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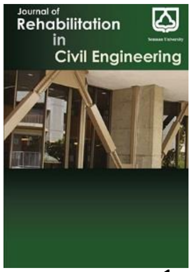

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Prediction of Lightweight Aggregate Concrete Compressive Strength

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ABSTRACT

Nowadays, the better performance of lightweight structures during earthquake has resulted in using lightweight concrete more than ever. However, determining the compressive strength of concrete used in these structures during their service through a none-destructive test is a popular and useful method. One of the most original approach of non-destructive testing to obtain of compressive strength of concrete used in structures is ultrasonic pulse velocity test. The purpose of this research is predicting the compressive strength of LWA concrete by proposing an accurate mathematical formulation. Many samples of lightweight aggregate concrete, made by expanded clay, have been produced and tested. After determining the actual compressive strength and indirect ultrasonic pulse velocity for each sample, a relationship was derived to estimate the compressive strength through Gene Expression Programming (GEP). The results show the presented equation shows high accuracy in predicting the compressive strength of LWA and the estimated outcomes have a considerable compatibility with actual samples.

1. Introduction

Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as reliability and lessened the dead weight [1]. It is lighter than the conventional concrete with a dry density of 300 kg/m3 up to 1840 kg/m3; 87 to 23% lighter. It was first introduced by the Romans in the second century where 'The Pantheon' has been constructed using pumice, the most common type of aggregate used in that particular year [2]. The main specialties of lightweight concrete are its low density and thermal conductivity. Its advantages are that there is a reduction of dead load, faster building rates in construction and lower haulage and handling costs [3]. A large

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number of users acknowledge the profits of this materials as they suggest flexibility in design and impressive cost savings [4-7].

As the lightweight concrete can decline the weight of earthquake resistant structures with many applications, many researchers have conducted a considerable number of researches on the Specification and behavior of various sort of LWA concretes [8, 9].

Using non-destructive methods for evaluating the properties of concrete needs high accuracy relationships, moreover many of these relationships are not suitable for all types of concrete require a different calibration comparing other types of concrete, which can be considered as the main effect of these methods. On the other hand, evaluation the concrete properties such as compressive strength in the service area through non-destructive tests has a growing popularity, because these method are easy to conduct and low cost and time saving. Moreover, UT is One of the most original approach of non-destructive testing to obtain of compressive strength of concrete used in structures. Therefore, much research has been done on the combination of non-destructive methods to improve evaluation. But, the problems of preparing calibration graphs for every kind of concrete have been used still remains. In this regard, considering mentioned problems, the use of mathematical and evolutionary models such as fuzzy logic, neural networks, artificial intelligence and GA which can be managed based on empirical studies have been developed [10-14].

Gene Expression Programming (GEP) is capable of solving user-defined problems through computer programs which is a progressive Evolutionary Algorithm (EA) [14, 15]. In GEP, computer programs are typically encoded by fixed-length gene expression strings that are evolved through nature-inspired operators such as mutation and crossover. Nowadays, GEP is defined as a powerful method in finding accurate and concise equations [15, 16]. It has been used in many actual applications with acceptable success reported, including time series predictions [17], classification problems [15], regression problems [15], data mining and knowledge discovery [18-20], etc.

It is necessary first to give feedback on the ultrasonic tests on concrete that may be the most important non-destructive test on the concrete. By conducting multiple tests on concrete samples made of different kinds of aggregates, Facaoaru has provided the pulse velocity ranges with considering the kind of the aggregates [21]. Malhotra has investigated the pulse velocity of samples of concrete made with different water-cement proportions and diverse aggregates [22]. Gaydecki investigated the propagation and attenuation of ultrasonic pulses in samples [23]. Manish et al., and Kewalramani and Gupta in the separate studies, through artificial neural networks and using UT, predicted the compressive strength of concrete and compared the outcomes of neural networks and multiple variable regressions [12, 24]. Trtnik et al. suggested a model for predicting the compressive strength of concrete based on UT and Programming in MATLAB [10, 13]. Using GEP, Mousavi et al. offered a new model for estimating the compressive strength of high performance concrete [25]. Fakharian et al. presented a model for compressive strength prediction of FRP-Confined rectangular columns based on GEP [26]. Using GEP, Ebtehaj and Bonakdary presented a model to predict sediment transport in sewer [27].

