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Recycled Concrete Containing Limestone Filler

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Abstract: *The utilization of recycled aggregates is becoming a common practice and a method to improve concrete sustainability. The use of a cheap filler as partial replacement of the Portland cement, which is a high energy consuming material, is another technique to further improve sustainability. The use of fillers is more beneficial in the case of high strength concrete where both water and space are limited to achieve full hydration of cement. In this work the behavior and properties of concrete produced using 10% of filler as partial replacement of Portland cement in addition to partial replacement of conventional aggregates with recycled ones are investigated. Aggregates replacement ratios are 0, 10, 20 and 30%. Two types of fillers are utilized, crushed limestone and crushed dolomite. In general, it was found that the introduction of up to 30% recycled aggregates with 10% fillers will greatly improve sustainability with almost no effect on compressive strength. The resulting concrete is also of lighter weight for both fillers. The lightest weight was for 30% recycled aggregates with 10% Dolomite.*

Keywords: *Limestone, Dolomite, Filler, Recycled Aggregates, Concrete, Sustainability.*

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I. Introduction

The production of Portland cement leads to the release of a huge amount of carbon dioxide (CO_2) which is one of the greenhouse gases. The world annual production of Portland cement is about 3 billion tons. The production of one ton of cement results in the release about 0.9 ton of CO_2 into the environment. Greenhouse gases are the main cause of the currently experienced global warming. Due to its deleterious effects, it is necessary to reduce the CO_2 release into environment. Several methods to reduce cement utilization have been investigated. One of those methods is the partial replacement of Portland cement with a 'green' material [1]. The utilization of high strength concrete is becoming a common practice. The utilization of some types of fillers is gaining popularity as a method to achieve a cheaper, more sustainable concrete, especially with high strength concrete with low water to cement ratio, where no enough water or space are available for full cement hydration. Limestone is the most common type of filler. Dolomite is another promising type of filler that is considered in the current research investigation due to its availability in Kuwait.

The use of limestone fillers has been thoroughly investigated by many researchers. Portland Limestone cement (PLC) may be defined as cement that containing ground limestone as a partial replacement for Portland cement (PC). It is produced by blending Portland cement and limestone or intergrinding Portland cement clinker, limestone, and calcium sulfate [2]. The performance of Portland limestone cement is almost similar to Portland cement. The ASTM and CSA specifications both limit the amount of limestone in Portland Limestone Cement to 15%. The purpose of using limestone is to reduce the amount of cement clinker, to reduce the consumption of raw materials, and to achieve sustainable concrete [3].

Dolomite and limestone are considered carbonate rock. They are sedimentary rocks which can be grinded and used as a partial replacement for cement. Using dolomite as a partial replacement of cement to produce Portland Dolomite Cement (PDC) decreases the amount of cement which in turn reduce the CO_2 emissions [4]. Its use is not as common as limestone and research studies on the properties of dolomite as a partial cement replacement are limited [5].

The use of recycled concrete as aggregates is another common method of improving concrete sustainability. Characteristics and durability of concrete containing recycled aggregates were investigated by many researchers [6-8]. Quality improvement was also investigated [9].

The scope of this research is to investigate the properties and examine the performance of concretes produced using fine ground dolomite and limestone as partial replacements of Portland cement. Strength and durability properties such as compressive strength, tensile strength, shrinkage, permeability, absorption and Alkali-Silica Reaction are determined and compared. Sustainability of the resulting concrete is also investigated.

