EFFECT OF GRADING AND TYPES OF COARSE AGGREGATES ON THE COMPRESSIVE STRENGTH AND UNIT WEIGHT OF CONCRETE [+]

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Abstract:

Nine concrete mixes were prepared using natural river sand and uncrushed river gravel, with respect to the 7 and 28-day compressive strength results, it was found that the optimum combined grading group was Coarse Gravel + Fine Sand (CG+FS). Using the (CG+FS) grading group, results indicated that, concrete mixes prepared with natural river sand and uncrushed river gravel give the highest compressive strength among the four concrete mixes made of natural river sand with crushed limestone, crushed ceramic, and crushed glass waste as coarse aggregates respectively.On the other hand, concrete mixes prepared with natural river sand and crushed limestone waste give lower fresh, wet, and dry unit weight than those mixes prepared with natural river sand and crushed ceramic, crushed glass, and uncrushed gravel waste as coarse aggregate respectively.

Key words: Optimum Combined Grading, Compressive Strength, Unit Weight of concrete.

تأثير تدرج ونوع الركام الخشن على مقاومة انضغاط ووحدة وزن (كثافة) الخرسانة

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المستخلص:

تم صب تسعة مزجات خرسانية باستخدام الرمل النهري الطبيعي كركام ناعم والحصى النهري غير المكسر كركام خشن ، عند اخذ مقاومة الانضغاط للخرسانة بعمر ٧ يوم و٢٨ يوم بنظر الاعتبار ، تبين ان التدرج المشترك المثالي هو استخدام مجموعة الحصى الخشن + الرمل الناعم (CG+FS). باستخدام التدرج المشترك المثالي (CG+FS) أعلاه ، النتائج اظهرت ، ان المزجات الخرسانية المهيأة باستعمال الرمل النهري الطبيعي والحصى النهري الطبيعي غير المكسر تعطي مقاومة انضغاط اعلى مقارنة مع مزجات مشابهة مهيأة من الرمل النهري الطبيعي ومخلفات حجر الحلان المكسر ، السيراميك المكسر ، والزجاج المكسر كركام خشن على التوالي من ناحية اخرى ، فان المزجات الخرسانية المهيأة من الرمل النهري الطبيعي ومخلفات حجر الحلان يعطي كثافة طرية ، رطبة ، وجافة اقل مقارنة مع تلك المزجات المهيأة من الرمل النهري الطبيعي ومخلفات السيراميك المكسر ، الزجاج المكسر ، والحصى غير المكسر كركام خشن على التوالي.

الكلمات المفتاحية: التدرج المشترك المثالي ، مقاومة الانضغاط ، وحدة وزن الخرسانة.

Introduction:

Waste crushed glass, ceramic, and limestone has low-cost and aesthetic potential as

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aggregate. Glass concrete: a major research effort has been underway at Columbia University for a number of years, to develop new applications for waste glass as an aggregate for concrete. It was recognized early on that glass concrete is basically a new material that requires the development of appropriate production technologies, as well as answers to other questions that need to be addressed by basic research[1,2].

Concrete masonry block unit: was the first product to be developed for commercial production. Because modest goal was to replace just 10% of the fine aggregate with finely ground glass. Four batches were produced, the 28-day strength results were barely affected by the glass substitutions. This result was not surprising, because a 10% substitution was not expected to have much of an effect. Whereas replacing just the sand by finely ground glass may be of modest economic benefit, replacing also part of the cement by glass powder, which is obtained during crushing anyway, improves the economical outlook[3].

Architectural and decorative applications: the most exciting applications appear to be in the architectural and decorative fields. It is also can create surface textures and appearances using techniques well known in the field of architectural concrete, while fully utilizing the esthetic potential of colored glass. To name just a few : building façade elements, precast wall panels, partition walls, floor tiles, wall tile and panels, elevator paneling, table top counters, park benches, planters, trash receptacles, and ashtray[4].

The Taiwanese production of TFT–LCD front-panels comprises a global share of 43%, the highest production rate in the world. Inevitably, a large amount of waste is produced in the fabrication process. How to deal with waste LCD glass is an important work. In this study, the water-to-binder ratios were 0.28, 0.32, and 0.36,and four kinds of sand replaced by glass were used at volume with replacement ratios of 0%, 10%, 20%, and 30%. Hence, the partial replacement of sand by waste LCD glass can meet Japan Society of Civil Engineers (JSCE) SCC R2 property standards. Experimental data are provided and summarized for the efficiency of adding very fine quartz glass (VFQG) in high-alumina and corundum ceramic concrete technology. Similar suspensions are prepared for very fine quartz sand (VFQS) and a mixed suspension in the bauxite–VFQS system. The properties of both mixed suspensions and some materials based on them are studied[5,6].

