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Mechanical Properties of Self-Compacted Concrete

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Abstract
In this research, trial mixes were conducted according to Self-Compacted Concrete (SCC) specifications, a mix that gave a higher compressive strength to the age of seven days has been selected. Then after selecting the appropriate mix, concrete samples had poured and were distributed into five groups; each group consists of six cubes, six cylinders, and six prisms. The samples of each group are testing for compressive, tensile splitting, and flexure strengths respectively for the ages of 7, 14, 28, 60, and 90 days respectively. Before of conduction of destructive tests, the samples were tested using ultrasonic waves to determine the relationship between the concrete strength and pulse velocity and in the same way for all ages in above. Experimental results showed that, all concrete mechanical properties have improved, and the maximum improve was in flexural strength followed by compressive strength and tensile splitting strength. The cube compressive strength increased according to (G1 at 7 days curing) from 34.3% to 71.8%, the percentage of increase of tensile strength according to (G1 at 7 days curing) from 16.8% to 64.3% , modulus of rupture increased according to (G1 at 7 days curing) from 34.6% to 98.7% for ages (14, 28, 60, 90 days) respectively. Pulls velocity increased according to (G1 at 7 days curing): For cube from 5.1% to 23.9%, for cylinder from 21.4% to 40.3%, for prisms from 7.1% to 29.2%.

Keywords: Self-Compacted Concrete, Mechanical Properties, Pulse Velocity, Compressive Strength.

الخصائص الميكانيكية للخرسانة ذاتية الرص

الخلاصة
تم في هذا البحث اجراء خلطات مرجعية وفقا لمحددات الخرسانة ذاتية الرص، وقد تم انتخاب الخلطة التي اعطت اعلى مقاومة انضغاط بعمر 7 ايام. بعد اختيار الخلطة المناسبة تم انتاج خمس مجاميع من النماذج كل مجموعة تتألف من ستة مكعبات بأبعاد (150x150x150) ملم، ستة اسطوانات بأبعاد (150x300) ملم وستة مواشير بأبعاد (50x10x10) ملم وتم فحص هذه النماذج بأعمار مختلفة (7، 14، 28، 60، 90) لمقاومة الانضغاط والانشطار ومقاومة الانثناء وقد تم اجراء الفحوصات الغير اتلافية (امواج فوق الصوتية) لكل مجموعة الغرض منها هو ايجاد علاقة بين سرعة الموجة و مقاومة الانضغاط، الانشطار ومقاومة الانثناء.اظهرت النتائج التجريبية ان جميع الخواص الميكانيكية لها تحسن ملموس بزيادة عمر الخرسانة وكان اقصى تحسين هو في مقاومة الانثناء تليها مقاومة الانضغاط واخيرا مقاومة الانشطار للخرسانة. كانت نسبة الزيادة في مقاومة الانضغاط بالمقارنة مع المجموعة الاولى بعمر 7 ايام من 34.3% الى 71.8% وكذلك النسبة المئوية لزيادة مقاومة الانشطار هي بين 16.8% الى 64.3% الزيادة في معامل الكسر كانت بين 34.6% الى 98.7% للأعمار (7، 14، 28، 60، 90) على التوالي.بالنسبة للموجات الفوق الصوتية زادت سرعة انتقال الموجات بالنماذج مقارنة مع المجموعة الاولى بعمر 7 ايام كالاتي: للمكعبات من 5.1% الى 23.9% للاسطوانات من 21.4% الى 40.3% للمواشير من 7.1% الى 29.2%.

الكلمات الدالة: الخرسانة ذاتية الرص، الخصائص الميكانيكية، سرعة النبضة، مقاومة الأنضغاط.

Introduction

SCC (the new class of high performance concrete) has been first developed in Japan, then employed in several countries in cast-in-place and precast applications [1,2,3,4,5]. The use of SCC in the United States has developed dramatically especially in producing of ready mixed concrete. It has used in theconstruction of parking lots and for architectural purposes. The estimated amount of SCC has produced was around of 135,000 m^3 in the United States in theyear of 2002, then increased to be 1.8 million m^3 in theyear of 2003. In theyear of 2002, 40% of ready mixed concrete manufacturers have used the new technology of SCC [6].

Materials

Optimal ratios of SCC ingredients are selected according to the requirements of EFNARC [7], considering the characteristics of all the materials used. Satisfactory SCC is obtained by selecting suitable materials, good quality control and proportioning. The constituents are used in theproduction of SCC are shown in Figure (1).

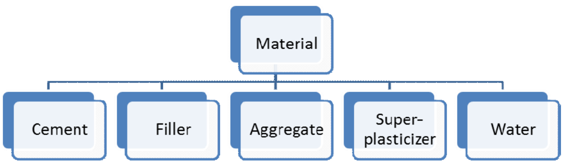

Fig. 1. Materials used in self-compacting concrete

Cement

Ordinary Portland cement type I was used in all mixes throughout this research. It was stored in air-tight plastic containers to avoid exposure to atmospheric conditions likehumidity. The physical and chemicalproperties of cement used in thestudy are presented in Table (1). Test results indicate that the adopted cement conformed to the Iraqi specification 5/1984 [8].

