Some Mechanical Properties of Retempered High Strength Concrete

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Abstract

Iraq climate is characterized by the temperature increase during most of the months. The ambient temperatures are considered the most important factor that effects the production, properties and durability of the concrete.

This study aims to evaluate the effect of retempering concrete after 60 minutes from cast by three different methods (retempring by water, retempring by Superplasticizer (G51) and retempring by remixing) on some of the mechanical properties of High Strength Concrete (HSC).

In this work, different tests methods are adopted such as compressive strength, splitting tensile strength, ultrasonic pulse velocity and a hammer rebound Schmidt tests. These tests are investigated at different ages (7, 14, 28, and 56 days).

The results show the high strength concrete that retempered by superplasticizer (G51) leads to higher strengths, higher Ultrasonic Pulse Velocity (UPV) and higher hammer rebound than direct cast. The rate of increase in the mechanical properties of the high strength concrete that retempered by G51 relative to direct cast concrete at age 56 days were 28.29% ,16.37%, 2.76%,and 16.02% for compressive strength, splitting strength, Ultrasonic Pulse Velocity (U.P.V.) and hammer rebound respectively.

While the concrete that retempered by water leads to lower strengths , lower Ultra Sonic Pulse Velocity (UPV) and lower hammer rebound than the other mixes.

For the High Strength Concrete (HSC) mixes, the compressive strength and splitting tensile strength are closely related to UPV with a high correlation coefficient, R2.

الخلاصة

يتميز مناخ العراق بارتفاع درجات الحرارة خلال معظم اشهر السنة ، حيث تعتبر درجة الحرارة المحيطة من اهم العوامل التي تؤثرعلى انتاج وخواص وديمومة الخرسانة .

هذه الدراسة تهدف لتقييم بعض الخواص الميكانيكية للخرسانة عالية المقاومة ودراسة تاثير اعادة تطبيع الخرسانة على هذه الخواص بعد 60 دقيقة من الخلط وبثلاثة طرق مختلفة (اعادة تطبيع بالماء ، اعادة تطبيع بالمضاف (G51)، و اعادة تطبيع بأعادة الخلط بدون اي اضافة) .

تم خلال هذا العمل تبّني عدة فحوص مختلفة مثل فحص مقاومة الانضغاط ،فحص مقاومة شد الانشطار، فحص سرعة الذبذبات فوق الصوتية و فحص الارتداد بأستخدام مطرقة شميدت ولعدة اعمار من الفحص (7,14,28,56) يوم.

اظهرت النتائج ان خلطات الخرسانة التي أعيد تطبيعها بالمضاف (G51) اعطت اعلى مقاومة واعلى سرعة للذبذبات فوق الصوتية واعلى رقم للارتداد بمطرقة شميدت. حيث بلغت نسبة التحسن (٢٨.٣% و١٦.٣٧% و٢.٧٦% و١٦.٠٢%) لمقاومة الانضغاط و الانشطار وسرعة الذبذبات فوق الصوتية وفحص الارتداد بأستخدام مطرقة شميدت على التوالي ولعمر ٥٦ يوم مقارنة بالخرسانة التي تم صبها مباشرة. بينما اثبتت النتائج ان الخرسانة معادة التطبيع بالماء تمتلك اقل مقاومة مقارنة بالخلطات الاخرى.

فيما يتعلق بالخرسانة عالية المقاومة اثبتت النتائج ان هناك ارتباطا وثيقا بين مقاومة الانضغاط والانشطار و فحص الموجات فوق الصوتية من خلال عامل الارتباط R2.

