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Recycled Aggregate Self-curing High-strength Concrete

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Abstract

The use of recycled aggregates from demolished constructions as coarse aggregates for concrete becomes a need to reduce the negative effects on the environment. Internal curing is a technique that can be used to provide additional moisture in concrete for more effective hydration of cement to reduce the water evaporation from concrete, increase the water retention capacity of concrete compared to the conventionally cured concrete. High strength concrete as a special concrete type has a high strength with extra properties compared to conventional concrete. In this research, the combination of previous three concrete types to obtain self-curing high-strength concrete cast using coarse recycled aggregates is studied. The effect of varying water reducer admixture and curing agent dosages on both the fresh and hardened concrete properties is studied. The fresh properties are discussed in terms of slump values. The hardened concrete properties are discussed in terms of compressive, splitting tensile, flexure and bond strengths. The obtained results show that, the using of water reducer admixture enhances the main fresh and hardened properties of self-curing high-strength concrete cast using recycled aggregate. Also, using the suggested chemical curing agent increased the strength compared to conventional concrete without curing.

Keywords: Self-Curing Concrete; High-Strength Concrete; Recycled Aggregate; Polyethylene Glycol PEG 400; Super Plasticizer.

1. Introduction

Recycled aggregates are those aggregates produced from the demolished constructions. The utilization of recycled aggregate in concrete production increases due to environmental and economic considerations to produce recycled aggregate concrete (RAC) [1, 2]. RAC is the concrete, which made with recycled aggregate as partially or fully replacement from natural coarse aggregate. Since recycled aggregate produced from different sources with an occupation of around 75% of the concrete volume, it is necessary to obtain suitable recycled aggregate with sufficient quality. This requires advancing processing techniques using special facilities to control the quality of recycled aggregate [3-5].

Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration processes to provide time for the hydration of the cement to occur [6]. Self-curing concrete (SC) is the concrete which able to cure itself by retaining its moisture content by adding curing admixtures or by the application of curing compounds [7-10]. Self-curing concrete caused in better hydration along time under drying condition compared to conventional concrete [8]. SC has good durable characteristics that water transport through SC is lower than air-cured conventional concrete [11, 12]. Also, it performs efficiently under elevated temperature such as conventional concrete [15]. Combining the use of recycled aggregate with SC concrete provides satisfactory characteristics [16].
High-strength concrete (HSC) is widely used in the construction industry, like tall buildings and bridges due to it is increased strength, higher stiffness, higher durability, reduced creep, economical cost, good impact resistance, drying shrinkage and resistance to abrasion. HSC is achieved by adding different mineral materials like fly ash, silica fume,

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super plasticizer, fibers etc. [17, 18]. HSC may or may not require special materials, but it surely requires high quality materials with adequate suitable proportions. In the manufacture of HSC, use of clean and strong aggregates is essential. Also, lower water-cement ratio along with super plasticizer is needed [19].

Using curing agents with high strength concrete to obtain self-curing high-strength concrete (SC-HSC) is efficient [17]. Subramanian et al., 2015 found that the using of self-curing agent for SC-HSC improves workability. Also, the strength of SC-HSC developed when using a silica fume as 10% replacement of cement weight and Rapid chloride permeability of the concrete decreases with silica fume of about 15% [17]. In this research, SC-HSC cast using recycled aggregate to be recycled aggregate self-curing high-strength (RA-SC-HSC) as a special concrete type to combine between the properties of RAC, SC, and HSC is studied. Because of the new properties of this modern type of concrete, it becomes more and more sensitive to achieve quality control procedures. Few researches covered the SC-HSC only [17] but the new in this research is to applying the use of recycled aggregate with this type of new concrete.

2. Research Significance

The main variables in this research are; recycled aggregate type (crushed concrete and crushed granite compared to dolomite as natural aggregate), replacement ratios (as 50% and 100% of natural aggregate), high range water reducer dosages (super plasticizer (SP) as 3, 3.5, 4 and 4.5% of cement weight) and chemical curing agent (PEG 400 as 1, 2, 3 and 4 % of cement weight). The optimum dosages of SP and PEG 400 are determined.

The fresh and hardened properties of SC-HSC cast using recycled aggregate are investigated. The importance of this research based on the need to know green alternatives to the conventional HSC to obtain recycled aggregate HSC. This research provides data for researchers concerning the properties of RA-SC-HSC cast using recycled aggregates compared to SC-HSC as green high-strength concrete.

3. Materials and Test Specimens

3.1. Materials

The cement used is ordinary Portland cement (CEM I, 52.5N) from Misr Beni-swef Company. Its chemical and physical characteristics satisfy the requirements of the Egyptian Standard Specifications (E.S.S. 4756-1/2009) [20].

The fine aggregate used in the experimental program is natural siliceous sand. Its characteristics satisfy the requirements of the Egyptian Code of Practice (E.C.P. 203/2007) [21] and (E.S.S. 1109/2008) [22]. It is clean and nearly free from impurities with a specific gravity 2.58 with a fineness modulus of 2.72. Its physical properties are shown in Table 1. Its grading is shown in Table 2. The coarse aggregates used are two types; natural and recycled aggregates. Crushed dolomite as a natural aggregate and two types of recycled aggregate (crushed normal strength concrete, with average compressive strength of 20-35MPa, and crushed granite) are used. They had a maximum nominal size of 25 mm. The grading of all coarse aggregates followed the limits of (ASTM C-33) [23]. Their physical properties are shown in Table 3. Its grading is shown in Table 4 and Figure 1. Mixing water of drinkable clean water, fresh and free from impurities is used for mixing processes of the tested samples according to the (E.C.P. 203/2007) [21]. Reinforced steel bars high strength steel (steel 52) of 16 mm diameter and 16 cm high rebars are used as embedded rebars in standard concrete of dimensions $150 \times 150 \times 150\ mm$ to determine the bond strength between concrete and steel bars. It meets the requirements of (E.S.S. 262/2011) [24].

