STRENGTH PREDICTION OF NORMAL STRENGTH CONCRETE MADE USING LOCALLY AVAILABLE MATERIALS IN PAKISTAN BY ACCELERATED CURING

Z. A. Siddiqi[1], Rashid Hameed[1,*], Qasim Shaukat Khan[1], M. Rizwan Riaz[1], Usman Akmal[1]
[1]*Civil Engineering Department, University of Engineering and Technology Lahore, Pakistan*
[*] *Corresponding Author, E-mail: rashidmughal@uet.edu.pk, cell # +92-322-3064000*

ABSTRACT: *Prediction of 28 days compressive strength of concrete using early age strength value is the primary objective of the experimental study reported in this paper. In most of the cases, accelerated curing method is a requisite to determine early age mechanical properties of concrete. A simplified accelerated curing method similar to boiling method as described in ASTM C 684-74 is developed and described in this paper. Concrete used in this work was made using locally available materials in Pakistan. Concrete cylinders cured by using proposed accelerated method and normal curing method were tested for compressive strength at early age (28.5h) and at 7 & 28 days of age. Based on the results obtained, 7-D and 28-D strength prediction relationships have been proposed. Testing of proposed relationships showed satisfactory results.*

Keywords: Concrete; early age strength; accelerated curing method, strength prediction

1. INTRODUCTION

During the construction of any RC structure, prediction of 28 days strength of concrete is necessary for the following important reasons: (1) to enable the earlier removal of formwork; (2) to provide adequate times for any remedial measure if needed; (3) to put the structures into full service loads earlier; and (4) to expedite new mix designs as the trial mixes can be checked earlier.

Concrete is not a mill produced material and is manufactured at or close to construction sites. Final properties of concrete are affected by a number of factors like quality of materials, proportion of the mix, thoroughness with which the ingredients are intermixed, and placing and curing techniques [1,2]. To provide structural safety, systematic quality control is necessary in concrete construction. Structural design is generally based on the 28 day strength and therefore the testing for strength is usually carried out when concrete has attained the age of 28 days, the period is reduced to 7 days in some of the standards. The current advancement in concrete construction technology points towards the need of earlier determination of compressive strength of concrete. Confirmation of satisfactory strength and detection of possible later trouble at an early stage will permit more productivity and less delay in progress of construction work on site. In the past, much work had been carried out on accelerated testing of concrete by which the strength potential of concrete can be determined within 30 hours of its placing [3-5].

Due to advanced concrete construction, there is a need for more rapid control and acceptance test for concrete than the standard 7 days or 28 days strength tests. A number of methods are being used for the accelerated testing of concrete specimens. Further, a number of variables affect the accelerated cured strength. For example, initial moist curing of test specimens, types of cements and aggregates may affect the accelerated strength results while aggregate to cement ratio may also be a factor affecting the accelerated strength.

Akroyd and Smith [6] reported a method for determining the accelerated-cured strength of concrete cubes. The accelerated-cured strength results were then used successfully to predict the 28 day strength of concrete.

Malhotra and Zoldners **[7]** after a detailed research study concluded that the accelerated test can predict the 28 day strength probably as accurately as the standard 7 day test. In practice, one has to rely on 7-day strength but it is obvious that even greater benefits would be derived from obtaining results within 28.5h.

The research study presented in this article has been carried out to achieve following objectives: (1) to study the feasibility and application of accelerated strength tests to concretes made from locally available materials and to predict 28 day strength as early as possible using cylindrical specimens of diameter 150 mm and 300 mm height; (2) to set up a simple equipment for the accelerated curing of concrete specimens which would easily be used in the field; and (3) to establish relationships between accelerated strength and strength of moist cured specimens at ages of 7 and 28 days.