In order to reduce the volume of ceramic waste from the construction industry, it is possible, among other applications, to use it as aggregates in the production of non-structural concrete artefacts. The results show that there is a potential for the use of these ceramic aggregates in elements in which the primary requirement is not compressive strength but tensile strength and abrasion resistance, such as for concrete pavement slabs. Experiments were carried out to determine the compressive, splitting tensile and flexural strengths and the modulus of elasticity of concrete with ceramic waste coarse aggregate and to compare them with those of conventional concrete made with crushed stone coarse aggregate. The properties of the aggregates were also compared. Test results indicate that the workability of ceramic waste coarse aggregate concrete is good and the strength characteristics are comparable to those of the conventional concrete[7,8]. Crushed limestone waste may be used satisfactorily as coarse aggregate for making quality concrete of a desirable compressive strength, and it may be suggested to be a solution for regions where natural aggregate are scarce as well as a reduction in the dead weight of structure may be desirable. The unit weight of the crushed limestone concrete is (2060) kg/m^3 which is about (10)% lower than that of the uncrushed river gravel concrete. The absorption capacity of the crushed limestone concrete is lower than that of the uncrushed river gravel concrete[9].

The aim of this research included, obtaining the optimum combined grading group of sand and gravel, using nine mixes prepared with natural river sand and uncrushed river gravel, in order to determine the compressive strength and the unit weight of concrete produced with different types of coarse aggregates, such that, natural river sand and uncrushed river gravel, crushed waste of glass, ceramic, and limestone respectively.

Experimental Program:

1-. Mix proportions:

Different mixes were prepared using combined grading of sand and gravel and different types of crushed waste, as follows:

(a) In order to compare results objectively, a control mix (Reference Mix) made from natural river sand and uncrushed river gravel is needed to benchmark the results.

Using the British mix design method, concrete mixes are designed for the following data: the 28-day target strength of 40 MPa; maximum aggregate size = 10 mm.; sand zone No. 2; medium workability, and the resulting mix proportions for the uncrushed and crushed coarse aggregates were shown in Table (1).

Table (1): Proportions of concrete mixes

Constituents (kg/m^3)	Uncrushed coarse aggregates	Crushed coarse aggregates
Cement	346	394
Water	180	205
Sand	624	620
Gravel	1240	1231
Mix proportions	1.00 : 1.80 : 3.58 , w/c = 0.500	1.00 : 1.57 : 3.12 , w/c = 0.550

(b) Glass concrete mixes with natural river sand and 100 % of the uncrushed river gravel replaced by a crushed glass waste;

(c) Ceramic concrete mixes with natural river sand and 100 % of the uncrushed river gravel replaced by a crushed ceramic waste; and

(d) Limestone concrete mixes with natural river sand and 100 % of uncrushed river gravel replaced by a crushed limestone waste.

2- Materials Used:

Materials used in this research included:

(a) Cement: Turkish Ordinary Portland cement (OPC, Elazig, TSEN 197-1, 42.5), its physical properties are shown in Table (2).

Table (2): Physical properties of the used cement

Properties	Used cement	Typical value (Iraqi Specification No. 5)[10]
Blain fineness, cm^2/gm.[11]	3400	2250 , min.
Setting time (Vicat method)[12]:		
Initial time, minutes.	185	60 , min.
Final time, hours.	3.35	10 , max.
Compressive strength (average)[13]:		
3-day age, kg/cm^2.	200.0	160 , min.
7-day age, kg/cm^2.	297.0	240 , min.
Soundness, Autoclave test, %.[14]	0.6	0.8 , max.

(b) Aggregates: Natural river sand and uncrushed river gravel, crushed glass waste, crushed ceramic waste, and crushed limestone waste. Aggregate gradation, sieve analysis of

fine and coarse aggregates is done in accordance with BS : 882 : 1992.
Natural river sand is prepared by washing the sand on sieve No. 200, drying it in an oven 100-110^oC for 24 hours, separating the sample in many sizes using the standard sieves used in fine aggregates, and then remix these individual sizes using the calculated satisfying percentages retained on each sieve to prepare the tested specimen
used in concrete.
The uncrushed river gravel is also prepared by washing the gravel, drying it in an oven 100-110^oC for 24 hours, separating the sample in many sizes using the standard sieves used in coarse aggregates and then mix these individual sizes using the calculated satisfying percentages retained on each sieve to prepare the tested specimen used in concrete.
The gradation of the crushed glass, ceramic, and limestone wastes aggregates was the same as that of the uncrushed river gravel.
The grading requirements and physical properties for all types of fine and coarse aggregates are tabulated in Tables (3 to 9)[15,16,17,18,19].
(c) All aggregates were in dry condition, w/c ratios are adjusted for S.S.D. condition.