Table 1. Physical and mechanical properties of the sand used

Property	Value
Specific gravity	2.58
Volume weight *(t/m^3)*	1.73
% Absorption *(%)*	0.78
Void ratio *(%)*	33.8
Fineness modulus	2.72

Table 2. Grading of the sand used according to (E.S.S. 1109/2008)

Sieve size *(mm)*	2.36	1.18	0.6	0.3
% Passing used sand	100	98	94	65
% Passing (E.S.S. 1109/2008) (E.S.S.1109/2008)	80-100	75 – 100	55 - 100	5 - 70

Table 3. Physical properties of the crushed dolomite crushed concrete and crushed granite used

Property	crushed dolomite	Crushed concrete	Crushed granite
Specific gravity (t/m3)	2.64	2.5	2.68
% Absorption (%)	0.74	4	0.69
Aggregate crushing value (ACV) (%)	17.5	22	17

Table 4. Grading of the crushed dolomite, crushed concrete and crushed granite used

Sieve size (*mm*)	37.5	25	19	12.5	9.5
%Passing (ASTM C-33)	100	90 - 100	20 - 55	0 - 10	0 - 5
% Passing used crushed Dolomite	100	93	50	5	0
% Passing used crushed Concrete	100	94	26	5	0
% Passing used Crushed Granite	100	91	23	1	0

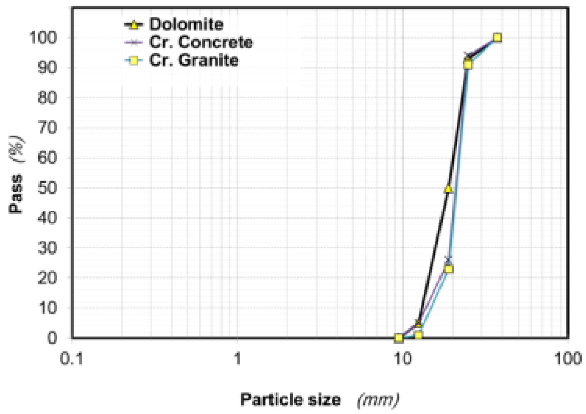

Figure 1. Sieve analysis of coarse aggregates used

Three types of admixtures are used as; water reducer chemical admixture, pozzolanic additive, and chemical curing agent. A high-range water-reducing (HRWR) admixture (Sikament R-2004) is used to improve the workability of concrete without additional amount of water. It meets the requirements of (ASTM C-494, Types G and F) [25]. Its main properties are shown in Table 5. The self-curing agent used in this study is Polyethylene glycol (PEG400), produced by Morgan Chemicals Pvt. Ltd in Egypt. PEG 400 as a shrinkage-reducing admixture "SRA" is used. This chemical agent is a liquid for internal curing of concrete. It is free of chlorides. It produces an internal membrane, which protects fresh concrete against over-rapid water evaporation. Table 6 shows the characteristics of PEG400 as provided by the manufacturer. Silica fume as a pozzolanic admixture, which contains silica of about 95% in powder form, is used. Physical and mechanical properties are shown in Table 7 as provided by the manufacturer.

Table 5. Technical information of SP (Sikament R-2004) used (as provided by the manufacturer)

Base	Appearance	Density	Chloride content	Air entrainment	Compatibility
Aqueous solution of modified polycarboxylate	Turbid liquid	1.08±0.005 kg/liter	Nil	Nil	All types of Portland cement

Table 6. Technical information of Polyethylene Glycol 400 "PEG400" used (as provided by manufacturer)

PEG type	Average molecular weight	HydroxylNumber, Mg KOH/g	Liquid Density, g/cc			Melting or Freezing range ºC	Solubility in Water at 20°C,% by wt	Viscosity at 100°C,
			20°C	60°C	80°C			
PEG 400	380 to 420	264 to 300	1.1255	1.0931	1.0769	4 to 8	Complete	7.3

Table 7. The chemical components of the used silica fume (as provided by the manufacturer)

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	L.O.I.
Average (%)	95.93	0.52	0.05	0.2	0.18	0.1	0.4	2.9

3.2. Preparing and Testing of Concrete Samples

Figure 2. shows the flow chart of the experimental program. The proportions of high-strength concrete mix used are chosen based on previous research conducted by Burg and Ost, 1994 [26].