Aggregate

<u>Fine Aggregate</u>

It has used natural Sand River from quarries located on the Tigris River north of Tikrit. Physical and chemical properties as well as the grading of fine aggregate are indicated in Tables 2 and 3 respectively.

<u>Coarse Aggregate</u>

It has used natural river gravel also from quarries located on the Tigris River north of Tikrit with a maximum size of 14 mm. Physical and chemical properties as well as the grading of coarse aggregate are indicated in Tables 4 and 5 respectively.

Admixtures

<u>Superplasticizer</u>

The product Structuro 502 designed for SCC production was used in this research. Thetypical properties of the product as reported by the manufacturer are listed in Table (6).

<u>Silica Fume</u>

Type (MEYCO® MS610) has used,it is ultra-fine material consists of ultra-fine spherical particles of an average diameter of 150 mm.It can be obtained as aby-product of silicon industry, and due to ultra fineness and higher content of silica, silica fume is considered as an effective pozolanic material. This type above has conformed to requirements of ASTM C1240-03 [14]. Silica fume can affect fresh and hardened concrete properties as in below [15]:

a- Workability: The addition of silica fume reduces the slump of fresh concrete versus time due to increased surface area which leads to obtaining cohesive mix.

b- Segregation and Bleeding: The addition of silica fume reduces bleeding of fresh concrete due to consuming agreater quantity of mixing water to wet higher surface area of fine particles which causes reducing free water is available in themix. Also, it acts to seal the pores of the concrete which prevent the water from moving towards the surface and evaporates.

Table (7) shows Pozzolanic activity and Chemical decomposition of silica fume as reported by the manufacturer are listed.

Table 1. Physical and chemical properties of cement

Physical Properties	**Specification**	**Test Results**	**Limit of IQS 5/1984** [8]
Specific surface area (Blaine method), (m^2/kg)	R.G.D 198/1990 [9].	430	230 m^2/kg lower limit
Setting time (vacate apparatus) Initial setting, hrs:min Final setting, hrs:min		1:10 3:10	Not less than 45min Not more than 10 hrs
Compressive strength MPa For 3-day For 7-day		20.0 30.0	15 MPa lower limit 23 MPa lower limit
Expansion by Autoclave method		0.38	0.8 % upper limit
Oxides composition	**Specification**	**Content %**	**Limits of IQS 5/1984.**
CaO	R.G.D 472/1993 [10].	61.5	-
SiO_2		21.87	-
Al_2O_3		4.81	-
Fe_2O_3		3.04	
MgO		3.40	5 % Max.
SO_3		2.35	2.8 % Max.
L.O.I		1.53	4 % Max.
Insoluble material		1.5	1.5 % Max.
Lime Saturation Factor, (L.S.F)		0.8	(0.66-1.02)

Table 2. Physical and chemical properties of fine aggregate *

Properties	**Specification**	**Test Result**	**Limits of Specification**
Specific Gravity	ASTM C128-01[12]	2.57	-
Absorption (%)	ASTM C128-01[12]	2.35	-
Sulfate Content (as SO_3) %	IQS # 45/1984 [11]	0.22	≤ 0.5%.
Material finer than 0.075 mm (%)	IQS # 45/1984 [11]	1.01	≤ 5.0%.

*Tests were conducted by the Civil and Chemical Engineering Laboratory\ Tikrit University

Table 3. Sieve analysis of fine aggregate *

Sieve Size (mm)	**Cumulative Retained (%)**	**Cumulative Passing (%)**	**Limits of IQS # 45/1984 (Zone II)** [11]
10	0	100	100
4.75	9.05	90.95	90-100
2.36	13.38	88.62	85-100
1.18	21.45	78.55	75-100
0.6	33.04	66.96	60-79
0.3	83.26	16.74	12-40
0.15	95.66	4.34	0-10

*Tests were conducted by the Civil Engineering Laboratory\ Tikrit University

Table 4. Physical and chemical properties of coarse aggregate*

Properties	Specification	Test Result	Limits of Specification
Specific Gravity	ASTM C128-01 [12]	2.7	-
Absorption (%)	ASTM C128-01 [12]	0.8	-
Sulfate Content (as SO_3) %	IQS # 45/1984 [11]	0.07	≤ 0.1%.

*Tests were conducted by the Civil and Chemical Engineering Laboratory\ Tikrit University

Table 5. Sieve analysis of the coarse aggregate *

Sieve Size (mm)	Cumulative Passing (%)	Limits of IQS # 45/1984 (Zone III) [11]
14	93.98	90-100
10	83.51	50-85
4.75	0	0-10

*Tests were conducted by the Civil Engineering Laboratory\ Tikrit University

Table 6. Typical properties of Structuro 502 [13]

Description	Superplasticizer
Appearance	Light brown colored liquid
Volumetric Mass	1.10 kg/ltr. At 20 °C.
pH Value	6.5
Chloride Content	Nil
Alkali Content	Typically less than 1 gm Na_2O equivalent per liter of admixture

*Properties of the product as reported by the manufacturer.