Hadianfard and Jafari proposed some mathematical equations to estimate the compressive strength of LWA concrete using from the ultrasonic pulse velocity testing outcomes obtained from gene expression programming [10].

Regarding to increasing importance and application of structural lightweight aggregate concrete, this paper proposed a equation to calculate the compressive strength of the concrete by indirect ultrasonic testing method which is a non-destructive test where elevation of direct ultrasonic pulse velocity is not possible. The important results of this study are as follows: The model is simple to use, easy to use and relatively low cost to gain strength lightweight concrete which is not studied yet.

2. Experimental Program

To reach the aim of this paper, more than 32 batch of LWAC have been produced and tested. The location of laboratory was Shiraz University of Technology. The properties of Expanded Clay as the LWA used as well as determination of the LWAC mixing ratio were based on the ASTM C330 [28] and ACI 211.2 [29], respectively. Even though certain differences, especially in proportioning and batching procedures are observed which is important to be notified to make a high quality finished product, the other steps are similar to the procedures for normal weight concrete [30, 31].

2.1. Material Proportion and Mix Design

Fineness modulus of the modified fine sand after sifting and amendment was 3. Moreover, the experiments undertaken the sand moisture content was 1%. In addition, the specific gravity of the fine sand was 1717.65Kg/m^3, which was determined in base on ASTM C 29 [32]. In the mix design, the saturated surface dry (SSD) condition for the sand measured 6% water.

The gradation of aggregates was in accordance with the mentioned requirements mentioned in ASTM C 330 [28]. The sizes of expanded clay as coarse aggregate was 9.6mm, pycnometric specific density factor was 1.1, specific gravity was 365.72Kg/m^3 and the proportion of water in the aggregates in the laboratory environment was 0. Moreover, 13% of water was needed to reach to the SSD condition.

To produce the LWAC, The first step is to determine a slump regarding to the type of construction being considered afterwards, then choosing the maximum size of lightweight aggregates. These two initial steps determine the amount of water, afterwards, the following step involves selection of the approximate water-cement ratio in accordance with the expected compressive strength. Obtaining of the cement content is the fifth step, with the amount of cement per unit volume of concrete being fixed. The next step is determining the lightweight coarse aggregate content based on the maximum size of aggregates and volume of oven-dry loose coarse aggregates per unit volume of concrete for different fineness moduli of sand. As the quantities of water, cement, and coarse aggregate was determined, in the final step, fine aggregate content was determined [4]. The proportioning follows a sequence of straightforward steps that fit the characteristics of the materials. Table 1. Shows the concrete mixture designs and density of the LWAC in 1m^3 of fresh concrete based on SSD aggregate.

Table 1. Summary of the LWAC mix design [4].

W/C	Water W_W (Kg)	Cement W_C (Kg)	Sand W_S (Kg)	LWA W_L (Kg)	ρ (Kg/m^3)
0.4	210	525	710	155	1659
0.6	230	380	835	155	1529
0.8	210	260	975	155	1631

2.2. Ultrasoni Velocity Testing

According to standard ASTM C 597 [33] the method of Ultrasonic testing is conducted. The frequency was 54 KHz and the voltage was 500 V in conducting the test. Fig. 1 indicates the device which includes a processor unit that carries out sending and receiving ultrasonic pulses and measuring the time between the two operations (sending and receiving). It also includes two probes and two cables, which do the transmission of ultrasonic pulses and a cylinder to calibrate the device. The sound pulse passing time has been inserted on the cylinder [10]. The instrument is lightweight, portable and straightforward to apply and can also be used with and without electricity in and out of the lab. The device has two probes that actually transfer the sound energy. One probe sends the sound energy to the concrete and the recipient probe receives this energy and the pulse flow rate has been achieved according to the time difference between these two acts [10]. As fig. 2 shows, in this study, the indirect transfer (opposite surfaces) is used to measure the pulse flow rate.

Fig. 1. Ultrasonic testing device (Pundit).