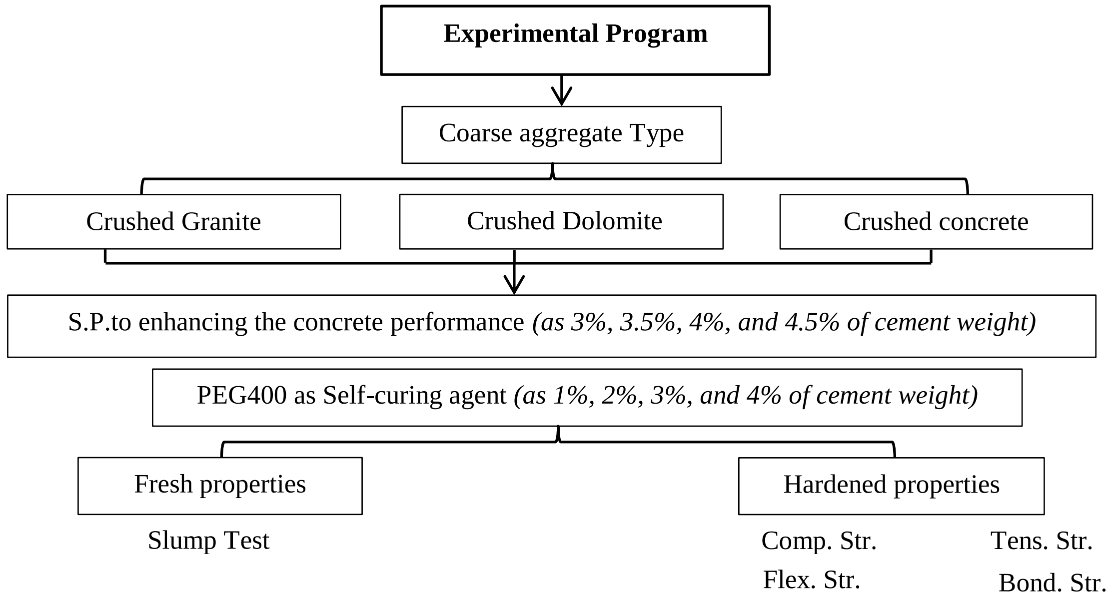

Figure 2. The flow chart of the experimental program

The conducted experimental program is divided in to two stages. The first stage is performed to study the effect of using the HRWR on the fresh and hardened concrete properties of high-strength concrete cast using different aggregate types. Natural (dolomite) as well as (crushed concrete and crushed granite) with replacement ratios of 50% and 100% of dolomite are used. Table 8. shows the proportions of concrete mixes used in "stage 1" and "stage 2". Conventional curing by water is used in stage "1". Based on the test results of that stage, the best-recorded values are used in the second stage to obtain self-curing high-strength concrete SC-HSC cast using recycled aggregate. Based on the obtained results in stage "1", the best three suggested aggregate types, which are obtained as (crushed dolomite, crushed concrete and crushed granite) with their optimum SP dosages, are used for mixes at stage "2". At stage "2", the main variable is chemical curing agent dosage (Poly Ethylene Glycol "PEG 400" as ratio of 1, 2, 3, and 4 % of cement weight) to obtain self-curing high-strength concrete cast using suggested recycled aggregate. There is no curing in this stage.

Table 8. The Proportions of concrete mixes design used in stages (1) and (2)

Stage	Mix Code	Cement (kg/m^3)	Water (kg/m^3)	Silica fume (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse aggregate Type	Coarse aggregate Weight (kg/m^3)	Superplasticizer %	Superplasticizer Weight (kg)	P.E.G 400 %	P.E.G 400 Weight (kg)	Curing Method
	D1							3%	16.92			
	D2					Crushed Dolomite		3.5%	19.74	0.00%	------	
	D3*							4%	22.56			
	D4							4.5%	25.38			
	C1							3%	16.92			
	C2*					Crushed Concrete		3.5%	19.74	0.00%	------	
	C3							4%	22.56			
	C4							4.5%	25.38			
	G1							3%	16.92			
Stage 1	G2*	564	158	89	593	Crushed Granite	1068	3.5%	19.74	0.00%	-----	Conventional Curing By Water
	G3							4%	22.56			
	G4							4.5%	25.38			
	DC1							3%	16.92			
	DC2					50% Crushed Dolomite + 50% Crushed Concrete		3.5%	19.74	0.00%	-----	
	DC3*							4%	22.56			
	DC4							4.5%	25.38			
	DG1							3%	16.92			
	DG2					50% Crushed Dolomite + 50% Crushed Granite		3.5%	19.74	0.00%	-----	
	DG3*							4%	22.56			
	DG4							4.5%	25.38			
	D3-1									1 %	5.64	
	D3-2					Crushed Dolomite		4 %	22.56	2 %	11.28	
	D3-3*									3 %	16.92	
	D3-4									4 %	22.56	
	C2-1									1 %	5.64	
Stage 2	C2-2	564	158	89	593	Crushed Concrete	1068	3.5 %	19.74	2 %	11.28	Conventional Curing in air
	C2-3*									3 %	16.92	
	C2-4									4 %	22.56	
	G2-1									1 %	5.64	
	G2-2					Crushed Granite		3.5%	19.74	2 %	11.28	
	G2-3*									3 %	16.92	
	G2-4									4 %	22.56	

***** Optimum obtained mixes.

The specimens used in this study are cubes having the dimensions of $100 \times 100 \times 100\ mm$, Cylinders having the dimensions of $100 \times 200\ mm$, Prisms having the dimensions of $100 \times 100 \times 500\ mm$ and cubes having dimensions of $150 \times 150 \times 150\ mm$ are cast to determine the compressive, the splitting tensile, the flexure, and the bond strengths, respectively as shown in Figures 3 to 6.

Figure 3. Compressive strength test

Figure 4. flexural strength test

Figure 5. Bond strength test

Figure 6. Indirect tensile strength test

4. Test Results and Discussions

4.1. Effect of Using Super Plasticizer "SP"

The fresh and hardened properties are discussed due to the effect of varying superplasticizer "SP" dosages. The fresh properties recorded in terms slump test as shown in Figure 7. The slump values are shown in Table 9 and Figure 8. Figure 8. shows the relationship between slump values and superplasticizer "SP" dosages (as a ratio of cement content). The results show that, the slump value increases as the SP dosage increases.

Figure 7. Slump test

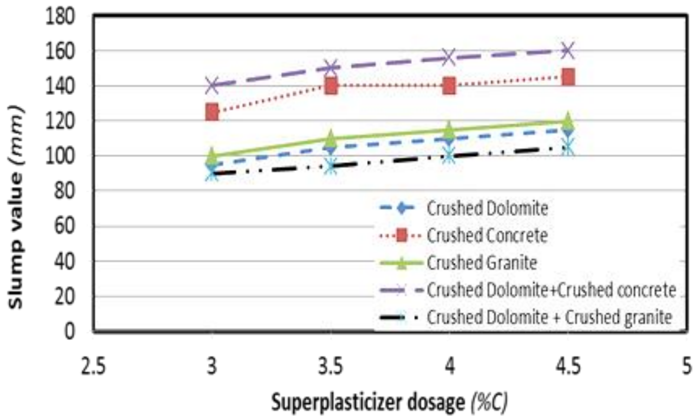

Figure 8. Slump values at different SP dosages

Table 9. The effect of SP on the slump values of different mixes (as obtained from the tests)

Mixes		Slump Values *(mm)*
Coarse Aggregate Type	**Mix Code**	
Crushed Dolomite	D1	95
	D2	105
	D3	110
	D4	115
Crushed Concrete	C1	125
	C2	140
	C3	140
	C4	145
Crushed Granite	G1	100
	G2	110
	G3	115
	G4	120
50% Crushed Dolomite + 50% Crushed concrete	DC1	140
	DC2	150
	DC3	156
	DC4	160
50% Crushed Dolomite + 50% Crushed Granite	DG1	90
	DG2	94
	DG3	100
	DG4	105

The slump values considered are those of better mix contributed to the strength of mixes. The slump value of crushed dolomite is 110 mm as a control mix. The slump values increased by about 27.27 % and 41.82 % for the mixes cast with crushed concrete and 50% replacement of crushed concrete as a coarse aggregate, respectively. That may refer to the viscosity properties of HRWR used. However, when using 50% replacement of crushed granite, the slump decreased by about 9.1 % compared to the control mix. Finally, when using crushed granite as a coarse aggregate, the slump value is nearly the same of the control mix.