Table 7. Pozzolanic activity and chemical composition of (Microsilica)*

Pozzolanic Activity	Limits of ASTM C1240-03 [14]	Chemical Composition		Limits of ASTM C1240-03 [14]
		Oxides	Result (%)	
121.5%	105%	L.O.I	3.82	6% Max.
		SiO_2	90.5	85% Min.
		Al_2O_3	4.1	
		Fe_2O_3	0.35	
		SO_3	0.71	

*Properties of the product as reported by the manufacturer

Mixture Proportions

EFNARC [7] specification is used for proportioning self-compacted concrete by changing the superplastiisizer's dosage and keeping the water powder ratio is constant. The trail mixes details are shown in Table (8). The procedure that is followed for proportioning SCC (Self-Compacting Concrete) is as in below [15];

1- Fine and coarse aggregate which of saturated surface dry are mixed in the mixing drum with one third of thewater for two minutes.
2- Adding the powder (silica fume and cement) and mix for one minute.
3- Adding the superplasticzer and the two third quantities of water, and mixing for three minutes.
4- Each trial mix is subjected to tests for verifying the adherence of the resulting mix to the SCC requirements.

The proportions in Table (8) are within the EFNARC guidelines for SCC [7] as in below;

1- Water-powder ratio by volume is (0.8-1.0).
2- Total powder content is (400-600) kg per cubic meter.

3- Coarse aggregate content is normally (28-35) % by volume of the mix.
4- Water content does not exceed 200 liters per cubic meter.
5- Sand content balances the volume of other constituents.

Table 8. A detail of trial mixes of self-compacting concrete

Trail Mix #.	Filler (%)	Str. 502 (%)	Quantities of Mix ingredients (kg/m^3)							
			Water	Powder		w/cm ratio	Fine Aggregate	Coarse Aggregate	Str. 502	Density
				Filler Content	Cement Content					
1	10	2.65	146	40.0	400	0.33	880	800	11.66	2277.66
2	11	2.85	147	44.0	400	0.33	880	800	12.65	2283.65
3	12	3.00	150	48.0	400	0.33	880	800	13.44	2291.44
4	10	3.00	165	45.0	450	0.33	880	750	14.85	2304.85
5	11	3.10	170	49.5	450	0.34	880	750	15.48	2314.98
6	12	3.50	170	54.0	450	0.34	880	750	17.64	2321.64
7	11	3.00	175	49.5	450	0.35	900	750	14.99	2339.49
8	11	3.30	170	49.5	450	0.34	900	750	16.48	2335.98

Table 9. Results of fresh self-compacting concrete tests

Trial Mix #	Self-Compactibility Properties.			
	Flow Table (mm)	T_{50} (Sec.)	V-Funnel (Sec.)	L-Box
1	650	5	9	0.95
2	690	4	8	0.95
3	740	3.5	6	0.97
4	745	4.5	6	0.97
5	680	4	8	0.94
6	720	3.5	8	0.95
7	772	4	5	0.96
8	765	2.5	6	0.95

Table 10. Compressive strength test results of SCC trial mixes

Trial Mix #	Compressive Strength at 7 days age (MPa)
1	26.70
2	28.30
3	27.20
4	29.60
5	30.20
6	29.10
7	32.00
8	32.75

Mechanical Tests

Compressive Strength

The compressive strength test hasevaluated according to B.S. 1881: part 116: 1989 [16]. The test has conducted on (150 x 150 x 150) mmcube samples using an electrical testing machine as shown in Figure (2) with a capacity of 2000 kN at aloading rate of 7 MPa per minute. The average of six cubes was adopted for each test, the test was conducted at ages of (7, 14, 28, 60, and 90) days.

Tensile Splitting Strength

The tensile splitting strength test has performed according to ASTM C49, 2004[17]. Cylindrical concrete specimens (150 mm diameter □ 300 mm height) had used. The specimens had tested by using an electrical testing machine shown in Figure (3) with acapacity of 2000 kN. This test was conducted at ages of (7, 14, 28, 60, and 90) days.

Flexural Toughness

Flexural strength test was carried out on (100×100×500) mm simply supported prisms with a clear span of 400 mm under the third points loading according to ASTM C1018-97, 2004 [18]. This test was conducted at ages of (7, 14, 28, 60, and 90) days. The specimens were tested using a Universal Machine in the Laboratory of College of Engineering of Tikrit University as shown inFigure (4). To facilitate deflection reading despite the fact that the test was performed upside down without harming the dial gauge. The load was applied by using ahydraulic machine with acapacity of 2000 kN. The mid span deflection reading was measured using a dial gauge sensitive to 0.01 mm then the load deflection was drawn according to (ASTM C1018-97, 2004) [18] as shown in Figure (4) below.

Non-Destructive Tests

Ultra-Sonic Test

The main idea on which the examination of concrete using vibrational ultrasound here in this research is the possibility of finding out the relationship between the speed of the pulse (or wave) and the compressive, tensile splitting, and flexural strength respectively.Samples are tested after taking out the water treatment tank, and this test is performed for all samples supposed to be later destructively test. Reading of waves of ultrasound taken for each sample twice, and then the average value of transit time is recorded. Figure (2), shows the three arrangements of testing. The speed of ultrasound wave can be evaluated using equation 1 below;

□= □/□.. (1).

