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PREDICTING THE COMPRESSIVE STRENGTH OF CONCRETE CONTAINING RECYCLED FINE AGGREGATE USING EARLY AGE TEST

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Abstract

The present research aims to make an attempt to predict the compressive strength for 28 and 56 days of concrete containing recycled fine aggregate by taking advantage of the compressive strength for early ages for the same mixture. Four groups of concrete mixtures were prepared, the variable in the groups is the compressive strength (25, 30, 35, and 40MPa), and for each strength, the natural fine aggregate was replaced with four different percentages of recycled fine aggregate (RFA) (0, 10, 20, and 30%) as volume ratios. After standard curing (water immersion) of the concrete samples, they were tested to obtain the compressive strength at different ages (3, 7, 28, 56 days), and based on experimental results, mathematical models were made through which the compressive strength for 28 and 56 days can be predicted based on the results of the compressive strength for 3 and 7 days. According to the proposed mathematical models, early age tests may be utilized to predict the compressive strength of concrete at 28 and 56 days, where the values of the determination coefficient for 28 and 56 days of compressive strength based on (3 and 7) days compressive strength were (84.8%), (86%), (79.2%). and (79.2%), respectively.

Keywords:

Fine Recycle aggregate;
Compressive strength;
Prediction;
Statistical analysis;
Concrete waste.

1 Introduction

Currently, various types of waste materials and industrial by-products such as recycled concrete aggregate, plastic, glass, fly ash, ceramics, slag, and others are being used, with and without natural aggregate and ordinary Portland cement (OPC). These materials have been found to have properties suitable for producing new concrete to a certain extent [1-5]. The use of recycled aggregate produced from construction and demolition waste (CDW) is considered a sustainable alternative to natural aggregate in the construction sector, contributing to the protection of natural resources and reducing the area of landfills designated for waste disposal. [6,7]. As is known, concrete undergoes a water curing stage immediately after pouring, and the purpose of treatment is to maintain the temperature and moisture movement to and from the concrete [8], as water treatment helps develop the properties of concrete and reach the required degree. This stage is very important and has a direct impact on the properties of hardened concrete, as proper treatment increases the durability of concrete, compressive strength, corrosion resistance, volumetric stability, as well as increasing its resistance to freezing and thawing [9]. The compressive strength can be obtained after curing the concrete models for (28) days using standard curing (water immersion). Due to the importance of this property to researchers, they have resorted to searching for other methods that enable them to know the compressive strength of concrete in a shorter period. The aim of this is to solve and treat many of the problems they face during work, including that the process of designing concrete mixtures is done according to special specifications and determinants, and it also requires previous experience. Therefore, the lack of accuracy in designing concrete mixtures or preparing them on site directly affects the required design strength. In this case, there will be a need to repeat the process completely, which is usually expensive and takes a long time, not to mention that each time you must wait for (28) days to know the compressive strength [10]. In addition, it is well known that concrete projects involve pouring concrete in successive stages. If the concrete strength is less than required, it will be too late to take the correct and necessary action. On the other hand, if the concrete strength is higher than required, it will be uneconomical. Therefore, the money lost resulting from the unnecessary high strength must be preserved [11]. To overcome this problem, researchers have made several attempts to predict the compressive strength of concrete at the age of (28) days by examining early aged models. The term (prediction) means the possibility of knowing the compressive strength of concrete with appropriate accuracy by creating a mathematical model that relates the standard compressive strength and early compressive strength of concrete specimens, provided that the specimens are from the same mixtures (i.e. prepared at the same time) and under the same conditions [6,7]. Based on these attempts, researchers have proposed several methods for predicting compressive strength, which can be summarized as follows [10,12]:

- Standard curing method: Here, a relationship is established between the concrete strength at early ages (3 days or 7 days) and the strength of the same concrete at 28 days, 56 days, or 90 days, using standard curing (water immersion).
- Accelerated curing methods: The title of the method indicates that it relies on accelerating the curing process by heating the samples under normal pressure or high pressure and establishing a relationship between the accelerated strength and the strength obtained through standard curing.
- Methods for predicting standard compressive strength by relating it to other properties: Here, relationships are established between strength and the chemical composition and fineness of cement, or between strength and ultrasonic pulse velocity, or between strength and concrete mix components.