The hardened properties drive in terms of compressive, splitting tensile, flexure and bond strengths. Table 10 and Figures 9 to 28. showed the results of hardened properties. The results showed that the optimum SP dosages obtained for crushed dolomite, crushed concrete, crushed granite, 50% replacement with crushed granite, and 50% replacement with crushed concrete as 4%, 3.5%, 3.5%, 4%, and 4%, respectively as ratio of cement weight. The variation in optimum dosages may because the variation in properties of recycled aggregate used.

Table 10. Hardened concrete properties due to the effect of varying SP dosage

Mechanical Properties (MPa)		**Compressive strength (MPa)**			**Tensile strength**			**Flexure strength**			**Bond strength**		
Mix Code	Coarse Aggregate Type	7 day day	28 day	56 day	7 day	28 day	56 day	7 day	28 day	56 day	7 day	28 day	56 day
D1	Crushed Dolomite	29	49.5	67	2.75	3.2	3.85	4.6	8	10.6	2.4	4.25	5.55
D2		35	53	73	2.9	3.65	4.65	5.5	8.6	11.7	3	4.45	6.25
D3 *		57	76	89	4.3	5.65	6.4	9.1	12.1	14.2	4.75	6.5	7.7
D4		32.5	48	70	3.35	4.5	5.1	5.2	7.7	11.1	2.85	3.9	5.9
C1	Crushed Concrete	35	50	59	2.55	3.2	3.85	5.5	7.9	9.3	3.1	4.35	5.05
C2 *		45	66	72	3.35	4.95	5.75	7.2	10	11.6	3.85	5.4	6.25
C3		41.5	55	66.5	3.2	3.95	4.65	6.6	8.7	10.8	3.75	4.75	5.7
C4		32	49.5	57	2.4	3.45	4	5.3	8.1	9.3	2.8	4.25	4.9
G1	Crushed Granite	39	58	67	2.9	3.35	3.7	6.1	9.3	10.8	3.35	4.85	5.6
G2 *		50	69.5	88	4.05	5	5.45	8	11.2	14.2	4.25	6.3	7.6
G3		48.5	68.5	79	3.95	4.5	4.8	7.7	10.9	12.6	4	5.75	6.75
G4		42	62	68	3.45	4.15	4.4	6.75	10	10.9	3.6	5.35	5.85
DG1	50% Crushed Dolomite + 50% Crushed Granite	40	52	60	2.9	3.35	3.7	6.3	8.4	9.6	3.45	4.35	5.1
DG2		49	54.5	62	3.65	4.05	4.3	7.85	8.75	10.1	4	4.7	5.3
DG3*		50	61.5	68	3.75	4.15	4.95	8.1	9.9	10.9	4.25	5.45	5.85
DG4		42	49.5	58	3.1	3.45	3.85	6.2	8.1	9.35	3.65	4.25	4.95
DC1	50% Crushed Dolomite + 50% Crushed Concrete	36	52	61	2.9	3.2	3.7	5.85	8.3	9.6	2.9	4.45	5.1
DC2		41	56	69	3.2	3.85	4.3	6.5	8.9	11.1	3.4	4.7	6
DC3 *		46	60	75	3.55	4.4	4.8	7.45	9.6	12	3.9	5.3	6.4
DC4		35	50	60	2.8	3	3.85	5.8	8.1	9.4	2.7	4.45	4.9

*Optimum obtained mixes

4.2. Effect of Aggregate Type

Experimental program tests are conducted based on 7, 28, and 56 days tests. The results discussed in terms of 28 days tests. The considered slump values refereed to the slump of mixes with better strength values. The slump value of crushed dolomite is 130 mm as a control mix. The slump values increased by about 11.53% and 3.84% when cast using crushed concrete and crushed granite, respectively compared to cast using crushed dolomite. That may refer to the smother surface and higher specific gravity of granite compared to dolomite.

When the crushed dolomite is used as a natural aggregate, the obtained values at optimum SP dosage are 76, 5.65, 12.1, and 6.50 MPa for compressive, splitting tensile, flexure and bond strengths, respectively.

When considering the effect of changing aggregate type on all strengths, compressive strength decreased by about 13.15%, 8.55%, 19,07%, and 21.05% for crushed concrete, crushed granite, 50% replacement with crushed granite and 50% replacement with crushed concrete, respectively compared to using crushed dolomite as shown in Figure 9. Also, splitting tensile strength decreased by about 12.38%, 11.50%, 26.54%, and 22.12% for the same previous four aggregate types as shown in Figure 10. For flexure strength, the values decreased by about 17.35%, 7.43%, 18.18%, and 20.66%, respectively for the same previous four aggregate types compared to that recorded for crushed dolomite as shown in Figure 11. Bond strength decreased by about 16.92%, 3.07%, 16.15%, and 18.46%, respectively for the four aggregate types used compared to using crushed dolomite as shown in Figure 12. Based on these results, cast using crushed granite is better than cast using crushed concrete as recycled aggregates. That may refer to lower absorption of granite as well as its lower crushing factor, which led to higher strength compared to crushed concrete.