1. Introduction

With the gradual improvement in concrete technology and concrete practice over the years there has been an increasing use of concrete in higher strengths, in which one or more specific characteristics have been enhanced through the selection and proportioning of its constituents. The high strength concrete (HSC) has a simple definition " concrete with compressive strength above the present existing limits in national code about 40 MPa up to 130 MPa" ***(ACI 363R, 1997)***. Most of the time high strength concrete has to be made in a ready - mix plant, and it has to be transported and placed in the forms at the job sites. Thus, in situations like delivery of HSC from central mixing plant, using a normal well-designed concrete mix, should arrive at its destination with sufficient workability to enable it to be properly placed and fully compacted ***(John and Ban, 2003)***. In such circumstances, where there is a significant period of time between mixing and placing the concrete, there will be a noticeable reduction in the workability of the fresh concrete. Therefore, retempering of the concrete by water, while normally considered to be bad practice, may be contemplated as a possible course of action ***(West, 1990)***. The 'Retempering' process is defined as the addition of water and remixing of concrete or mortar which has lost enough workability in order to restore concrete or mortar slump back to specified limits ***(ACI 116, 2000)***. This process, which evolved as a solution to long hauls and placing delays, is adaptable to the production of high strength concrete where it is desirable to retain the workability as long as possible. Laboratory research, as well as field experience, shows that strength reduction and other detrimental effects are proportional to the amount of retempering water added. Therefore, water addition in excess of the propotioned maximum water content or w/cm to compensate for loss of workability should be prohabited, while adding chemical admixtures, particualry high - range water reducing admixtures, may be very effective to maintain workability of concrete in hot weather conditions ***(ACI 305R, 1999)***. Indeed, Iraq is characterized by a long, dry and hot summers. The average maximum summer temperature is as high as 45 C̊ accompanied by blazing sunshine, which has a strong impact on concrete's workability and accelerate the loss of slump with time. Therefore, the addition of water to ready mixed concrete at the jobsites is particularly more serious during these hot weather conditions. From the preceding discussion, it could be inferred that, there is a real need to enlighten practitioners in the field of the construction about the importance and effectiveness of different retempering conditions on durability and mechanical properties of high strength concrete.

The main objective of this study is to evaluate the influence of different retempering methods, including: ***retempering by G51, retempering by water and retempering by remixing***, on some hardened properties of high strength concrete such as compressive strength, splitting tensile strength, ultrasonic pulse velocity and rebound hammer test, and finally identifies the most effective retempering method for high strength concrete.

2. Experimental Program

2.1 Materials

2.1.1 Cement

The cement used in this study is ordinary Portland cement type I. This cement is tested and checked according to Iraqi standard specification ***(IQS No.5:1984)***. The chemical and physical properties of this cement are illustrated in Tables 1 and 2, respectively.

Table 1: Chemical composition and main compounds of cement*

Compound composition	Chemical composition	Percentage by weight	Limits of (IQS NO.5 /1984)
Lime	CaO	58.75	/
Silica	SiO_2	20.38	/
Alumina	Al_2O_3	3.52	/
Iron oxide	Fe_2O_3	4.68	/
Sulfate	SO_3	1.88	≤ 2.5 %
Magnesia	MgO	3.21	≤ 5 %
Loss on ignition	L.O.I.	3.8	≤ 4 %
Insoluble residue	I.R.	1.2	≤ 1.5 %
Lime saturation factor	L.S.F.	0.93	0.66 – 1.02
(Al_2O_3÷Fe_2O_3)	/	1.2	/
Main compounds (Boque'sequations)		**Percent by weight of cement**	
Tricalcium silicate (C_3S)		65.17	
Dicalcium (C_2S)		13.36	
Tricalcium aluminate (C_3A)		1.41	
Tetracalciumaluminoferrite (C_4AF)		12.24	

***Chemical tests were conducted by the construction materials laboratory of University of Karbala**

Table 2: Physical properties of cement*

Physical properties	Test results	Limits of (IQS NO.5 /1984)
Setting time (Vicat's Method)		
Initial, min	190	≥ 45 min
Final, min	330	≤ 600 min
Fineness (Blaine Method) ,m^2/kg	278	≥230 m^2/kg
Compressive strength, MPa		
3 days	17.28	≥ 15, MPa
7 days	25.97	≥23, MPa

***Physical tests were conducted by the constructional materials laboratory of University of Karbala**

2.1.2 Sand

Locally available natural sand with 4.75mm maximum size was used in presented work. It's grading was within the limits of the Iraqi specification ***(IQS No.45:1984)***. Tables 3 and 4 show the grading and physical properties of this fine aggregate, respectively.