II. Materials And Mix Designs

The recycled aggregate (RA) used in the current work are produced commercially in Kuwait. Three different sizes (3/4 inches, ½ inches, and 3/8 inches) were utilized. Grading is determined by using wire-mesh sieves with square opening. Physical properties of recycled coarse aggregate are shown in Table1 while the properties of fine aggregates and conventional coarse aggregates are shown in Tables 2 and 3, respectively. Fine Aggregates are natural sand, acquired from local quarries in Kuwait while the natural coarse aggregates utilized are crushed stone (Gabbro), obtained from Ras al- Khaimah in the United Arab Emirates. Eight concrete mixes were prepared to investigate the compressive strength at 28 days of concrete with different ratios of recycled coarse aggregate as a partial replacement of natural coarse aggregate that combined with fixed percentage of filler (10% filler by the weight of cement) at different curing period (1, 3,7, and 28 days). Details of experimental mixes are shown in Table 4.

Table 1: Physical Properties of Recycled Coarse Aggregate

Sr.No.	*Properties*	Observed values (3/4 inches)	Observed values (1/2 inches)	Observed values (3/8 inches)
1	Bulk Specific Gravity(SSD)	2.47	2.43	2.39
2	Bulk Specific Gravity(OD)	2.38	2.31	2.25
3	Absorption (%)	4.09	5.14	6.12
4	Moisture Content (%)	1.24	3.36	3.5
5	Oven Dry Compacted Density(kg/m³)	1264	1208	1151

Table 2: Physical properties of fine aggregates

Properties	Observed values
Bulk Specific Gravity(SSD)	2.59
Bulk Specific Gravity(OD)	2.57
Absorption (%)	1.13
Moisture Content (%)	0.91
Fineness Modulus	2.46

Table 3: Physical properties of coarse aggregates

Properties	Observed values (3/4 inches)	Observed values (1/2 inches)	Observed values (3/8 inches)
Bulk Specific Gravity(SSD)	2.65	2.62	2.69
Bulk Specific Gravity(OD)	2.62	2.59	2.66
Absorption (%)	1.25	1.21	1.24
Moisture Content (%)	0.381	0.71	0.5
Oven Dry Compacted Density(kg/m³)	-	1609.71	1645.43

Table 4: Experimental matrix for mixes

Mixture No.	Composition (% by cement mass)			Replacement (%)		Designation
	OPC	Limestone	Dolomite	Natural Agg	Recycled Agg.	
M1	90	0	10	100	0	PDC 0 R
M2	90	0	10	90	10	PDC 10 R
M3	90	0	10	80	20	PDC 20 R
M4	90	0	10	70	30	PDC 30 R
M5	90	10	0	100	0	PLC 0 R
M6	90	10	0	90	10	PLC 10 R
M7	90	10	0	80	20	PLC 20 R
M8	90	10	0	70	30	PLC 30 R

The selected water to cement ratio was 0.35 to make sure part of cement will not be hydrated, the slump was kept between 50-100 mm, air content was 2-2.4%, coarse aggregate content was 1100 kg /m^3, and cement was 410 kg/m^3. Concrete mix proportion is shown in Table 5. Mixes were designed for compressive strength of 50 Mpa.

Table 5: Concrete Mix Proportion of Series A and B

Mixture No.	Value
W/c	0.35
Cementitious materials (Kg/m³)	410
Water (Kg/m³)	143.5
Sand (Kg/m³)	705
SSD Coarse Aggregate 3/8" (Kg/m³)	500
SSD Coarse Aggregate 1/2" (Kg/m³)	340
SSD Coarse Aggregate 3/4" (Kg/m³)	260
Super-plasticizer Dosage (L/100Kg CM)	2-2.5
Air Temperature (ºC)	22-23

Portland cement Type I was provided by Kuwait cement company (KCC). This type of cement is produced in accordance with the Kuwaiti standards specifications (KSS 381-383), and the American specifications (ASTM C150).Fine ground dolomite was obtained from National Industries Company of Kuwait (NIC). The chemical composition ranges of the acquired type of dolomite are shown in Table 6. Particle size distributions of cement, limestone and dolomite are shown in Figure1.

