Regression Analysis Models to Predict the 28 -day Compressive Strength Using Accelerated Curing Tests

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ABSTRACT

Regression analysis models are adopted by using SPSS program to predict the 28-day compressive strength as dependent variable and the accelerated compressive strength as independent variable. Three accelerated curing method was adopted, warm water (35ºC) and autogenous according to **ASTM C C684-99** and the British method (55ºC) according to **BS1881: Part 112:1983**. The experimental concrete mix design was according to ACI 211.1. Twenty eight concrete mixes with slump rang (25-50) mm and (75-100)mm for rounded and crushed coarse aggregate with cement content (585, 512, 455, 410, 372 and 341)Kg/m^3.

The experimental results showed that the accelerated strength were equal to about (0.356), (0.492) and (0.595) of the 28-day compressive strength for warm water, autogenous and British curing methods respectively. A statistical regression analysis using SPSS program is implemented for the experimental results of the 28-day compressive strength ranging from (16 to 55.2)Mpa and accelerated strength for different curing methods. The linear models with high R^2 and F-value are adopted for different curing methods while the Power model with constant is the best model for non parametric analysis.

Key words: accelerated compressive strength, regression analysis models

موديلات تحليل الانحدار لتوقع مقاومة الانضغاط بعمر 28 يوم باستخدام فحوص الانضاج المعجل

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الخلاصة

تم أعتماد موديلات تحليل الانحدار بأستخدام برنامج SPSS لتوقع مقاومة انضغاط الخرسانة لعمر 28 يوم كمتغير ومقاومة الانضغاط للانضاج المعجل كمتغير معتمد .تم اعتماد ثلاثة طرق وهي طريقة الماء الدافئ (35˚م) وطريقة الانضاج الذاتي المعتمدة في المواصفة الامريكية ASTM C684-99 والطريقة البريطانية(55˚م) المعتمدة في الطريقة البريطانية BS 1881:Part 112:1983. تم تصميم الخلطات الخرسانية وفق ACI 211.1. تم تحضير 28 خلطة خرسانية بمدى هطول (25-50) ملم وكذلك (75 -100) ملم لركام خشن مدور ومكسر على التوالي وبمحتوى سمنت (410،372،341،585،512،455) كغم /م^3 .

النتائج العملية لمقاومة الانضغاط المعجل تساوي حوالي (0.356) ، (0,492) و(0,595) من مقاومة الانضغاط بعمر 28 يوما لطريقة الماء الدافئ، الانضاج الذاتي والطريقة البريطانية على التعاقب . تم تنفيذ تحليل الانحدار الخطي بأستخدام برنامج SPSS للنتائج العملية بين مقاومة الانضغاد الاعتيادية بعمر 28 يوم و المقاومة المعجلة . تم تبني الموديلات الخطية و لمختلف طرق الانضاج وبقيم عالية لـR^2 وF-value بينما الموديل الاسي و بوجود الثابت هو الموديل الافضل في التحليل اللاخطي للبيانات.

الكلمات الرئيسيه : مقاومة الانضغاط المعجل ، موديلات تحليل الانحدار.

1. INTRODUCTION

The predicted 28-day compressive strength of a concrete can be estimated in lesser time by accelerating methods mentioned in ASTM C684 and BS1881: Part 112.

Abbas and Auad, 2011 studied the accelerated strength testing method using the British standard methods was performed to predict the strength at later ages. Four different chemical compositions were used with two mean compressive strength equals to 35 and 45MPa. Comparison between the three methods adopted by the British standard refers to despite the fact that the 35 ºC method is the simplest and most convenient of the three; the correlations for a range of different concretes may be somewhat more widely dispersed than for the 55 ºC method. The third way of 82 ºC method is more complex and it needs high water temperature. The percent of accelerated strength test (35 ºC, 55 ºC and 82 ºC methods) of 7-day normal curing strength approximately were 0.4, 0.6 and 0.7 respectively.

Atwan, 2012 studied the effect of accelerated curing methods on mechanical properties of superplasticized and retarding concrete. The adopted accelerating tests are warm water and boiling water method according to the ASTM C684-99.

Two concrete mixes with ordinary and crushed gravel were studied. The effect of surface texture of gravel, curing test methods and admixture doses were studied. The main conclusions that the accelerated strength for both methods was larger than the compressive strength of normal cured concrete specimens at the same age and the specimen's strength for boiling water method were higher than the warm water method.

Fawzi and Tawfeeq, 2012 investigated the effect of curing temperatures (30, 40, and 50˚C) on compressive strength development of high performance concrete and standard conditions at curing temperature (21˚C). The experimental results showed that at early ages, the rate of strength development at high curing temperature is greater than at lower curing temperature, the optimum increasing percentage in compressive strength is 10.83% at 50˚C compared with 21˚C in 7days curing age.

Abbas, 2013 studied the lightweight concrete- no fine concrete. The specimens concrete mixes were (cement: porcelinite coarse aggregate) ratios (1:4), (1:5) and (1:6). The cement content were (200, 300 and 400) kg/m^{3}for each mixes. The tests of density, absorption, porosity, ultrasonic pulse velocity and compressive strength at 7, 28 and 90-day were studied. The correlation between accelerated compressive strength at 1- day and normal compressive strength at 28-day are approximately (0.245 ±0.005) for water bath (55°C) and (0.335±0.05) for water bath (82°C).

2. PREVIOUS MODELS OF THE ACCELERATED STRENGTH TEST AND THE NORMAL CURING TEST

Al- Qassab, 2006, models adopts the linear regression analysis equations of an ordinary Portland cement and sulfate resisting cement respectively:

$$Y7\text{-}day = 2.45 + 1.17X \quad R^2 = 0.97 \qquad (1)$$

$$Y7\text{-}day = 2.17 + 0.88X \quad R^2 = 0.97 \qquad (2)$$

Regression analysis shows the relationship as a second equation of an ordinary Portland cement and sulfate resisting cement respectively:

$Y28\text{-}day = 5.39 + 2.24X - 0.03\,X^2$ $R^2 = 0.95$ (3)

$Y28\text{-}day = 4.38 + 1.91X - 0.02\,X^2$ $R^2 = 0.95$ (4)

The correlation for all cements as presented equation:

$Y28\text{-}day = 6.06 + 2X - 0.03\,X^2$ $R^2 = 0.91$ (5)

The **ASTM C684 -99** for method B, illustrate the procedure, considered the 12 pairs of accelerated and standard-cured at 28-day strengths.

Therefore, the equation of the relationship between the accelerated strength (X) and the standard-cured strength (Y) is as follows:

$Y = 19.50 + 1.19\,X$ (6)

Abbas, et al., 2012 adopted three accelerated curing test methods which are warm water, autogenous and the proposed method. A good correlation was presented between the accelerated strength and normal strength at ages 7 and 28 day. Five different chemical composition of cement in concrete mixes and different water to cement ratios equal to 0.45, 0.55, and 0.65 and 0.75 were studied.

The regression models for linear relationship between accelerated strength (warm water and autogenous method) and 28-day compressive strength are presented respectively:

7-day Comp. strength = 1.797+ 1.744x accelerated strength-warm $R^2 = 0.942$ (7)

28-day Comp. strength = 2.357+ 2.540x accelerated strength-warm $R^2 = 0.969$ (8)

7-day Comp. strength = -0.171+ 1.677x accelerated strength-autogenous $R^2 = 0.987$ (9)

28-day Comp. strength = 0.062+ 2.398x accelerated strength-autogenous $R^2 = 0.979$ (10)

3. EXPERIMENTAL PROGRAM

3.1 Material

3.1.1 Cement

Sulfate resistance Portland cement (Abu Al Jasser) conforming to the IQS 5/1984 and ASTM C150 was used. The chemical and physical properties are listed in **Tables 1 and 2** respectively.