Table 3: Grading of fine aggregate

Sieve size (mm)	Cumulative passing%	Limits of Iraqi specification No.45/1984 /zone (2)
10	90.10	100
4.75	78.39	90-100
2.36	71.19	75-100
1.18	58.08	55-90
0.6	22.65	35-59
0.3	1.33	8-30
0.15	0.0	0-10

Table 4: Physical properties of fine aggregate*

Physical properties	Test result	Limits of Iraqi specification No.45/1984
Specific gravity	2.62	/
Sulfate content	0.32%	≤ 0.5 %
Absorption	2.21%	/
Dry-Loose density (kg/m^3)	1610	/
Fineness modulus	2.98	/

***Physical tests were conducted by the constructional materials laboratory of University of Karbala**

2.1.3 Gravel

Natural rounded gravel of maximum size 14 mm was used in presented work. Table 5 shows the grading of this aggregate, which conforms to the Iraqi specification ***(IQS No.45:1984)***. The specific gravity, sulfate content and absorption of coarse aggregate are illustrated in Table 6.

2.1.4 Water

The water used in the mix design was potable water from the water-supply network system; so, it was free from suspended solids and organic materials, which might have affected the properties of the fresh and hardened concrete.

Table 5: Grading of coarse aggregate

Sieve size (mm)	Cumulative passing%	Limits of Iraqi specification No.45/1984
20	100	100
14	97.5	90-100
10	82.4	50-85
5	6	0-10
2.36	/	/

Table 6: Physical properties of coarse aggregate*

Physical properties	Test result	Limits of Iraqi specification No.45/1984(101)
Specific gravity	2.65	/
Sulfate content	0.03%	≤ 0.1 %
Absorption	0.5%	/
Dry rodded density (kg/m^3)	1635	/

***Physical tests were conducted by the constructional materials laboratory of University of Karbala**

2.1.5 Super plasticizer

A chemical admixture based on modified poly carboxylic ether, which is known (Glenium 51) was used in producing HSC as a high range water reducing admixture (HRWRA). Glenium 51 is considered one of a new generation of copolymer-based super plasticizer that complies with ASTM C 494 type A and F. Typical properties of Glenium 51 are shown in Table 7.

Table 7: Typical properties of Glenium 51*

Form	Viscous liquid
Color	Light down
Relative density	1.1 at 20°C
pH	6.6
Viscosity	128 cps at 20°C
Chloride content	Free

***Given by manufacture.**

2.2 Mix proportion

High strength concrete mix was designed to give a 28 days compressive strength 40 MPa. The design was made in accordance with American method for mix design method ***(ACI 211, 1998)***. The cement content was 550 kg/m^3 . After trial mixes, a mix proportion of (1:1.2:1.8) by weight was adopted through this work. Four mixes of HSC were investigated, direct casting HSC , HSC retempered by water after waiting 60 min. HSC retempered by G51 after waiting 60 min. and HSC retempering by remixing after waiting 60 min. Table (8) shows the details of these mixes.

Table 8: Details of mix proportion

Concrete Mix	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	sp %	w/c	Retempering process
Direct Cast	550	660	990	1.25	0.32	/
HSC retempered by water	550	660	990	1.25	0.32	Add 1.6%water
HSC retempered byG51	550	660	990	1.25	0.32	Add 0.05% G51
HSC retempering by remixing	550	660	990	1.25	0.32	/

2.3 Results and Discussions

2.3.1 Compressive Strength

The compressive strength is one of the most important properties of hardened concrete. To study the effect of retempering process on compressive strength of HSC, standard (10×10×10) cm cubes where used within this test. Table 9 and Fig.1 represent the results of compressive strength test at 7, 14, 28 and 56 days and it is shown that the compressive strength increases with age for all mixes. From the results of compressive strength shown in Fig.1, it can be seen that HSC-retempered by G51 exhibited a considerable increase in compressive strength at all ages relative to their reference HSC-direct cast. The percentage increase in compressive strength of HSC-retempered by G51 measured relative to HSC-direct cast were 55.4%, 23.5%, 27.6% and 28.3% at 7, 14, 28 and 56 days, respectively. This improvement could be attributed to inclusion the extra amount of HRWRA in HSC mix during retempering process which leads to a significant reduction in capillary porosity. As well as, SP surfactant prone to disagglomerate and disperse the cement grains in the mortar matrix, therefore, on continuing hydration there is a greater statistical chance of intermeshing of hydration products with fine and coarse aggregate to produce a system of higher internal integrity and hence higher strength ***(Mehta &Monteiro, 2006)***.