2. MATERIALS AND METHODS

2.1 CONCRETE CONSTITUENTS

To study the effect of the type of materials on the concrete strength, type of cement and nature of fine and coarse aggregates were varied in making concrete of different strengths. Properties of two different types of locally manufactured OPC cements (named in this paper as OPC-I and OPC-II cements) used in this study are given in Table 1. Two different types of sands named as Lawrencepur sand and Ravi sand were used as fine aggregates. Properties of both types of sands are given in Table 2. Gradating curves of Lawrencepur and Ravi sands are shown in Fig.1. Two different types of locally available coarse aggregates named as Margala crush and Sargodha crush, were used to develop concretes of different strengths. Properties of both types of coarse aggregates are given in Table 3. Gradating curves of Margala Crush and Sargodha crush are shown in Fig. 2.

2.2 CONCRETE MIXES

To develop relationship between 28.5h accelerated compressive cylinder strength and 7-D and 28-D cylinder strength of normal strength concrete, tentative mix proportions of concretes and their w/c ratios were selected and designated by Mix 1 to Mix 24 in this study. Detail of concrete constituent, mix proportion by weight and w/c ratio value of each mix is given in Table 4.

Table 1: Properties of cements

Properties	OPC-I Cement	OPC-II Cement
Standard consistency	31	29
Initial Setting time	105 min	110 min
Final setting time	2h - 5min	3h - 15min
Soundness	7 mm	8 mm
Fineness	8%	7%
3-Days compressive strength using mortar cubes	14.8 MPa	15.7 MPa

Table 2: Properties of fine aggregates

Properties	Lawrencepur sand	Ravi Sand
Water Absorption Capacity (%)	0.9	1.6
Moisture Contents (%)	0.4	3.5
Specific Gravity	2.61	2.60
Rodded Density (kg/m^3)	1641	1456
Fineness Modulus	2.4	1.21

Table 3: Properties of coarse aggregates

Properties	Margala Crush	Sargodha Crush
Max. Aggregate Size (mm)	19	19
Water Absorption Capacity (%)	0.5	0.7
Moisture Contents (%)	0.1	0.3
Specific Gravity	2.65	2.63
Rodded Density (kg/m^3)	1536	1568
Aggregate Impact Value (%)	17.3	12.4

2.3 TEST SPECIMEN

Concrete compressive strength was determined using cylindrical specimen. Diameter and height of the cylindrical test specimen was 150 mm and 300 mm, respectively. A total of 6 specimens were cast for each mix to be tested at the age of 28.5h, 7 and 28 days. Average compressive strength of two specimens for each concrete mix at different ages is reported in this paper.

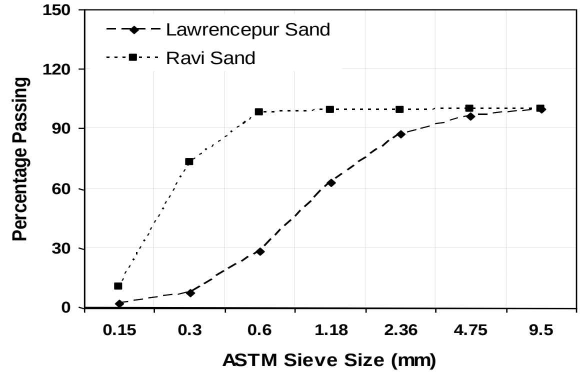

Figure-1 Grading curves of fine aggregates

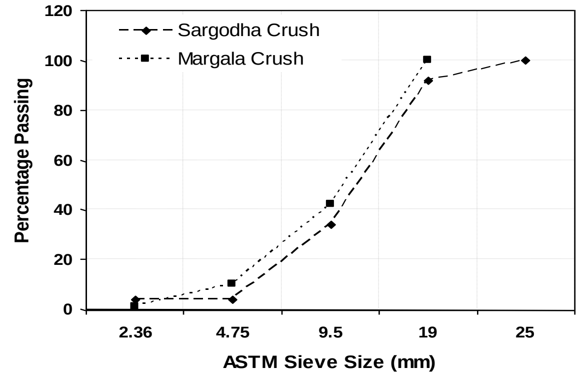

Figure-2 Grading curves of coarse aggregates

2.4 MIXING, CASTING AND NORMAL CURING OF CONCRETE

For mixing concrete, pan type mixer capable of holding 0.056 m^3 of wet concrete was used. Coarse aggregates were added first, and then cement followed by sand. Dry mixing of all ingredients was done for about one minute. Water was then added and the concrete was mixed for 3-minutes, followed by 3 minutes rest followed by 2 minute final mixing. Concrete specimens were compacted on a vibrating table in three layers for a time period depending upon the workability of the mix to allow proper compaction but to prevent segregation. After compaction, the top surface of the cylinders was finished with trowel.