3.1.2 Fine Aggregate (sand)

The sand from Al-Ukhaider region with grading conforms to the Iraqi specification IQS 45/1984-zone two and the ASTM C33-03. The physical properties and sulfate content are shown in **Table 3**.

3.1.3 Coarse Aggregate

Natural crushed and rounded coarse aggregate with maximum size of 20mm from Al-Niba`ee quarry was used. The aggregate conform to the Iraqi specification IQS 45/1984. The sulfate content and the physical properties are presented in **Table 4**.

3.1.4 Mixing Water

Tap water is used for mixing and curing of concrete mixes, conforming to the IQS 1703/1992.

3.2 Mix Proportions

The concrete mix design was according to ACI 211.1. Twenty eight concrete mixes with slump rang (25-50) mm and (75-100)mm for rounded and crushed coarse aggregate and cement content (585, 512, 455, 410, 372 and 341)kg/m^{3}as presented in **Table 5**.

3.3 Mixing and Curing of Concrete

The dry constituents of mix were initially mixed for 1.5 minutes using a rotary mixer. The required amount of water was then added, and the whole mix constituents were re-mixed for further 1.5 minutes. The molds, with dimensions of (100) mm are used.

The molds were covered with thick nylon bag for normal curing for 24hrs and then the specimens were transformed to the curing tank with water till the time of testing (7 and 28-day). The procedure is mentioned in the curing methods for the specimens of accelerated curing test.

3.4 Tests Performed

3.4.1 Fresh Concrete- Slump Test

The fresh concrete is illustrated by slump test according to ASTM C143M– 00. The adopted slump range (25-50mm) and (50-75mm) for both mixes using crushed and rounded coarse aggregate.

3.4.2 Compressive Strength Test

The compressive strength test was carried out according to the BS 1881: Part 116: 1983 for concrete cubes of (100) mm.

4. RESULTS AND DISCUSSION

The accelerated strength methods (warm water (35ºC), autogenous and (55ºC)) and normal curing (7 and 28-days) results are presented in **Table 6**.

The effect of cement content (C-585, C-512, C455, C410, C372, C341 andC-315) for crushed and rounded cores aggregate and slump (S25 and S75) on accelerated and normal curing are shown in the **Figs. 1** to **4**. The figures indicated that as cement content increase the compressive strength for accelerated and normal curing and it is conforms to the literatures, **Abbas, 2012** and **Al-marsomy, 2010**.

For the same cement content (C-585) and the slump (S25) and (S75) as shown in the **Figs. 5** and **6** for crusted and rounded coarse aggregate respectively. The accelerated strength with different method and (7 and 28-days) for normal curing strength, concrete mixes with crushed coarse aggregate is more than rounded and that is may be attributed to natural rounded uncrushed gravel has lower specific surface area and smoother texture than crushed gravel so the bond strength is increase led to increase the compressive strength, **Al Attar, 2008**. **Figs. 7** and **8** shows the accelerated and normal curing concrete (7 and 28-days) for the same cement content (C-315) and the slump (S25) and (S75).

The **Figs. 9** to **12** shows the cumulative compressive strength for different curing methods with different W/C ratio for crushed and rounded cores aggregate and slump (S25 and S75) on accelerated and normal curing. The compressive strength decreased with the increase w/c ratio and that is conforms to the literatures, **Abbas, 2012**.

5. REGRESSION ANALYSIS MODELS

5.1 Descriptive Statistics

The objective is to develop statistical models to predict the 28 –day normal strength as a function of independent variable. It is necessary to examine the existence of the required range of variation in the data. This is achieved by performing a preliminary (descriptive) statistical analysis as presented in **Table 7**.

1. Mean, median and mode (central tendency)
2. Minimum and maximum, range and standard deviation (dispersion).

5.2 Regression Models of Warm Water Method (35ºC),Autogenous and British Curing Method (55ºC)

Using SPSS program version 17.1 for linear and non parametric analysis are presented in **Table 8** and **Figs. 13** and **14** for warm water method, while **Table 9** and **Figs. 15** and **16** for autogenous and **Table 10** and **Figs 17** and **18** for British curing method.

From **Tables 8, 9 and 10** and **Figs. 13 to 18**, it is found that:

1. Model 2-linear is better than model 1-linear with higher R^2 and F-calculated and the experimental data close to the line.
2. The accelerated strength approximately equal to (0.356),(0.492) and (0.595) of 28-day compressive strength of warm water, autojenous and British curing methods respectively for linear regression analysis.
3. For non-parametric regression analysis the models with constant is more convents.
4. The model 5-power is the best with high $R^2$and F-calculated and the experimental data close to the curve.

6. CONCLUSIONS

1. The accelerated curing methods (warm water and autogenus) according to ASTM C and 55ºC according to BS can be adopted to predict the 28-day compressive strength.
2. The accelerated strength approximately equal to (0.356),(0.492) and (0.595) of 28-day compressive strength of warm water, autojenous and British curing methods respectively for linear regression analysis.
3. Statistical linear analysis models presents the best correlation between accelerated strength with different curing methods and 28-day compressive strength ranging (16 to 55.2)Mpa with high (R^2).

4. For non-parametric regression analysis the models (power) with constant for different curing methods is the best with high $R^2$and F-calculated.

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Table 1. Chemical composition of SRP cement*.

Abbreviation	Percentage by weight	Limit of Iraqi Specification No. 5/1984	Limit of ASTM Specification C150-12
CaO	61.74	-	
SiO_2	20.84	-	
Al_2O_3	3.82	-	
Fe_2O_3	5.24	-	
SO_3	2.15	≤ 2.5 %	≤3.0 if C_3A≤8% ≤3.5 if C_3A≤8%
MgO	3.38	≤ 5.0 %	≤ 6.0 %
L.O.I.	2.47	≤ 4.0 %	≤ 3.0 %
I.R.	0.72	≤ 1.5 %	≤ 0.75 %
L.S.F	0.9	0.66-1.02	
Main Compounds (Bogue′s equations)			
C_3S	49.86	-	-
C_2S	22.38	-	-
C_3A	1.26	≤ 3.5	-
C_4AF	15.92	-	-

* The test was carried out in Building Research directorate / ministry of construction and Housing

Table 2. Physical properties of SRP cements*.

Physical properties	Test results	Limits of Iraqi Specification No. 5/1984	Limits of ASTM Specification C150-12
Specific surface area (Blaine method) (m^2/ kg)	325.9	≥ 230	≥ 280
Setting time (Vicat′s method) Initial setting (hrs. : min) Final setting (hrs. : min)	 110 4:30	 ≥ 45 min ≤ 10 hrs.	 ≥ 45 min ≤375min
Compressive strength (MPa) 3 days 7 days	 20 29	 ≥ 15 ≥ 23	 ≥ 12 ≥ 19

* The test was carried out in Building Research directorate / ministry of construction and Housing

Table 3. Physicals properties and sulfate content of fine aggregate*.

Sieve size (mm)	% passing by weight	Iraqi specifications No.45/1984 (Zone 2)	ASTM specification C33-03
10	100	100	100
4.75	95.6	90-100	95 -100
2.36	80.4	75-100	80 – 100
1.18	59.9	55-90	50 - 85
0.6	37	35-59	25 - 60
0.3	9.3	8-30	5 - 30
0.15	1.3	0-10	0 - 10
Material finer than 0.075 mm	3.8	Max. 5	Concrete subject to abrasion (Max. 3) All other concrete(Max.5)
Fineness modulus =2.148 , Specific gravity=2.58			
Sulfate content (%)	0.1	Max. 0.5	-

*The test was carried out in Building Research directorate / ministry of construction and Housing

Table 4. Physical properties and sulfate content of coarse aggregate*.