Table 6: Chemical composition ranges of dolomite

Chemical Composition	Percentage (range)
Silicon Dioxide	2-3
Aluminum Oxide	0.1-0.15
Ferric Oxide	0.2-0.25
Calcium Oxide	25-30
Magnesium Oxide	15-20
Carbon Dioxide	45-50
Calcium Carbonate	65-80

KUT PLAST SP-400 superplasticizing, high range, water reducing admixture was used in all concrete mixes, meeting the requirements ASTM C494 Type F.

III. Mixing And Samples Preparation

The eight concrete mixes and samples were prepared according to ASTM C192 (Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory).A 1200 kg rotating mixer was used to mix concrete. The three sizes of SSD coarse aggregate were added into the pan, and the aggregates were mixed for 30 seconds. The natural sand was then added and mixed for another 30 seconds. Cement and filler were added over the aggregates and the mixer was restarted. Half of the total amount of water was added to the mixer within a minute. The mixer was stopped, and the paddles of the pan were cleaned. Mixing restarted and the remaining water and admixture were added within 30 seconds. Mixing continued for 3 minutes before casting. Concrete was cast in moulds in two layers, each was compacted using a vibrator and vibrating table until the air bubbles disappeared on the surface of moulds. The finishing trowel was used to finish the surfaces. All moulds were covered with a wet burlap and polyethylene sheet and were kept at 20(±2) º C. The specimens were removed from moulds after 24 hours and were transferred to water tank for curing. The sample sizes cast are 150 mm cubes.

IV. Testing And Discussion

Fresh Concrete Properties

Slump and air content for all mixes were determined and found to be within target design ranges. Unit weight tests were performed at the age of 28 days. Three samples were tested for each property, averages are reported. Fresh properties results are shown in table 7. It can be observed that the slump values of mixtures M1 and M5 were low because these two mixtures were mixed in small size mixer while volume of concrete was large which resulted in much stiffer concrete , while the remaining mixtures achieved the required slump except M8 where the slump was slightly lower than the range. The unite weight was influenced by the amount of coarse aggregates replacement. The unit weight was reduced with the increase in the coarse aggregates replacement by reducing aggregates for both lime and dolomite cement replacement. It can be also noticed that the increase in the recycled aggregates percentage reduce the concrete unit weight as seen in Figure 1.

Compressive Strength

Eight mixtures that contain different level of recycled coarse aggregates (0, 10, 20, and 30%) as a partial replacement of natural coarse aggregates combined with fixed amount (10% by the weight of cement) of dolomite or limestone were tested at 28 days after being cured under water for different periods of 1, 3, 7, and 28days and then stored in laboratory for the rest of the 28 days. Twenty one cubes 150x150x150 mm for each mixture were tested for compression to determine the effect of different curing periods on cube compressive strength at 28 days. The results of the cube specimens are presented in Table 8.

Table 7: Fresh properties of concrete mixtures

Mixture No.	Designation	Superplasticiser (L/100Kg CM)	Air Content (%)	Slump (mm)	Unit Weight (Kg/m³)
M1	PDC 0 R	2	2.5	16	2443.2
M2	PDC 10 R	2	2.4	100	2424.5
M3	PDC 20 R	2	2.5	49	2392.5
M4	PDC 30 R	2	2.4	80	2372.9
M5	PLC 0 R	2	2.7	21	2442.7
M6	PLC 10 R	2	2.6	86	2421.4
M7	PLC 20 R	2	2.6	62	2401.7
M8	PLC 30 R	2	2.4	43	2391.3