Fig. 2. Velocity test for indirect transmission of pulses.

3. Experimental Results

In accordance with ASTM C 39-83b, the compressive strength of samples was measured by breaking cylindrical concrete specimens in a compression-testing instrument, [34-36]. Moreover, the theoretical density was calculated from ASTM C 138/C 138 M [37].

3.1. Factors Effecting the Compressive Strength and Indirect Ultrasonic Pulse Velocity in LWAC

It is evident from Table 2 that there is a direct connection between compressive strength, the density and ultrasonic pulse velocity of LWAC. Moreover, it can be observed the direct ultrasonic pulse velocity has a direct relationship with indirect ultrasonic pulse, which means that indirect pulse velocity can be used to estimate the compressive strength on concrete as well. Fig. 3 shows diagrams for Compressive strength of concrete based on the indirect transfer velocity of sound pulses for LWAC. This figure reveals a close relationship between compressive strength and indirect transfer velocity of sound pulses for the different mixes of lightweight concretes increasing the weight ratio of LWA to all aggregates declines the compressive strengths as well as the direct and indirect ultrasonic pulse velocity.

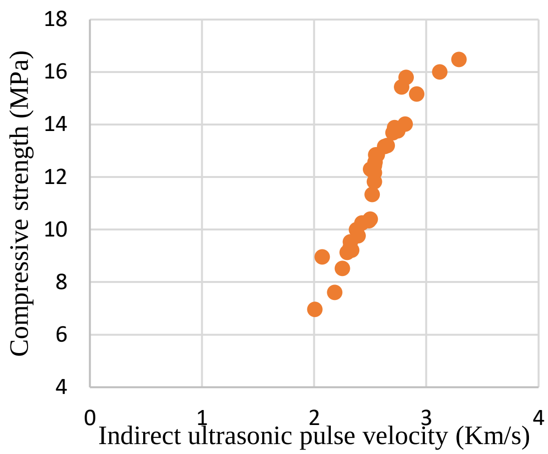

Fig. 3. Compressive strength of concrete according to the indirect transfer velocity of sound pulses.

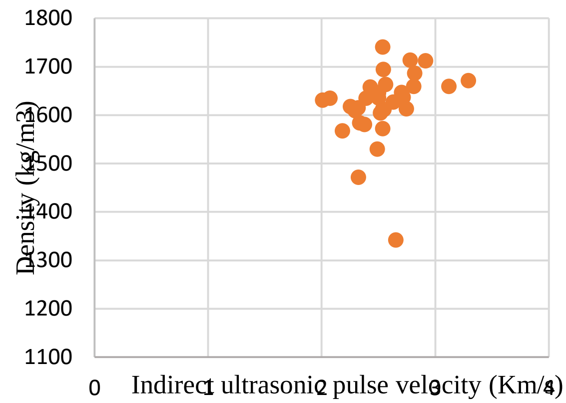

Fig. 4. Density of concrete according to the indirect transfer velocity of sound pulses.

Fig. 4 presents diagrams for density of concrete according to the indirect transfer velocity of sound pulses for Lightweight Aggregate Concrete for LWA01. This diagram shows a relationship between density of lightweight concretes and their corresponding indirect ultrasonic pulse velocity which these parameters have a direct relationship with compressive strength.

Table 2. Compressive strength and density of samples [10].

