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Lightweight concrete design using gene expression programing

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ABSTRACT

The use of lightweight concrete (LWC) in earthquake resistant buildings is beneficial because of the weight and mass reduction of the structures. LWC has been used in the construction industry for many years and while attempts have been made to develop a practical and reliable code for lightweight concrete design worldwide a satisfactory, practical standard for mix design is required. There are a few standards which present methods for designing the mix of LWC such as ACI 211.2. However, in these standards the proposed compressive strength and density determinations cannot be used for all types of lightweight aggregates. The aim of this study is to provide references for three types of lightweight concretes containing clay and natural (mineral) pumice aggregates with the maximum nominal sizes of 12.7 mm (½ in.) and 19.2 mm (¾ in.) respectively. With this intent, hundred specimens of lightweight concrete were made and then tested in the laboratory using these aggregates. After presenting a standard for propositioning and adjusting propositions of the concrete mix three equations were derived using Gene Expression Programing (GEP) to obtain the compressive strength of a specific mixture. Comparison between the actual properties and their predicted counterparts indicated that the proposed derivations are a useful and reliable practical method for use by practicing engineers when designing lightweight concrete mixes.

1. Introduction

Structural lightweight aggregate concrete is an important and versatile material for use in modern construction. It has many and varied applications including multistory building frames and floors, bridges, offshore oil platforms, and prestressed or precast elements of all types. Many architects, engineers, and contractors recognise the inherent economies and advantages offered by this material as evidenced by the many impressive lightweight concrete structures found today throughout the world [1]. For more than 80 years structural lightweight aggregate concrete has solved weight and durability problems in buildings and exposed structures [2]. Lightweight concrete has strengths comparable to normal weight concrete, yet is typically 25–35% lighter. Structural lightweight concrete offers design flexibility and substantial cost savings by providing: less dead load, improved seismic structural response, longer spans, better fire ratings, and thinner sections, decreased story height, smaller size structural members, less reinforcing steel, and lower foundation costs. Lightweight concrete precast elements offer reduced transportation and placement costs [3].

The use of lightweight structural concrete to reduce the weight of earthquake resistant buildings is useful material having many applications. Therefore, research on the properties of different types of lightweight concretes and the evaluation of the corresponding concrete strength has been considered by many researchers [4,5].

Research has been conducted worldwide on a large number of natural and artificial lightweight aggregates used in the manufacture of mortar and concrete. Natural lightweight aggregates include diatomite, pumice, scoria, sawdust, oil palm shells, bottom ash, and starch-based aggregates. Artificial aggregates include expanded shale, slate, perlite, sintered fly ash, bonded fly ash, solidified blast furnace slug, and vermiculite. Use of natural lightweight aggregates instead of processed artificial aggregates can significantly reduce the cost of such concretes [6]. Shannag [7] investigated the properties of fresh and hardened concretes containing locally available natural lightweight aggregates, and mineral admixtures. Test resulted indicated that replacing cement in the structural lightweight concrete developed, with 5–15% silica fume on weight basis, caused up to 57% and 14% increase in compressive strength and modulus of elasticity, respectively, compared

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List of notation

F_C	is the compressive strength of concrete
W	is water
S	is sand
L	is lightweight aggregate
C	is cement
LWA	is the lightweight aggregate
GEP	is the gene expression programming
GP	is the genetic programming
GA	is the genetic algorithm

to mixes without silica fume. In a study, the surface of large pumice aggregate was coated with cement + colemanite (CLM) dual mixtures (0%, 7.5%, 12.5% and 17.5%). Lightweight concretes were produced by using coated aggregates. Then by exposing to temperatures at 20 °C (Control), 200 °C, 400 °C and 600 °C, the unit weight, compressive strength, ultrasonic pulse velocity and weight loss of concrete samples were determined. As a result of the study, the optimum value was obtained from 12.5-CLM samples. It is determined that the lightweight concretes that would be produced with pumice aggregates coated with cement + colemanite dual mixture would have a high performance against high temperature [8].

