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Statistical Analysis and Prediction Models for Performance of Re-mixed Concrete in Hot Climate Regions

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ABSTRACT

Prediction models are proposed to estimate features such as strength and physical properties of concrete mixes which are subjected to re-mixing process. The effects of re-mixing concrete mixes after adding additional water on the physical properties (final slump, dry unit weight and pulse velocity) and hardened concrete strength (compressive strength, tensile splitting strength, modulus of rupture, static and dynamic modulus of elasticity) of concrete at 7 and 28 days are studied. The empirical equations are proposed in terms of the fresh properties according to the characteristics of the mixture of concrete (ratio of water to cement, humidity, mix air content, mix temperature, proportions of mix and unit weight). It is concluded that the predicted values using the developed models fairly agree with the experimental results collected from previous studies.

Key words: Concrete mix proportions, Concrete strength, Fresh concrete, Hot weather, Statistical analysis.

1. INTRODUCTION

Serious challenges face the engineers working on placing concrete in hot climate areas or in summer season when the temperature of the atmosphere rises. In such conditions, concrete may be exposed to high temperature, wind, and dry air (low humidity air). Although high temperature is usually occur in summer season, winds and dry air are critical drying factors and may arise any time, particularly in arid or tropical climates. These could affect the concrete's performance in an adverse way. Therefore, the process of placement of concrete, including: handling, placing, finishing and curing of concrete, should be undertaken with considering special precautions to guarantee decent performance of concrete both in the fresh and the hardened states. [1], [2].

The surface of concrete loses moisture (water) when exposed to high temperature by the evaporation process. High temperatures not only accelerate the evaporation of the water from the concrete surface but also increase reaction of the cement hydration. These could result in quick hardening of the fresh concrete and promote fast development of plastic shrinkage and associated cracking. The cracking of concrete surface can also develop as a result of the large difference in the temperature of day time (hot) and the night time (cold). For example; a concrete slab is cast at mid-day time on a hot day followed by a quick decrease in that temperature after hours in the night time. The rate hydration of cement can also be increased due to high temperature which can potentially contribute to the cracking concrete if it cast in massive quantities. [1]-[3].

There are other issues associated with the placement of concrete in hot climate areas. Among these are: the increase of water demand which in tut increases the ratio of water-cement resulting in weaker concrete (lower strength), the loss of slump increases, the setting times accelerates demanding that the finishing process to be undertaken in short time [4].

Concrete mixtures incorporating superplasticizers are also prone to the loss of workability under hot and dry climates and when the casting of concrete is delayed. If such loss of workability happens; it can be recovered through adding extra water (or spuerpalstizers) and remixing the fresh concrete. It is expected for the mechanical properties of the concrete to decrease when the water content is increased. Therefore, in some cases adding only superpalctizizers may be more beneficial than adding extra water. There is no wide agreement in the literature about the effect of the remixing of the fresh concrete on its associated mechanical properties. The use of extra water or superplasticizers (or may be both) is usually practiced on construction sites in hot or dry climates to enhance the workability of fresh concrete aiming at extending the time that allow handling of concrete and saving the time and effort needed for compaction. But this can alter the mechanical properties of the hardened concrete. Therefore, testing or the prediction of the properties of the hardened concrete is curial [5], [6].

The extent of compaction of the fresh concrete significantly affects the strength of concrete mix. Hence, the fresh state of the concrete should be in a state which permits the concrete to be transported, cast and finished in an easy way with no segregation. Meeting such condition can lead to workable fresh concrete. It is well-known that when time passes, fresh concrete tends to became stiff. This can be attributed to the absorption of the water by the ingredients of the concrete and may be due to evaporation. This manifestation is usually accelerated by factors such as heat (exposing concrete to direct sun) or wind. The expected result of such loss of moisture of fresh concrete is a decrease in the workability of the fresh concrete (lower values of slump and compacting factor) [1], [2]. Thus, it is obvious that when concrete is cast in hot and dry conditions, the water content should be increased and the fresh concrete should be remixed to maintain the workability of the fresh concrete [3].

In a research undertaken by Haneyneh and Itani in 1989 [4], the residual mechanical properties of remixed concrete was examined. They studied different concrete mixtures having various strengths. They assessed the workability (slump) and mechanical properties such as f'_c (compressive) and f_{sp} (splitting) strength, poisson's ratio, f_r (modulus of rupture), and E; elastic moduli) after adding extra water and remixing the fresh concrete.

Sobhani et al. [7] studied the effect of re-mixing method on the strength of concrete under compression loads and the permeability of concrete by applying three kinds of remixing (melamine sulphonate superplasticizer, water and water-hold remixing). They indicate that compressive strength and permeability of re-mixed concrete using superplasticizer and with water-hold remixing increased with further delay in concrete casting, while decreasing in water remixing. In a study undertaken by Sai and Sambasivarao [8], it is shown that superplasticizer re-mixing needs less amount of water compared to water re-mixing. They found that the final w/c ratio of the mixes with superplasticizer re-mixing is lower than the mixes with water re-mixing. The decrease in the compressive strength of superplasticizer re-mixing concrete is less than the water re-mixing concrete. Also, relationship between the re-mixing water and mixing time is parabolic, while the relation between re-mixing water and compressive strength is linear. They found that the relation between the superplasticizer content and the mixing time is linear too.

