	120 min	180 min
70% cement, 30% powder	28.00%	115 min	175 min

The initial and final setting times of the produced samples are shown in Table 5. It can be observed that a two-hour initial setting is sufficient for a complete placement and compaction of concrete. The addition of recycled concrete powder slightly decreases the initial setting time which indicates that the addition of recycled concrete powder allows the reaction of hydration to start earlier. The period of the reaction took a longer time, this is due to the fact that the hydration reaction of the powder is slower than the reaction of pure cement.

3.3 Compressive Strength of Mortar Samples

It can be observed from Figure 1 that the addition of recycled concrete powder decreases the compressive strength of the prepared samples, but the addition of the powder up to 20 wt. % slightly decreased the compression strength but it remains at the acceptable range. The compressive strength of the sample containing 100 wt.% cement after 28 days was found to be 52.20±2.18 MPa while it decreased to 50.91±0.57 MPa and 47.59±0.20 MPa when 10 wt.% and 20 wt.% recycled powder concrete was added, respectively. The improvement in the compressive strength of mortar samples by replacing the natural sand with recycled fine aggregate with the same particle size distribution was reported [5].

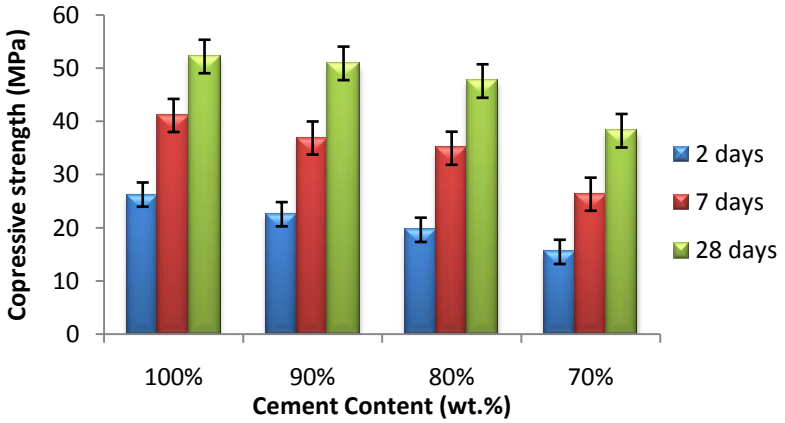

Figure 1: Effect of recycled concrete powder content on the compressive strength of mortar samples

3.4 Slump Test Results of Concrete Samples

The slump test results of the prepared samples after 20 minutes of mixing are shown in Table 6. The slump of concrete decreases with the decreasing in cement ratio, and it has a range between (6-7) cm. According to PS- 55; the types of concrete obtained were S_2 (4.1-6.5 cm) and S_3(6.6-9.0 cm), so they can be used for simple strip footings and cast in-situ hard-standing slabs.

Table 6: Slump test results

Concrete samples	Slump (cm)
Mix with 100% cement	7.0
Mix with 90% cement, 10%powder	6.5
Mix with 80% cement, 20% powder	6.0
Mix with 70% cement, 30% powder	6.0

3.5 Compressive Strength of Concrete Samples

It can be observed from Figure 2 that the compressive strength of samples decreases as the percentage of powder increases, but this decrease is in the acceptable range, it decreased from 35.18±0.29 MPa to 33.67±0.29 MPa when 10 wt.% powder was added. This can be related to the increase in the density of the produced concrete samples. As shown in Figure 3, the density of the samples increased from 2.33 g/cm^{3}to 2.41 g/cm^{3}when 20 wt.% of the recycled concrete powder was used, which is related to the small size of added recycled powder. The increase in the density of the produced samples improves their compressive strength. It was found that the compressive strength of concrete samples was not affected by the addition of fine aggregate replacement ratio, at least for up to 10 wt.% replacement ratios [7].

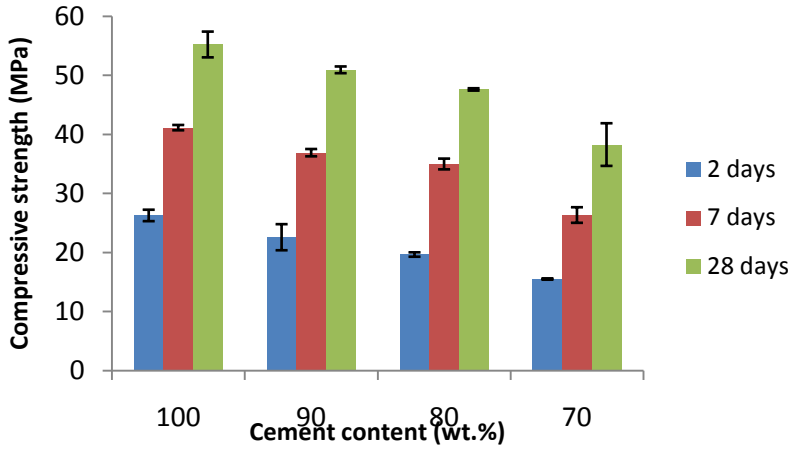

Figure 2: Compressive strength of concrete mixtures.

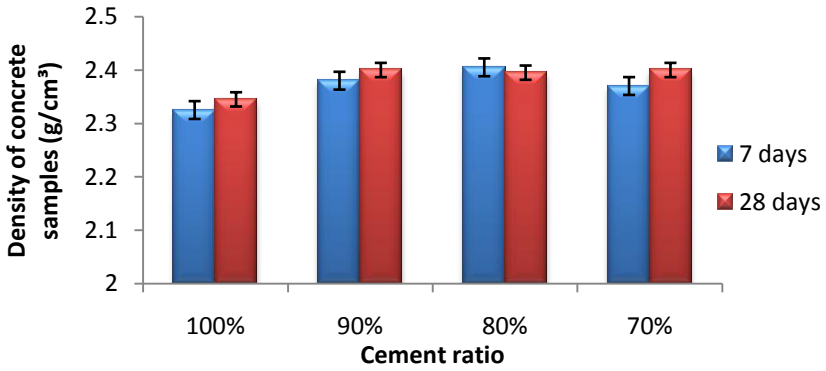

Figure 3: Density of concrete samples.

IV. CONCLUSION

It can be concluded that the addition of 10 wt.% of recycled concrete powder is the best percentage according to cost and concrete quality. It can save 8% of the total cost of cement because the most important step in concrete recycling is the crushing step which requires about 100 Nis for a ton, while the price of one ton of cement is in Palestine is about 500 Nis, so the replacement of cement with 10 wt.% of recycling concrete powder saves about 8% from the price of cement. Also, it was found that the addition of 10 wt.% recycled concrete powder reduces the compressive strength of the mortar and concrete samples 2.5% and 4.3%, respectively. The reduction in the compressive strength is acceptable according PS standard because the minimum required compressive strength of concrete grade B30 is 33 MPa after 28 days.

ACKNOWLEDGMENTS

The authors would like to thank Geotechnical & Material Center (GMT) staff in Ramallah-Palestine, Birzeit University Laboratories, Environmental Quality Authority in Ramallah stuff and Eng. AmranKharouby from UNDP – Gaza, Palestine.

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RaedMa'ali . "Production of Low-Cost Concrete Using Powder from Demolition Concrete. "IOSR Journal of Engineering (IOSRJEN), vol. 08, no. 9, 2018, pp. 50-55.