Many studies have been conducted in this field. The aim of the study by researchers (Suhair and Zena) [13] was to predict the 28-day compressive strength using accelerated curing methods. Three accelerated curing methods were adopted: warm water curing at a temperature of (35°C), autogenous curing according to American specifications (ASTM C684), and warm water curing at a temperature of (55°C) according to British specifications (BS 1881: Part 112:1983). The results indicated that the accelerated strength using warm water curing at (35°C), autogenous curing method, and warm water curing at (55°C) reached approximately (0.356, 0.492, 0.595) respectively of the 28-day compressive strength. Regression analysis for Linear and Nonparametric equations was studied using statistical software, and good correlation results were obtained between the 28-day compressive strength and the accelerated strength using different curing methods. Researcher Iqbal and others [14] sought to develop a simple mathematical equation based on simple linear regression analysis to estimate the 28-day compressive strength of concrete containing recycled coarse aggregate. The results of compressive strength tests at an early age (28.5 hours) were used instead of (3) or (7) days. The proposed equation requires the value of accelerated curing compressive strength for (28.5) hours to predict the compressive strength of concrete containing recycled coarse aggregate after (28) days. The compressive strength results obtained using the proposed equation showed good agreement when compared with the compressive strength values obtained experimentally after 28 days. Researchers (Hasan and Kabir) [15] in 2011 attempted to develop a simple mathematical model known as a rational polynomial, based on the nature of concrete strength gain, to predict the 28-day compressive strength of concrete from early test results (7, 14 days). They concluded that the proposed model has good potential to predict concrete strength at different ages with high accuracy. The aim of all the studies conducted was to facilitate the process of predicting concrete strength and increase its efficiency.

2 Research Objective

There has been a growing trend in recent years toward utilizing concrete waste and converting it into environmentally friendly materials. This waste serves as an alternative to traditional materials used in concrete production, helping to preserve the environment and protect natural resources from depletion. The compressive strength of concrete containing concrete waste is no less important than the compressive strength of concrete containing natural materials, and there is a scarcity of research that focused on predicting the compressive strength of concrete containing both fine and coarse recycled aggregates. Therefore, predicting the compressive strength of this type of concrete is essential. Accordingly, the current research aims to predict the compressive strength of concrete containing fine aggregates at 28 and 56 days of age by knowing the compressive strength of the same concrete but at earlier ages (3 and 7 days) and using standard curing.

3 Experimental Program

3.1 Materials

3.1.1 Cement

Locally manufactured ordinary Portland cement was used, and after chemical and physical tests it was in accordance with the Iraqi Standard Specification (IQS 5:2016) [16]. Tables (1) and (2) show the chemical composition and physical properties for the cement used.

Table 1: Chemical Composition for the Cement.

Chemical Composition	Value [%]	Limits Iraqi Standard (No.5, 2016)	Chemical Composition	Value [%]
SiO_2	21.4	----	C_3S	45.8
Al_2O_3	4.16	----	C_2S	26.57
Fe_2O_3	3.13	----	C_3A	5.73
CaO	59.81	----	C_4AF	9.53
MgO	2.27	≤ 5	L.S.F	88.39
SO_3	0.89	≤ 2.8	Solid Solution	14.08
Free Lime	2.56	----		
L.I (Loss on ignition)	0.19	≤ 4		
I.R (insoluble residues)	0.7	≤ 1.5		

Table 2: Physical properties for the cement.

Physical properties	Test results	Limits Iraqi Standard (No.5, 2016)
Initial setting time (min)	135	≥ 45 min
Final setting time (hr)	4:00	≤ 10 hr
Fineness sieves no 170 mm (90ɥm)	4.6 %	≤ 10%
Compressive strength (MPa) 3 days 7 days	 19.87 27	 ≥ 15 ≥ 23

3.1.2 Coarse Aggregate

Round river pebbles of maximum size (19mm) were used. Tables 3 and 4 show the sieve analysis and physical properties for the coarse aggregate, which were conducted according to specifications (ASTM C33) [17] and (ASTM C127-15) [18].

Table 3: Sieve analysis for coarse aggregate.

Sieve size [in]	Passing [%]	(ASTM C33)
1	100	100
3/4	100	90-100
3/8	40	20-55
No. 4	0	0-10

Table 4: Physical properties for coarse aggregate.

Apparent Specific Gravity	2.74
Absorption Capacity [%]	0.43
Unit Weight [kg/m³]	1728

3.1.3 Fine Aggregate

River sand was used in the concrete mixes with a fineness modulus of (2.8), Tables (5) and (6) show the sieve analysis and physical properties, which were conducted according to specifications (ASTM C33) [17] and (ASTM C128-15) [19].

Table 5: Sieve analysis for fine aggregate.

Sieve size [in]	Passing (NFA) [%]	(ASTM C33)
No.4	100	95-100
No.8	81.1	80-100
No.16	60.2	50-85
No.30	44.6	25-60
No.50	25	5-30
No.100	5	0-10

Table 6: Physical properties for fine aggregate.