Table (3): BS : 882 : 1992 / for fine aggregate[15]

Sieve Size		Percentage Passing(%)		
ASTM	B.S. (mm.)	FINE	MEDIUM	COARSE
3/8 in.	10	100	100	100
No. 4	4.75	**100 – 89**	**100 – 89**	**100 – 89**
No.8	2.36	80 – 100	65 – 100	60 – 100
No.16	1.18	70 – 100	45 – 100	30 – 90
No.30	0.60	55 – 100	35 – 80	15 – 54
No.50	0.30	5 – 70	5 – 48	5 – 40
No.100	0.15	15 – 0	15 – 0	15 – 0

Table (4): BS : 882 : 1992 / for coarse aggregate[15]

Sieve Size		Percentage Passing(%)		
ASTM	B.S. (mm.)	5 – 14 mm. (FINE)	5 – 20 mm. (MEDIUM)	5 – 40 mm. (COARSE)
2.0 in.	50	-	-	100
$1^1/2$ in.	40	-	100	90 – 100
3/4 in.	20	100	90 – 100	35 – 70
1/2 in.	14	90 – 100	40 – 80	25 – 55
3/8 in.	10	50 – 85	30 – 60	10 – 40
No. 4	4.75	0 – 10	0 – 10	0 – 5

Table (5): Grading requirement for sand

Sieve Size		Percentage Retained on each sieve (%)		
B.S. (mm.)	ASTM	Coarse Sand CS	Medium Sand MS	Fine Sand FS
4.75	No. 4			
2.36	No. 8	40	20	
1.18	No.16	30	10	
0.60	No.30	5	10	
0.30	No.50	20	30	30
0.15	No.100	5	30	55
0.075	No.200			15
Fineness Modulus (FM)		3.80	2.60	1.15

Table (6): Grading requirement for gravel

Sieve Size		Percentage Retained on each sieve (%)		
B.S. (mm.)	ASTM	Coarse Gravel CG	Medium Gravel MG	Fine Gravel FG
40	$1^1/2$ in.			
20	3/4 in.	65	5	
14	1/2 in.	10	35	
10	3/8 in.	15	15	15
4.75	No. 4	10	40	75
2.36	No. 8		5	10
Fineness Modulus (FM)		8.30	6.95	6.05

Table (7): Summary of sand and gravel grading

Sieve Size		Percentage Retained on each sieve (%)					
		SAND			GRAVEL		
B.S. (mm.)	ASTM	Coarse Sand CS	Medium Sand MS	Fine Sand FS	Coarse Gravel CG	Medium Gravel MG	Fine Gravel FG
40	$1^1/2$ in.						
20	3/4 in.				65	5	
14	1/2 in.				10	35	
10	3/8 in.				15	15	15
4.75	No. 4				10	40	75
2.36	No. 8	40	20			5	10
1.18	No.16	30	10				
0.60	No.30	5	10				
0.30	No.50	20	30	30			
0.15	No.100	5	30	55			
0.075	No.200			15			
Fineness Modulus (FM)		3.80	2.60	1.15	8.30	6.95	6.05

Table (8): Combined grading groups of sand and gravel

Group No.	1	2	3	4	5	6	7	8	9
Combined Grading Groups	CG + FS	CG + MS	CG + CS	MG + CS	MG + MS	MG + FS	FG + CS	FG + MS	FG + FS

Table (9): Main properties of coarse and fine aggregates used

Property	River Uncrushed Gravel	Crushed Glass Wastes	Crushed Ceramic Wastes	Crushed Limestone Wastes	Natural River Sand
Dry sp. Gravity	2.658	2.38	2.029	2.015	2.64
S.S.D. sp. Gravity	2.685	2.51	2.273	2.164	2.67
App. sp. Gravity	2.732	2.47	2.45	2.368	2.722
Absorption capacity (%)	1.01	0	12	7.4	1.15
Rodded Unit Weight (kg/m^3)	1715	1650	1200	1150	1765
Voids content (%)	37.2	33.3	51	51.4	35.2
Angularity No.	4.2	0.2	18	18.4	2.2
Angularity Index	1.63	1.03	3.7	3.76	1.32

*** Maximum aggregate size of coarse aggregates is = 10 mm.**

3-Specimens prepared:

The mentioned materials were used in preparing and casting a concrete specimens, such that:
(a) For conventional concrete (Reference Mix): 100x100x100 mm. cubes using natural (uncrushed) river sand and gravel, with (1 : 1.80 : 3.58, w/c = 0.50) mix proportions (by weight), in order to perform the compressive strength and unit weight tests[20,21].
(b) For glass concrete: 100x100x100 mm. cubes using natural river sand and crushed glass waste as coarse aggregate, with (1 : 1.57 : 3.12, w/c = 0.55) mix proportions (by weight), in order to perform the compressive strength and unit weight tests[20,21].
(c) For ceramic concrete: 100x100x100 mm. cubes using natural river sand and crushed ceramic waste as coarse aggregate, with (1 : 1.57 : 3.12, w/c = 0.55) mix proportions (by weight), in order to perform the compressive strength and unit weight tests[20,21].
(d) For limestone concrete: 100x100x100 mm. cubes using natural river sand and crushed limestone waste as coarse aggregate, with (1 : 1.57 : 3.12, w/c = 0.55) mix proportions (by weight), in order to perform the compressive strength and unit weight tests[20,21].

Notes:

1. Tap water for mixing and curing is used;
2. Concrete is mixed mechanically;
3. Pond curing is applied (23^{o}C, 95% relative humidity);
4. No admixtures are used;
5. All experiments and tests were done in concrete and material laboratories of Building & Construction Department / Technical College of Mosul.