Also, the results indicate that the HSC-retempered by remixing yielded higher compressive strength when compared with HSC-direct cast, Fig.1. The compressive strength of HSC- retempered by remixing was 36.8, 44.7, 51.3 and 55MPa at 7, 14, 28 and 56 days, respectively. The improvement of compressive strength of HSC-retempered by remixing may be attributed to remixing process, which was agitated HRWRA in concrete mix, resulting in a uniform dispersion of cement grains in the concrete mixture. This leads to efficient hydration process and a higher early strength. Furthermore, the lower compressive strength for the four mixes was found for HSC-retempered by water. It showed a reduction in compressive strength values of 4.4%, 14.1%, 8.7% and 3.4% at 7, 14, 28 and 56 days, respectively compared with HSC-direct cast. This behavior is ascribed to the increase in the amount of water which was used to retempering the concrete mix. This tendency is in accord with what has been reported in ***(John & Ban, 2003)*** which indicates that retempering water is offsetting the effects of insufficient water batched initially or higher rates of evaporation and/or absorption than anticipated. However, once hydration has started a loss of strength can be expected.

Table 9: Results of compressive strength of HSC

Age (days)	Compressive Strength (MPa)			
	HSC Retempered by G51	HSC Retempered by remixing	HSC Direct Cast	HSC Retempered by water
7	59.7	45.3	38.4	36.8
14	63	58	51	44.7
28	71.2	60.8	55.8	51.3
56	73	69.7	56.9	55

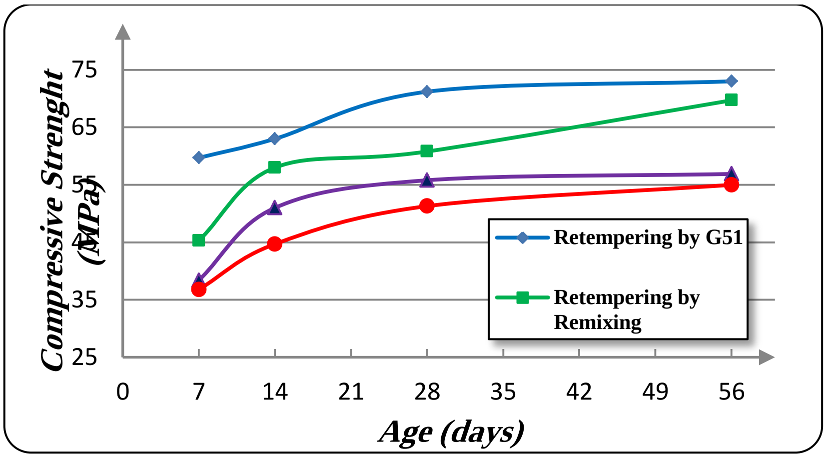

Fig.1: Effect of retempering process on compressive strength of concrete

2.3.2 Splitting tensile strength

The results for splitting tensile strength have been presented in Table 10 and Fig. 2. The splitting tensile strength of the concrete increased continuously as the age of concrete progressed for all concrete mixes. The splitting tensile strength of HSC-retempered by G51 exhibited a noticeable strength decrease at 7 days of curing. The decreasing in splitting tensile strength at early ages for HSC-retempered by G51 is most properly attributed to high dosage of G51,which may lead to retardation of the cement hydration at early ages. Beyond this period, 7 day, a remarkable improve in splitting tensile strength was observed. After 56 days of curing, the percentage increases in tensile strength of HSC-retempered by G51 were 29.6%, 16.37% and 11.28% relative to HSC-retempered by water, HSC-direct cast and HSC-retempered by remixing, respectively. This improvement is imputed to the significant reduction in capillary porosity of the cement matrix as well as, a good dispersion of the cement grains throughout the mix ***(Neville, 1995)***.

Moreover, HSC-retempered by remixing showed a clear increase in splitting tensile strength compared to the direct cast concrete mixes. This increase is mainly associated with agitation process of HRWRA in concrete mix. Such process can contribute to the dispersion of cement agglomerates into primary particles to produce a more consistent system, thereby strengthening the transition zone and reducing the micro-cracking leading to a significant increase in tensile strength. The percentage increase in tensile strength of HSC-retempered by remixing relative to direct cast were 8.24%, 5.07%, 6.92% and 4.57% at 7, 14, 28 and 56 days, respectively.