Where,

□: Pulse velocity(km/sec).

□ Length of path (mm).

□ Time of transition (sec.).

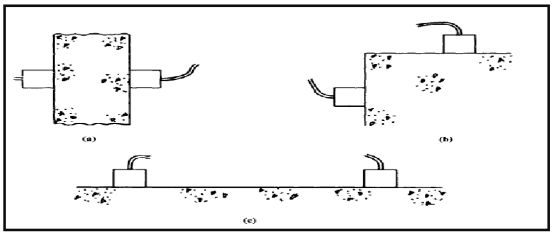

Fig. 2. Measuring of ultrasound pulse velocity; (a) Direct method; (b) Semi-Indirect method; (c) Indirect method

Results and Discussion

Hardened Concrete Test

Compressive Strength

According to experimental test results, the concrete cube compressive strength increase with theage of concrete (increase thetime of curing), as has shown in Figure (3). The percentage of increase according to G1 was varying from 34.3% to 71.8%. □ at an age of 90 days is the largest one. Figure (4) shows the percentage of increase in compressive strength with reference to G1.

Tensile Splitting Strength

Experimental test results revealed that the concrete tensile splitting strength increases versus age of concrete as has showing in Figure (5). Table (12) shows the percentage of increase in tensile splitting strength with reference to Group # 1 (G1). Percentage of increase with reference to G1 was varying from 16.8% to 64.3%. Tensile splitting strength (□) at an age of 90 days is the largest one. Figure (6) shows the percentage of increase in tensile splitting strength with reference to G1.

Flexural Strength

The concrete flexural strength increase with the age of concrete also like the compressive and tensile splitting strengths, as it has shown in Figure (7). Table (13) shows the percentage of increase inmodulus of rupture with reference to G_1. It is obvious from Table (13) that the Modulus of Rupture (MoR) is increased with increasing the age of concrete, and the percentage of increase with reference to G_1 from 34.6% to 98.7% as in Figure (8). MoR for day 90 is the largest one.

Ultrasonic Test

The ultrasound pulse velocity increases with the age of concrete. Table (14) shows the % of theincrease in pulse velocity versus curing age, whereas Tables (15) and (16) are showing the percentage of increase for all specimens. Thedevelopment of pulse velocity versus concrete's strength for selected mixes is shown in Figures (9), (10), and (11). The percentage of increase in pulse velocity with reference to G1, is shown in Figures (12), (13), and (14).

It is obvious from Table (17) and Figure (15) that the greatest value of pulse velocity was in cylinder specimens, followed by prisms, and at last the cube specimens. Table (18) and Figure (16) show the increase in flexural, compressive, and tensile splitting strength.

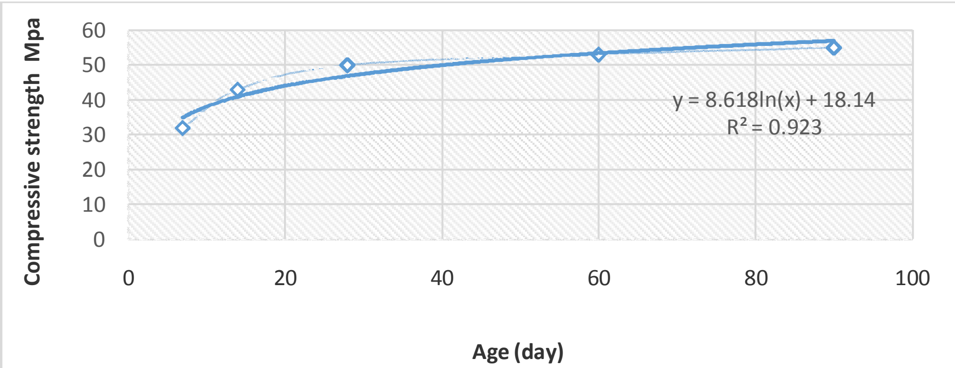

Fig. 3. Compressive strength versus curing age

Table 11. Compressive strength results

Age (Days)	Group #	Compressive Strength of Cube [illegible] (MPa)	% of increase in Compressive Strength
7	G_1	32	-
14	G_2	43	34.3
28	G_3	50	56.2
60	G_4	53	65.6
90	G_5	55	71.8