Ziad et al. [9] examined the effect of using water and superplasticizer re-mixing on the workability and the compressive strength. They recommended using superplasticizer re-mixing to increase both workability and strength in comparison to water re-mixing.

In another study conducted by AL-Hozaimy in 2007 [5], the influence of re-mixing of the concrete cast in a hot and dry climate on its workability and strength was examined. The concrete was ready-mixed concrete. The study talked ready mixes concretes from 12 construction sites. The ready mixed concrete was delivered by various suppliers. In this study, the addition of water to the mix and remixing the concrete resulted in a decrease in the strength of concrete and this decrease was directly linked to the associated increase in slump The drop in the strength was under 10% when the extra water was added to recover the workability of the concrete represented in slump values to the specified limits of (100 ± 25 mm). Nevertheless, when the intention was increasing the slump values beyond these specified limits by adding more water, the drop in the strength reached higher ratios (35%). In this study, it was concluded that the decrease the strength induced by the change in slump values, which caused by adding extra water to the concrete on site, can be estimated if true values of w/c ratio cannot be determined due to practical issues.

In another study which was undertaken by Erdogu, in 2005 [6], the effect of using superplasticizer Type F according to ASTM C (494) on the re-mixing of fresh concrete aiming at recovering its workability (measured in slump values) was assessed. Two groups of mixes were examined. In the first one, water was used to remix the fresh concrete and to recover its target workability (slump 19 cm), whereas in the second group, superplasticizer was used to recover the initial workability. For each group, cubes (150 mm) were cast to assess the compressive strength of the mixes at the age of 28 days. The outcomes of the study show that when the concrete mixtures is remixed using superplasticizer, considerable higher strength observed in comparison with the mixtures remixed using water [10-11] .

This theoretical research aims at developing prediction models of fresh and hardened characteristics of remixed concrete. The research utilizes statistical analysis to achieve this aim. The research attempts to use basic data of the concrete mixtures and the quantity of the extra water used for the remixing of the concrete to develop the equations that can predict the performance of the concrete in both conditions, fresh and hardened. Experimental outcomes from previous studies [3] available in the literature are used to develop the predicting models.

2. STATISTICAL ANALYSIS

To develop models to predict the properties of concrete in the states of fresh and hardened, the approach of regression analysis; in particular multi-linear, and least square method are employed to propose various models by relaying on the basic mix characteristics of concrete mixture and its properties. The broad form of proposed equation is as follow:

$$Y = a_0 + a * X_1 + a_2 * X_2 + a_3 * X_3 + a_4 * X_4 + a * X_5 + a_6 * X_6 \qquad (1)$$

where:
$(X_1, X_2, X_3, X_4, X_5 \; \& \; X_6)$ are independent variables.
$(a_0, a_1, a_2, a_3, a, a \; \& \; a_6)$ are coefficients.

The determination of these values of the value of these coefficients are achieved by employing the experimental results from previous studies and utilizing a computer program. According to the least square principle:

$$S = \sum_1^N (Y - y)^2 \qquad (2)$$

$S =$ Error function equal to square of differences in (calculated and experimental) results (total).
$y =$ Data of experimental results (dependent variable).
$Y =$ Data of Calculated results (dependent variable).
$N =$ Number of observations.

$$S = \sum_1^N (a + a_1 * X_1 + a_2 * X_2 + a_3 * X_3 + a_4 * X_4 + a_5 * X_5 + a_6 * X_6 - y)^2 \qquad (3)$$

The determination of the values of the coefficients requires that the (S) (function of error) to be minimized:

$$\frac{\partial s}{\partial ai} = 0 \qquad (4)$$

where $i = 1,2,3, \ldots \ldots 6$

A set of simultaneous equations are generated by using these equations and written in a matrix form. These equations are solved by employing PC generated programs and utilization of data from experimental observations to find the coefficients value at various cases.