Results and discussion:

1-Results of stage (1):
In order to obtain the optimum combined grading group, nine concrete mixes with natural river sand and uncrushed gravel, and (1 : 1.80 : 3.58, w/c = 0.50) mix proportions by weight were prepared using the nine combined grading groups.
Compressive strength and unit weight results were shown in Tables (10 to 19) and illustrated in Figs. (1 and 2).

Table (10) : Compressive strength and unit weight results for Group No. (1) mixes, using natural river sand and uncrushed gravel, and the combined grading group (CG + FS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2480	2465	2420	2520	2495	2510	2482
Wet unit weight (kg/m^3)	2465	2450	2410	2515	2515	2500	2476
Dry unit weight (kg/m^3)	2350	2330	2340	2440	2435	2425	2387
7-day compressive strength (MPa)	16.27	14.49	15.90	--	--	--	15.55
28-day compressive strength (MPa)	--	--	--	23.60	25.90	25.00	24.83

Table (11): Compressive strength and unit weight results for Group No. (2) mixes, using natural river sand and uncrushed gravel, and the combined grading group (CG + MS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2530	2510	2560	2530	2510	2525	2528
Wet unit weight (kg/m^3)	2515	2500	2545	2510	2495	2505	2512
Dry unit weight (kg/m^3)	2415	2390	2495	2440	2475	2465	2447
7-day compressive strength (MPa)	15.60	16.30	16.20	--	--	--	16.03
28-day compressive strength (MPa)	--	--	--	24.20	25.10	25.20	24.83

Table (12): Compressive strength and unit weight results for Group No. (3) mixes, using natural river sand and uncrushed gravel, and the combined grading group (CG + FS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2495	2490	2475	2485	2455	2430	2472
Wet unit weight (kg/m^3)	2470	2480	2460	2470	2435	2425	2457
Dry unit weight (kg/m^3)	2370	2395	2325	2385	2365	2375	2369
7-day compressive strength (MPa)	22.00	21.10	22.8	--	--	--	21.97
28-day compressive strength (MPa)	--	--	--	31.00	32.50	33.00	32.17

Table (13): Compressive strength and unit weight results for Group No. (4) mixes, using natural river sand and uncrushed gravel, and the combined grading group (MG + CS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2485	2530	2525	2560	2570	2540	2535
Wet unit weight (kg/m^3)	2470	2500	2480	2535	2530	2525	2507
Dry unit weight (kg/m^3)	2445	2450	2415	2475	2480	2485	2458
7-day compressive strength (MPa)	16.30	15.00	15.90	--	--	--	15.73
28-day compressive strength (MPa)	--	--	--	24.00	22.30	24.20	23.50

Table (14): Compressive strength and unit weight results for Group No. (5) mixes, using natural river sand and uncrushed gravel, and the combined grading group (MG + MS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2330	2355	2430	2435	2435	2390	2396
Wet unit weight (kg/m^3)	2305	2345	2415	2405	2415	2380	2393
Dry unit weight (kg/m^3)	2255	2270	2335	2330	2375	2365	2322
7-day compressive strength (MPa)	16.70	14.90	16.10	--	--	--	15.90
28-day compressive strength (MPa)	--	--	--	23.80	25.90	25.00	24.90

Table (15): Compressive strength and unit weight results for Group No. (6) mixes, using natural river sand and uncrushed gravel, and the combined grading group (MG + FS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2410	2450	2455	2455	2445	2415	2438
Wet unit weight (kg/m^3)	2395	2435	2450	2435	2405	2395	2419
Dry unit weight (kg/m^3)	2345	2375	2395	2385	2365	2350	2369
7-day compressive strength (MPa)	18.20	17.40	17.90	--	--	--	17.83
28-day compressive strength (MPa)	--	--	--	28.34	26.30	28.24	27.63

Table (16): Compressive strength and unit weight results for Group No. (7) mixes, using natural river sand and uncrushed gravel, and the combined grading group (FG + CS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2540	2450	2550	2685	2520	2580	2554
Wet unit weight (kg/m^3)	2525	2425	2540	2640	2505	2560	2533
Dry unit weight (kg/m^3)	2430	2390	2485	2575	2450	2490	2470
7-day compressive strength (MPa)	17.20	18.00	18.70	--	--	--	17.97
28-day compressive strength (MPa)	--	--	--	28.30	28.80	27.90	28.33

Table (17): Compressive strength and unit weight results for Group No. (8) mixes, using natural river sand and uncrushed gravel, and the combined grading group (FG + MS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2430	2445	2465	2475	2435	2420	2445
Wet unit weight (kg/m^3)	2420	2430	2460	2415	2430	2420	2429
Dry unit weight (kg/m^3)	2355	2375	2385	2380	2375	2395	2378
7-day compressive strength (MPa)	14.60	14.50	14.20	--	--		14.43
28-day compressive strength (MPa)	--	--	--	24.70	25.10	25.20	25.00