Physical properties	NFA
Apparent Specific Gravity	2.72
Absorption Capacity [%]	1.8
Fineness Modulus	2.8
Unit Weight [kg/m³]	1798

3.1.4 Fine Recycled Aggregate

Fine aggregate was used, which is a product of concrete wastes found in Mosul city and was obtained from Al-Adhbah area. Samples with particle size (0-5mm) were taken. Fig.1 shows the fine aggregate. Tables (7) and (8) show the sieve analysis [17] and physical properties of this aggregate[19].

Fig. 1: Recycled Fine Aggregate.

Table 7: Sieve analysis for recycled fine aggregate.

Sieve size [in]	% Passing (RFA)	(ASTM C33)
No.4	100	95-100
No.8	80.6	80-100
No.16	57.5	50-85
No.30	40.3	25-60
No.50	22	5-30
No.100	8.2	0-10

Table 8: Physical properties for recycled fine aggregate.

Physical properties	RFA
Apparent Specific Gravity	2.67
Absorption Capacity [%]	8.3
Fineness Modulus	2.9
Unit Weight [kg/m³]	1481

3.2 Concrete Mixtures

Four groups of concrete mixes were prepared, the compressive strength of these groups was (25, 30, 35, 40MPa), Which are considered the target strengths that were used to reach the tables in the American concrete design method, and for each strength, the natural fine aggregate was replaced with four alternative ratios of fine recycled aggregate (0, 10, 20, 30%), which were added as volumetric ratios. The concrete mixes were designed according to (ACI 211.1-91) [20]. This means that 16 concrete mixes were poured, and for each mix, 12 standard cubes with dimensions (150*150*150mm) were prepared, and they were tested at different ages (3, 7, 28 and 56 days). After (24 hr) of pouring the samples, they were transferred to the curing tanks to be treated by immersion in water (standard curing) for the required age, after that the samples were tested according to the specification (BS EN 12390-3:2002) [21]. Table (9) shows the practical results of the compressive strength for each mix and at each age.

Table 9: Details of concrete mixes (kg/m3).

Mix	Cement [kg/m^3]	Sand [kg/m^3]	FRA [%]	Gravel [kg/m^3]	Water [kg/m^3]	Compressive Strength [MPa]			
						3 day	7 day	28 day	56 day
M25 (Control)	302	789	0	1071	174	15.45	21.68	29.42	36.67
M25 (10%RFA)	302	724	10	1071	174	16.2	23.45	31.7	38.59
M25 (20%RFA)	302	659	20	1071	174	18.88	25.09	32.44	38.84
M25 (30%RFA)	302	594	30	1071	174	16.34	21.1	28.7	34.3
M30 (Control)	364	738	0	1071	177	20.59	25.76	34.12	40.67
M30 (10%RFA)	364	677	10	1071	177	20.5	25.86	35.51	41.75
M30 (20%RFA)	364	616	20	1071	177	22.99	26.8	36.3	42.96
M30 (30%RFA)	364	555	30	1071	177	21.53	25.94	34.32	41.58
M35 (Control)	400	708	0	1071	184	23.65	29.27	36.2	41.2
M35 (10%RFA)	400	650	10	1071	184	24.9	30.365	38.3	43.96
M35 (20%RFA)	400	592	20	1071	184	25.62	30.465	37.96	44.71
M35 (30%RFA)	400	534	30	1071	184	24.9	30.06	37.08	42.22
M40 (Control)	440	675	0	1071	182	28.1	33.29	38.345	43.91
M40 (10%RFA)	440	519	10	1071	182	29.82	33.2	39.7	45.59
M40 (20%RFA)	440	563	20	1071	182	29.96	35.22	42.27	49.52
M40 (30%RFA)	440	507	30	1071	182	29.29	34.23	41.81	47.9

4 Limitations of mathematical model formation

The mathematical model derived based on the practical results can be used to obtain (28 and 56) days resistance but according to the following specifications: the amount of cement for the mixtures ranges from (302 – 440 kg/m^3), the cement used is (OPC), the percentage of fine aggregate recycled ranges from (0 - 30), there are no additives in the concrete mixture, the maximum size of aggregate used (19 mm), the compressive strength does not exceed (40MPa), the water/cement ratio (0.58 – 0.39), and the resistance resulting from using the mathematical model is the compressive strength of standard cubes (150*150*150mm).

5 Mathematical Models

Based on the obtained practical results, 4 mathematical models were created. The first and second models predict the compressive strength for 28 days, by establishing the models on the results of compressive strength for ages 3 and 7 days. The third and fourth models were created to predict the compressive strength for 56 days, and these mathematical models were also based on the results of compressive strength for ages 3 and 7 days. The SPSS program was used to derive the mathematical models through statistical analysis (simple linear regression analysis).