On the other hand, the mixes that are retempered by water give lower splitting tensile strength than direct cast mixes. The percentage decrease in splitting tensile strength of HSC-retempered by water relative to HSC-direct cast were 12.36%, 20.07%, 7.69% and 10.21% at 7, 14, 28 and 56 days, respectively. These results are due to the water addition which increases the micro-cracking and weakening the transition zone between the cement paste and aggregate.

Table 10: Results of splitting tensile strength of HSC

Age(days)	Splitting Tensile Strength (MPa)			
	HSC Retempered by G51	HSC Retempered by remixing	HSC Direct Cast	HSC Retempered by water
7	4.47	4.99	4.61	4.04
14	5.43	5.39	5.13	4.1
28	5.83	5.56	5.2	4.8
56	6.61	5.94	5.68	5.1

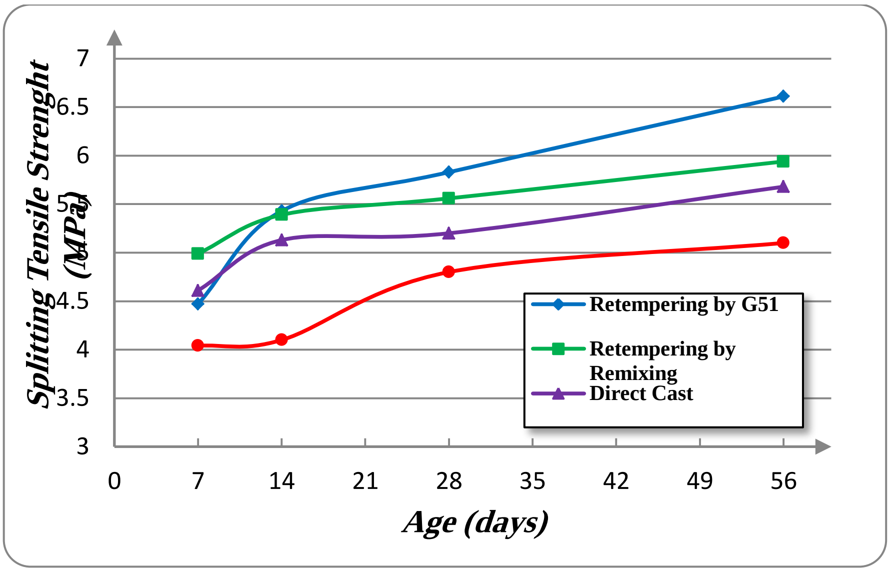

Fig.2: Effect of retempering process on splitting tensile strength of concrete

2.3.3 Ultrasonic Pulse Velocity

The results of ultrasonic pulse velocity have been presented in Table 11 andFig.3. Test results show that the velocity of the ultrasonic waves for all specimens increases slightly with age increasing up to 56 days. This enhancement in strength is because of the progress of hydration which decreases the void space within the concrete mass. The increase in the gel/space ratio causes a rise in wave speed, since the velocity of ultrasonic through materials is larger than that if it transfers through space. Hence, the increase in the concrete mass within the same volume increases the ultrasonic pulse velocity.

HSC-retempered by G51 demonstrated a noticeable increase in pulse velocity at all ages compared with other mixes. For instance, the percentage increase in ultrasonic pulse velocity after 56 days of curing relative to HSC-retempered by remixing, HSC-direct cast and HSC-retempered by water were 1.64%, 2.76% and 3.14%, respectively. This behavior is attributed to the reduction in water due to evaporation and using G51 for retempering without adding any additional water. However, the HSC-retempered by water give lower pulse velocity than other mixes by about 3.05%, 1.45% and 0.36% for HSC-retempered by G51, HSC-retempered by remixing and HSC-direct cast, respectively.

Although, the pulse velocity is not related directly to compressive strength but it is agreed that as the concrete compressive strength increases, the pulse velocity increases. This increment is not linear and could be logarithmic relationship, as shown in Fig.4.