Sieve size (mm)	Passing by weight (%) Crushed	Passing by weight (%) Rounded	Iraqi specification No. 45/1984 (5-20)mm	ASTM specification C33-03
37.5	100	100	100	-
25	100	100	-	100
20	99.3	99.0	95-100	90-100
10	30	30	30-60	20-55
5	0.05	1.0	0-10	0-10
Material fine than 0.075 mm	0	1.0	Max. 3	-
Sulfate content (%)	0.002	0.001	Max. 0.1	-
Specific gravity	2.6	2.6	-	-

* The test was carried out in Building Research directorate / ministry of construction and Housing

Table 5. Mix proportion for different concrete mixes.

Mix	Number	Cement (kg/m^3)	Water (kg/m^3)	Fine agg. (kg/m^3)	w/c	Mix
C.A-S25	1	585	190	603	0.32	1:1.031:1.735
C.A-S25	2	512	190	663	0.37	1:1.294:1.982
C.A-S25	3	455	190	710	0.42	1:1.560:2.23
C.A-S25	4	410	190	747	0.46	1:1.821:2.475
C.A-S25	5	372	190	778	0.51	1:2.091:2.728
C.A-S25	6	341	190	803	0.55	1:2.354:2.976
C.A-S25	7	315	190	825	0.60	1:2.619:3.222
C.A-S75	8	585	205	514	0.35	1:0.878:1.735
C.A-S75	9	512	205	573	0.4	1:1.119:1.982
C.A-S75	10	455	205	620	0.45	1:1.362:2.23
C.A-S75	11	410	205	661	0.5	1:1.612:2.475
C.A-S75	12	372	205	687	0.55	1:1.846:2.728
C.A-S75	13	341	205	714	0.6	1:2.173:2.976
C.A-S75	14	315	205	735	0.65	1:2.333:3.222
R.A-S25	15	585	190	603	0.32	1:1.031:1.735
R.A-S25	16	512	190	663	0.37	1:1.294:1.982
R.A-S25	17	455	190	710	0.42	1:1.560:2.23
R.A-S25	18	410	190	747	0.46	1:1.821:2.475
R.A-S25	19	372	190	778	0.51	1:2.091:2.728
R.A-S25	20	341	190	803	0.55	1:2.354:2.976
R.A-S25	21	315	190	825	0.60	1:2.619:3.222
R.A-S75	22	585	205	514	0.35	1:0.878:1.735
R.A-S75	23	512	205	573	0.4	1:1.119:1.982
R.A-S75	24	455	205	620	0.45	1:1.362:2.23

R.A-S75	25	410	205	661	0.5	1:1.612:2.475
R.A-S75	26	372	205	687	0.55	1:1.846:2.728
R.A-S75	27	341	205	714	0.6	1:2.173:2.976
R.A-S75	28	315	205	735	0.65	1:2.333:3.222

The aggregate content =1015kg/m^3 for all concrete mixes

Table 6. Compressive strength for accelerated and normal curing methods.

Number	Mix	Accelerated curing (MPa)			Normal curing (MPa)	
		Warm (35ºC)	Aut.	55ºC	7-day	28-day
1	C.A-S25	20.8	28.0	33.8	44.5	55.2
2	C.A-S25	18.1	24.5	30.0	39.2	48.5
3	C.A-S25	17.2	23.6	27.8	36.5	46.8
4	C.A-S25	15.8	22.8	26.5	34.2	44.8
5	C.A-S25	15.0	22.0	25.8	32.9	43.1
6	C.A-S25	14.7	21.3	25.0	31.2	42.2
7	C.A-S25	13.2	19.2	24.1	30.0	40.6
8	C.A-S75	17.8	22.0	26.5	33.5	43.3
9	C.A-S75	12.6	16.8	21.2	25.2	33.1
10	C.A-S75	11.0	15.2	18.2	24.2	30.6
11	C.A-S75	10.0	12.2	16.0	20.6	27.1
12	C.A-S75	8.6	11.8	15.1	18.8	24.5
13	C.A-S75	7.4	10.8	13.2	16.5	20.8
14	C.A-S75	6.5	8.5	10.8	14.0	17.8
15	R.A-S25	18.6	26.1	31.6	41.8	51.8
16	R.A-S25	16.2	22.8	28.1	37.1	45.1
17	R.A-S25	15.5	21.6	26.0	33.6	44.8
18	R.A-S25	14.2	20.7	24.5	31.2	43.2
19	R.A-S25	13.5	19.0	23.2	29.7	42.2
20	R.A-S25	13.2	18.2	22.0	28.0	40.8
21	R.A-S25	11.7	17.0	21.5	27.2	37.5
22	R.A-S75	16.0	20.2	24.1	30.0	41.0
23	R.A-S75	11.1	16.1	20.1	23.1	32.0
24	R.A-S75	9.6	14.2	16.0	22.6	28.1
25	R.A-S75	8.8	11.3	14.1	18.8	26.0
26	R.A-S75	7.6	10.5	12.8	16.5	22.1
27	R.A-S75	6.4	9.2	11.2	14.2	18.5
28	R.A-S75	5.2	7.5	9.0	11.8	16.0

Table 7. Descriptive statistics for experimental data

Curing type		Accelerated curing methods			Normal curing	
Statistics		warm(35ºC)	Autogenic	55ºC	7-days	28-days
N	Valid	28	28	28	28	28
	Missing	0	0	0	0	0
Mean		12.72	17.61	21.36	27.38	35.98
Std. Deviation		4.185	5.718	6.737	8.822	11.092
Minimum		5.20	7.50	9.00	11.80	16.00
Maximum		20.80	28.00	33.80	44.50	55.20

Table 8. Regression models summery for warm water curing method (35ºC)

Model No.	Regression models	R^2	F-tabulated
1-linear	3.02+2.59x acce. str.(35ºC)	0.955	556.08
2-linear	2.805x acce. str.(35ºC)	0.996	6167.3
3-Logarithmic	-37.441+29.562 x log[acce. str.(35ºC)]	0.956	563.3
4-Logarithmic	14.798xlog[acce. str.(35ºC)]	0.976	1091.5
5-Power	3.291x acce. str.(35ºC) $^{0.941}$	0.971	878.04
6-Power	acce. str.(35ºC) $^{1.411}$	0.997	10371.7
7-Exponential	12.264+ exp[0.08x acce. str.(35ºC)]	0.921	303.3
8-Exponential	Exp[0.259 x acce. str.(35ºC)]	0.952	536.03

Table 9. Regression models summery for autogenous curing method.

Model No.	Regression models	R^2	F-tabulated
1-linear	2.16+1.921x acce. str.(Aut.)	0.98	1290.4
2-linear	2.032x acce. str.(Aut.)	0.998	13729.8
3-Logarithmic	-48.113+29.933 x log[acce. str.(Aut.)]	0.97	832.3
4-Logarithmic	13.082xlog[acce. str.(Aut.)]	0.971	911.79
5-Power	2.351 x acce. str.(Aut.) $^{0.952}$	0.983	1491.3
6-Power	acce. str.(Aut.) $^{1.251}$	0.999	24704.4
7-Exponential	11.935+ exp[0.06x acce. str.(Aut.)]	0.946	455.2
8-Exponential	Exp[0.187x acce. str.(Aut.)]	0.954	564.6

Table 10 . Regression models summery for British curing method (55ºC).