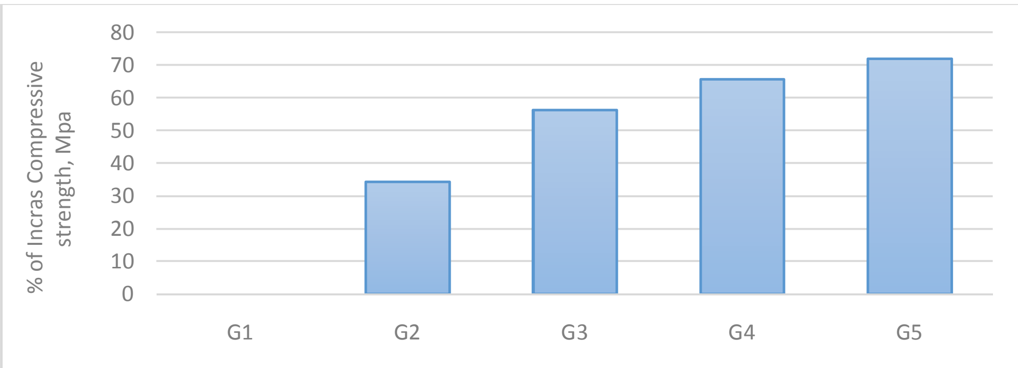

Fig. 4. The percentage of increase in compressive strength with reference to G_1

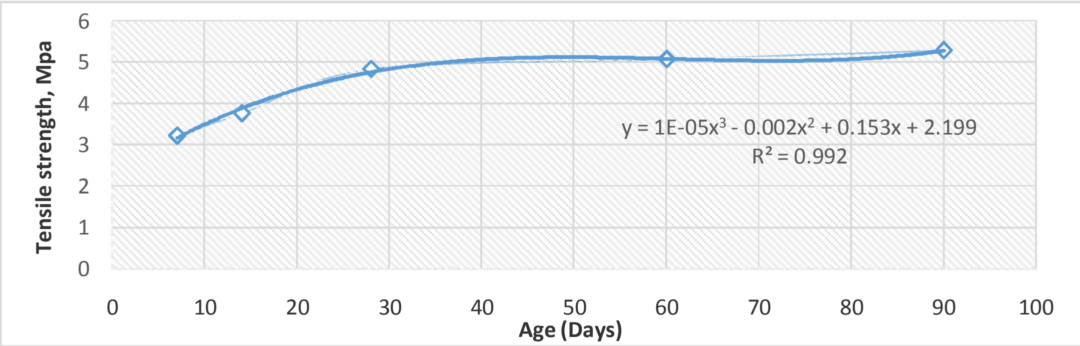

Fig. 5. Tensile strength versus curing age

Table 12. Tensile splitting strength results

Age (Days)	Group #	Tensile Splitting Strength (MPa)	% of increase in Tensile Splitting Strength
7	G1	3.211	-
14	G2	3.753	16.8
28	G3	4.824	50.2
60	G4	5.063	57.6
90	G5	5.277	64.3

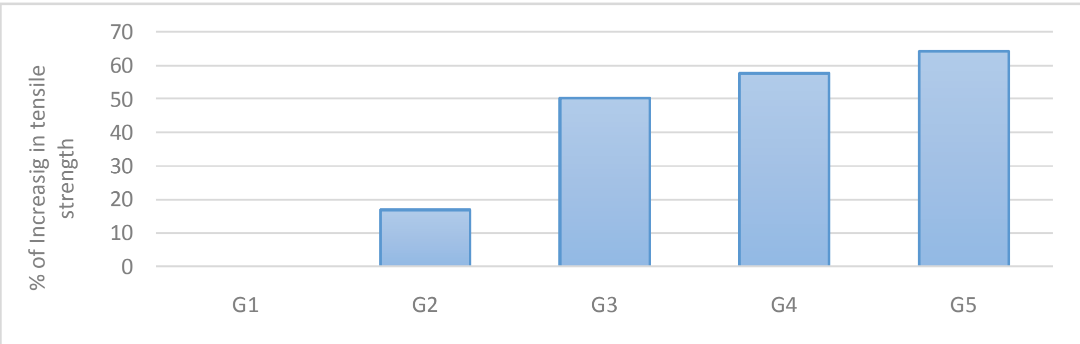

Fig. 6. The percentage of increase in tensile splitting strength with reference to G_1

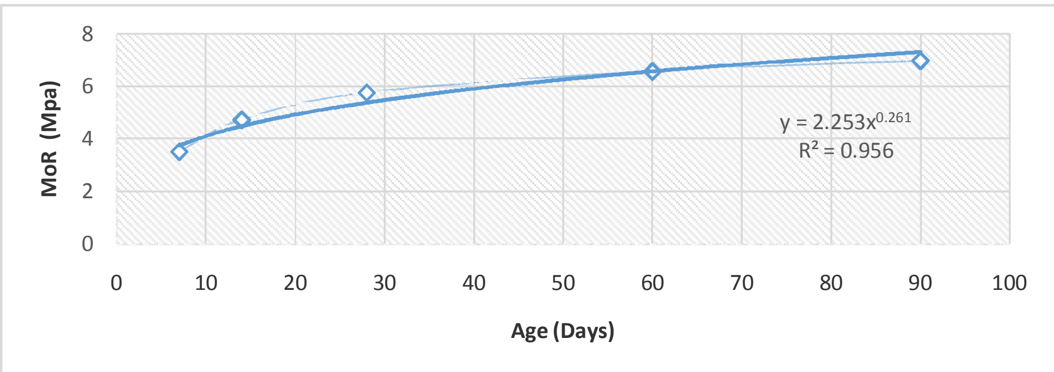

Fig. 7. Modulus of rupture versus curing age

Table 13. Modulus of rupture results

Age (Days)	Group #	Flexure Force (kN)	Modulus of Rupture MoR (MPa)	% of increase in MoR
7	G_1	7.8	3.51	-
14	G_2	10.5	4.725	34.6
28	G_3	12.8	5.76	64.1
60	G_4	14.6	6.57	87.1
90	G_5	15.5	6.975	98.7