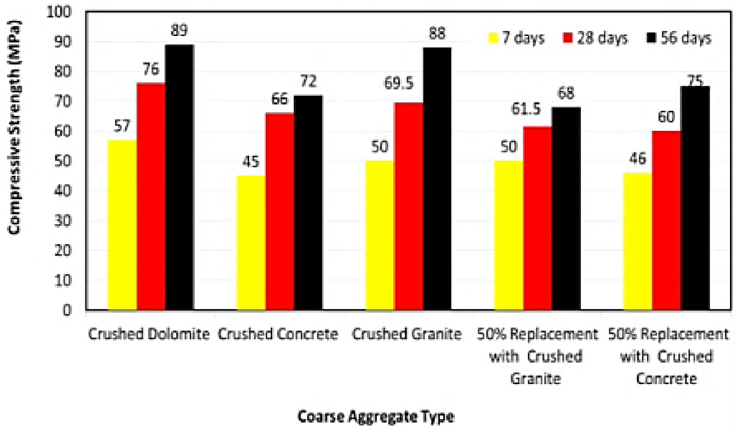

Figure 9. Compressive strength of SC-HSC cast using different coarse aggregate types at optimum SP dosage

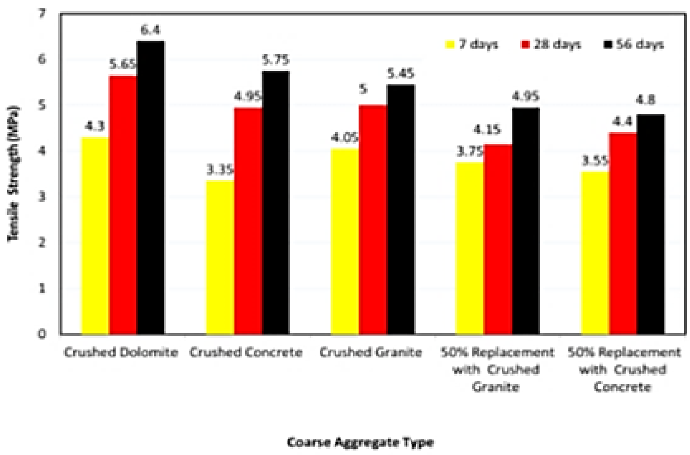

Figure 10. Splitting tensile strength of SC-HSC cast using different coarse aggregate types at optimum SP dosage

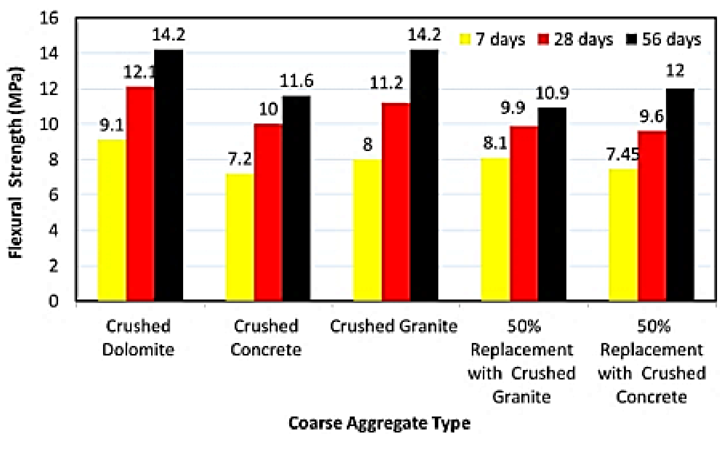

Figure 11. Flexure strength of SC-HSC cast using different coarse aggregate types at optimum SP dosage

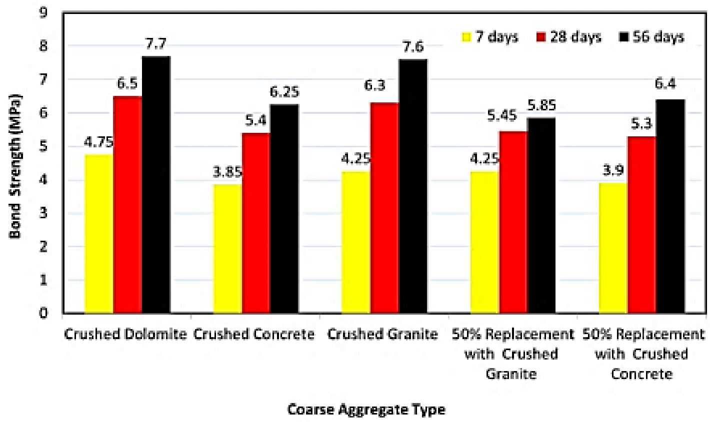

Figure 12. Bond strength of SC-HSC cast using different coarse aggregate types at optimum SP dosage

4.3. Effect of Using Chemical Curing Agent "PEG 400"

The effect of using "PEG 400" on both fresh properties represented in slump test. The hardened properties represented in compressive, splitting tensile, flexure, and bond strengths.

The effect of using "PEG 400" on the slump values of concrete mixes are shown in Table 11 and Figure 13. Increasing the dosage of PEG400 increased the flowability of self-curing high-strength concrete mixes cast using suggested recycled aggregates.

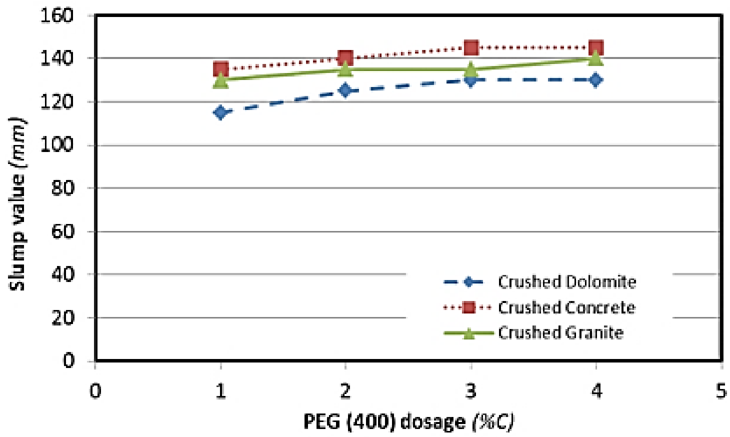

Figure 13. Slump values at different PEG dosages

Table 11. The effect of PEG 400 on the slump values of different mixes

Mixes		Slump Values (mm)
Coarse Aggregate Type	**Mix Code**	
Crushed Dolomite	D3 - 1	115
	D3 - 2	125
	D3 - 3	130
	D3 - 4	130
Crushed Concrete	C2 - 1	135
	C2 - 2	140
	C2 - 3	145
	C2 - 4	145
Crushed Granite	G2 - 1	130
	G2 - 2	135
	G2 - 3	135
	G2 - 4	140

The results of hardened properties are shown in Table 12. It show that the optimum dosage of PEG 400 is obtained as 3% of cement weight for all suggested three recycled aggregate types obtained from stage "1" as shown in Figures 14 to 25. The specimens of that stage tested after 7 and 28 days. The results discussed in terms of 28 days tests. The results show that the strengths values at optimum PEG dosage when cast using crushed dolomite are 68, 4.85, 10.5, and 5.9 MPa for compressive, splitting tensile, flexure and bond strengths, respectively.