$$[A]\{a\} = \{b\} \qquad (5)$$

Where $[A]$ = the matrix coefficients

$$\begin{bmatrix} N & \sum X_1 & \sum X_2 & \sum X_3 & \sum X_4 & \sum X_5 & \sum X_6 \\ \sum X_1 & \sum X_1^2 & \sum X_1X_2 & \sum X_1X_3 & \sum X_1X_4 & \sum X_1X_5 & \sum X_1X_6 \\ \sum X_2 & \sum X_2X_1 & \sum X_2^2 & \sum X_2X_3 & \sum X_2X_4 & \sum X_2X_5 & \sum X_2X_6 \\ \sum X_3 & \sum X_3X_1 & \sum X_3X_2 & \sum X_3^2 & \sum X_3X_4 & \sum X_3X_5 & \sum X_3X_6 \\ \sum X_4 & \sum X_4X_1 & \sum X_4X_2 & \sum X_4X_3 & \sum X_4^2 & \sum X_4X_5 & \sum X_4X_6 \\ \sum X_5 & \sum X_5X_1 & \sum X_5X_2 & \sum X_5X_3 & \sum X_5X_4 & \sum X_5^2 & \sum X_5X_6 \\ \sum X_6 & \sum X_6X_1 & \sum X_6X_2 & \sum X_6X_3 & \sum X_6X_4 & \sum X_6X_5 & \sum X_6^2 \end{bmatrix} \begin{Bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{Bmatrix} = \begin{Bmatrix} \sum Y \\ \sum X_1Y \\ \sum X_2Y \\ \sum X_3Y \\ \sum X_4Y \\ \sum X_5Y \\ \sum X_6Y \end{Bmatrix}$$

$$\{a\} = [A]^{-1}\{B\} \qquad (6)$$

The experimental data used for developing the theoretical models are collected from previous studies. These data are the fresh and mechanical properties of concrete mixtures tested at three stages, initial, first and second stages. The initial stage represents the original condition of the mixture meaning no extra water has been added to the mixture. The first stage (first stage of remixing) is the condition of the concrete mixture 30 minutes after the initial stage. In this stage, extra water is added to rise the workability of the concrete mixture. The second stage (second stage of remixing) is the condition of the concrete mixture 60 minutes after the initial stage. In this stage water is added to recover the workability of the concrete mixture to its value in the initial stage.

All characteristics of the concrete in fresh and hardened conditions are related with the variables, which includes simple properties of concrete mixture. The variables (independent) X1: Temperature (T) , X2: Ratio of water to cement (W/C), X3: represents the mix proportions [(C+w)/(S+G)], X4: mix air content (%); X5: humidity (H)(%), X6: density (γ) kg/m^3.

The set of the equations resulted from the application of equations 6, are solved by developing a computer program and based on the experimental data provided in reference number 4 (NCCL,1984) and depicted in Table 1.

Table 1: Data from Experimental Observations[Ref. NCCL, 1984]

MIX	TEMP. C	W/C	C+W / S+G	AIR CONT. %	HUMI. %	UNIT WEIGHT kg/m^3	WATER DOSAGE 7 DAY	WATER DOSAGE 28 Day	FINAL SLUMP mm	Dry U. Wt. kg/m^3 INIT.	Dry U. Wt. 1 R.	Dry U. Wt. 2 R.	PULSE VELOCITY m/sec INIT.	PULSE VELOCITY 1 R.	PULSE VELOCITY 2 R.	Losses in Slump mm Before R.	Losses in Slump mm After R.
G1	30	0.4	0.430	2.0	22	2,388	0.45	0.79	76	2394	2405	2371	0.4776	0.4687	0.4632	10	37
G2	40	0.4	0.430	2.0	21	2,365	1.36	0.88	104	2369	2366	2376	0.4585	0.4498	0.4502	64	68
G3	50	0.4	0.430	1.8	28	2,348	1.95	2.26	101	2360	2351	2347	0.4561	0.4493	0.4491	68	63
G4	60	0.4	0.430	1.9	27	2,324	2.54	3.55	101	2347	2308	2265	0.4529	0.4478	0.4279	63	114
G5	65	0.4	0.430	1.9	30	2,263	2.66	1.80	114	2290	2251	2216	0.4383	0.4333	0.4267	90	114
G6	30	0.5	0.347	1.8	30	2,388	0.90	0.84	88	2423	2429	2430	0.4595	0.4335	0.4458	19	19
G7	40	0.5	0.347	1.8	30	2,408	0.99	0.76	71	2435	2422	2413	0.4766	0.4675	0.4646	29	25
G8	50	0.5	0.347	1.8	29	2,376	1.30	1.08	95	2426	2404	2368	0.4648	0.4638	0.4597	67	67
G9	60	0.5	0.347	1.8	30	2,386	1.02	1.26	88	2399	2381	2379	0.4657	0.4625	0.4604	35	50
G10	65	0.5	0.347	1.7	30	2,403	1.10	1.06	88	2404	2415	2389	0.4677	0.4598	0.4569	69	75
G11	30	0.6	0.297	1.2	30	2,383	0.00	0.50	127	2411	2381	2405	0.4714	0.4622	0.4591	26	32
G12	40	0.6	0.297	1.2	30	2,409	0.82	0.70	88	2392	2392	2388	0.4640	0.4617	0.4595	26	38
G13	50	0.6	0.297	1.3	30	2,393	1.06	1.23	114	2417	2386	2359	0.4636	0.4604	0.4548	70	57
G14	60	0.6	0.297	1.3	30	2,406	1.23	0.98	95	2403	2383	2398	0.4654	0.4596	0.4565	32	42
G15	65	0.6	0.297	1.2	30	2,402	1.27	0.94	95	2408	2390	2391	0.4656	0.4590	0.4564	61	51
G1A	30	0.4	0.430	2.0	46	2,358	0.86	0.30	76	2392	2383	2377	0.4572	0.4505	0.4405	32	13
G6A	30	0.5	0.347	1.8	50	2,290	0.37	0.36	82	2414	2376	2369	0.4858	0.4810	0.4696	60	52

Table 1.
Continue.