Figs. 2, 3 show the relationship between the compressive strength at (3) and (7) days with the compressive strength at (28) days for the same mixtures. The figs. also show the obtained equations that link the strength of early ages with later ages. The linear equations showed good agreement and correlation with the practical results, which is evident from the coefficient of determination (R^2) values for the equations shown in Table (10), equal to (0.848) and (0.86) for equations based on ages (3) and (7) days, respectively. Table (10) represents the results of simple linear regression analysis for the relationship between compressive strength at early ages (3) and (7) days and compressive strength at later age (28) days.

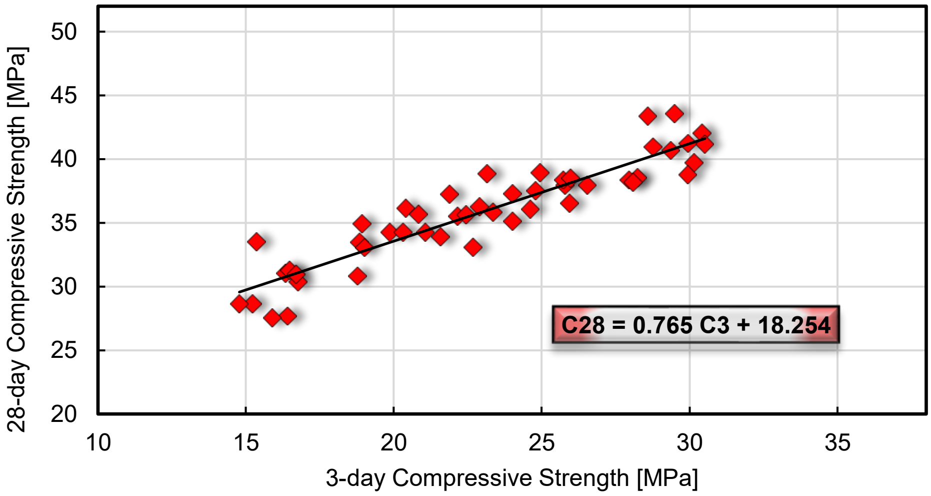

Fig. 2: The Relationship between compressive strength at ages (3 and 28) days.

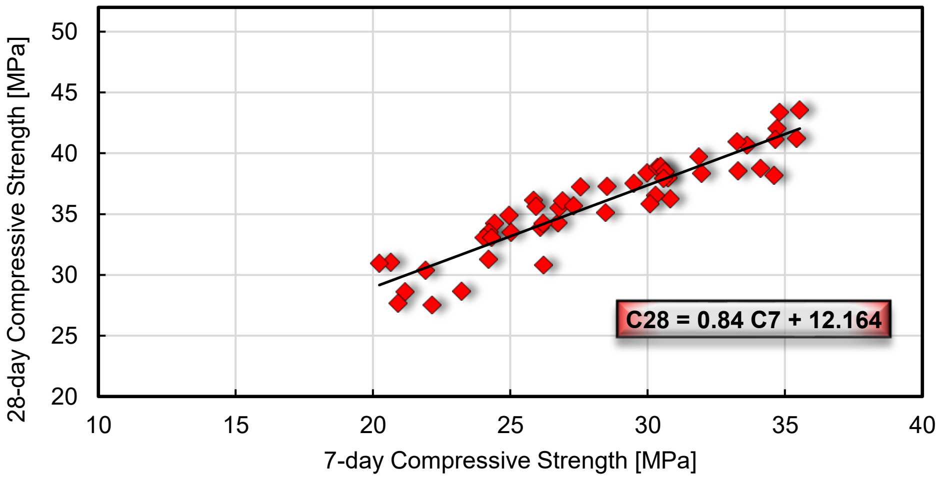

Fig. 3: The Relationship between compressive strength at ages (7 and 28) days.

$$C_{28} = 0.765\ C_3 + 18.25 \quad (1)$$

$$C_{28} = 0.84\ C_7 + 12.164 \quad (2)$$

Equations (1) and (2) shown above represent the predicted compressive strength at 28 days based on the results of compressive strength at early ages (3) and (7) days respectively,
where:
C_{28} - Compressive strength at 28 days [MPa],

C_7 - Compressive strength at 7 days [MPa],
C_3 - Compressive strength at 3 days [MPa].

Table10: Results of linear regression analysis for the relationship between compressive strength at 28 days and early ages.