Table 11: Results of UPV of HSC

The Ultrasonic Pulse Velocity (km/s)				Age(days)
HSC Retempered by G51	HSC Retempered by remixing	HSC Direct Cast	HSC Retempered by water	
5.46	5.45	5.28	5.24	7
5.51	5.46	5.3	5.29	14
5.55	5.48	5.43	5.38	28
5.58	5.49	5.43	5.41	56

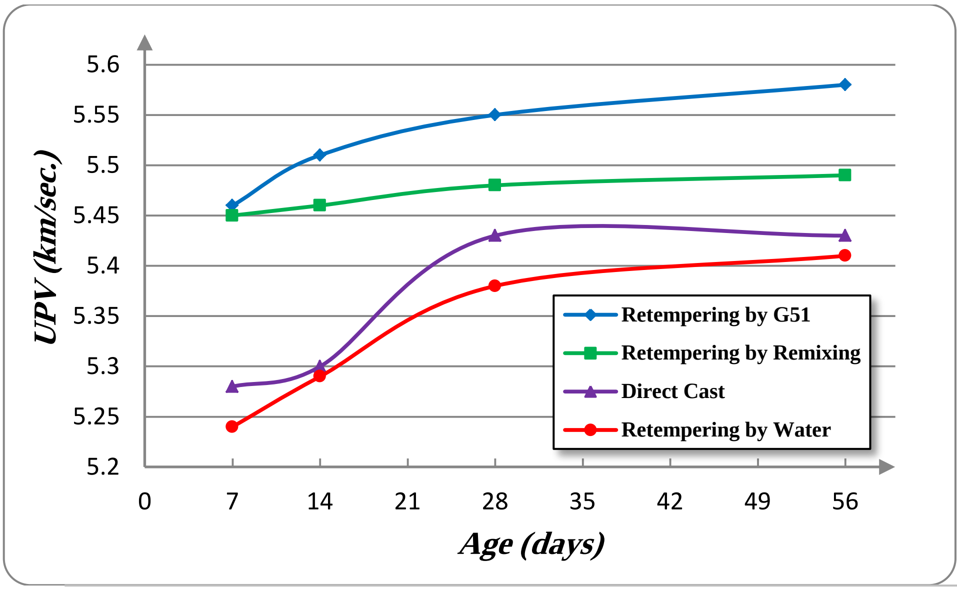

Fig. 3: Effect of retempering process on the ultrasonic pulse velocity of concrete

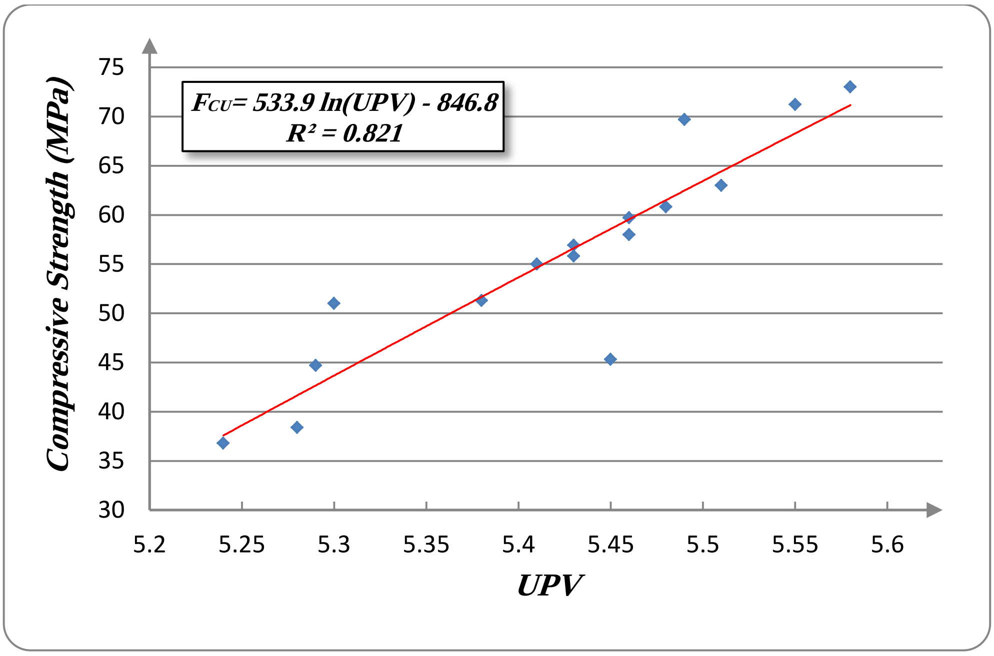

Fig. 4: Relationship between compressive strength and UPV

2.3.4 Rebound Hammer

The surface hardness of the 10 cm HSC cubes is assessed by the, "Schmidt Rebound Hammer" test, according to the BS1881: Part 201: 1986. The results of the rebound number concrete specimens are shown in Table 12 and Fig.5.