Model No.	Regression models	R^2	F-tabulated
1-linear	1.147+ 1.631 x acce. str.(55ºC)	0.981	1329.1
2-linear	1.68x acce. str.(55ºC)	0.998	15929.6
3-Logarithmic	-56.428+30.742 x log[acce. str.(55ºC)]	0.967	750.9
4-Logarithmic	12.2x log[acce. str.(55ºC)]	0.967	799.7
5-Power	1.793x acce. str.(55ºC) $^{0.98}$	0.984	1585.2
6-Power	acce. str.(55ºC)$^{1.171}$	0.999	52758.6
7-Exponential	11.544+ exp[0.051x acce. str.(55ºC)]	0.95	492.6
8-Exponential	Exp[0.155 x acce. str.(55ºC)]	0.958	614.0

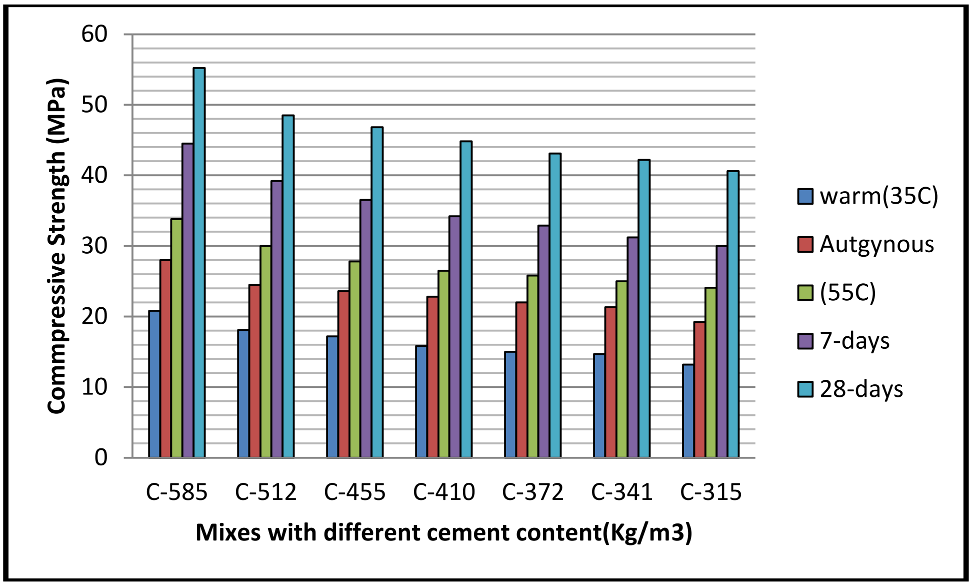

Figure 1. Compressive strength for concrete mixes with different cement content (C.A –S25) for accelerated and normal curing methods.

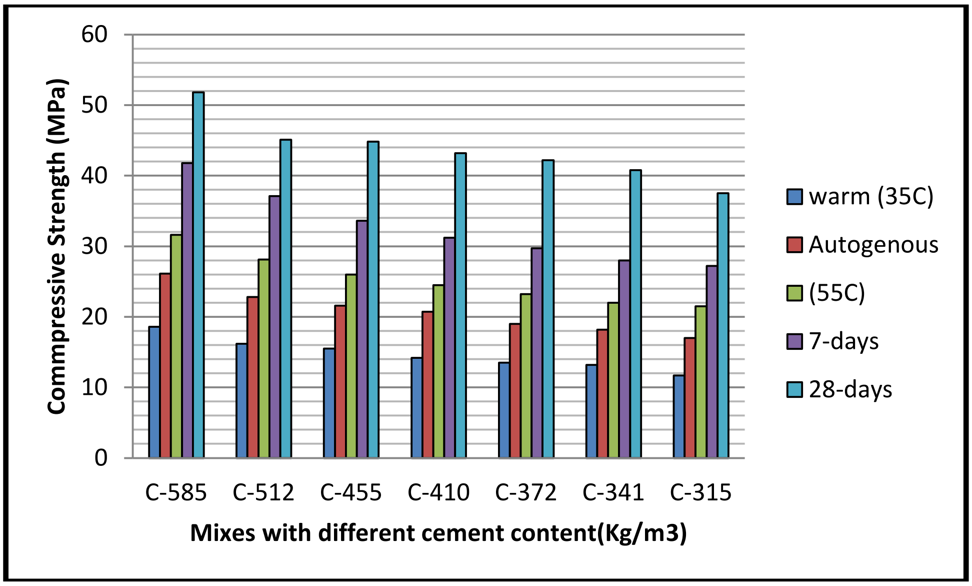

Figure 2. Compressive strength for concrete mixes with different cement content (R.A –S25) for accelerated and normal curing methods.

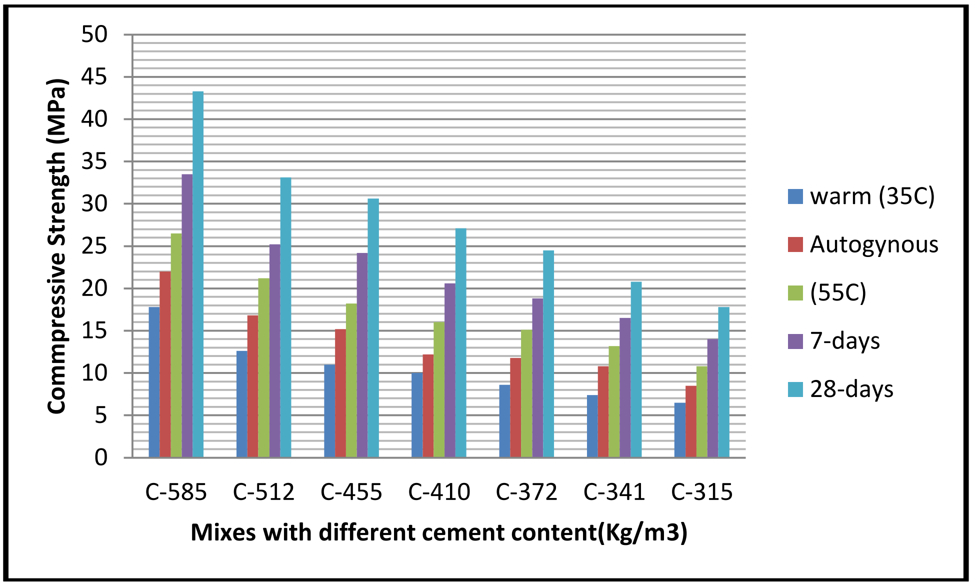

Figure 3. Compressive strength for concrete mixes with different cement content (C.A –S75) for accelerated and normal curing methods.

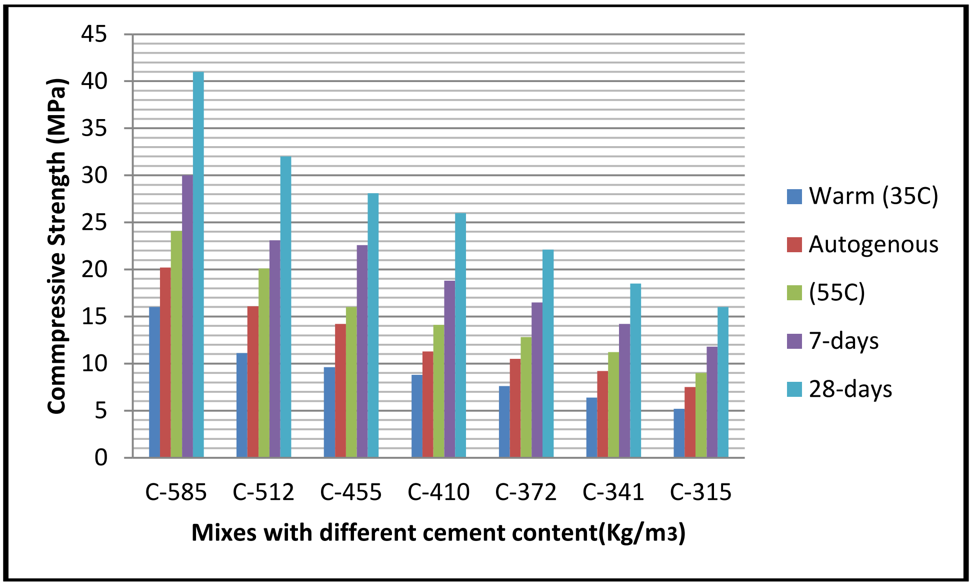

Figure 4. Compressive strength for concrete mixes with different cement content (R.A –S75) for accelerated and normal curing methods.