MIX	f_c' MPa 7 DAY	f_c' MPa 28 Day	f_c' 1st RET. 7 DAY	f_c' 1st RET. 28 Day	f_c' 2nd RET. 7 DAY	f_c' 2nd RET. 28 Day	f_r Mpa INIT.	f_r Mpa 1 R.	f_r Mpa 2 R.	f_{sp} Mpa INIT.	f_{sp} Mpa 1 R.	f_{sp} Mpa 2 R.	E_{st} * 10E4 Mpa INIT.	E_{st} 1 R.	E_{st} 2 R.	E_{dy} * 10E4 Mpa INIT.	E_{dy} 1 R.	E_{dy} 2 R.
G1	35.72	51.64	34.82	45.99	33.59	43.72	5.10	5.20	3.93	4.75	5.06	4.00	3.478	3.174	3.084	4.019	3.785	3.821
G2	35.85	42.05	36.13	44.68	34.13	42.06	5.37	4.86	4.55	4.60	4.55	3.89	3.441	3.233	3.092	3.620	3.620	3.745
G3	35.16	43.37	35.65	43.75	33.72	41.72	5.20	4.88	4.56	4.92	4.60	4.17	3.210	2.923	2.874	3.663	3.661	3.685
G4	33.58	41.44	34.01	38.96	31.09	38.27	5.06	4.58	3.72	4.33	4.29	3.70	3.021	2.974	2.570	3.521	3.243	3.139
G5	31.71	40.28	33.62	39.20	29.60	36.93	4.90	4.72	4.03	4.20	3.23	3.00	2.776	2.520	2.162	3.317	3.191	3.054
G6	33.48	36.96	30.75	37.79	29.31	37.65	5.03	4.65	4.65	3.72	3.73	3.41	3.237	3.387	3.378	3.795	3.607	3.786
G7	34.82	39.72	33.24	37.44	31.17	36.41	4.96	5.06	4.65	4.03	3.58	3.10	3.445	3.311	2.898	4.179	3.935	3.941
G8	31.58	36.64	28.90	34.97	27.10	34.20	4.79	4.79	4.31	3.72	3.51	3.31	3.321	3.273	3.236	4.056	3.805	3.957
G9	31.37	36.82	30.96	34.34	27.03	32.97	4.82	4.61	4.55	3.72	3.17	3.06	3.445	3.293	3.431	3.899	3.976	3.866
G10	31.03	38.34	30.68	37.44	29.37	35.44	5.03	4.55	4.43	3.65	2.99	3.17	3.376	3.129	3.084			
G11	25.27	34.96	26.27	35.03	27.44	35.44	4.44	4.62	4.31	3.37	2.99	3.37	3.177	3.129	3.170			
G12	27.10	34.41	26.00	33.03	24.34	30.27	4.41	4.40	3.96	3.34	2.82	2.41	3.143	3.116	2.831			
G13	24.34	31.51	24.68	31.17	23.03	27.24	4.58	4.41	3.86	3.20	2.81	2.96	3.196	3.018	2.913			
G14	24.62	30.34	23.65	29.58	22.68	29.44	4.31	3.68	3.65	3.03	2.75	3.03	3.143	3.116	2.831			
G15	23.51	32.13	22.27	32.27	21.93	32.57	4.48	4.17	4.24	3.44	3.03	2.86	3.177	3.191	3.170			
G1A	36.48	42.62	34.68	41.44	32.82	40.20	5.22	5.00	4.86	3.79	3.55	3.44	1.374	1.374	1.367			
G6A	33.38	37.65	31.93	36.96	31.51	36.75	5.50	5.19	5.13	3.51	3.27	3.17	1.382	1.408	1.367			

3 RESULTS OF STATISTICAL ANALYSIS

3.1 Properties of Fresh Concrete

Eleven different characteristics of concrete in the fresh condition related with the variables $(X_1, X_2, X_3, X_4, X_5 \,\&\, X_6)$; and the value of the coefficients $(a_0, a_1, a_2, a_3, a, a \,\&\, a_6)$ are determined based on the experimental data and presented in

Table 2.