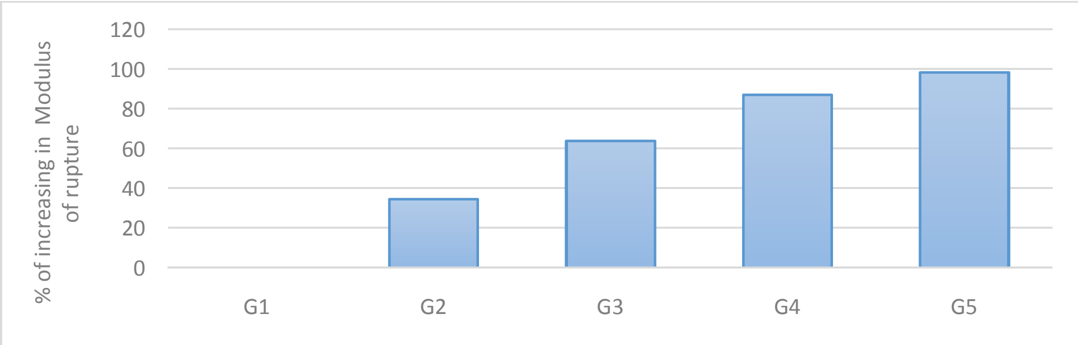

Fig. 8. The percentage of increase in modulus of rupture according to G_1

Table 14. Pulls velocity for cubes specimens results

Age (Days)	Group #	Pulse Velocity (kM/sec)	% of increase in Pulse Velocity
7	G_1	3.7	-
14	G_2	3.9	5.10
28	G_3	4.2	10.7
60	G_4	4.4	16.90
90	G_5	4.6	23.90

Table 15. Results of pulls velocity for cylinders specimens

Age (Days)	Group #	Pulse Velocity (kM/sec)	% of increase in Pulse Velocity
7	G_1	3.3	-
14	G_2	3.9	21.4
28	G_3	4.3	32.1
60	G_4	4.4	34.8
90	G_5	4.6	40.3

Table 16. Results of pulls velocity for prisms specimens

Age (Days)	Group #	Pulse Velocity (kM/sec)	% of theincrease in Pulse Velocity
7	G_1	3.6	-
14	G_2	3.9	7.1
28	G_3	4.3	20.5
60	G_4	4.6	25.7
90	G_5	4.7	29.2