Initial curing for the specimens was carried out at temperature range of 25-38°C and relative humidity about 80-90%. Molds were removed after 23 to 24 hours of casting. For moist curing of specimens after initial curing the samples were dipped into a water tank having a temperature close to 23°C.

2.5 ACCELERATED CURING METHOD

ASTM [8] describes standard methods of accelerated curing intended to accelerate the development of strength. These methods are warm water method, boiling water method and autogenous method. Since the boiling water method is the easiest method available for accelerated curing of the samples which can easily be performed in the field and also it has worked well in the past, this method has been used with little modification from the standard procedure. Another advantage and simplicity of this method is that it requires only a container of water, burner and simple means of dipping cylinders into the boiling water. No specialized control or skill is required while using this method.

2.5.1 Procedure of accelerated curing

After 22 hours of casting, two specimens per mix were removed from the molds which were kept at the laboratory conditions of temperature and humidity. These were weighed, marked and were placed into the metallic cylinder cages. The cylindrical cages along with the concrete specimen (refer to Fig.3) were lifted and dipped into the boiling water at an age of 23 to 24 hours with the help of lifting rod. The drum was covered with lid leaving some gap for escape of the steam. After 3.5 hr +/- 5 minutes of boiling, the cylinder cages were taken out and the samples were allowed to cool under an electric fan. After 1 to 1.5 hour of cooling, the samples were taken out of their cages, capped, weighed and tested in the compression testing machine.

Figure-3 Cage used to dip concrete cylinders in boiling water

Table 4: Description of the concrete mixes

Mix No.	Constituent Materials	Mix Proportions by Weight	w/c ratio
1	OPC-I Cement + Lawrencepur sand + Margalla Crush	1 :1.5 : 3	0.40
2			0.55
3			0.65
4		1 : 2: 4	0.50
5			0.65
6			0.80
7		1: 2.5 : 5	0.60
8			0.85
9			0.95
10		1 : 3 : 6	0.70
11			0.85
12			1.00
13	OPC-II Cement + Ravi Sand + Sargodha Crush	1 : 1 : 3.5	0.40
14			0.55
15			0.65
16		1 : 1.5 : 4.5	0.50
17			0.65
18			0.80
19		1 : 2 : 5.5	0.60
20			0.80
21			0.90
22	OPC-II Cement + Ravi Sand + Margala Crush	1: 2.5 : 6.5	0.70
23			0.85
24			1.00

2.6 TESTING OF THE SPECIMENS

Capping of the cylinders was done according to ASTM standard [9]. The testing machine used was 300 ton Denison compression testing machine. Before testing each specimen was weighed and its dimensions were noted. The bearing surfaces of the testing machine were wiped clean from material of any sort sticking to the compression platens every time before testing of a new specimen. Each cylinder after proper drying of the capping material was placed vertically within platens of the testing machine having the same direction in which it was cast. The center of the specimen was carefully aligned with the center of thrust of the spherically seated platen. The platen was gently lowered to bear on the specimen resulting in a uniform seating. The load was applied without shock and was continuously increased at a rate of approximately 13.8 MPa per minute (25 tons per minute). The maximum load resisted by cylindrical specimen was recorded and the appearance of concrete or any unusual feature in the type of failure, if any, was also noted.

3. RESULTS AND DISCUSSION

The results of compressive strength tests performed on all concrete mixes listed in Table 4 are presented in Table 5. These results were used to develop relationship between 7 & 28 days moist cured cylinder strength and 28.5h accelerated cured cylinder strength of concrete.