Form the recoded results in Table 12, it can be seen that the rebound number for HSC specimens increased continuously, as the age of concrete progressed. Itvaried from 31.33 to 50.67 for various ages and different retempering methods. The increase in rebound hammer followed a trend similar to that of ultrasonic pulse velocity. However, the rate ofincrease in rebound hammer was lower than that observed in case of ultrasonic pulse velocity. It indicates that the Rebound Hammer is less sensitive to the micro-structural changes in concrete, as compared to ultrasonic pulse velocity.

HSC-retempered by G51 exhibited the highest level of rebound hammer. However, HSC- retempered by remixing provided slightly lower rebound hammer than HSC-retempered by G51,but it provided higher rebound hammer than reference concrete. On the contrary, HSC-retempered by water produced the lowest level of rebound hammer. The reasons are probably the same as discussed before. More precisely, the reduction in rebound hammer ofHSC-retempered by water is related to the highwatercontent of themixture, resulting in microscopic pores that will reduce the final compressive strength of concrete. For instance, the percentage decrease in rebound number for HSC-retempered by waterat 7, 14, 28 and 56 days were18.41%, 7.56 %, 5.38% and 5.35 %, respectively measured relative to HSC- direct cast. While, the percentage increase in rebound number for HSC-retempered by G51 at 7, 14, 28 and56 days were 16.33 %, 21.81%, 17.88 % and 16.03, respectively measured relative to HSC- direct cast.

Fig.6 shows the relationship between compressive strength and rebound number for HSC mixes. It appears from the figure that rebound number increases with increase in compressive strength of concrete mix.

Table 12: Results of Rebound hammer of HSC

The Rebound Number				Age(days)
HSC Retempered by G51	HSC Retempered by remixing	HSC Direct Cast	HSC Retempered by water	
44.67	40.67	38.4	31.33	7
44.67	41.33	39.67	36.67	14
48.33	45.33	43.33	41	28
50.67	48	43.67	41.33	56