Table 12. Hardened concrete properties due to the effect of varying PEG400 dosage

Mechanical Properties (MPa)		**Compressive Strength (MPa)**		**Tensile Strength (MPa)**		**Flexure Strength (MPa)**		**Bond Strength (MPa)**	
Mix Code	**Coarse Aggregate Type**	7 day	28 day	7 day	28 day	7 day	28 day	7 day	28 day
D3-1	Crushed Dolomite	26.5	45.5	2.45	2.9	4.3	7.4	2.2	3.8
D3-2		32.5	48.5	2.6	3.35	4.8	7.7	2.8	3.9
D3*-3		54	68	3.8	4.85	8.4	10.5	4.2	5.9
D3-4		27.5	44.5	3	4	4.5	7	2.5	3.51
C2-1	Crushed Concrete	33	46	2.3	3	4.5	6.8	2.85	4.1
C2-2		37	49	2.9	3.5	5.8	7.5	3.2	4.3
C2*-3		42	60	3	4.2	6.8	8.9	3.2	5
C2-4		31.5	47	2.3	3.1	5	7.8	2.7	4
G2-1	Crushed Granite	37	54	2.4	2.8	5.5	8.4	2.9	4.2
G2-2		46	55	3.6	4.1	7.4	9.1	3.5	4.7
G2*-3		51	63	4.2	4.6	7.5	9.9	4	5.7
G2-4		42	53	3.25	4	6	8.9	3	4.9

*Optimum obtained mixes

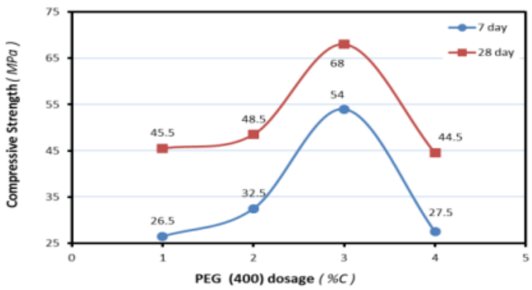

Figure 14. Compressive strength at different PEG dosages for crushed dolomite.

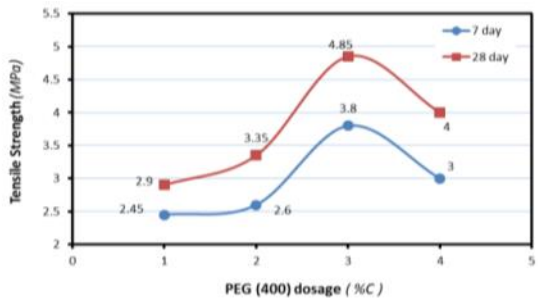

Figure 15. Tensile strength at different PEG dosages for crushed dolomite.

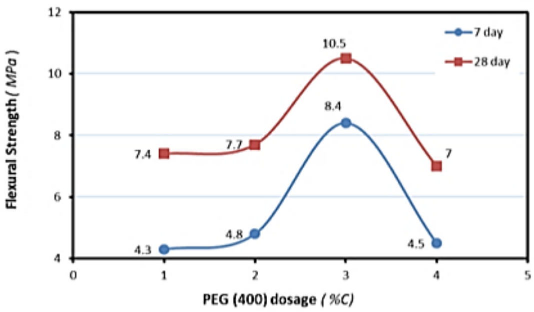

Figure 16. Flexure strength at different PEG dosages for crushed dolomite.

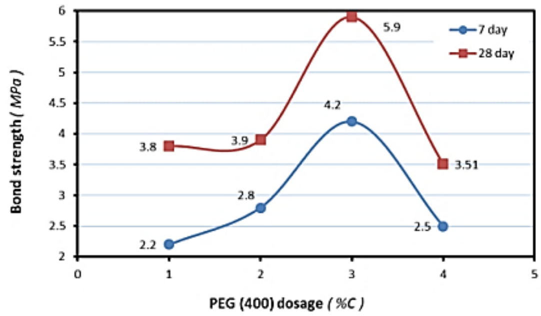

Figure 17. Bond strength at different PEG dosages for crushed dolomite.

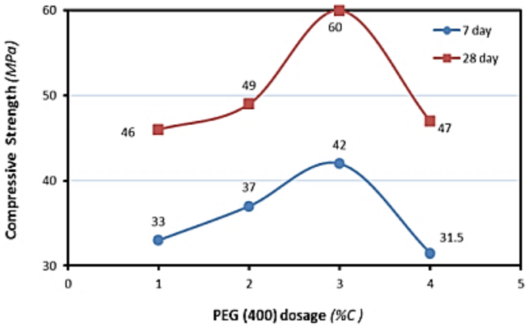

Figure 18. Compressive strength at different PEG dosages for crushed concrete.

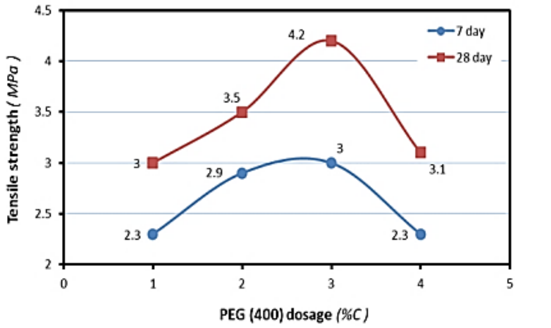

Figure 19. Tensile strength at different PEG dosages for crushed concrete.

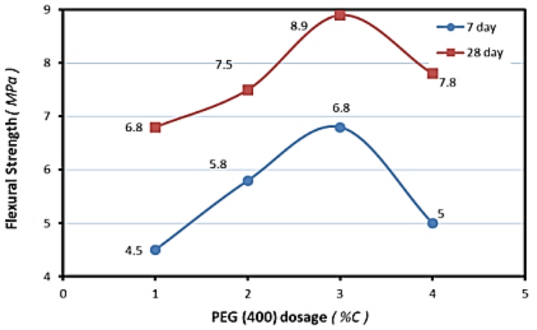

Figure 20. Flexure strength at different PEG dosages for crushed concrete.