3.1 RELATIONSHIP BETWEEN 28-DAYS AND 28.5H ACCELERATED COMPRESSIVE CYLINDER STRENGTH

3.1.1 FOR OPC-I CEMENT

Results of compressive strength tests performed at 28.5h and 28-D of age for Mix1 to Mix12 made using OPC-I cement are plotted as shown in Fig.4. Using the data presented in this figure, relationship between 28.5h accelerated strength and 28-D strength was obtained and is given in Equation 1, where "y_{28}" represents 28 days compressive cylinder strength in MPa and "x" represents 28.5h accelerated cylinder compressive strength in MPa. The correlation coefficient for this equation is 0.98. For concrete made using constituents similar to Mix1 to Mix12, and with early age strength

Table 5: Compressive strength

Mix No.	28.5h Cylinder Strength (MPa)	7-Day Cylinder Strength (MPa)	28-Day Cylinder Strength (MPa)
1	16.1	30.2	35.2
2	9.6	14.1	25.4
3	7.4	15.2	21.0
4	11.7	22.7	26.5
5	7.7	17.6	23.6
6	4.5	11.8	16.3
7	9.3	19.0	24.6
8	3.6	8.8	13.2
9	2.9	6.8	11.3
10	5.7	10.8	19.8
11	3.8	9.4	12.4
12	2.7	7.0	10.4
13	15.8	20.5	27.9
14	9.3	12.7	18.2
15	6.6	10.8	14.0
16	12.2	18.2	23.9
17	9.0	15.3	19.7
18	5.5	9.6	15.4
19	8.7	15.8	19.5
20	5.7	8.9	14.0
21	3.8	8.1	10.6
22	7.1	11.7	15.8
23	4.9	8.1	12.7
24	3.4	6.4	9.8

between 2.75 to 15.85 MPa, equation 1 may be used to predict 28-D strength.

$$y_{28} = 5.57 \times x^{0.67} \quad \text{(MPa)} \qquad (1)$$

3.1.2 FOR OPC-II CEMENT

For Mix13 to Mix24 made using OPC-II cement, relationship between 28.5h strength and 28-D strength given in Equation 2 was obtained using the tests results presented in Fig.5. In this equation, "y_{28}" and "x" are same as defined earlier. The correlation coefficient for this equation is 0.97. For concrete made using constituents similar to Mix13 to Mix24, and with early age strength between 3.45 to 15.85 MPa, equation 2 may be used to predict 28-D strength.

$$y_{28} = 4.36 \times x^{0.67} \quad \text{(MPa)} \qquad (2)$$

3.1.3 COMBINED RELATIONSHIP

Since two types of cements used in this study represents almost all cement brands available in Pakistan except slag cement, data of compressive strength of Mix1 to Mix24 have been used to develop relationship between 28.5h strength and 28-D strength. Results of compressive strength for Mix1 to Mix24 were plotted as shown in Fig.6 and using this data, an equation to predict 28-day strength using accelerated strength was obtained as given in Equation 3. In this equation, "y_{28}" and "x" are same as defined earlier. The correlation coefficient for this equation is 0.85. If type of the cement is not known, equation 3 may be employed to predict 28-D strength using accelerated strength. It is important to note that this equation is valid for early age accelerated strength of 2.75 to 15.85 MPa.

$$y_{28} = 5.24 \times x^{0.64} \quad \text{(MPa)} \qquad (3)$$

3.2 RELATIONSHIP BETWEEN 7-DAYS AND 28.5H ACCELERATED COMPRESSIVE CYLINDER STRENGTH

3.2.1 FOR OPC-I CEMENT

Results of compressive strength tests performed at 28.5h and 7-D of age for Mix1 to Mix12 made using OPC-I cement are plotted as presented in Fig.7. From this data, a relationship between 28.5h accelerated strength and 7-D strength was obtained and is given in Equation 4, where "y_7" represents 7 days compressive cylinder strength in MPa and "x" represents 28.5h accelerated cylinder compressive strength in MPa. The correlation coefficient for this equation is 0.94.