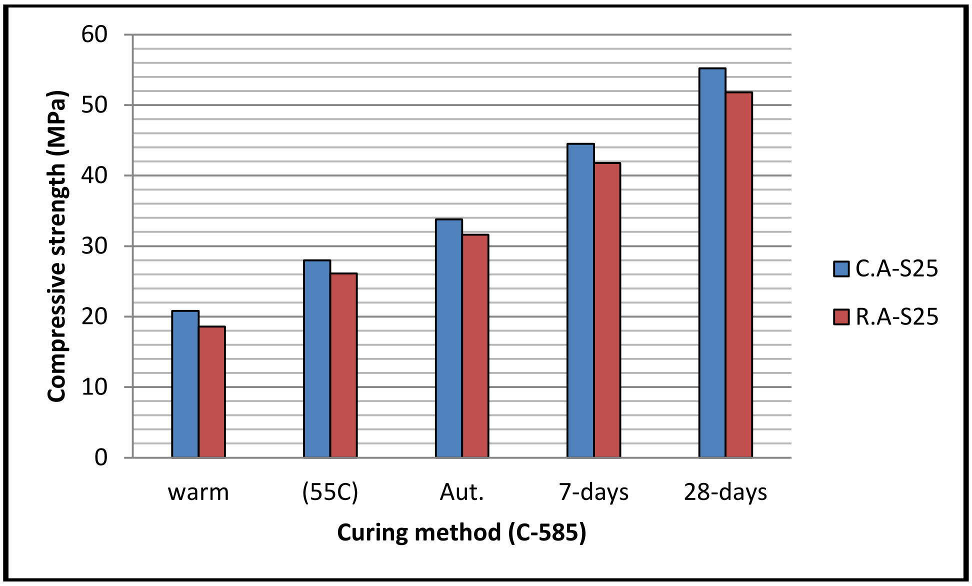

Figure 5. Compressive strength with different curing method for crushed and rounded coarse aggregate with cement content (C-585)kg/m^3 and S25.

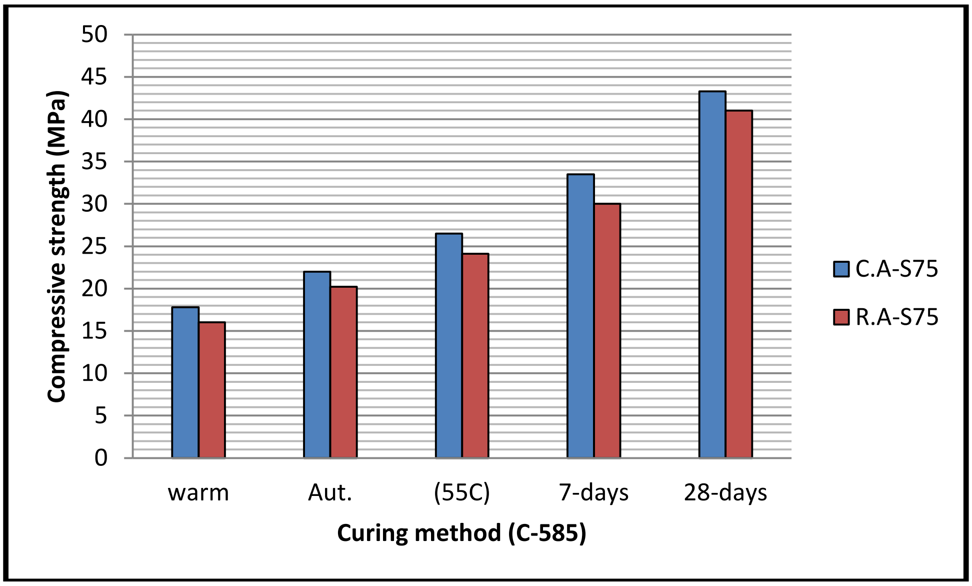

Figure 6. Compressive strength with different curing method for crushed and rounded coarse aggregate with cement content (C-585)kg/m^3 and S75.

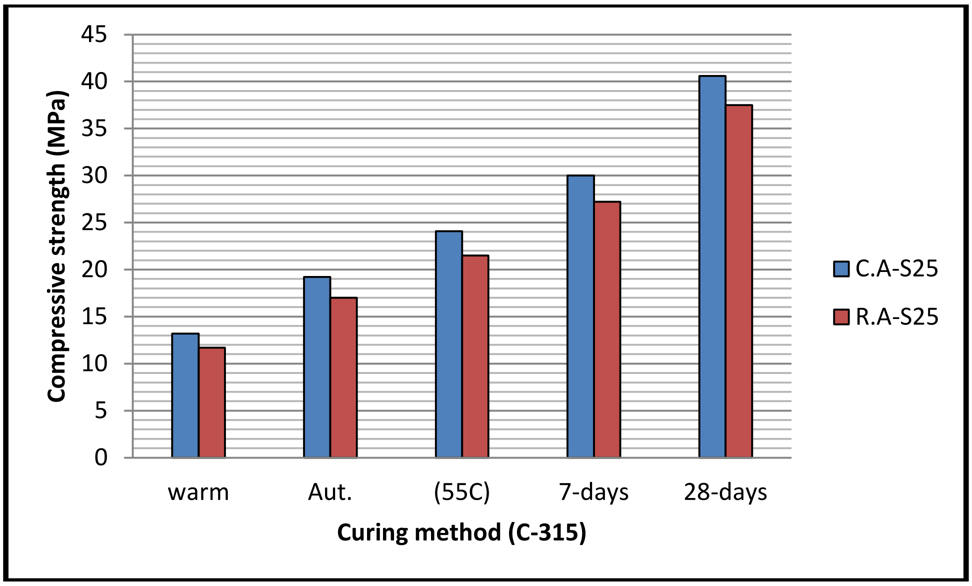

Figure 7. Compressive strength with different curing method for crushed and rounded coarse aggregate with cement content (C-315)kg/m^3 and S25.