(Regression analysis)					
Dependent variable: Compressive strength at 28 days.					
Model		**B**	**P-value**	**R^2**	**MSE**
3-28	Constant	18.25	< 0.001	0.848	2.483
	3-day	0.765	< 0.001		
	$C_{28} = 0.765\ C_3 + 18.25$ ……. (1)				
7-28	Constant	12.164	< 0.001	0.86	2.285
	7-day	0.84	< 0.001		
	$C_{28} = 0.84\ C_7 + 12.164$ ……. (2)				

where:
P-Value - Helps determine whether the results obtained from statistical analysis are statistically significant or not.
Mean Square Error (MSE) - The average of the squared differences or residuals between the actual and estimated values, which reflects the accuracy of the proposed statistical equation.
Coefficient of Determination (R^2) - Represents the proportion of the effect of change in compressive strength at early stages on the compressive strength at 28 days. The coefficient value ranges between (0-1); the closer the value is to one, the more accurate the model. Table (11) refers to the classification of statistical equations based on the values of the coefficient of determination (R^2) [22]. A high value of the (R^2) indicates that the model fits well with the available experimental data.

Table11: Classification of equations based on R^2 values [22].

Criteria	**[R^2]**
excellent	> 0.9
good	0.7 - 0.89
fair	0.4 - 0.69
poor	0.2 – 0.39
very poor	< 0.19

From observing the results in Table (10), it is evident that the compressive strength at early ages has a significant effect on the compressive strength at later ages. This is clear from the probability value (P-Value) result; the probability value equals (<0.001), which is less than the significance level (0.05). Also, the values of the coefficient of determination (R^2) for equations (1) and (2) are equal to (84.8%, 86%) respectively. For equation (1), the compressive strength at age (3) days contributes 84.8% of the change in compressive strength at age (28) days. In equation (2), it is observed that the compressive strength at age (7) days contributes 86% of the change in compressive strength at age (28) days. The high value of the coefficient of determination indicates that the proposed model fits well with the available practical data.

We note that the (MSE) values in Table (10) equal (2.483, 2.285) for equations (1) and (2) respectively. The lower the (MSE), the better the model is at prediction. A high (MSE) indicates that there are large differences between the predicted values and the actual values, meaning that the proposed model is inaccurate.

Fig. 4 represents the relationship between the actual and estimated compressive strength at 28 days and predicted from the compressive strength at 3 days, while Fig. 5 shows the relationship between the actual and estimated compressive strength at 28 days and predicted from the compressive strength at 7 days.

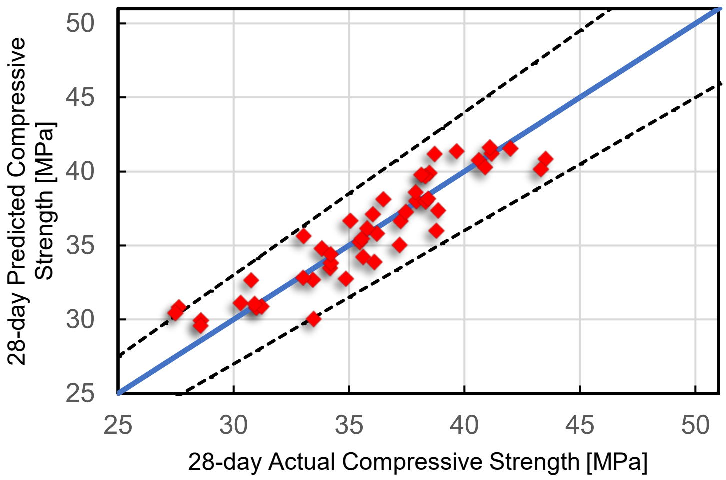

Fig. 4: Relationship between actual and estimated compressive strength predicted from the 3 day age.

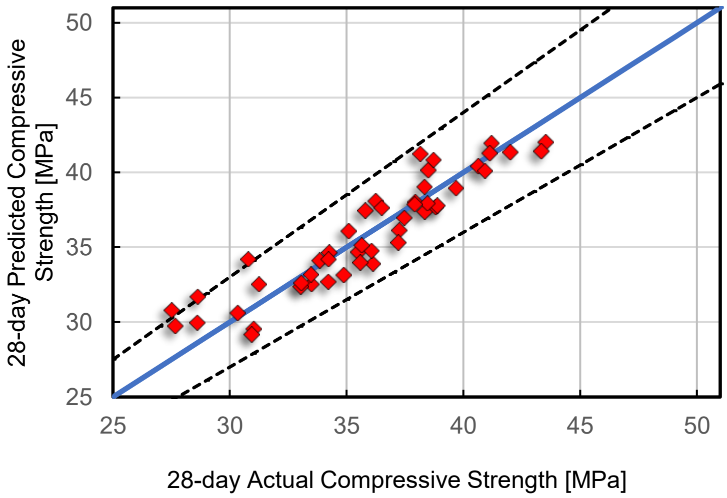

Fig. 5: Relationship between actual and estimated compressive strength predicted from the 7 day age.