Table (18): Compressive strength and unit weight results for Group No. (9) mixes, using natural river sand and uncrushed gravel, and the combined grading group (FG + FS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2420	2400	2415	2420	2410	2435	2417
Wet unit weight (kg/m^3)	2395	2380	2410	2410	2405	2420	2403
Dry unit weight (kg/m^3)	2365	2325	2340	2355	2340	2375	2350
7-day compressive strength (MPa)	20.20	20.50	20.10	--	--	--	20.27
28-day compressive strength (MPa)	--	--	--	29.00	28.20	29.10	28.76

Table (19): Summary of compressive strength and unit weight results using the NINE combined grading groups with natural river sand and uncrushed gravel

Group No.	1	2	3	4	5	6	7	8	9
Combined Grading Groups	CG + CS	CG + MS	CG + FS	MG + CS	MG + MS	MG + FS	FG + CS	FG + MS	FG + FS
Fresh unit weight (kg/m^3)	2482	2528	2472	2535	2396	2438	2554	2445	2417
Wet unit weight (kg/m^3)	2476	2512	2457	2507	2393	2419	2533	2429	2403
Dry unit weight (kg/m^3)	2387	2447	2369	2458	2322	2369	2470	2378	2350
7-day compressive strength (MPa)	15.55	16.03	21.97	15.73	15.90	17.83	17.97	14.43	20.27
28-day compressive strength	24.83	24.83	32.17	23.50	24.90	27.63	28.33	25.00	28.76

(MPa)									