No. of sample	F_C (MPa)	Density (Kg/m^3)	V (Km/s)	U (Km/s)	No. of sample	F_C (MPa)	Density (Kg/m^3)	V (Km/s)	U (Km/s)
1	15.15	1742.2	3.22	2.91	17	13.68	1676.4	3.19	2.7
2	12.55	1724.1	3.1	2.54	18	12.84	1693.3	3.03	2.56
3	12.43	1770.4	3	2.53	19	9.98	1610.1	2.86	2.38
4	7.6	1597.3	2.47	2.18	20	8.51	1647.1	2.71	2.25
5	9.21	1613.6	2.57	2.33	21	15.79	1715.9	3.26	2.82
6	14.01	1689.2	3.18	2.81	22	13.75	1642.7	3.03	2.74
7	12.84	1641.2	3.14	2.54	23	13.19	1371.9	3.01	2.65
8	12.16	1601.5	3.13	2.54	24	12.29	1675.9	3	2.5
9	9.52	1501.0	2.98	2.32	25	10.33	1559.4	2.92	2.49
10	6.95	1660.7	2.99	2	26	11.32	1634.1	2.9	2.51
11	13.87	1666.4	3.04	2.72	27	9.13	1638.8	2.8	2.29
12	10.39	1665.5	2.99	2.5	28	16.47	1700.7	3.45	3.29
13	11.82	1642.4	2.99	2.54	29	15.99	1689.2	3.33	3.12
14	9.76	1664.6	2.83	2.39	30	13.15	1656.9	3	2.62
15	8.95	1664.9	2.74	2.07	31	10.24	1688.0	2.86	2.43
16	15.42	1743.4	3.19	2.78	32	9.29	1645.0	2.78	2.32

4. Comparing the Mixture Design Used in This Study to Other Research Results

Bastos et al. [38] in an experimental study offered a procedure to design the lightweight concrete mix with expanded clay aggregates, they produced and examined 28 LWAC batches using four various amounts of cement with densities between 853 and 1,418 kg/m^3. In a comparison of this paper with their research, the size of the LWA were smaller and in some samples they were used as fine aggregates. In Fig. 5, the outcomes for both works are shown. LWAC in this paper have higher densities as well as higher compressive strengths.

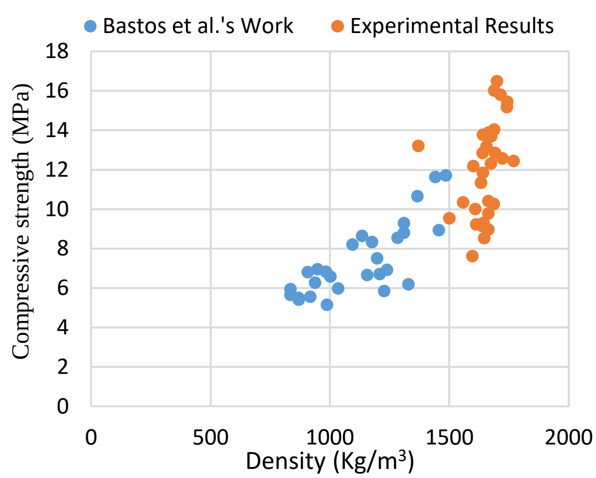

Fig. 5. Comparison of the compressive strength VS density obtained from experimental outcomes of this study and Bastos et al. [38].

5. Obtaining of LWAC Compressive Strength Using Indirect Ultrasonic Pulse Velocity through GEP

The reason for measuring and testing the velocity of ultrasonic pulses to evaluate the Compressive strength of concrete is the relationship between elasticity modulus and compressive strength and the velocity of ultrasonic pulses [10, 12].

Gene expression programming is a method for obtaining of the most fit computer programs by means of artificial evaluation [39, 40]. In GEP, the genome or chromosome consists of a linear, symbolic string of fixed length composed of one or more genes. It will be shown that despite their fixed length, GEP chromosomes can code ETs with different sizes and shapes. The structural organization of GEP genes is better understood in terms of open reading frames (ORFs). In biology, an ORF, or coding sequence of a gene, begins with the “start” codon, continues with the amino acid codons, and ends at a termination codon. However, a gene is more than the respective ORF, with sequences upstream from the start codon and sequences downstream from the stop codon. Although in GEP the start site is always the first position of a gene, the termination point does not always coincide with the last position of a gene. It is common for GEP genes to have noncoding regions downstream from the termination point.