Wd_{R1} = Water dosage for first retempering (kg).
Wd_{R2} = Water dosage for second retempering (kg).
S_f = Final slump (mm).
γ_D = Dry unit weight (kg/m^3) for initial stage.
γ_{DR1} = Dry unit weight (kg/m^3) for first stage.
γ_{DR2} = Dry unit weight (kg/m^3) for second stage.
V = Pulse velocity (m/sec) for initial stage.
V_{R1} = Pulse velocity (m/sec) for first stage.
V_{R2} = Pulse velocity (m/sec) for second stage.
S_L = Slump losses before retempering (mm).
S_{LR} = Slump losses after retempering (mm).

$$\gamma_D = a_0 + a_1 * T + a_2 * \frac{W}{c} + a_3 * \frac{c+w}{s+G} + a_4 * A + a_5 * H + a_6 * \gamma \quad \ldots(7)$$

Table 2: Values of Coefficients of Equation 1of Fresh Properties of Concrete.

	a_0	a_1	a_2	a_3	a_4	a_5	a_6	r
Wd_{R1}	6.6570	0.0336	-1.0285	6.8370	-0.6370	-0.0014	-0.0033	0.8970
Wd_{R2}	18.0080	0.0347	-86.1540	-80.8000	-3.3600	-0.0800	-0.0019	0.7940
S_f	372.0060	0.0946	162.3440	313.1620	-89.6540	-0.7180	-0.1636	0.7280
γ_D	1970.7200	-0.8337	-330.6400	-1054.7000	69.0080	0.2900	0.2686	0.8132
γ_{DR1}	1914.5700	-1.0874	-1217.4000	-1903.2000	10.4970	0.2500	0.75056	0.8450
γ_{DR2}	1945.3500	-1.6392	-1358.6000	-2016.1000	-29.5600	0.4789	0.8814	0.8076
V	0.6284	-0.0004	-0.1666	-0.2715	0.0099	-0.0005	0.000030	0.7650
V_{R1}	0.4425	-0.0002	0.0502	-0.0554	0.0229	-0.0004	-0.0000030	0.5495
V_{R2}	0.4270	-0.0003	-0.2536	-0.4904	0.00344	-0.0000	0.000000	0.8072
S_L	1106.9900	0.9010	-360.5700	-411.1300	-29.9370	-0.3015	-0.3016	0.8090
S_{LR}	1018.2000	1.2290	-167.0100	-725.650	-24.9500	-1.7575	-0.3458	0.8391

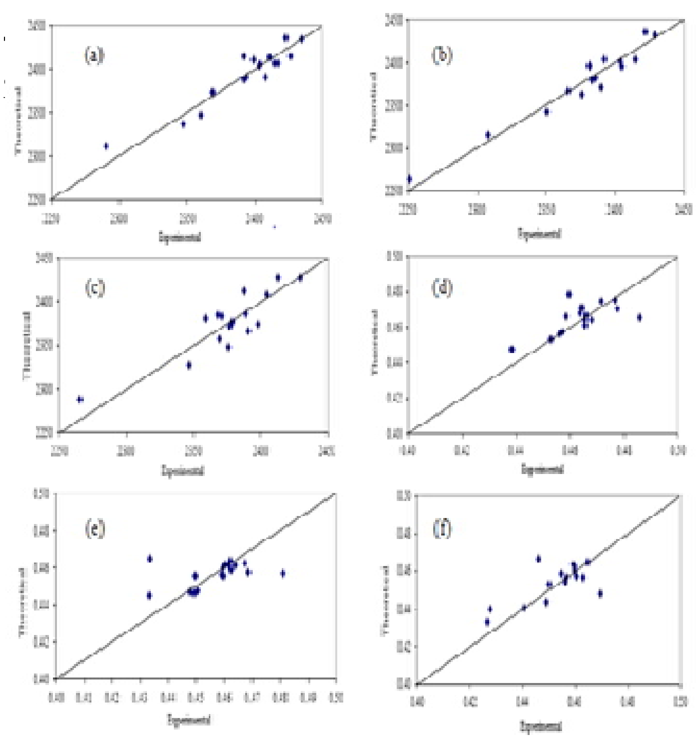

Figure 1: Predicted (Theoretical) versus experimental results

In Figure above the predicted (Theoretical) versus the experimental results of : a-dry density (γ_D) (Kg/m^3); b- dry density after 1st re-mixing (γ_{DR1}) (Kg/m^3); c- dry unit weight after 2nd re-mixing (γ_{DR2}) (Kg/m^3); d- pulse velocity (V) (m/sec); e- pulse velocity (PV)after 1st re-mixing (V_{R1}) (m/sec); f- PV after 2nd re-mixing (V_{R2}) in m/sec

3.2 Properties of Hardened Concrete

The compressive strength (f_c') at 7 days and 28 days are considered after the first and second remixing stages; flexural strength (f_r) after the first and second remixing stages; tensile splitting strength (f_{sp}) after the first and second remixing stages; static and dynamic modulus of elasticity ( ) ( ) after the first and second remixing stages; are predicted using the developed models. Also, the losses in the aforementioned mechanical properties are considered after the first and second remixing stages.