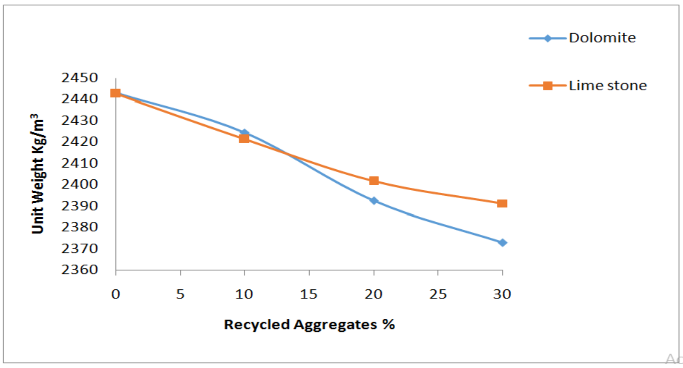

Figure 1: Effect of Recycled Aggregates on Unit Weight

Table 8: Average Cube Compressive Strength at 28 days

Average Cube Compression Strength (Mpa)	PDC 0R	PDC 10R	PDC 20R	PDC 30R	PLC 0R	PLC 10R	PLC 20R	PLC 30R
Strength at 1 day curing	45.72	41.64	40.14	37.86	38.72	35.77	40.74	40.64
Strength at 3 days curing	49.12	48.77	42.27	47.75	46.40	53.21	51.02	45.59
Strength at 7 days curing	53.73	51.87	48.19	49.01	42.05	54.07	52.11	50.05
Strength at 28 days curing	45.39	46.00	44.76	42.50	45.76	46.07	46.06	47.04

It is shown in Figure 2 that average cube compressive strength at 28 days increases with water curing time between 1 and 7 days for all concrete mixtures while it decreases for water curing periods between 7 and 28 days except mixture (PLC 0R). It increased for mixtures (PDC 0R), (PDC 10R), (PDC 20R), (PDC 30R), (PLC 10R), (PLC 20R), and (PLC 30R) by 1.09%, 6.36%, 14%, 2.6%, 1.61%, 2.13%, and 9.78% respectively between 3 and 7 days curing, while it decreased 15.53%, 11.32%, 7.12%, 13.3%, 14.8%, 11.61%, and 6.014% at age between 7 and 28 days of water curing.

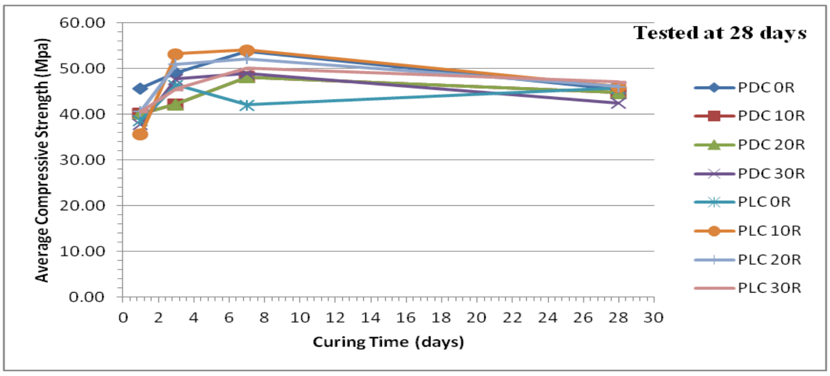

Figure 2: Comparison between average cube compressive strength at 28 days after different ages of water curing

The maximum average cube compressive strength (54.07 Mpa) was achieved for 7 days Water curing for mixture that contain 10% limestone as a partial replacement of cement and also 10% recycled coarse aggregates as a partial replacement of natural coarse aggregates (PLC 10R). This is due to two reasons, one is similar to the observation of Voglis et al (2005), who observed that the cement that contain limestone achieves higher early strength than the ordinary Portland cement or cement containing natural pozolona or fly ash up to 7 days, while, the second reason behind the 28 days curing was weaker than 7 days curing is due to the pressure of water on internal pores at 28 days curing since it was tested directly after removing samples from the water curing tank. On the other hand, the lowest strength was observed in mixture (PLC 10R) at age of 1 day strength.