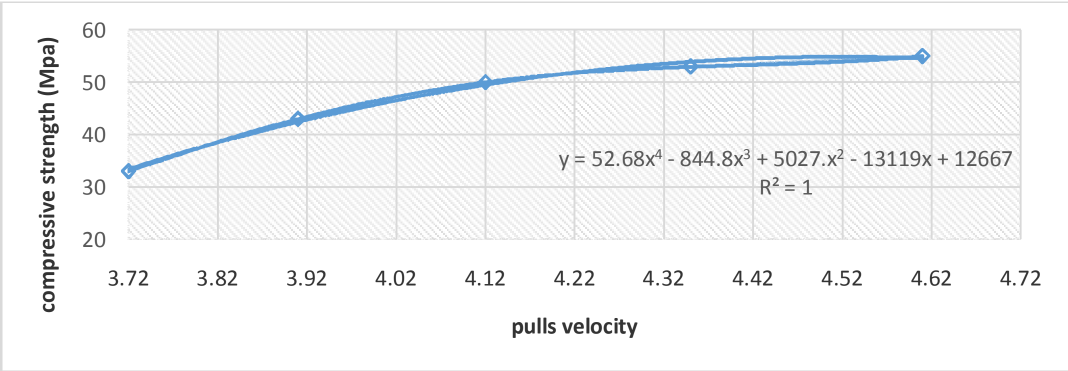

Fig. 9. Compressive strength versus pulls velocity

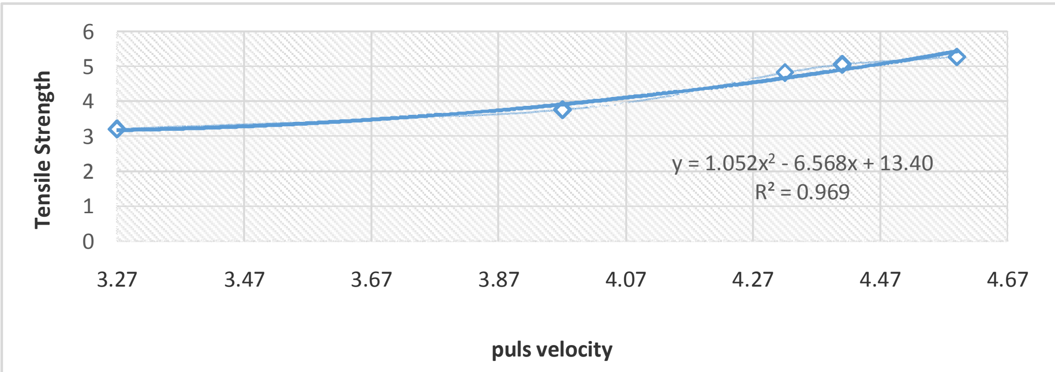

Fig. 10. Tensile strength versus pulls velocity

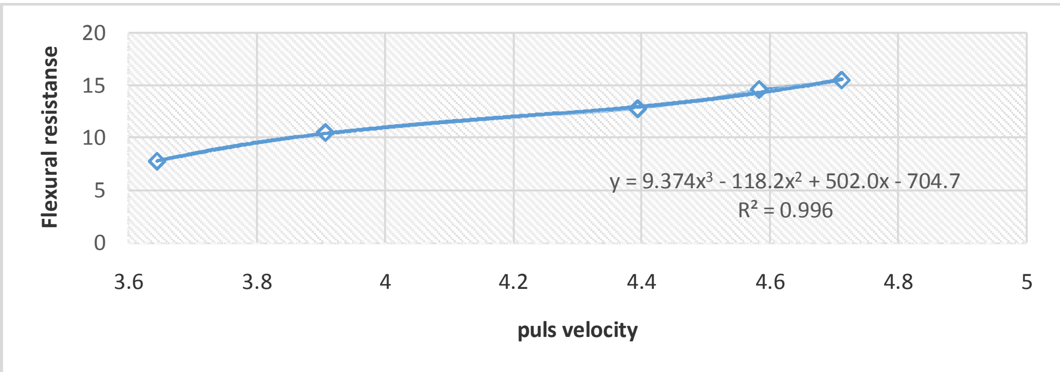

Fig. 11. Flexural strength versus pulls velocity

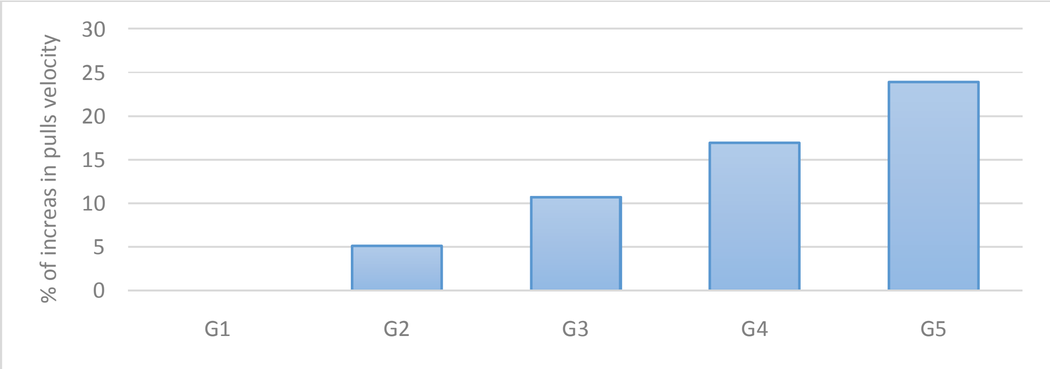

Fig. 12. The percentage of increase in pulls velocity for cubes according to G_1

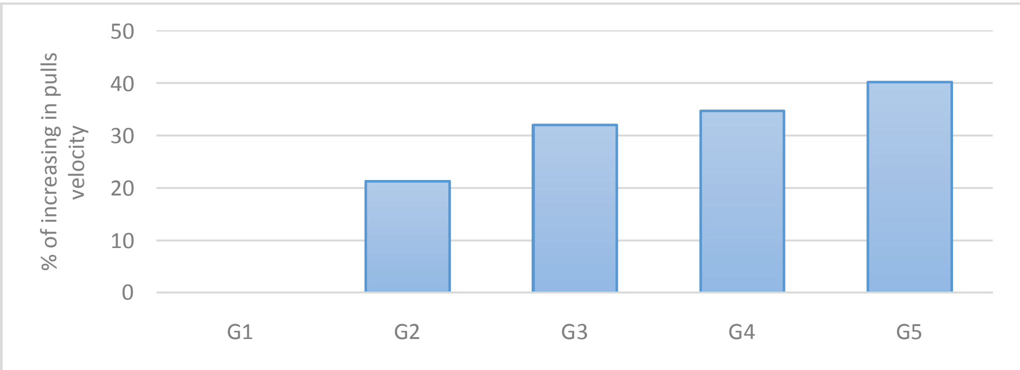

Fig. 13. The percentage of increase in pulls velocity for cylinders according to G_1

