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Non-linear models for the prediction of specified design strengths of concretes development profile

M. Aminul Haque *, Md. Rasel-Ul-Alam

Department of Civil Engineering, Leading University, Sylhet-3100, Bangladesh

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KEYWORDS

Compressive strength;
Strength prediction;
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Model validation

Abstract Different concrete structures are designed according to their concrete strength requirements. Consequently, concrete strength is one of the prime properties of concrete structures. In this study, compressive strength behavioral pattern of seven design strength concretes 21 MPa, 24 MPa, 28 MPa, 31 MPa, 35 MPa, 38 MPa and 42 MPa at curing ages of 3, 7, 14, 21, 28, 56, 90 and 180 days was examined. In order to evaluate the long term effects on compressive strength of target design concretes, 360 cylindrical samples were cast. On the basis of the existing experimental tested strength data, a polynomial equation based model having 2 degrees with fractional power of 0.5 degree interval of each term was found to have acceptable correlation for describing the compressive strength gaining profile with the tested concrete ages. Correlation of proposed model was justified against the statistical point of view for examining the best fit profile with the observations. Apart from the correlation approach, the accuracy of the proposed model was validated with corresponding experimental observations of target design concretes followed by the model parameters estimation with 95% confidence interval. From the predicted results, the study revealed that proposed polynomial equation based model possessed strong potential for predicting 3, 7, 14, 21, 28, 56, 90 and 180 days compressive strength of design concretes with high accuracy and trivial error rates.

Introduction

Compressive strength is the design property of concrete. An overall view of concrete quality is reflected by the concrete strength [1]. In addition, compressive strength is a structural engineering performance measure, employed for designing concrete structures [2]. In practice, design engineers use different specified concrete strengths to design the structural components. For instance, minimum compressive strengths (severe exposure) of concrete for interior slabs, foundations walls

* Corresponding author.
E-mail addresses: eman.cee2008@gmail.com, mahaque@lus.ac.bd (M.A. Haque).

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Nomenclature

(f'_c)	compressive strength of concrete (MPa)	t	curing age of concrete (day)
E_c, ME	modulus of elasticity of concrete (MPa)	R^2 (R-squared)	coefficient of determination
f_r, MR	modulus of rupture of concrete (MPa)	RMSE	root mean square error
λ	modification factor for type of concrete	NSE	Nash-Sutcliffe efficiency
f_{sp}, STS	splitting tensile strength of concrete (MPa)	CMO	correlated model option
P	maximum applied load on concrete (N)	OPC	ordinary Portland cement
l	length of the concrete sample (mm)	SD	standard deviation
d	diameter of the concrete sample (mm)	ASTM	American Society for Testing and Materials
M_S	weight of specimen at fully saturated condition	M_D	weight of oven dried specimen
a & b	model constant parameter	ACI	American Concrete Institute

and garage floor slabs are 17 MPa, 21 MPa and 24 MPa respectively [3].

Rashid and Mansur [4] provided data that concrete of compressive strength of 30 MPa was regarded as high strength in the 1950s. Gradually, concretes of compressive strength of 40–50 MPa in the 1960s, 60 MPa in the 1970s, and 100 MPa and beyond in the 1980s have evolved and were used in structures. Moreover, PCA [5] classified compressive strength of concrete as normal, high, very high and ultra-high strength of ranges from < 50 MPa, 50–100 MPa, 100–150 MPa and > 150 MPa respectively.

Dead loads and size of structural members can be reduced using the specified design high strength concrete than the normal strength concrete. Also, not only stronger but also lightweight durable structure can be designed with increasing the high strength concrete application that also minimizes the cost of the structures [5].

A numerous empirical equations have been used to predict the physical properties and compressive strength of concrete to design structural members. Therefore, prediction of concrete strength has been considered as an active area of research and a considerable number of studies have been carried out. Many attempts have been made to obtain a suitable mathematical Model which is capable of predicting concrete strength at various ages with acceptable high accuracy [6,7]. Additionally, early age strength prediction is very useful in reducing construction cost and ensuring safety of construction works. Furthermore, early age strength prediction has several practical applications [8]. Besides, a rapid and reliable concrete strength prediction would be of great significance [7] for the overall construction processes.

In this research, the findings were divided into three sections, physical properties of concrete constituent materials, different behavioral pattern of specified strength concrete, and the third approach was to develop a suitable high accuracy mathematical Model for predicting the compressive strength development profile of specified design concrete strength for 21 MPa, 24 MPa, 28 MPa, 31 MPa, 35 MPa, 38 MPa and 42 MPa on the basis of curing age. ACI mix design procedure was applied for all design strength concrete. All tests were conducted in the laboratory of the Department of Civil Engineering, Leading University, Sylhet, Bangladesh.

In this study, some non-linear models such as power equation, exponential equation, logarithmic equation and polynomial equation based model were applied to observe the best correlated model profile for 21 MPa, 24 MPa, 28 MPa, 31 MPa, 35 MPa, 38 MPa and 42 MPa strength development with curing age. The correlated model equations for each tested design strength concrete may be potential of use for observing the strength gaining pattern with the age of structures. The accuracy of the concrete strength predicted models was justified through statistic evaluation followed by validation and checking the 95% confidence level of the estimated model parameters.

Materials and experimental program

Physical properties of concrete materials

Coarse aggregate (CA)

Conventional CA was collected from the local stone crusher areas. The higher and lower sizes of CA were 19 mm and 12 mm. The unit weight (UW), specific gravity (SG), water absorption percentage (WA %) and water content of coarse aggregates were determined according to the ASTM standard methods [9–11] respectively. A summary of test results is presented in Table 1.

Fine aggregate (FA)

In the study, FA was collected from locally available natural valley sand collecting areas. Physical parameters of FA such as unit weight, specific gravity, water absorption percentage and fineness modulus (FM) were determined using the ASTM standard methods [9,12–14] respectively. These parameters were analyzed to compare the effect of sand on concrete prop-

Table 1 Physical properties of aggregates.

Properties	UW (g/cm^3)	SG	WA (%)	FM
CA	1.48 ± 0.12	2.75 ± 0.08	1.5 ± 0.05	–
FM	1.54 ± 0.1	2.6 ± 0.15	1.21 ± 0.06	2.45 ± 0.12