$$y_7 = 3.15 \times x^{0.79} \quad \text{(MPa)} \qquad (4)$$

3.2.2 FOR OPC-II CEMENT

For Mix13 to Mix24 made using OPC-II cement, relationship between 28.5h strength and 7-D strength given in Equation 5 was obtained using the tests results presented in Fig.8. In this equation, "y_7" and "x" are same as defined earlier. The correlation coefficient for this equation is 0.94.

$$y_7 = 2.56 \times x^{0.77} \quad \text{(MPa)} \qquad (5)$$

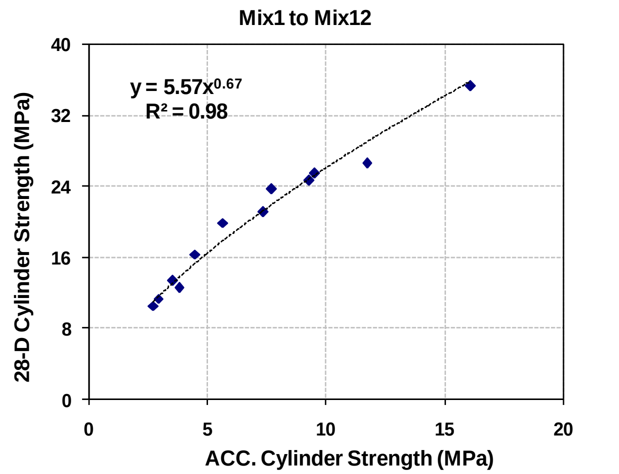

Figure-4 Graph between 28-days and accelerated compressive strength for Mix1 to Mix12

3.2.3 COMBINED RELATIONSHIP

In order to obtain a combined relationship between 28.5h compressive cylinder strength and 7-D compressive cylinder strength, results for Mix1 to Mix24 were plotted as shown in Fig.9 and through analysis of the results, an equation to predict 7-D strength using accelerated strength was obtained as given in Equation 6. In this equation, "y_7" and "x" are same as defined earlier. The correlation coefficient for this equation is 0.84.

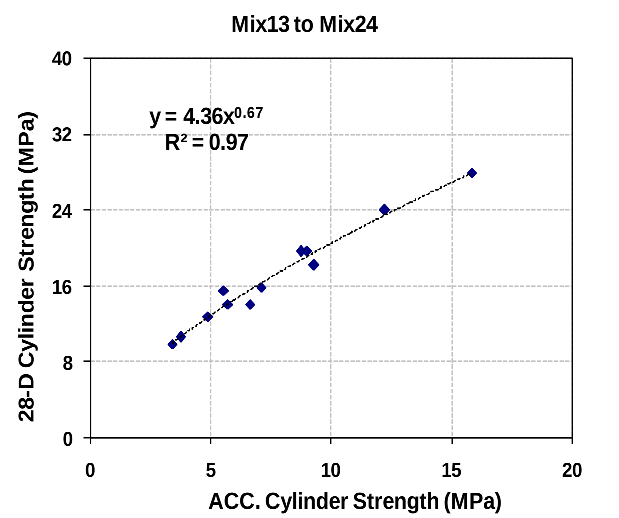

Figure-5 Graph between 28-days and accelerated compressive strength for Mix13 to Mix24