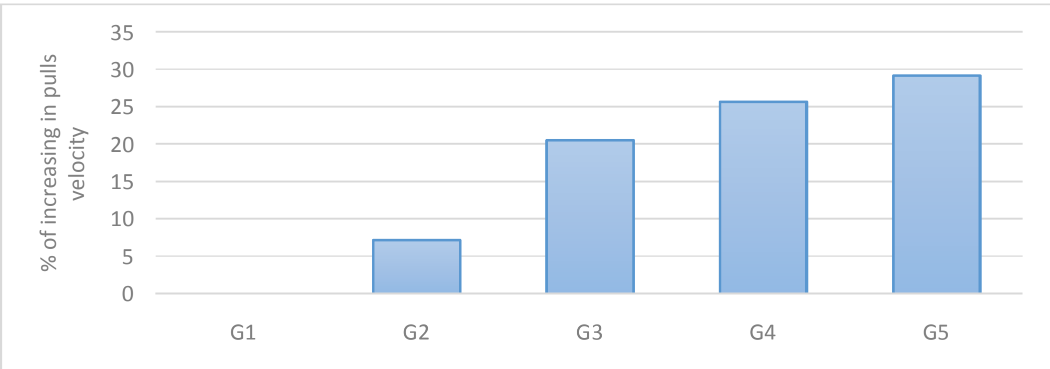

Fig. 14. The percentage of increase in pulls velocity according to G_1

Table 17. Achieved improvements in pulls velocity with reference to G_1

Age (Days)	Group #	% of increase in Pulse Velocity		
		Prisms	Cubes	Cylinders
7	G_1	-	-	-
14	G_2	7.1	5.1	21.4
28	G_3	20.5	10.7	32.1
60	G_4	25.7	16.9	34.8
90	G_5	29.2	23.9	40.3

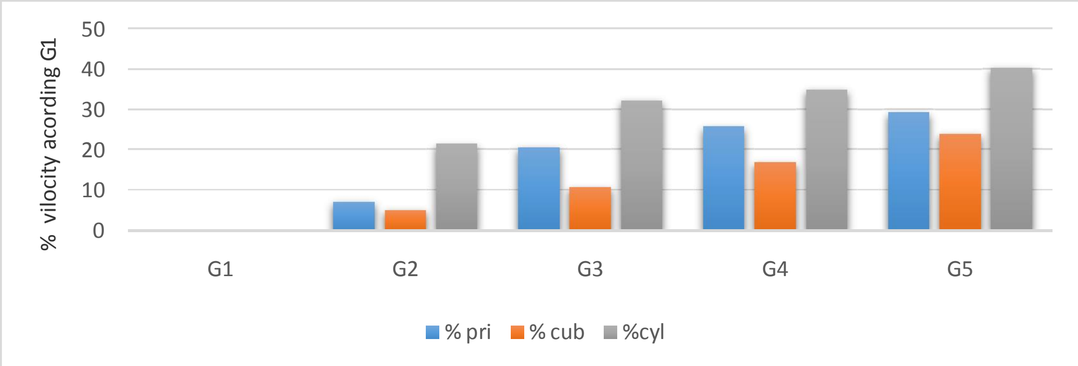

Fig. 15. Achieved improvements in pulls velocity with reference to G_1

Table 18. Achieved improvements for hardened concrete properties according to G_1

Age (Days)	Group #	% of theincrease in strength.		
		Compressive	Tensile Splitting	Flexural
7	G_1	-	-	-
14	G_2	34.3	16.8	34.6
28	G_3	56.2	50.2	64.1
60	G_4	65.6	57.6	87.1
90	G_5	71.8	64.3	98.7

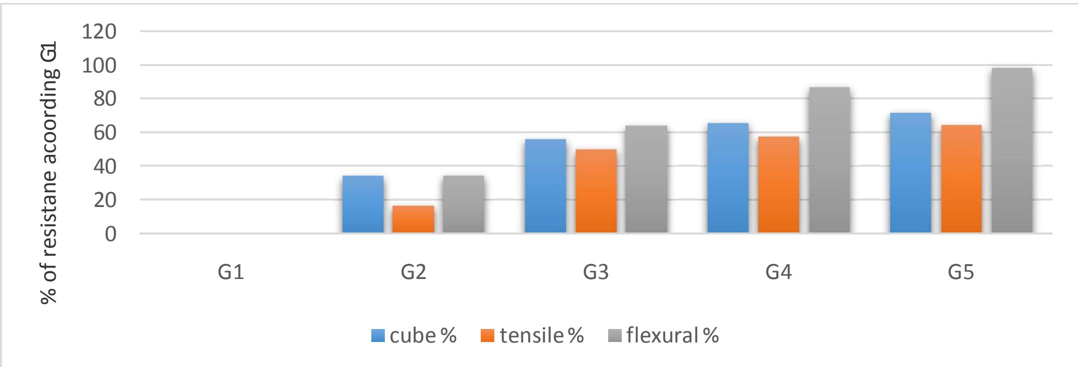

Fig. 16. Achieved improvements for hardened concrete properties according to G_1

Conclusions

The cube compressive strength increased according to (G1 at 7 days curing) from 34.3 % to 71.8% for ages of 14, 28, 60, and 90 days respectively. The percentage of increase of tensile strength according to (G1 at 7 days curing) from 16.8% to 64.3% for ages of 14, 28, 60, and 90 days respectively. Modulus of Rupture increased according to (G1 at 7 days curing) from 34.6% to 98.7% for ages of 14, 28, 60, and 90 days respectively.

Pulse velocity increased according to (G1 at 7 days curing);

a) For cube from 5.1% to 23.9%.
b) For cylinder from 21.4% to 40.3%.
c) For prisms from 7.1% to 29.2%.

The highest improvement was in flexure strength followed by cube compressive strength, and then tensile strength.

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