*** Results are average of six specimens.**

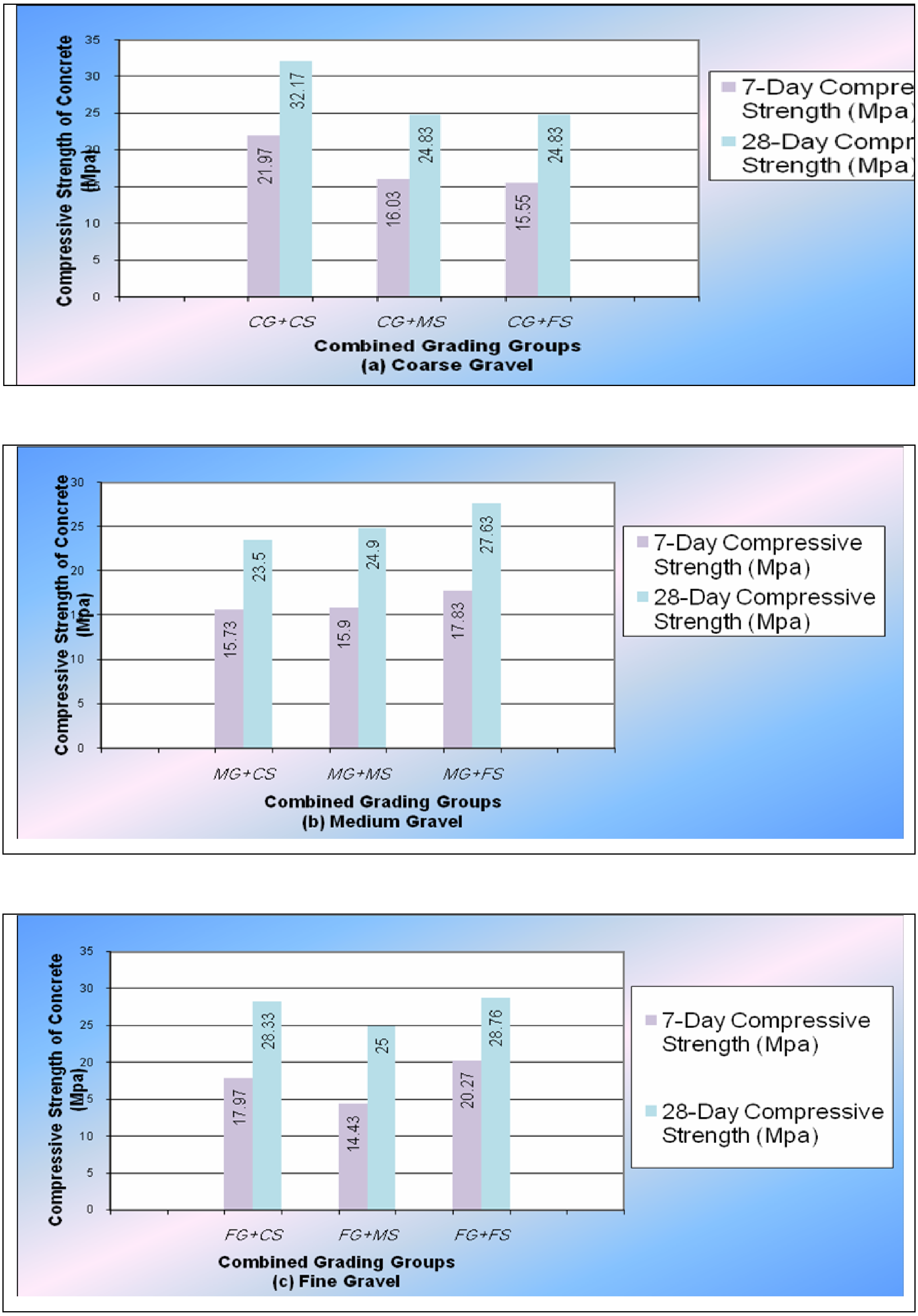
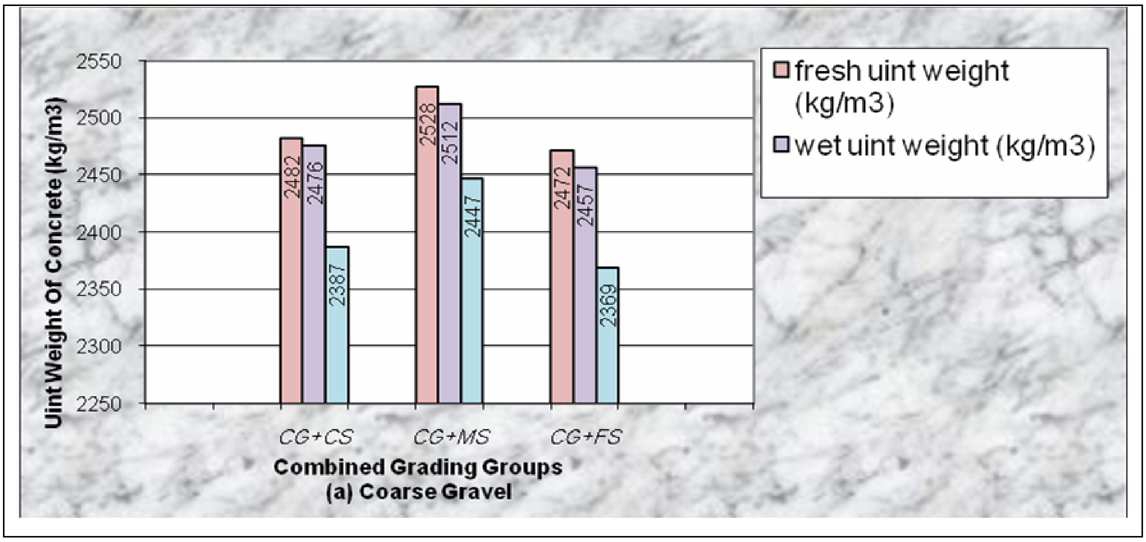
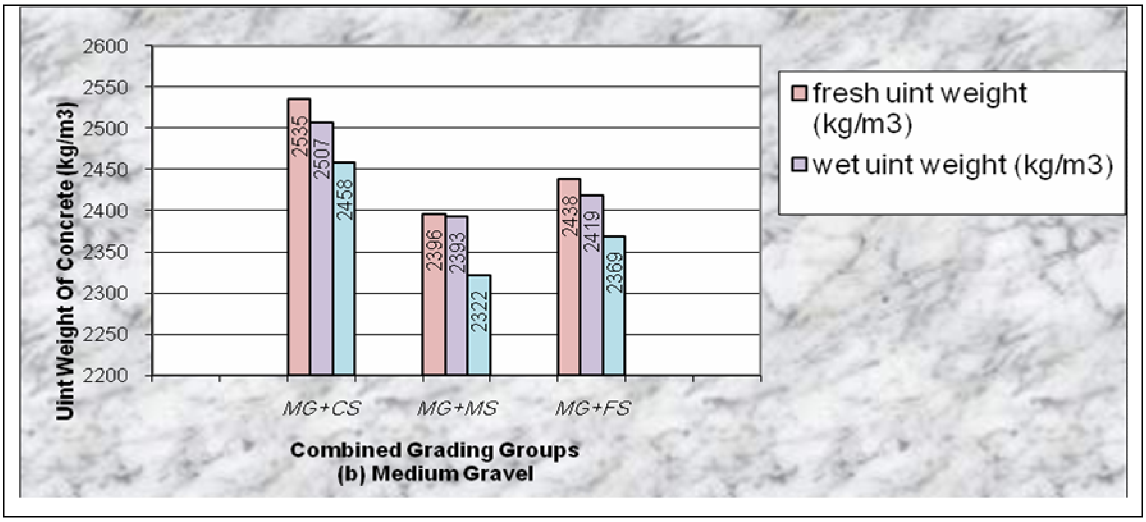


Fig. (1): Diagrammatic scheme for compressive strength using natural river sand and uncrushed river gravel