In Fig. 4, the alignment of predictions on the equality line is indicated within a range of (±10%); it shows that (96%) of the data falls within these bounds, while (4%) is outside. In Fig. 5, only (6%) of the data is outside the (±10%) limits, with 94% falling within the bounds, highlighting the accuracy of predicting compressive strength at 28 days.

Figs. 6, 7 represented the relationship between the compressive strength of concrete at age (56) days based on the compressive strength of the same concrete mixtures at early ages (3) and (7) days, using linear mathematical equations shown in the figs. Table (12) shows the results of simple linear regression analysis for this relationship between compressive strength at age (56) days and at early ages (3) and (7) days. The linear equations also showed good agreement and correlation with the practical results, which is evident from the coefficient of determination values (R^2) for the equations shown in Table (11), equal to (0.792) for equations based on ages (3) and (7) days.

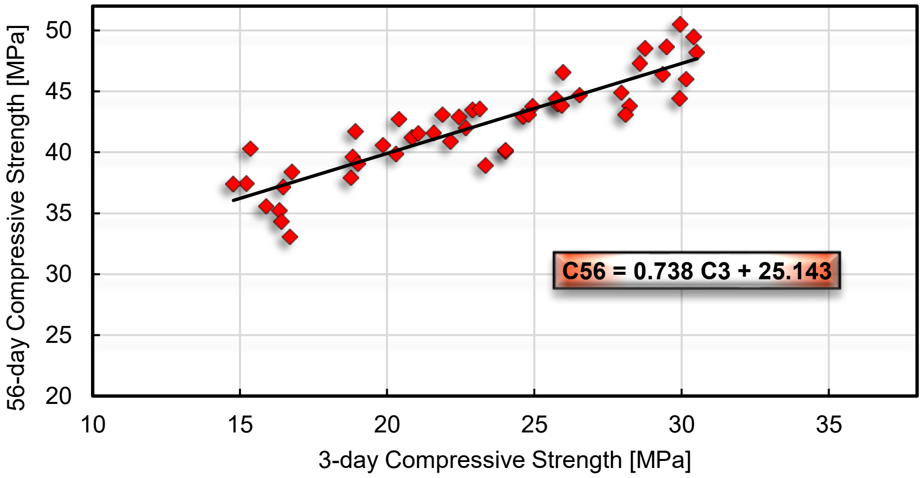

Fig. 6: The Relationship between compressive strength at ages (3 and 56) days.

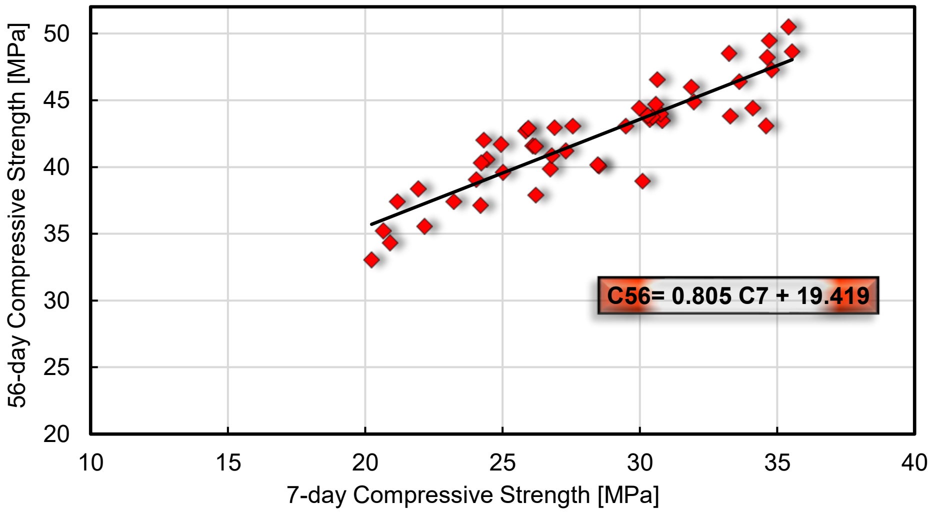

Fig. 7: The Relationship between compressive strength at ages (7 and 56) days.

The equations (3) and (4) above represent the predicted compressive strength at 56 days based on the compressive strength results at early ages (3 and 7 days), respectively.
where:
C_{56} - Compressive strength at 56 days [MPa],
C_7 - Compressive strength at 7 days [MPa],
C_3 - Compressive strength at 3 days [MPa].