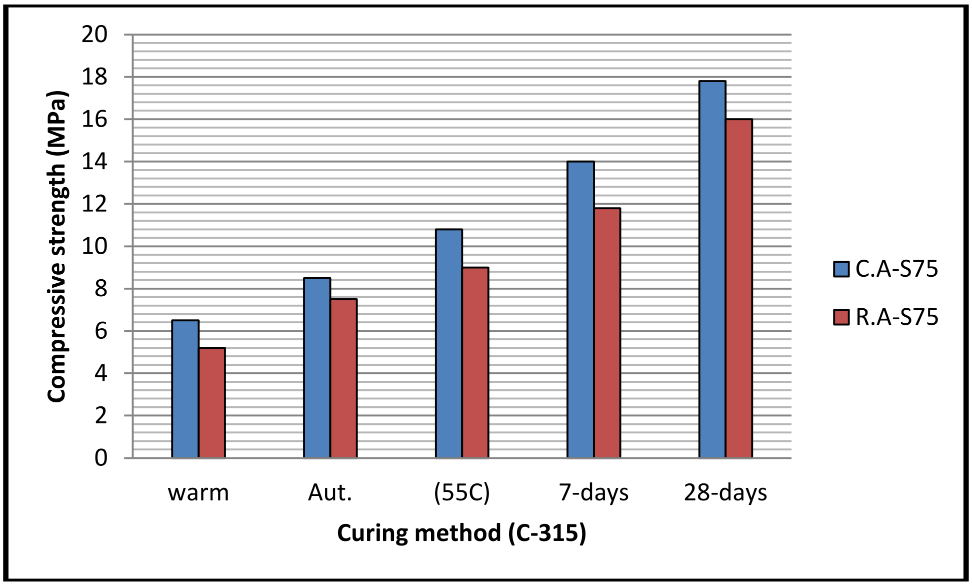

Figure 8. Compressive strength with different curing method for crushed and rounded coarse aggregate with cement content (C-315)kg/m^3 and S75.

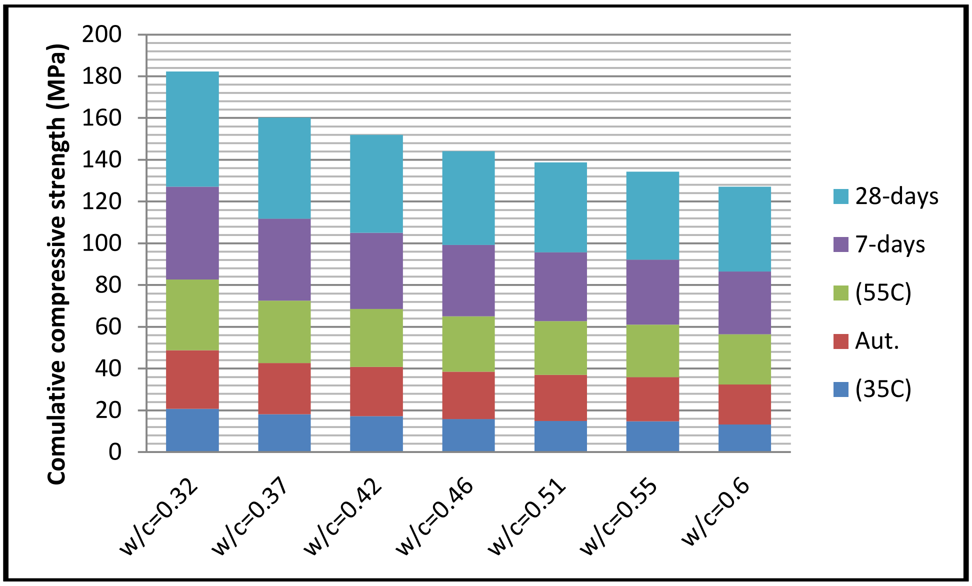

Figure 9. Cumulative compressive strength for different curing methods with W/C ratio for C.A-S25 concrete mixes.

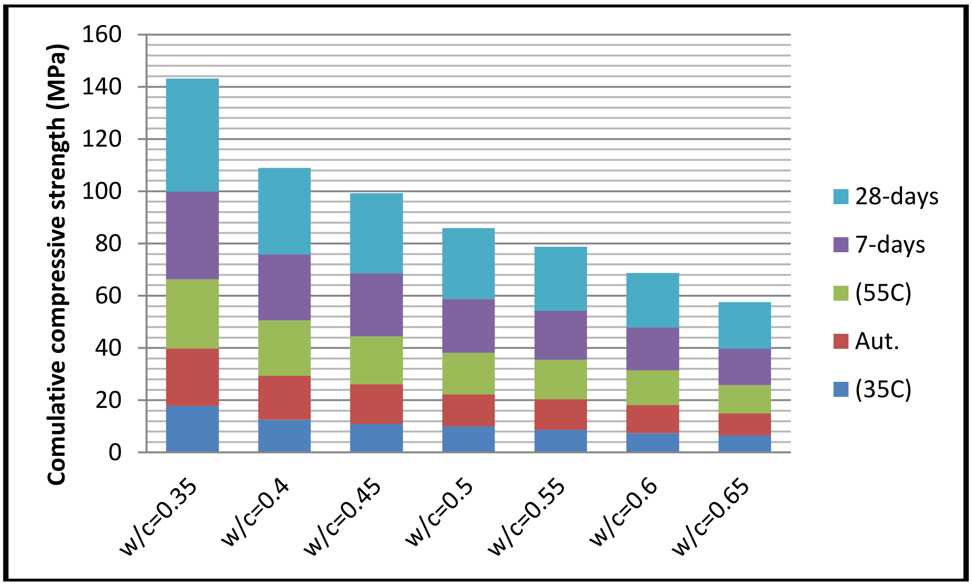

Figure 10. Cumulative compressive strength for different curing methods with W/C ratio for C.A-S75 concrete mixes.

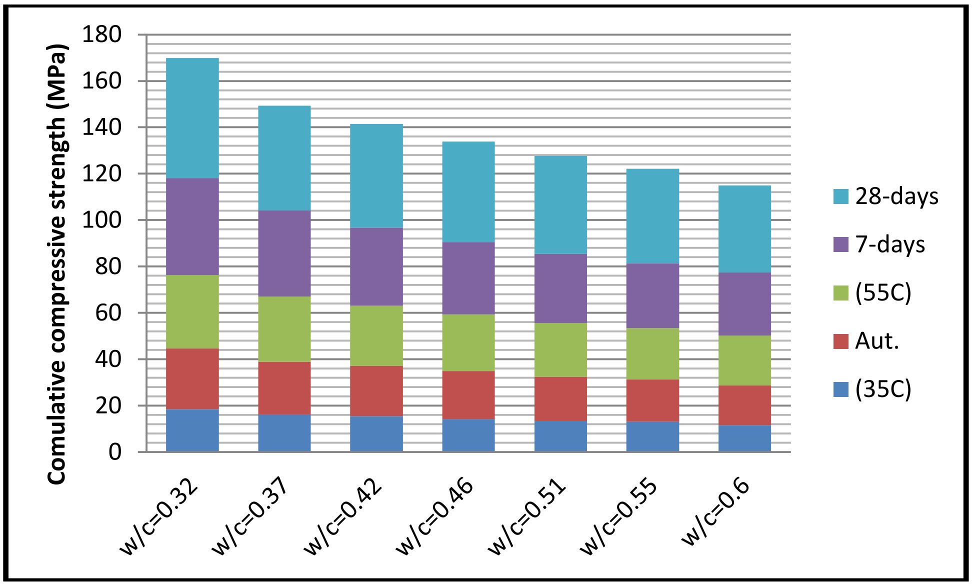

Figure 11. Cumulative compressive strength for different curing methods with W/C ratio for R.A-S25 concrete mixes.