f'_{c7} = f'_c at age (7 days) for initial stage (MPa).
f'_{c28} = f'_c at age (28 days) for initial stage (MPa).
f'_{c7R1} = f'_c at age (7 days) for first stage (MPa).
f'_{c28R1} = f'_c at age (28 days) for first r stage (MPa).
f'_{c7R2} = f'_c at age (7 days) for second stage (MPa).
f'_{c28R2} = f'_c at age (28 days) for second stage (MPa).
f_r = f_r for initial stage (MPa).
f_{rR1} = f_r for first stage (MPa).
f_{rR2} = f_r for second stage (MPa).
f_{sp} = f_{sp} for initial stage (MPa).
f_{spR1} = f_{sp} for first stage (MPa).
f_{spR2} = f_{sp} for second stage (MPa).
E_{st} = E_{st} for initial stage (MPa).
E_{stR1} = E_{st} for first stage (MPa).
E_{stR2} = E_{st} for second stage (MPa).
E_{dy} = E_{dy} for initial stage (MPa).
E_{dyR1} = E_{dy} for first stage (MPa).
E_{dyR2} = E_{dy} for second stage (MPa).
f'_{cL7R1} = loss in f'_c at age (7 days) after first stage (MPa).
f'_{cL28R1} = loss in f'_c at age (28 days) after first stage (MPa).
f'_{cL7R2} = loss in f'_c at age (7 days) after second stage (MPa).
f'_{cL28R2} = loss in f'_c at age (28 days) after second stage (MPa).
f_{rLR1} = loss in f_r after first stage (MPa).
f_{rLR2} = loss in f_r second first remixing (MPa).
f_{spLR1} = loss in f_{sp} after first stage (MPa).
f_{spLR2} = loss in f_{sp} after second stage (MPa).
E_{stLR1} = loss in E_{st} after first stage (MPa).
E_{stLR2} = loss in E_{st} after second stage (MPa).

The following model is developed for the compressive strength:

$$f_c' = a_0 + a_1 * T + a_2 * \frac{W}{c} + a_3 * \frac{c+w}{s+G} + a_4 * A + a_5 * H + a_6 * \gamma \quad \ldots(8)$$

By solving the Equation 6, using the experimental data, the value of the coefficients are determined. These values are tabulated in Table 3 for considered variables. The predicted results are in line with the experimental data to a great extent as can be seen in Figure 2 (a to f) for the compressive strength (f_c') ; modulus of rupture (f_r); tensile splitting strength (f_{sp}); static and dynamic moduli of elasticity (*Ec*) (*Ed*) and their losses after the first and second remixing stages.

Table 3: Hardened Properties of Concrete: Values of the Coefficients of the Equation.(1)

	a_0	a_1	a_2	a_3	a_4	a_5	a_6	r
f'_{c7}	153.8140	-0.0850	-174.8400	-175.5100	-1.8400	0.0179	0.0142	0.9880
f'_{c28}	83.4680	-0.1090	-134.7900	-64.6760	-9.0366	-0.1504	0.0293	0.9440
f'_{c7R1}	177.9500	-0.0655	-172.9300	-151.1900	-6.2070	-0.0414	0.0031	0.9770
f'_{c28R1}	144.6900	-0.1210	-173.8000	-105.9900	-14.2000	-0.0150	0.0214	0.9809
f'_{c7R2}	218.4630	-0.1200	-209.7000	-191.4000	-11.6410	-0.0620	0.0043	0.9710
f'_{c28R2}	207.6300	-0.1330	-221.8200	-172.5500	-16.6420	-0.1150	0.0160	0.9545
f_r	20.6480	-0.0070	-13.0800	-14.7600	-0.0850	-0.0034	-0.0014	0.9100
f_{rR1}	28.0900	-0.0157	-20.6320	-23.1490	-0.7920	-0.0042	-0.0011	0.9030
f_{rR2}	42.7660	-0.0137	-35.2910	-44.3800	-1.4000	0.0230	-0.0011	0.8228
f_{sp}	21.3556	-0.0049	-25.7700	-17.7610	-2.2010	-0.0348	0.0028	0.9780
f_{spR1}	-0.0380	-0.0142	-10.0800	1.1840	-0.9353	-0.0530	0.0050	0.9610
f_{spR2}	7.4130	-0.0089	-11.5090	-5.0530	-1.0867	-0.0023	0.00266	0.8468
E_{st}	-2.3770	0.0128	-16.8600	-16.3250	-1.3657	-0.0744	0.0099	0.9130
E_{stR1}	-0.6843	0.0098	-16.3610	-17.6400	-1.2507	-0.6756	0.0091	0.8944
E_{stR2}	3.6100	0.0074	-22.1400	-25.1800	-1.4604	-0.0614	0.0100	0.8850
E_{dy}	-16.9070	0.0025		0.3081	1.2270	0.0388	0.0724	0.9140
E_{dyR1}	-12.8730	0.0076		0.0664	-0.1458	-0.0032	0.0070	0.9188
E_{dyR2}	7.3513	-0.0020		-3.8340	-2.6673	-0.0877	0.0022	0.9500
f'_{cL7R1}	-24.1350	-0.0194	-1.9116	-24.3230	4.3677	0.0993	0.01111	0.7868
f'_{cL28R1}	-61.1110	0.0121	38.7480	40.9474	5.1608	-0.0001	0.00799	0.3160
f'_{cL7R2}	-64.6500	0.0347	34.8580	15.8860	9.8014	0.0800	0.00994	0.7770
f'_{cL28R2}	-124.1600	0.0240	87.0290	107.8800	7.6053	-0.0353	0.01336	0.4183
f_{rLR1}	-7.4420	0.0089	7.5730	8.3900	0.7071	0.0082	-0.0003	0.5090
f_{rLR2}	-23.3370	0.0048	23.2311	33.6734	0.8203	-0.0246	-0.0003	0.7445
f_{spLR1}	21.4766	0.0093	-15.8800	-19.2240	-1.2656	0.0184	-0.0022	0.7820
f_{spLR2}	13.9426	0.0040	-14.2610	-12.7090	-1.1145	-0.0117	0.00012	0.6118
E_{stLR1}	-1.7227	0.0030	-0.4992	1.3136	-0.1150	-0.0096	0.00078	0.7077
E_{stLR2}	-5.9870	0.0053	5.2800	8.8550	0.0947	-0.0130	0.00016	0.6560