Table12: Results of linear regression analysis for the relationship between compressive strength at 56 days and early ages.

<table>
<tr><th colspan="6">(Regression analysis)</th></tr>
<tr><td colspan="6">Dependent variable: Compressive strength at 56 days.</td></tr>
<tr><th colspan="2">Model</th><th>B</th><th>P-value</th><th>R^2</th><th>MSE</th></tr>
<tr><td rowspan="2">3-56</td><td>Constant</td><td>25.143</td><td>< 0.001</td><td rowspan="2">0.792</td><td rowspan="2">3.404</td></tr>
<tr><td>3-day</td><td>0.738</td><td>< 0.001</td></tr>
<tr><td colspan="6">$C_{56} = 0.738\ C_3 + 25.143$ …….(3)</td></tr>
<tr><td rowspan="2">7-56</td><td>Constant</td><td>19.419</td><td>< 0.001</td><td rowspan="2">0.792</td><td rowspan="2">3.393</td></tr>
<tr><td>7-day</td><td>0.805</td><td>< 0.001</td></tr>
<tr><td colspan="6">$C_{56} = 0.805\ C_7 + 19.419$ …….(4)</td></tr>
</table>

The results in Table (12) indicate that early-age compressive strength has a significant effect on compressive strength at later ages, as evidenced by the P-value of (<0.001), which is less than the significance level of (0.05). The R^2 values for equations (3) and (4), which are (79.2%), show that (79.2%) of the variation in compressive strength at 56 days is contributed by the compressive strength at 3 days. Similarly, for equation (4), it indicates that (79.2%) of the variation in compressive strength at 56 days is contributed by the compressive strength at 7 days. The MSE values are (3.393) and (3.404) for equations (3) and (4), respectively, representing the mean square error between the actual and predicted values.

Fig. 8 shows the relationship between the actual and predicted compressive strength at 56 days, as forecasted from the compressive strength at 3 days, while Fig. 9 illustrates the relationship between the actual and predicted compressive strength as forecasted from the compressive strength at 7 days.

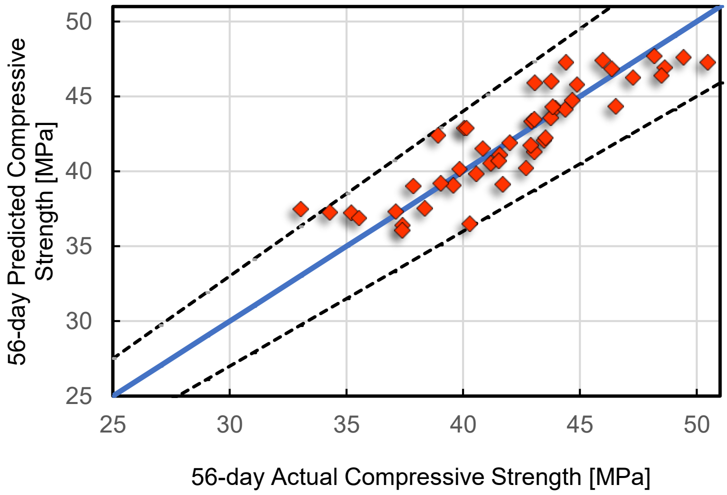

Fig. 8: Relationship between actual and estimated compressive strength predicted from the 3 day age.

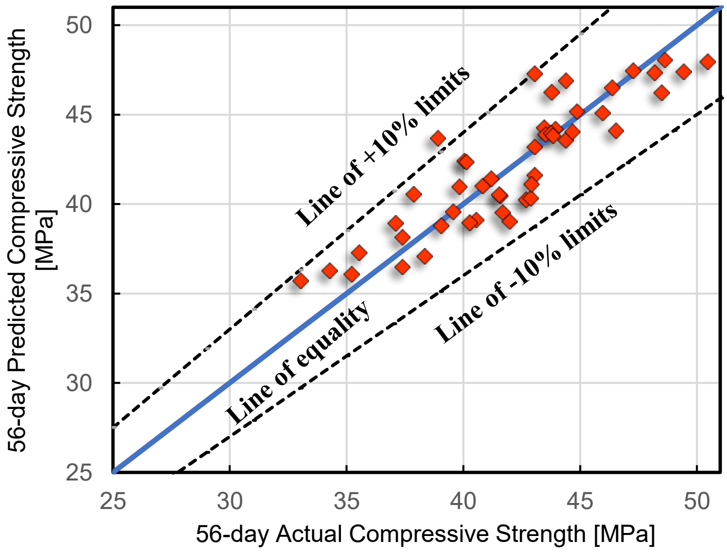

Fig. 9: Relationship between actual and estimated compressive strength predicted from the 7 day age.