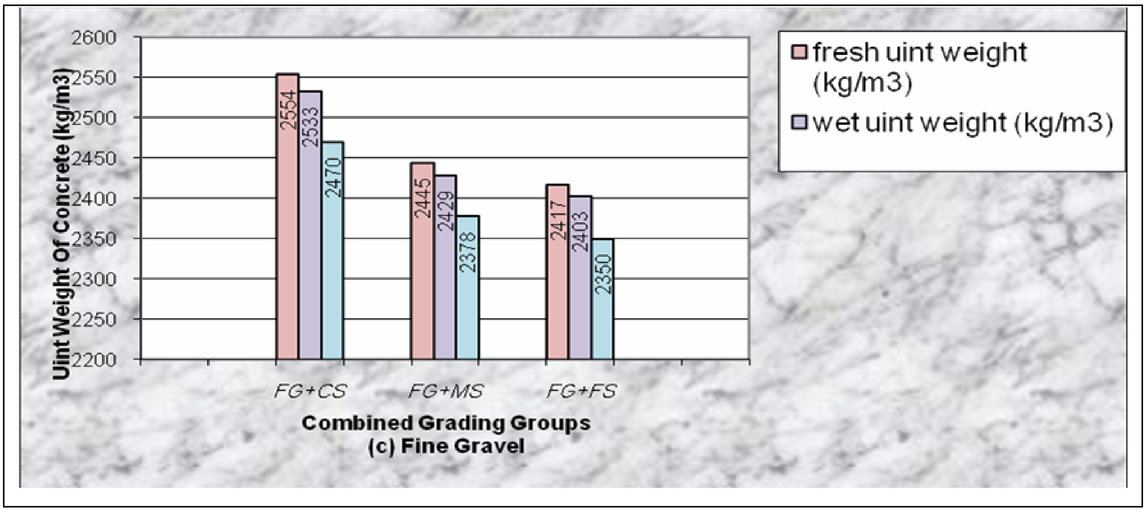


Fig. (2): Diagrammatic scheme for Fresh, Wet, Dry unit weight using natural

river sand and uncrushed river gravel

Depending on the compressive strength results, it is clear that the combined grading group Coarse Gravel + Fine Sand (CG + FS) gives the optimum combined grading group.

1- Results of stage (2):

In order to determine the compressive strength and fresh, wet, and dry unit weight of concrete using different types of crushed coarse aggregates obtained from waste, and the optimum combined grading group defined as Coarse Gravel + Fine Sand (CG + FS), (1.00 : 1.57 : 3.12 , w/c = 0.550 for crushed aggregates) is used to prepare four different concrete mixes, such that:

- Natural river sand with uncrushed river gravel mixes (Reference Mix);
- Natural river sand with crushed glass mixes;
- Natural river sand with crushed ceramic mixes;
- Natural river sand with crushed limestone mixes.

Compressive strength and unit weight results for natural river sand with uncrushed river gravel mixes are shown in Table (3), and results for crushed glass, crushed ceramic, and crushed limestone wastes were shown Tables (20 to 23) and illustrated in Figs. (3 and 4).

Table (20): Compressive strength and unit weight results for natural river sand and crushed glass mixes using the Optimum Combined Grading (CG + FS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2265	2275	2305	2365	2205	2295	2285
Wet unit weight (kg/m^3)	2235	2210	2245	2220	2250	2230	2232
Dry unit weight (kg/m^3)	2165	2140	2155	2150	2185	2145	2151
7-day compressive strength (MPa)	12.00	11.10	12.80	--	--	--	11.97
28-day compressive strength (MPa)	--	--	--	13.00	13.50	13.80	13.43

Table (21): Compressive strength and unit weight results for natural river sand and crushed ceramic mixes using the Optimum Combined Grading (CG + FS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2235	2220	2220	2225	2210	2240	2225
Wet unit weight (kg/m^3)	2150	2125	2185	2125	2180	2175	2157
Dry unit weight (kg/m^3)	1925	2040	1990	1985	2085	2010	2006
7-day compressive strength (MPa)	13.00	13.70	13.80	--	--	--	13.50
28-day compressive strength (MPa)	--	--	--	21.00	20.50	21.80	21.10

Table (22): Compressive strength and unit weight results for natural river sand and crushed limestone mixes using the Optimum Combined Grading (CG + FS)

Specimen No.	1	2	3	4	5	6	Averages
Fresh unit weight (kg/m^3)	2180	2220	2230	2145	2220	2215	2202
Wet unit weight (kg/m^3)	2140	2165	2175	2105	2135	2195	2153
Dry unit weight (kg/m^3)	1975	2005	1985	1975	2010	1985	1989
7-day compressive strength (MPa)	22.80	22.70	23.06	--	--	--	22.85
28-day compressive strength (MPa)	--	--	--	28.00	28.50	28.80	28.43

Table (23): Summary of compressive strength and unit weight results using the Optimum Combined Grading Group (CG + FS) with different types of crushed wastes as coarse aggregates

Types of Crushed Wastes	Natural River Sand and Uncrushed Gravel	Natural River Sand and Crushed Glass	Natural River Sand and Crushed Ceramic	Natural River Sand and Crushed Limestone
Fresh unit weight (kg/m^3)	2472	2285	2225	2202
Wet unit weight (kg/m^3)	2457	2232	2157	2153
Dry unit weight (kg/m^3)	2369	2151	2006	1989
7-day compressive strength (MPa)	21.97	11.97	13.50	22.85
28-day compressive strength (MPa)	32.17	13.43	21.10	28.43