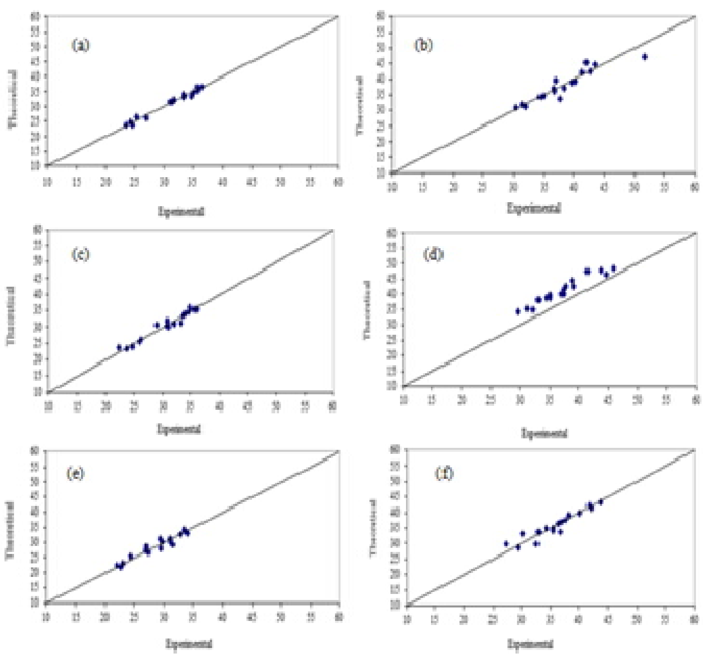

Figure 2: Predicted (Theoretical) versus experimental results of (f'_c) in MPa: a-at 7 days ; b- at 28 days ; c- 7 days (1st stage); d- 28 days (1st stage); e- 7 days (2nd stag); f- 28 days (2nd stage)

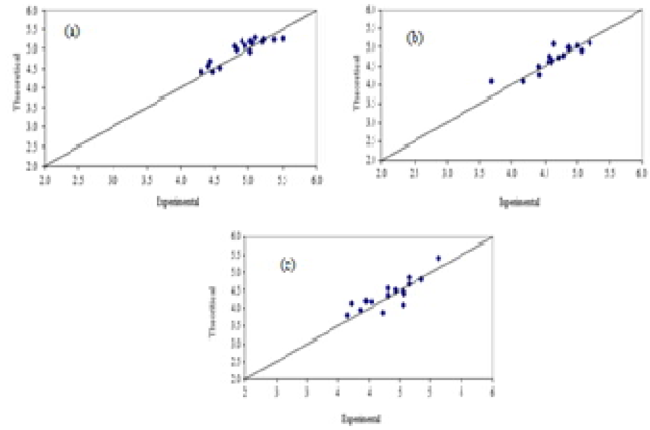

Figure 3: Predicted (Theoretical) versus experimental results of (f_r) in MPa : a- initial; b- after 1st stage; c- after 2nd stage