In Figs. 8, 9 we observe that only (2%) of the data falls outside the (±10%) range, while (98%) of the results are within the bounds. This highlights the accuracy of the prediction for the compressive strength at 56 days.

6 Validation of the proposed equations

The proposed equations were verified by utilizing the practical results of the concrete mix that was prepared and cast along with the concrete mixes using the same replacement ratios of recycled fine aggregate, which were tested at the same ages. The adopted concrete mix had cement: sand: gravel ratios of (1: 1.53: 2.43), with a (W/C) ratio of (0.42), and a cement content of (440 kg/m3). Its compressive strength at 28 days was (38.0 MPa). It should be noted that the results of this mix were not included in the data used for analysis and equation proposal. Tables (13) and (14) show the values of practical compressive strength and those predicted by the proposed equations at ages of (28) and (56) days, respectively.

Table 13: Practical compressive strength and predicted compressive strength from the proposed equations at age (28) days based on strengths at early ages (3) and (7) days.

Actual Compressive Strength [MPa]			Predicted Compressive Strength [MPa] 28 days		P_{28}/A_{28}	
3 day	7 day	28 day	Equ.(1)	Equ.(2)	Equ.(1)	Equ.(2)
23.89	32.49	37.08	36.53	39.45	0.985	1.063
25.13	32.67	37.38	37.5	39.6	1.003	1.059
26.85	30.95	39.54	38.79	38.16	0.981	0.965
24.84	32.44	40.05	37.25	39.4	0.93	0.983
27.45	31.1	38.86	39.25	38.29	1.01	0.985
23.97	31.67	39.65	36.59	38.77	0.922	0.977
29.98	33	39.75	41.18	39.887	1.035	1.003
29.7	32.26	41	40.97	39.267	0.999	0.957
28.53	33.63	38.3	40.08	40.4	1.046	1.054
29.01	33.61	36.58	40.44	40.39	1.105	1.104
27.29	33.67	37.81	39.13	40.45	1.035	1.069
27.09	30.29	38.24	38.97	37.6	1.019	0.983

Table 14: Practical compressive strength and predicted compressive strength from the proposed equations at age (56) days based on strengths at early ages (3) and (7) days.

Actual Compressive Strength [MPa]			Predicted Compressive Strength [MPa] 56 days		P_{56}/A_{56}	
3 day	7 day	56 day	Equ.(3)	Equ.(4)	Equ.(3)	Equ.(4)
23.89	32.49	43.36	42.77	45.57	0.986	1.05
25.13	32.67	44.24	43.69	45.72	0.987	1.033
26.85	30.95	45.05	44.96	44.33	0.998	0.984
24.84	32.44	44.49	43.47	45.53	0.977	1.023
27.45	31.1	42.47	45.4	44.45	1.068	1.046
23.97	31.67	41.4	42.83	44.91	1.034	1.084
29.98	33	45.37	47.27	45.98	1.041	1.013
29.7	32.26	49.3	47.1	45.39	0.955	0.92
28.53	33.63	46.87	46.2	46.49	0.985	0.99
29.01	33.61	46.55	46.5	46.47	0.999	0.998
27.29	33.67	48.34	45.28	46.52	0.936	0.962
27.09	30.29	47.62	45.13	43.8	0.947	0.919

Tables (13) and (14) show that most of the (P/A) (Prediction/Actual) results are close to one; the values ranged between (0.919-1.105) for both ages, which is a clear indicator of the validity of the proposed equations for predicting compressive strength at ages (28 and 56) days using compressive strength values at early ages (3) and (7) days. The experimental results for compressive strength at (28 and 56) days were very close to the predicted values.

7 Conclusion

• Based on the compressive strengths of concrete mixes at early ages (3,7) days, and using Simple Linear Regression analysis, mathematical relationships were derived for all replacement ratios and all concrete mixes. These relationships connect the compressive strength at (28) days with the compressive strength at early ages (3,7) days for all concrete mixes in the current study, and similarly for the age of (56) days.

• The equations provided an appropriate estimation of compressive strength values, which is evident from the coefficient of determination (R^2) values ranging between (84.8%) and (86%) for the age of (28) days, and (79.2%) and (79.2%) for the age of (56) days, respectively.

• In general, the addition of recycled fine aggregate had an effect on improving the compressive strength of concrete. An increase in compressive strength was observed up to an addition ratio of (20%). Then, when the fine aggregate content increased to (30%), the compressive strength decreased slightly, meaning its behavior regarding compressive strength was similar to that of the reference mix. We can conclude that addition ratios up to 30% have no negative impact on the compressive strength of concrete.

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