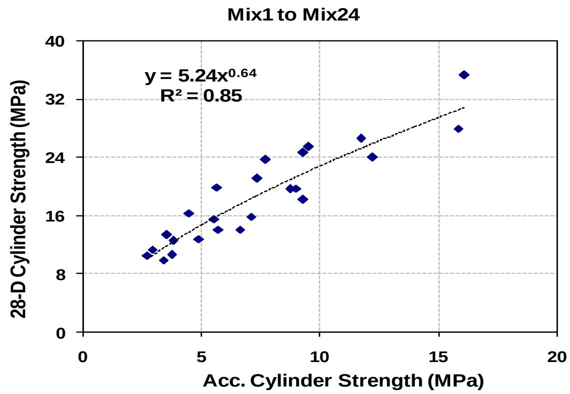

Figure-6 Graph between 28-days and accelerated compressive strength for Mix1 to Mix24

$$y_7 = 1.41x + 2.85 \quad \text{(MPa)} \qquad (6)$$

3.3 RELATIONSHIP BETWEEN 7-DAYS AND 28-DAY CYLINDER STRENGTHS

Compressive strength tests results presented in Table 5 were also used to develop relationship between 7-D compressive cylinder strength and 28-D compressive cylinder strength. The obtained relationship from the data plotted in Fig.10 is given in Equation 7, where "y" is 28-D strength in MPa and "x" is 7-days strength in MPa.

$$y = 2.76x^{0.73} \quad \text{(MPa)} \qquad (7)$$

3.4 RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND W/C RATIO

In order to predict 28-D compressive strength of concrete based on only w/c ratio, results presented in Table 5 were used to obtain relationship. 28-days strength values of Mix1 to Mix12 and Mix13 to Mix24 were plotted against their w/c ratios and are presented in Fig.10 and Fig.11, respectively. Relationship between 28-days strength and w/c ratio for Mix1 to Mix12 made using OPC-I cement and Mix13 to Mix24 made using OPC-II cement are given in equation 8 and equation 9, respectively, which were obtained through analysis of the data presented in Fig10 and Fig.11.

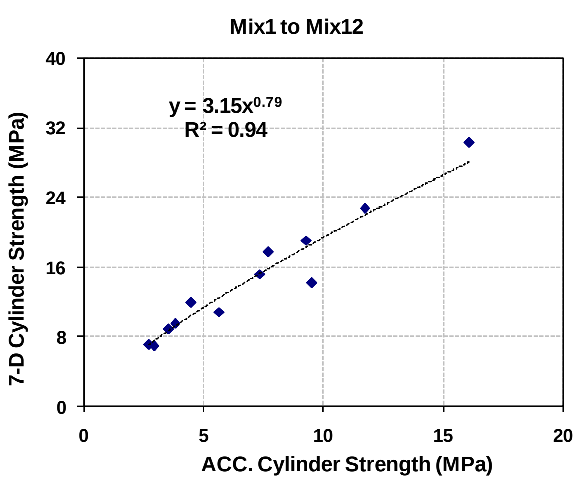

Figure-7 Graph between 28-days and accelerated compressive strength for Mix1 to Mix12

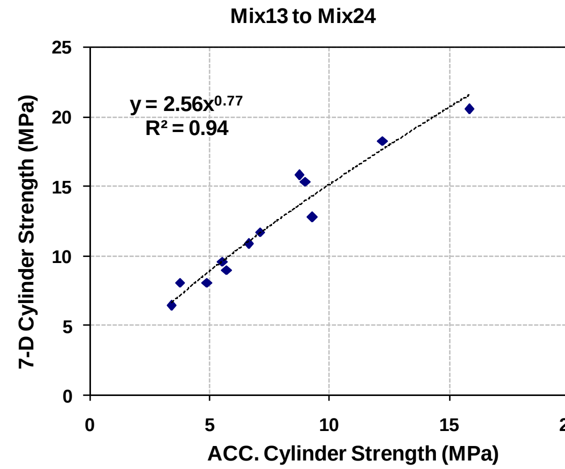

Figure-8 Graph between 7-days and accelerated compressive strength for Mix13 to Mix24