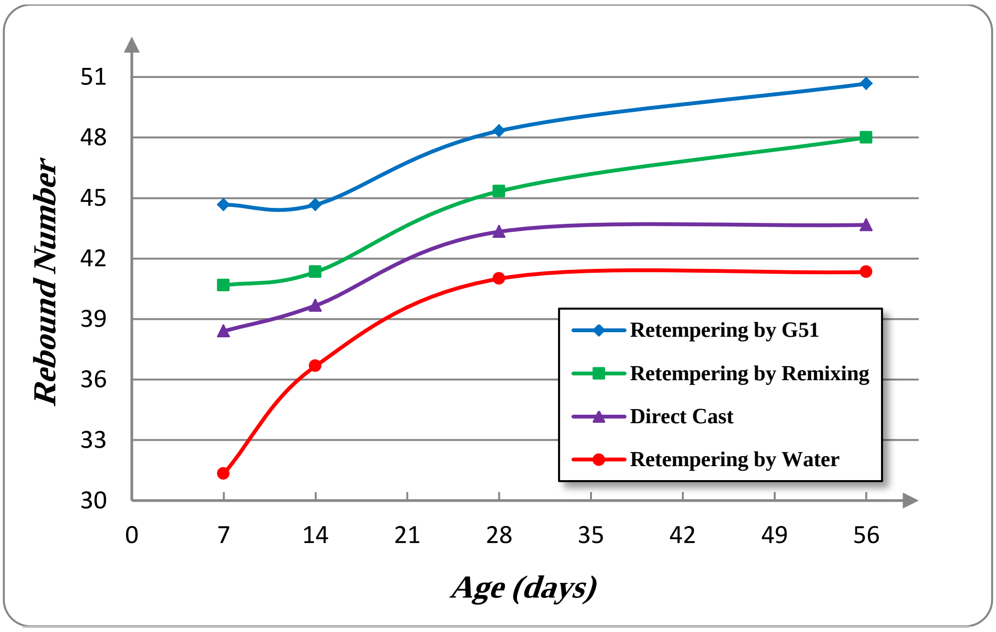

Fig. 5: Effect of retempering process on the Rebound Hammer of concrete

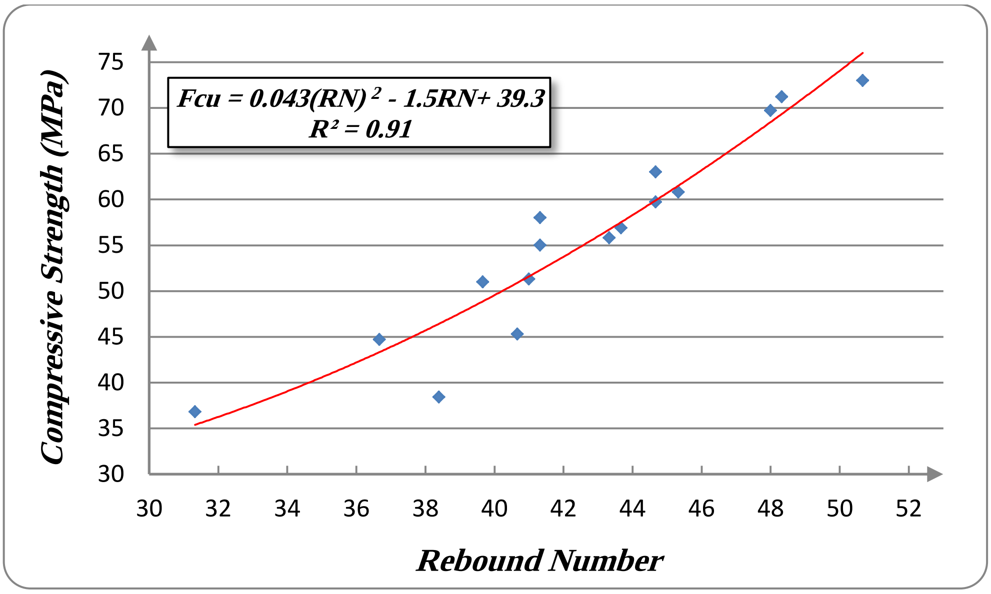

Fig. 6: Relationship between rebound hammer and compressive strength

2.4 Conclusions

The following conclusions can be drawn based on the experimental results and discussions of the study conducted are:

1. The most effective manner of retempering methods was retempering by G51. It is known to be an effective way to restore workability without adversely affecting other properties. As well as, it produced the highest mechanical properties, rebound numbers and pulse velocity.
2. HSC-retempered by G51 achieved a remarkable compressive strength compared to other mixes. The rate of increase in compressive strength at age 56 days were 32.72%, 28.29% and 4.73% relative to HSC-retempered by water, HSC-direct cast and HSC-retempered by remixing, respectively.
3. The results of splitting tensile strength of HSC-retempered by G51were 29.6%, 16.37% and 11.28% relative to HSC-retempered by water, HSC-direct cast and HSC-retempered by remixing, respectively.
4. The addition of water to HSC mix may result in a substantial reduction in strength. Therefore, it is strongly recommended that adding water to concrete mixes in order to compensate for loss of workability should be prohibited.
5. In compressive strength test, the maximum reduction in strength was assigned for the HSC- retempered by water. It exhibited a reduction in compressive strength values of 4.4%, 14.1%, 8.7% and 3.4% at 7, 14, 28 and 56 days, respectively compared with HSC-direct cast.

6. In splitting tensile strength, the maximum reduction in strength was assigned for the HSC- retempered by water. The percentage decrease in splitting tensile strength of HSC-retempered by water relative to HSC-direct cast were 12.36%, 20.07%, 7.69% and 10.21% at 7, 14, 28 and 56 days, respectively.
7. For HSC mixes, the compressive strength and splitting tensile strength are closely related to U.P.V with a high correlation coefficient, R2. This verifies the suitability of the proposed relationships for prediction of hardened HSC strengths from measured U.P.V values.

2.5 References

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