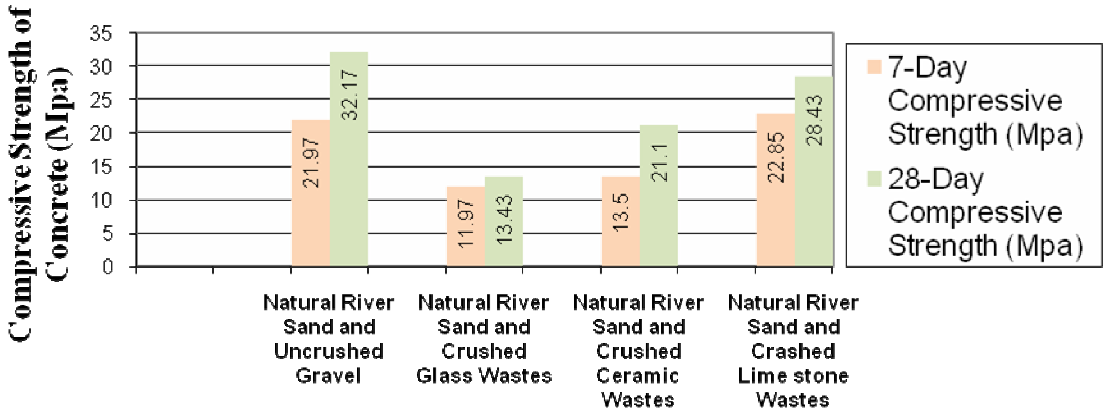


Fig. (4-3): Diagramatic Scheme for Compressive Strength of Concrete Using (CG+FS) Combined Grading Group

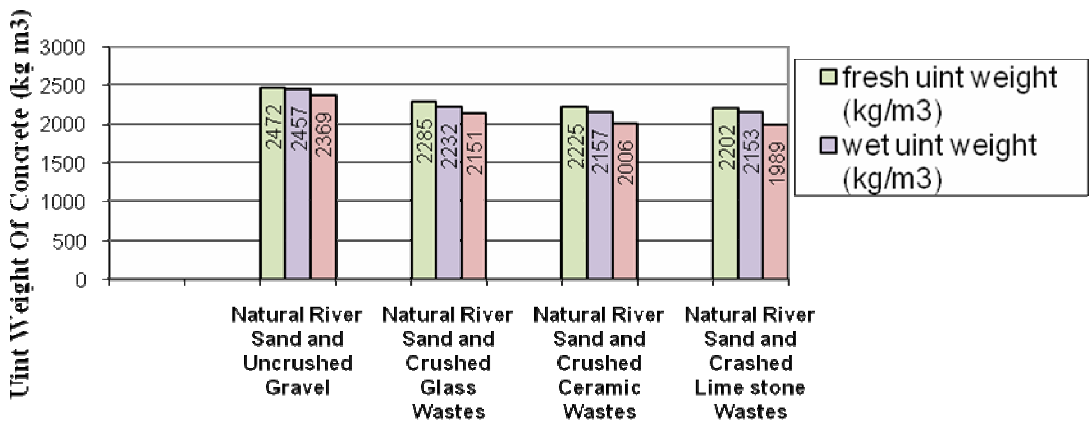


Fig. (4-4): Diagramatic Scheme for Fresh, Wet, and Dry Unit Weight of Concrete Using (CG+FS) Combined Grading Group

2- <u>Effect of type of coarse aggregates on the compressive strength of concrete</u>:

It is clear that concrete mixes of natural river sand with uncrushed river gravel give higher compressive strength than those mixes prepared of natural river sand with crushed glass, crushed ceramic, and crushed limestone waste as coarse aggregate respectively. This is due to that glass aggregate would affect the mechanical properties of concrete, such that, the bond strength between cement paste and aggregate is lower in the case of glass waste, i.e, the natural uncrushed river aggregate shaped with relatively rough surfaces is replaced by crushed glass particles with relatively smooth surfaces, in this case one would expect a drop in strength. On the other hand, the drop in compressive strength for crushed ceramic and limestone waste is due to the absorption capacity of these waste is higher than the natural river sand and gravel. The main problem with ceramic aggregates is their high water absorption, therefore, strength decreases as the quantity of ceramic aggregates in concrete increases, since they are lighter and less resistance than the primary river uncrushed gravel[7,8].

3- Effect of type of coarse aggregates on the fresh, wet, and dry unit weight:

It is clear that concrete mixes of natural river sand with crushed limestone give lower fresh, wet, and dry unit weight than those mixes prepared of natural river sand with crushed ceramic, crushed glass, and uncrushed gravel wastes as coarse aggregate respectively. This is due to specific gravity and unit weight of glass, ceramic, and limestone are smaller than those for the uncrushed river gravel as shown in Table (18).

Conclusions:

Based on the results obtained, the following conclusions can be drawn:

1. With respect to the 7 and 28-day compressive strength results, the optimum combined grading group was Coarse Gravel + Fine Sand (CG + FS).
2. Concrete mixes of natural river sand with uncrushed river gravel give the highest compressive strength among the FOUR concrete mixes made of natural river sand with crushed limestone, crushed ceramic, and crushed glass waste as coarse aggregates respectively.
3. Concrete mixes of natural river sand with crushed limestone waste give lower fresh, wet, and dry unit weight than those mixes prepared of natural river sand with crushed ceramic, crushed glass, and uncrushed gravel waste as coarse aggregates respectively.

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