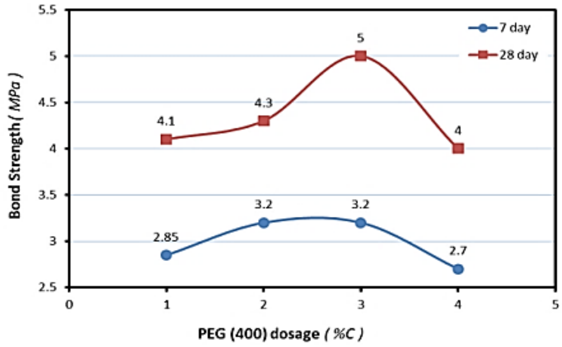

Figure 21. Bond strength at different PEG dosages for crushed concrete.

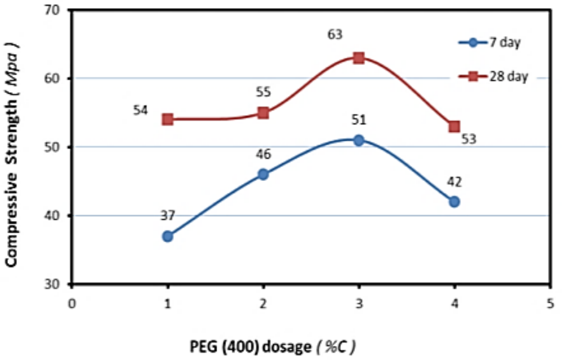

Figure 22. Compressive strength at different PEG dosages for crushed granite.

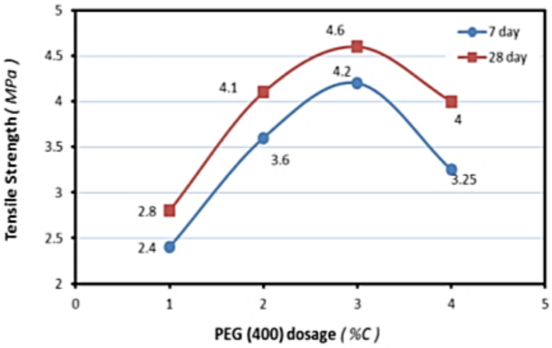

Figure 23. Tensile strength at different PEG dosages for crushed granite.

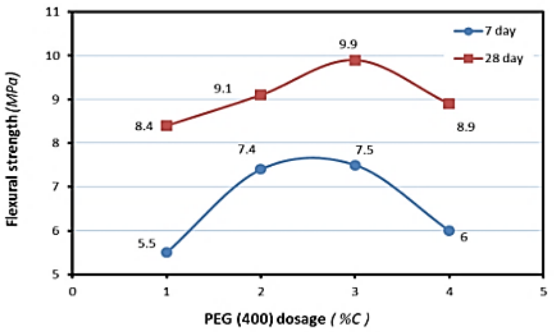

Figure 24. Flexure strength at different PEG dosages for crushed granite.

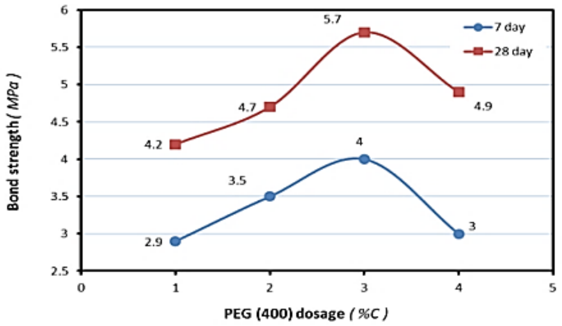

Figure 25. Bond strength at different PEG dosages for crushed granite.

Using PEG400 decreases the compressive strength by about 11.76% and 7.35% when cast using crushed concrete and crushed granite, respectively compared to crushed dolomite as shown in Figure 26. The splitting tensile strength decreased by about 13.4% and 5.15% when cast using crushed concrete and crushed granite, respectively compared to crushed dolomite as shown in Figure 27. For flexure strength, values decreased by about 15.23% and 5.71% when cast using crushed concrete and crushed granite, respectively compared to crushed dolomite as shown in Figure 28. From Figure 29, bond strength decreased by about 15.52% and 3.38%, respectively compared to crushed dolomite. These results in agree with previous researches [10, 16]. That may refer to lower absorption and higher crushing factor for crushed granite, which led to higher strength compared to crushed concrete.

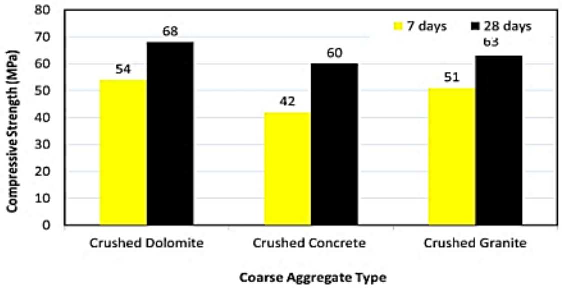

Figure 26. Compressive strength of SC-HSC cast using suggested aggregates at optimum PEG dosage.

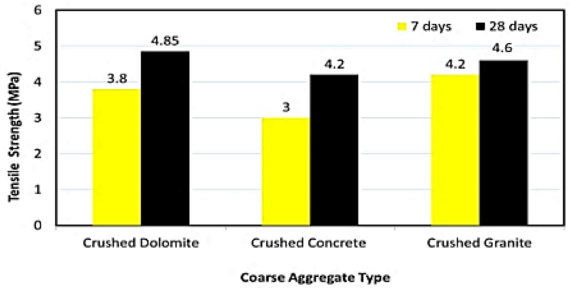

Figure 27. Splitting tensile strength of SC-HSC cast using suggested aggregates at optimum PEG dosage.