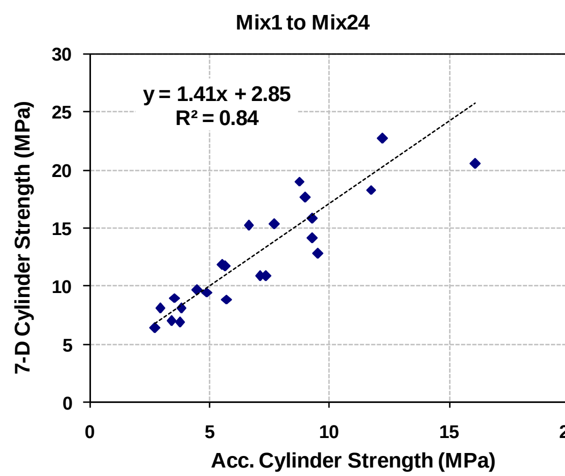

Figure-9 Graph between 7-days and accelerated compressive strength for Mix1 to Mix24

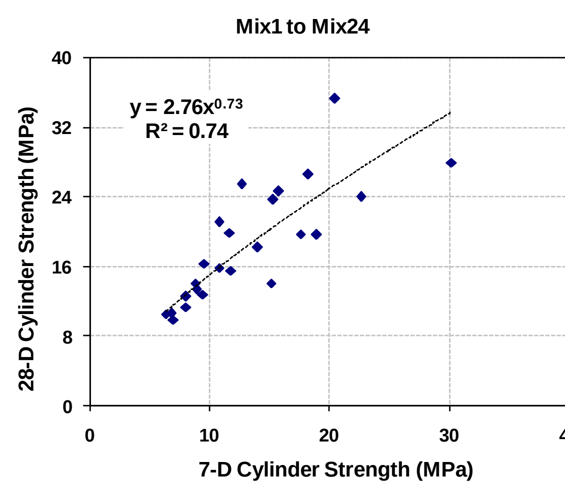

Figure-10 Graph between 7-day and 28-day compressive strength for Mix1 toMix24

$$y_{28} = \frac{11.09}{(w/c)^{1.38}} \quad \text{(MPa)} \qquad (8)$$

$$y_{28} = \frac{10.45}{(w/c)^{1.11}} \quad \text{(MPa)} \qquad (9)$$

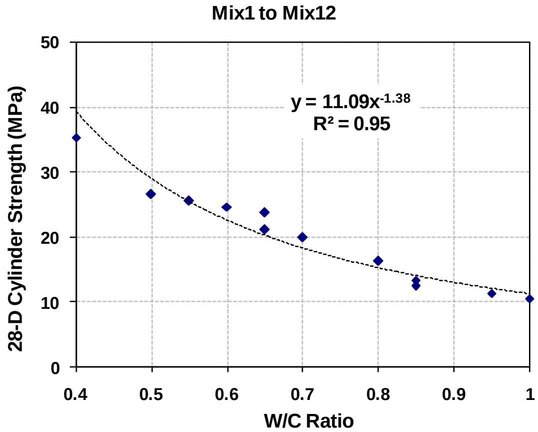

Figure-11 w/c ratio versus 28-D compressive cylinder strength (Mix1 to Mix12)

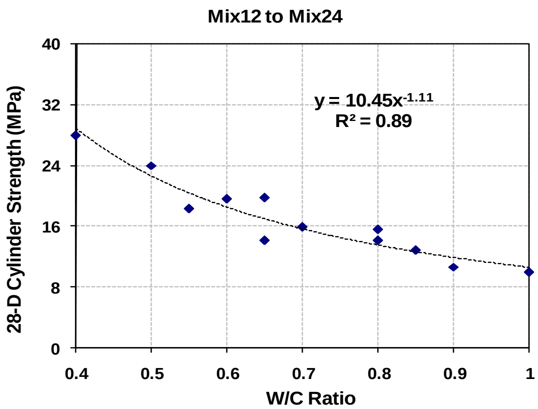

Figure-12 w/c ratio versus 28-D compressive cylinder strength (Mix13 to Mix24)

3.5 TESTING OF DEVELOPED RELATIONSHIPS

To test the developed relationships, two mixes (No.25 & 26) were designed for target compressive cylinder strength of 20.69 MPa and 31 MPa according to ACI-method of mix design. The detail of each mix is given in Table 6.