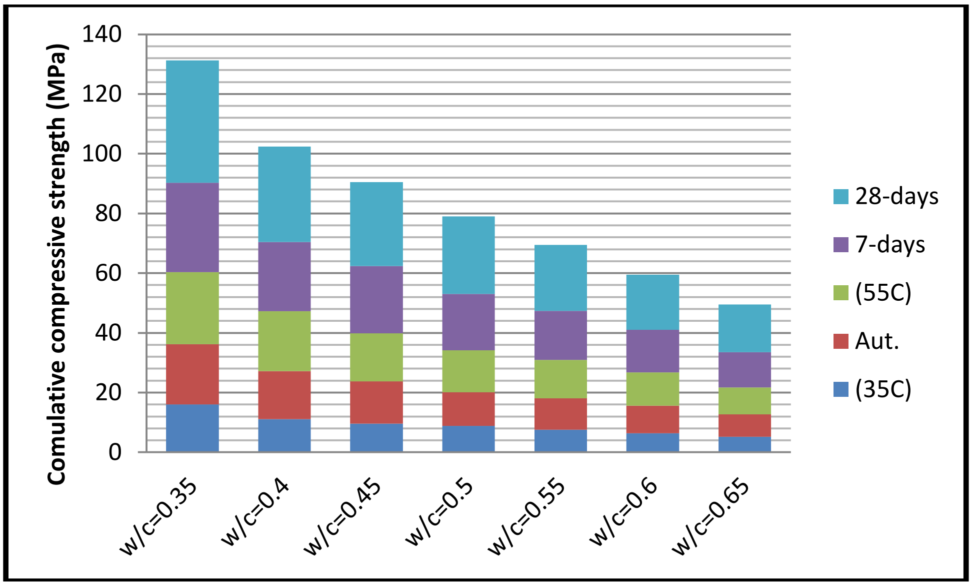

Figure 12. Cumulative compressive strength for different curing methods with W/C ratio for R.A-S75 concrete mixes.

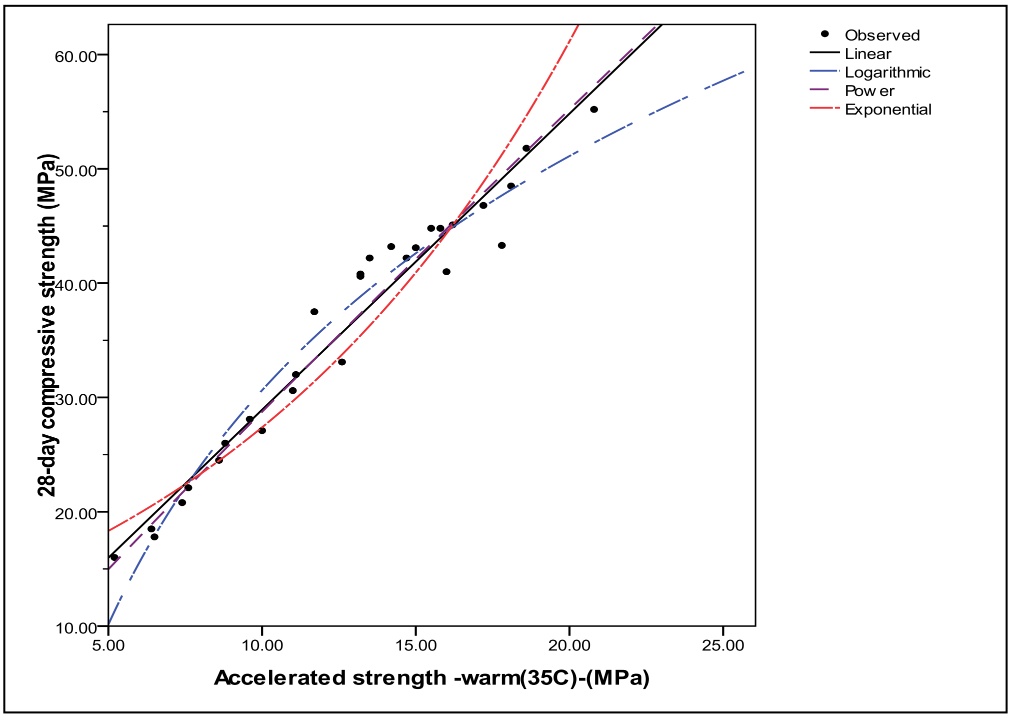

Figure 13. Relationship between 28-day compressive strength and accelerated strength (warm water method) for models with constant.

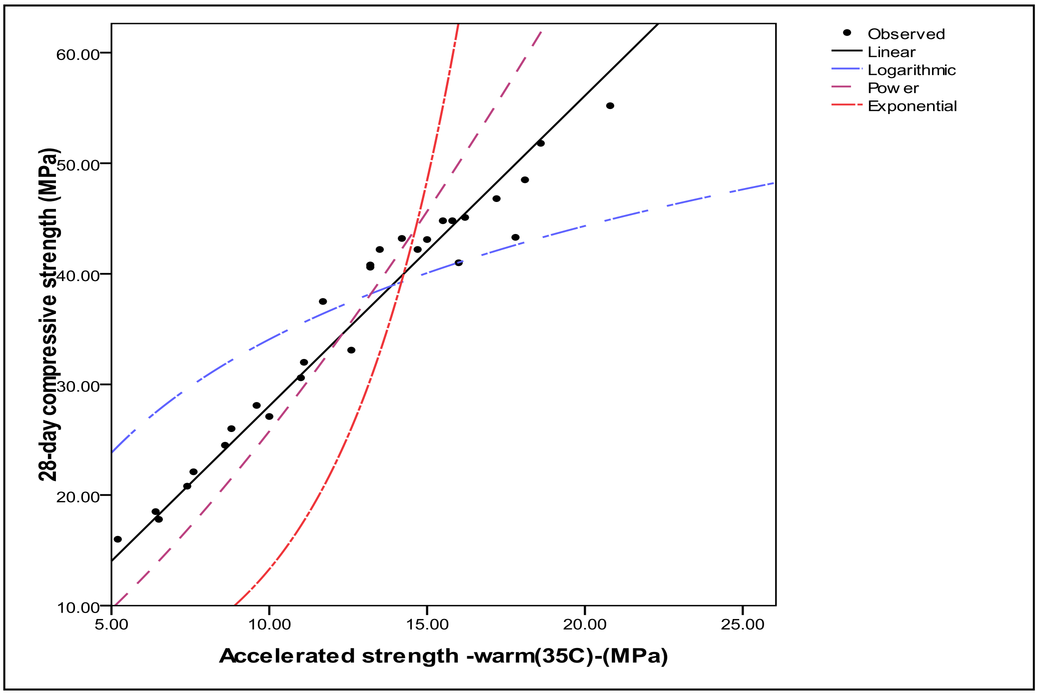

Figure 14. Relationship between 28-day compressive strength and accelerated strength (warm water method) for models without constant.

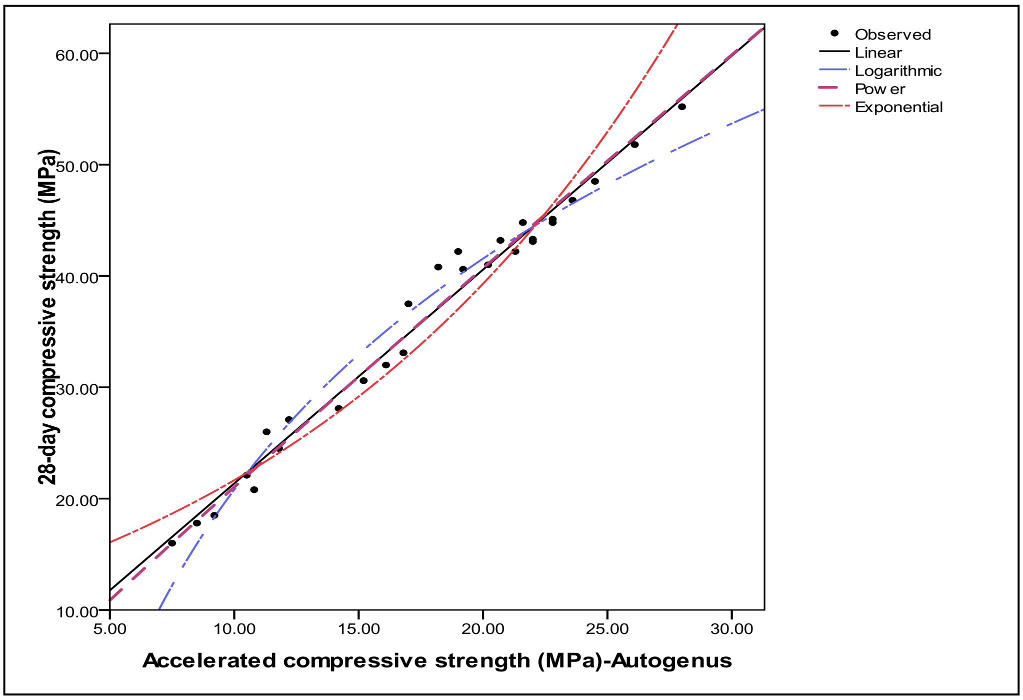

Figure 15. Relationship between 28-day compressive strength and accelerated strength (Autogenous method) for models with constant.