Gene expression programming (GEP) is, like genetic algorithms (GAs) and genetic programming (GP), a genetic algorithm as it uses populations of individuals, selects them according to fitness and introduces genetic variation using one or more genetic operators [9]. The fundamental difference between the three algorithms resides in the nature of the individuals: in GAs the individuals are linear strings of fixed length (chromosomes); in GP the individuals are non-linear entities of different sizes and shapes (parse trees); and in GEP the individuals are encoded as linear strings of fixed length (the genome or chromosomes) which are afterwards expressed as non-linear entities of different sizes and shapes (simple diagram representations or expression trees) [10].

Through artificial neural networks and using ultrasonic pulse velocity Kewalramani and Gupta tried to predict the compressive strength of concrete and compared the results of neural networks and multiple variable regressions [11]. Through Programming in the MATLAB environment and considering the number of parameters of concrete Trtnik et al. provided a model for concrete compressive strength based on neural networks and using ultrasonic pulse velocity [12]. Also Mousavi et al. proposed a new model for predicting the compressive strength of high performance concrete using gene expression programming [13]. In another study Hadianfard and Jafari suggested some equations to predict compressive strength of lightweight aggregate concrete using the ultrasonic pulse velocity test through gene expression programming [14].

The purpose of this study is to provide three specific applicable references for selecting and adjusting mixture proportions for three types of lightweight concrete made using three different lightweight aggregates.

Discussion in this study is limited to lightweight concrete containing clay, natural (mineral) pumices with the maximum nominal size of 12.7 mm (½ in.) and with the maximum nominal size of 19.2 mm (¾ in.) as lightweight aggregates. Structural LWC has an in-place density (unit weight) of the order of 1440–1840 kg/m^3 (90 –115 lb/ft^3) compared to normal weight concrete with a density in the range of 2240 –2400 kg/m^3 (140 –150 lb/ft^3). For structural applications the concrete strength should be greater than 17 MPa (2500 psi) [15]. The concrete mixture is made with a lightweight course aggregate. In some cases a portion or the entire fine aggregates may be a lightweight product. Lightweight aggregates used in structural lightweight concrete are typically expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure. Other products such as air-cooled blast furnace slag are also used. There are other classes of non-structural LWC with lower density, made with other aggregate materials and higher air voids in the cement paste matrix, such as in cellular concrete [16]. Samples made by natural pumices are considered structural lightweight concrete and samples containing clay are considered nonstructural lightweight concrete. The use of pozzolanic and chemical admixtures is not covered in this study, nor do the samples include non-air entertained concrete. Lightweight concretes have been proportioned by the weight method described in ACI 211.2-98.

The best approach to making a first trial mixture of lightweight concrete, which has given properties and uses a particular aggregate from a lightweight aggregate source, is to use proportions previously established for a similar concrete using aggregate from the same aggregate source. Such proportions may be obtained from the aggregate supplier and may be the result of either laboratory mixtures or of actual mixtures supplied to jobs. However, a purpose of this study is to provide a guide to proportioning a first trial mixture where such prior information is not available.

Changing the lightweight materials in LWC changes other properties of LWC like compressive strength and density which is not predictable for all types of lightweight aggregates. Accordingly for each kind and size of lightweight aggregate a new standard is needed. In this paper by making different samples according to the standard described in ACI 211.2-98 three type of Iranian lightweight aggregates are studied and their new properties obtained through experiment in order to determine three new standards which can provide guidance in the selection of mix proportions having the required specified properties. Through gene expression programing three equations have been derived for all three kinds of concretes which predict the compressive strength of each kind of concrete according to their proportions.

2. Experimental program

To study the above-mentioned issues three types of lightweight aggregate concrete were made and tested. The lightweight aggregates used were in compliance with the standard ASTM C330 [17] and determination of the lightweight aggregate concrete mixing ratio was based on standard ACI 211.2 [18]. Measuring, mixing, transporting, and placing operations for lightweight concretes are similar to the procedures for normal weight concrete. However, there are certain differences, especially in proportioning and batching procedures that should be considered to produce a finished product of the highest quality [19].

In this study more than 100 concrete samples have been tested. The batches were made in Shiraz University of Technology laboratory using the specific gravity method. The weight method procedure is applicable to sand-lightweight concrete comprised of lightweight coarse aggregate and normal weight fine aggregate. Estimating the required batch weights for the lightweight concrete involves determining the specific gravity factor of lightweight coarse aggregate and from this the first estimate of the weight of fresh lightweight concrete can be made. Also the absorption of lightweight coarse aggregate may be measured by the method