The effects of coarse recycled aggregates replacement ratios on the average 28 days cube compressive strength afterwater curing of 1, 3, 7, and 28 days are displayed in Figure 3. At zero level of recycled aggregates, the maximum strength was obtained for (PDC) mixture at 7 days curing, while the minimum was achieved for (PLC) mixture at 1 day curing. The highest cube compressive strength at 10% recycled replacement was observed at (PLC) mixture at 7 days curing, while the minimum was achieved at 1 day for the same mixture.
The maximum compressive strength for mixtures containing 20% or 30% recycled aggregates was observed for limestone mixes (PLC 20R) and (PLC 30R) at 7 days curing, while the minimum compressive strength was observed for dolomite mixtures (PDC 20R) and (PDC 30R) at 1 days curing. It can be concluded that, as the recycled aggregate content increased to 10% (by weight of natural aggregate) in mixtures of 10% filler, the 28 days cube compressive strength increased after 7 and 28 days of water curing for limestone, and after 28 days only for dolomite, when compared with 100% natural aggregates.

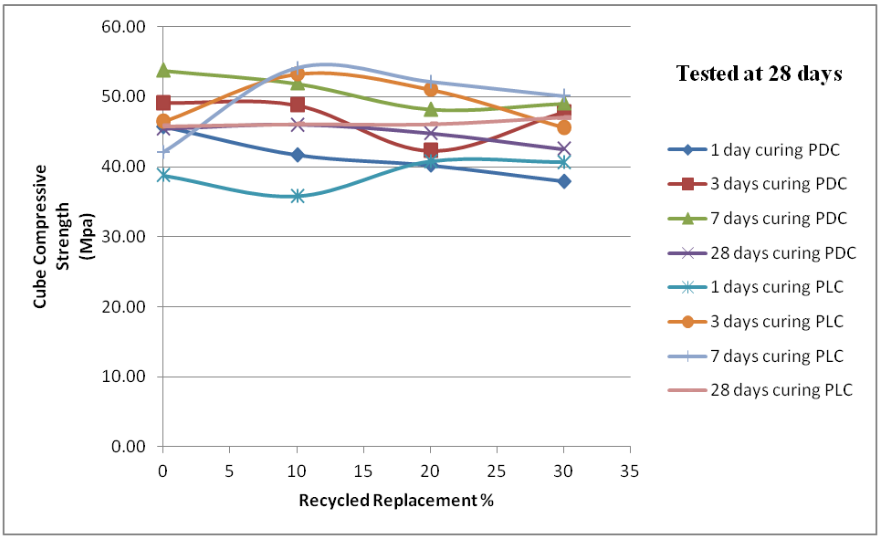

Figure 3: Effect of recycled aggregate replacement on compressive strength

V. Conclusions

In this paper, the properties of concrete produced using up to 30% recycled aggregates and incorporating 10% of either dolomite or limestone filler as partial replacement of cement were investigated. The following were concluded:

- It can be noticed that the increase in the recycled aggregates percentage reduce the concrete unit weigh.
- The compressive strength for mixtures containing recycled aggregates was found to decrease with the amount of recycled aggregates for mixes containing dolomite. The compressive strength, however, was found to increase with recycled aggregates percentage for mixes containing limestone filler.
- As the recycled aggregate content increased to 10% (by weight of natural aggregate) in mixtures of 10% filler, the 28 days cube compressive strength increased after 7 and 28 days of water curing for limestone, and after 28 days only for dolomite, when compared with 100% natural aggregates.
- The maximum average cube compressive strength (54.07 Mpa) was achieved for samples tested at the age of 28 days, subjected to 7 days of curing for the mixture containing 10% limestone as a partial replacement of cement and 10% recycled coarse aggregates as a partial replacement of natural coarse aggregates (PLC 10R).
- The use of filler as partial cement replacement reduces energy consumption in cement production and CO_2 emission by the same ratio. Concrete sustainability also improve due to the increased service life resulting from increased durability.
- Addition work is required to investigate the effect of the filler fineness on the properties and durability of resulting concrete.

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