To estimate the compressive strength according to the pulse rate several relationships has been suggested. One of these relationships is an exponential function. These relationships are empirical and their constant coefficients are empirically derived from multiple experiments [10, 13 and 41]. In order to have better equations, these was an odd date in experimental results which has been deleted.

$$F_c = Ae^{BV} \tag{1}$$

This relationship has been proposed for predicting the compressive strength of ordinary concrete the method of minimum set of squares is used to fit the diagram and to determine these constant coefficients. MATLAB software is used to perform the fit. The achieved relation for the LWAC is as follows [10]:

In these relations the velocity of direct ultrasonic pulses is according to Km / s and the compressive strength of 28 days concrete is obtained based on MPa.

$$F_c = 0.466 \times e^V \tag{2}$$

The correlation coefficient in this case is 0.76 [10]. The following equation is obtained for LWA01 concrete. In this equation, the velocity of ultrasonic pulses is according to Km / S. and the F_C of the 28-day concrete is predicted according to MPa. Also, the accuracy and the correlation coefficient are mentioned [10].

$$F_c = 0.101V - 0.220 \tag{3}$$

Where Fitness Function is MSE:

Training Fitness: 996.1

Training R-square: 0.96

Testing Fitness: 993.8

Testing R-square: 0.96

For LWAC concrete the following equation is obtained. Where V represents the indirect ultrasonic pulse velocity according to Km/s and F_C is the compressive strength on the 28-day samples according to MPa. The correlation coefficient in this case is 0.81. Fig. 7 and 8 indicate the relationships between the actual and the predicted compressive strength using equations derived from GEP. In table 3 the correlation coefficients of three obtained equations are presented.

$$F_c = 29.89 - \frac{51.7}{V} \tag{4}$$

Table 3. Comparing the correlation coefficients of obtained relations

Samples	Eq. 4	Eq. 5	Eq. 6
LWAC	0.76	0.96	0.81

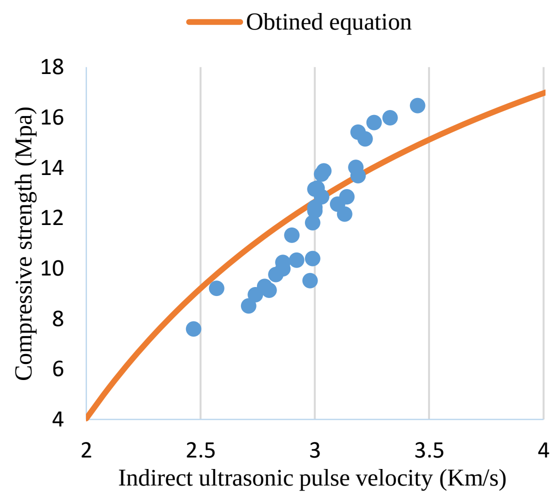

Fig. 7. Actual compressive strength Vs. the estimated compressive strength.

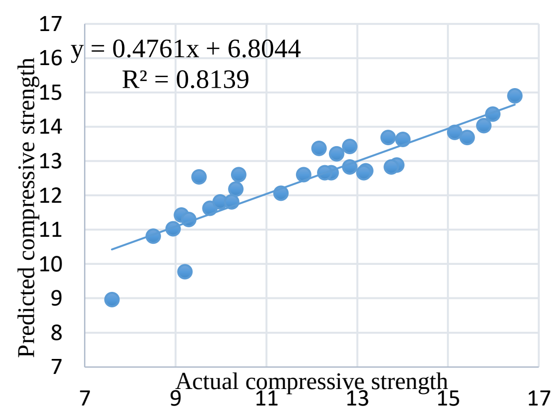

Fig. 8. Actual compressive strength Vs. predicted compressive strength for LWAC

6. Conclusion

Through analyzing the outcome of tests and the presented graphs and tables it can be concluded that using ultrasonic pulse velocity test can predict compressive strength of LWAC as a non-destructive test. Moreover, results indicate that GEP can generate equations which have more accurate than former presented equations. By fitting the diagram with the method of the least sum of squares it was found that the provided exponential equation is less accurate in a comparison with equations obtained through GEP. The correlation coefficient of equation based on direct ultrasonic pulse velocity shows that the direct ultrasonic pulse velocity has more reliable outcomes than indirect test for estimation of compressive strength of lightweight concrete. However, the accuracy of the obtained equation using indirect ultrasonic pulse velocity through GEP is acceptable. Therefore, is come conditions, where evaluating of direct ultrasonic pulse velocity is not possible or difficult to obtain, the indirect ultrasonic pulse velocity can lead to estimate the compressive strength of LWAC through the presented equation with acceptable results.

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