The experimentally determined compressive strength values of Mix25 and Mix26 are given in Table 7 along with predicted and the experimental values. Since Mix25 and Mix26 were made using OPC-II cement, equation 2 was used to predict 28-D compressive strength. The difference in the observed and predicted 28-D cylinder compressive strength using equation 2 for Mix25 was less than 5% and for Mix26, both values were almost same. If the type of cement is not known, then equation 3 can be used, the difference in the observed and predicted 28-D compressive strength using equation-3 for Mix25 and Mix26 was 7% and 11%, respectively. The developed equations based on w/c ratio also yielded satisfactory results when tested. The percentage difference in the experimentally observed and predicted 28-D compressive cylinder strength using equation-9 for Mix25 and Mix26 was about 15% and 2%, respectively. It can be observed in Table 7 that testing of the developed relations for prediction of 7-D strength using early age accelerated strength also exhibited good results.

Table 6: Mix design of Mix25 and Mix26

Mix No.	Constituents	Mix Proportion	w/c ratio
25	OPC-II cement + Ravi sand + Margala crush	1:2.05:4.61	0.66
26	OPC-II cement + Lawrencepur sand + Margala crush	1:3.03:2.67	0.51

Table 7: Compressive strength of Mix 25 and Mix26

Mix No.			25	26
28.5h accelerated compressive cylinder strength, MPa			8.5	11.0
28-day cylinder strength, MPa	Predicted	Equation 2	18.3	21.7
		Equation 3	24.2	28.4
		Equation 9	16.6	22.1
	Experimental value		19.1	21.6
7-day cylinder strength, MPa	Predicted	Equation 5	13.4	16.2
		Equation 6	14.9	18.4
	Experimental value		15.0	18.5

4. CONCLUSIONS

An experimental program was designed and carried out to determine relationships to predict 7-days and 28-days compressive strength using early age strength (28.5h after casting). Considering the testing program, strength prediction relationships and testing of proposed equations, following conclusions are drawn:

- The apparatus used in this investigation for accelerated curing of concrete cylinders consists of an ordinary steel drum, cylindrical cage along with lifting rod, which can easily be made available on construction sites. No special skill is required for this purpose.
- The two types of cements selected for this study nearly represent the whole variety of ordinary Portland cements available in Pakistan. Water/cement ratio, aggregate/cement ratio, and types of sand and coarse aggregate were varied in order to get concrete compositions with wide range of compressive strength considering the general practice in Pakistan about concrete strength used; therefore, the proposed relations in this paper may be used with confidence by the practicing Engineers in Pakistan.
- Testing of the proposed relationships to predict 7-D and 28-D concrete strength from early age strength has indicated satisfactory results.
- Method of accelerated curing affects the early age strength development; therefore, it is suggested to use the same accelerated curing method as adopted in this study in order to use the proposed strength development relationships in this paper.

ACKNOWLEDGEMENT

The financial support from University of Engineering and Technology Lahore for this experimental study is highly acknowledged.

REFERENCES

[1] A. M. Neville and J.J. Brooks; *Concrete Technology*, (2007).

[2] S.K. Duggal; *Building Materials,* third revised edition, New age international publishers, (2008)

[3] Tokyay M.; *Cement and concrete research*, 29 (1999) 1737-1741

[4] Malhotra V.M., and Berwanger C.; *ACI Journal Proceeding*, 68 (1971) 963-968.

[5] Khilji Z.M. and Chaudhry N.H.; *Research Bulletin (University of Engineering and Technology Lahore)*, 4 (1975).

[6] Akroyd T.N.W., and Smith G.R.G..; *Engineering (London)*, 81 (1956) 153–155.

[7] Malhotra V.M. and Zoldners N.G.; *ACI Journal Proceeding*, 66 (1969) 894-897.

[8] ASTM C684-99; Standard test method for making, accelerated curing, and testing concrete compression test specimen.

[9] ASTM C617- 12; Standard practice for capping cylindrical concrete specimens.