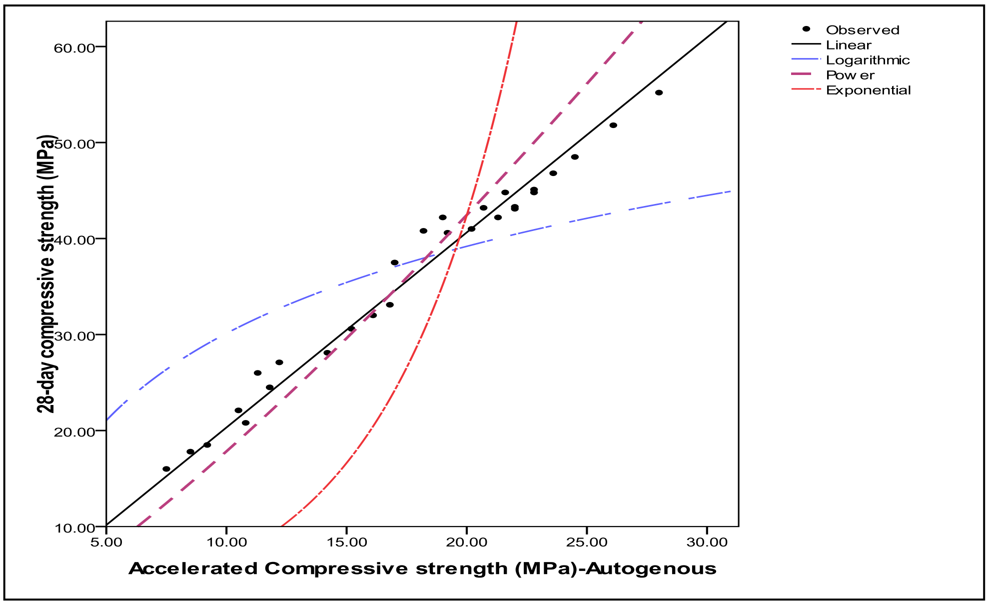

Figure 16. Relationship between 28-day compressive strength and accelerated strength (Autogenous method) for models without constant.

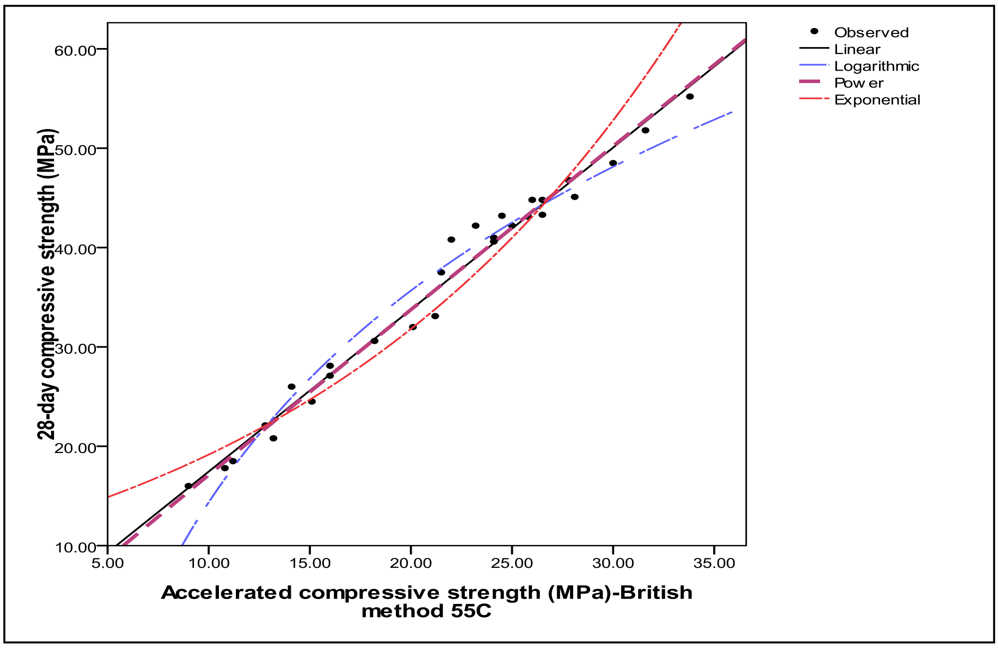

Figure 17. Relationship between 28-day compressive strength and accelerated strength (British method) for models with constant.

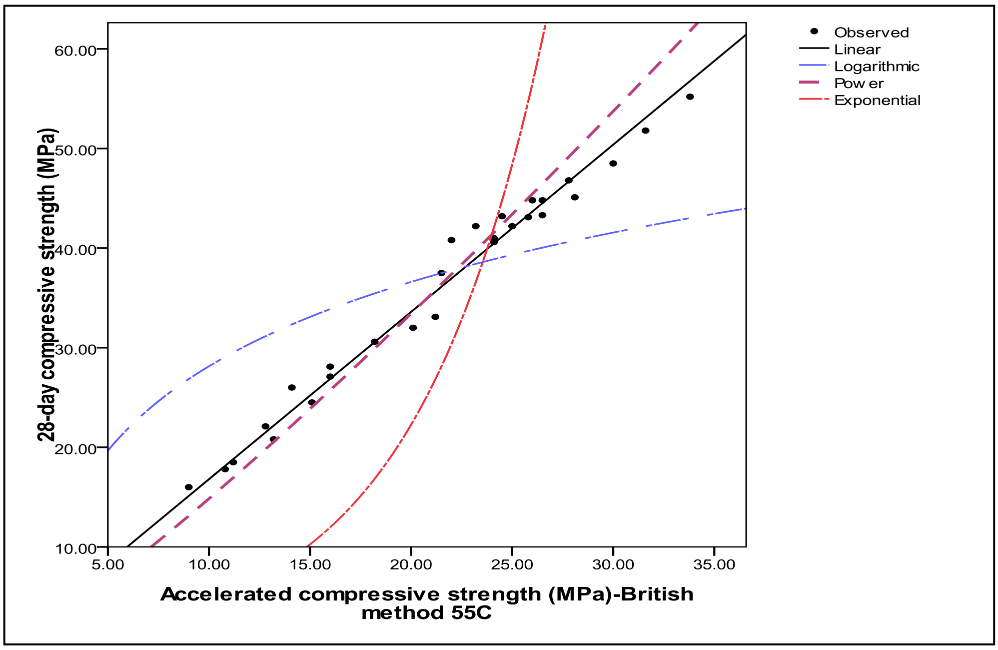

Figure 18. Relationship between 28-day compressive strength and accelerated strength (British method) for models without constant.