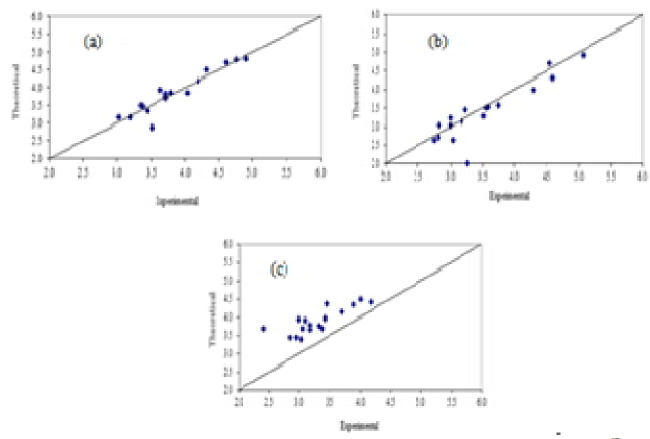

Figure 4: Predicted (Theoretical) versus experimental results of (f_{sp}) in MPa : a- initial; b-after 1st stag; c- after 2nd stage

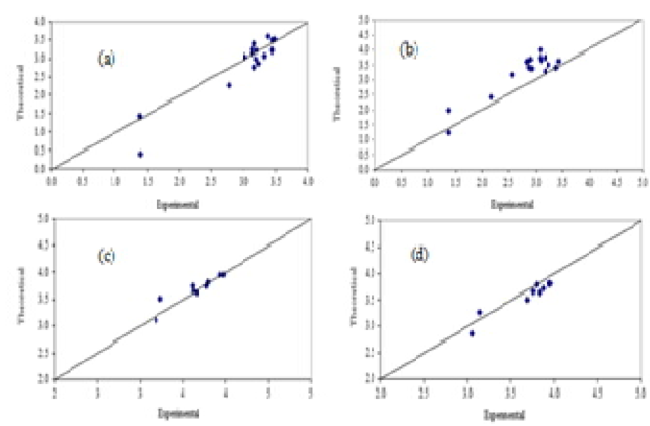

Figure 5: Predicted (Theoretical) versus experimental results of modulus of elasticity in(*10 GPa): a- static (E_{st}); b- static after 2nd stage (E_{stR2}); c- dynamic after 1st stage (E_{dyR1}); d- dynamic after 2nd stage (E_{dyR2})

3.3 Discussion

Re-mixing is the process of adding water or admixtures to the concrete to adjust the workability in hot and dry weather.

Many approaches of concrete re-mixing have been adapted such as water remixing, superplasticizer agents remixing and mineral admixtures. Mineral admixtures and superplasticizer result in increasing the strength of the concrete whereas using water re-mixing reduces the compressive strength of concrete. Other properties such as porosity, water absorption and workability are improved using s superplasticizer and mineral admixtures remixing compared to water re-mixing.

The re-mixing process should be in the initial time setting stage of the cement (i.e. the first hour after addition of water, the quantity of water used for the second stage of re-mixing is higher than the quantity of water used for the first stage of re-mixing, where in this research the first stage begins after 30 minutes from initial mixing time and the second stage starts after 60 minutes.

The results show that concrete properties in both states (fresh and hardened) are affected by the water re-mixing. It was determined that the workability and the compressive strength of concrete decrease when water re-mixing is used to adjust the workability (slump) of concrete to be more suitable for placing casting and finishing. Similar behavior was also reported by previous experimental studies ((NCCL 1984)

Empirical equation is suggested to predict the concrete properties in the states of fresh and hardened in climates characterized with high temperature and low humidity based on experimental observations available in previous studies (NCCL 1984). General equation is proposed to find the concrete properties at fresh and hardened conditions as a function of mix properties and some other variables such as water cement ratio, mix temperature, density, humidity and mix air content. The figures of the coefficients of the equations $(a_0, a_1, a_2, a_3, a, a \,\&\, a_6)$ are determined using multi-linear regression analysis least-square method for all concrete properties under consideration. The figures of coefficient of correlation (r) show that the predicted results are in a strong agreement with the experimental observations for properties of concrete in fresh condition (content of water in the first and second re-mixing, slump loss, final slump, pulse velocity and dry unit weight); and for hardened concrete properties (compressive strength at the age of 7 days and 28 days, modulus of rupture, elastic moduli (both static and dynamic). The relationships between the experimental observations and the predicted results are displayed in figures (1-5) for both fresh and hardened concrete properties.

4 CONCLUSION

The outcomes of the current study can lead to the following conclusions:

- The utilization of basic concrete's mixture properties such as the ratio of w/c, temperature, mix proportion, humidity, air content and density, can be used to develop prediction models. These models can predict fresh properties of such the water quantity of first and second stage of re-mixing, dry unit weight and slump value for the remixed concrete mixtures.
- The use of same basic properties of the concrete mixtures can help in developing strength prediction models to estimate the hardened properties of such mixtures. Mechanical properties such as compressive strength; tensile splitting strength and flexural strength as well as elastic moduli (both static and dynamic) can be predicted using such models. The models can predict the experimental values fairly well.
- Good agreement was found between the predicted values using the developed models with the experimental values of the previous studies.
- Such developed models can reduce cost needed to cast and prepare concrete samples to determine the properties of concrete (fresh and hardened). Also these models can save time for the process of the experimental determination of these properties.

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