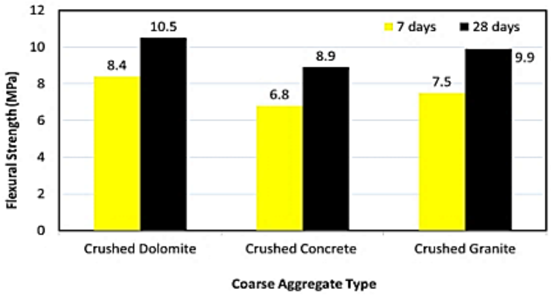

Figure 28. Flexure strength of SC-HSC cast using suggested aggregates at optimum PEG dosage.

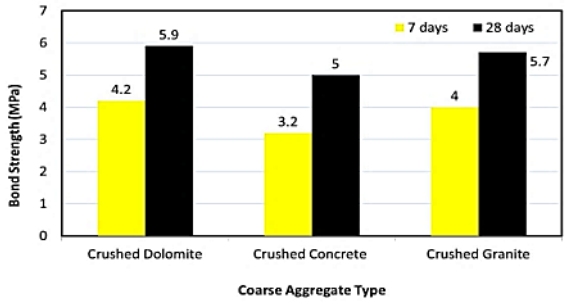

Figure 29. Bond strength of SC-HSC cast using suggested aggregates at optimum PEG dosage.

4.4. Effect of Using Chemical Curing Agent “PEG 400” Compared to Stage "1" (Conventional Curing).

At 28-days tests with optimum SP dosages, using PEG400 as a chemical curing agent instead of conventional curing by water caused a decrease in compressive strength by about 10.52%, 9.09%, and 9.35% for crushed dolomite, crushed concrete, and crushed granite, respectively compared to stage "1" (conventional curing) as shown in Figure 50. Splitting tensile decreased by about 14.15%, 15.15%, and 8% for crushed dolomite, crushed concrete, and crushed granite, respectively compared to stage "1" as shown in Figure 51. The flexure strength decreased by about 13.22%, 11%, and 11.6% for crushed dolomite, crushed concrete, and crushed granite, respectively compared to stage "1" as shown in Figure 52. The bond strength decreased by about 9.23%, 7.4%, and 9.52% for crushed dolomite, crushed concrete, and crushed granite, respectively compared to stage "1" as shown in Figure 53. That may refer to chemical shrinkage occurring during cement hydration, empty pores are created within the cement paste, leading to a reduction in its internal relative humidity and also to shrinkage which may cause early age cracking.

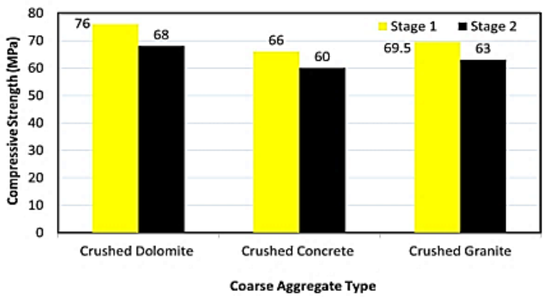

Figure 30. Comparison between obtained compressive strength values for aggregates used at stages "1" and "2".

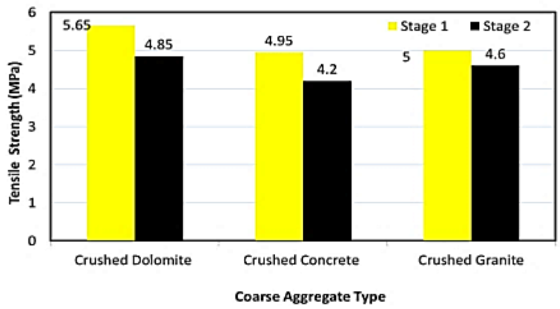

Figure 31. Comparison between obtained splitting tensile strength values for aggregates used at stages "1" and "2".

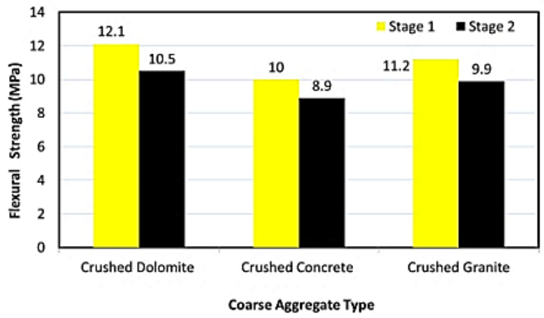

Figure 32. Comparison between obtained flexure strength values for aggregates used at stages "1" and "2".

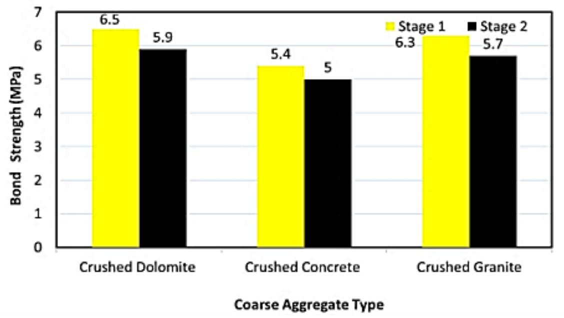

Figure 33. Comparison between obtained bond strength values for aggregates used at stages "1" and "2".

5. Conclusions

Based on the experimental results, the following conclusions can be drawn as follow:

- Natural aggregate is more efficient than using recycled aggregate for structural concrete.
- Using high range water reducer SP enhances the main fresh and hardened concrete properties of SC-HSC.
- The optimum dosage of SP for SC-HSC with crushed dolomite is 4% (as a ratio of cement content "C"), while it becomes 3.5% of "C" for SC-HSC concrete cast using crushed concrete and crushed granite.
- Using PEG 400 as chemical curing agent decreases compressive, splitting tensile, flexure, and bond strengths compared to conventional curing for SC-HSC.
- The optimum dosage of PEG 400 is about 3% of cement content "C" for SC-HSC with crushed dolomite, crushed concrete, and crushed granite.
- The strength of the SC-HSC with crushed dolomite is higher than that cast using crushed concrete and crushed granite as coarse aggregates by about 11.76% and 7.35%, respectively.

Generally, using recycled aggregate may provide sufficient strength compared to natural aggregates for self-curing high-strength concrete. Also, in urban areas with low water availability or at hot weathers using PEG 400 as a chemical curing agent for concrete is recommended instead of concrete without curing for HSC as well as conventional concretes [8]

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