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Prediction of ultrasonic pulse velocity for enhanced peat bricks using adaptive neuro-fuzzy methodology

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ABSTRACT

Ultrasonic pulse velocity is affected by defects in material structure. This study applied soft computing techniques to predict the ultrasonic pulse velocity for various peats and cement content mixtures for several curing periods. First, this investigation constructed a process to simulate the ultrasonic pulse velocity with adaptive neuro-fuzzy inference system. Then, an ANFIS network with neurons was developed. The input and output layers consisted of four and one neurons, respectively. The four inputs were cement, peat, sand content (%) and curing period (days). The simulation results showed efficient performance of the proposed system. The ANFIS and experimental results were compared through the coefficient of determination and root-mean-square error. In conclusion, use of ANFIS network enhances prediction and generation of strength. The simulation results confirmed the effectiveness of the suggested strategies.

1. Introduction

Researchers have shown growing interest in non-destructive testing techniques to measure the compressive strength of construction materials because of their evident advantages. Some of these techniques are pulse-echo [1], impact-echo [2], ultrasonic pulse velocity [3], resonant frequency measurements [4], wave reflection methods [5], and acoustic emission methods [6]. This paper introduces a novel approach to estimate propagation of the ultrasonic pulse velocity (UPV) in construction materials, such as peat bricks, using the adaptive neuro-fuzzy methodology.

In recent decades, the energy consumption has multiplied due to fast industrialization. In line with this, construction industry requires alternative materials to replace the conventional compositions. Especially, brickworks seek alternative materials over the inefficient conventional compositions. For example, brick manufacturers consider the peat with relatively high organic content as a sustainable alternative for the traditional materials (i.e. aggregates). The use of peat decreases the density, and increases the brick's porosity and permeability, which in turn reduces the production expenditure. Nonetheless, the compressive strength of peat bricks as the key performance indicator, still highly relies on the content of the cementation agents [7,8].

The use of UPV has been widely investigated for the non-destructive estimation of concrete quality. Many empirical equations were introduced to evaluate the compressive strength of the cementitious materials based on the non-destructive testing variables [9–11]. The old method for mathematical relationship using compressive tests and the UPV on cementitious material samples through regression analysis was not effective [12,13]. A correlation between compressive strength and UPV of concrete was reported for some combinations [14]. The study simultaneously measured the pulse velocity and compressive strength of 150-mm cubes at different ages from 1 day to 28 days and revealed a linear relation between the strength and velocity. Lin et al. [15] carried out an experimental study to establish mathematical models for predicting concrete pulse velocity based on aggregate content and water–cement ratio. Sahu and Jain [16] used the UPV as measure of concrete quality for different structural components, such as roof beams, crane girders, shell beams, columns, and shell roof.

The UPV has been mainly reported to predict the compressive strength of cementitious materials through linear regression analysis using few parameters. Notwithstanding, adaptation of soft computing methodologies to estimate the physic-mechanical

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properties as well as association between the UPV and compressive strength of peat-enhanced mixtures, especially the peat-bricks, have not been studied.

Application of artificial intelligence techniques is growing to examine structural components [17]. Although several mathematical functions are used to model the construction materials' UCS, disadvantages including extended calculation time should not be disregarded. The ANN's calculation power can be possibly used for the analytical methods. Some of the advantages of ANN are fast computation, independence from the information about internal system variables, and the compressed solution technique for multi-variable problems.

The current study aimed to accurately estimate UPV of peat bricks using ANFIS. To achieve that, a series of input and output parameters were obtained through laboratory experiments. The output parameter was the UPV of peat bricks, and input variables were percentage of peat, sand and cement content and curing period in days. The results of this study can be beneficial for future studies to determine the compressive strength of peat bricks using non-destructive testing methods.

2. Experimental methods

This study used a combination of experimental tests, soft computing technique (ANFIS), and sensitivity analysis to analyze peat–cement–sand based mixture.

2.1. Ultrasonic pulse velocity

The UPV has been employed to evaluate properties of cement-based materials through non-destructive technique [18]. A detailed description of UPV test can be found in the *Test for Pulse Velocity through Concrete* ASTM C 597-83 report [19].

The UPV test measures the speed of ultrasonic pulse through a concrete-based material. This value can be used to determine compressive strength of cementitious material. Correlations among compressive strength, the pulse velocity and elastic modulus were formerly reported [18,20,21]. Also, Whitehurst [22] stated relationship between pulse velocity and the concrete's compressive strength. Tharmaratnam and Tan [23] proposed an empirical equation showing relationship between unconfined compressive strength (UCS) and the concrete's UPV through the following function:

$$\mathrm{UCS} = a\, e^{bV} \tag{1}$$

where the properties of material determine a and b and V is the speed of ultrasonic pulse.

2.1.1. UPV experimental setup

In this study, the UPV test setup (in accordance with the ASTM C597-09 [19]) consisted of two transducers, data acquisition unit and a time measuring device, as shown in Fig. 1. This study measured the speed of ultrasonic wave (P-waves) using a pair of 50 kHz transducers. A 10 MHz pulse-receiver unit was used for exiting emitting transducer, and for conditioning the receiving transducer. Direct transmission was applied to the test specimen along 22 cm of the length. The test specimen was placed in contact with two transducers as shown in Fig. 1(a). A schematic circuit of pulse velocity test is shown in Fig. 1(b). At initial stage, the transducer-1 (transmitter) vibrates at the fundamental frequency, emitting the ultrasonic pulse. The vibrations travel through the test specimen and are received by the second transducer-2 (receiver) at the other end. The time measurement device indicates the time of ultra-sonic wave travel through the medium. The pulse velocity was determined as follows:

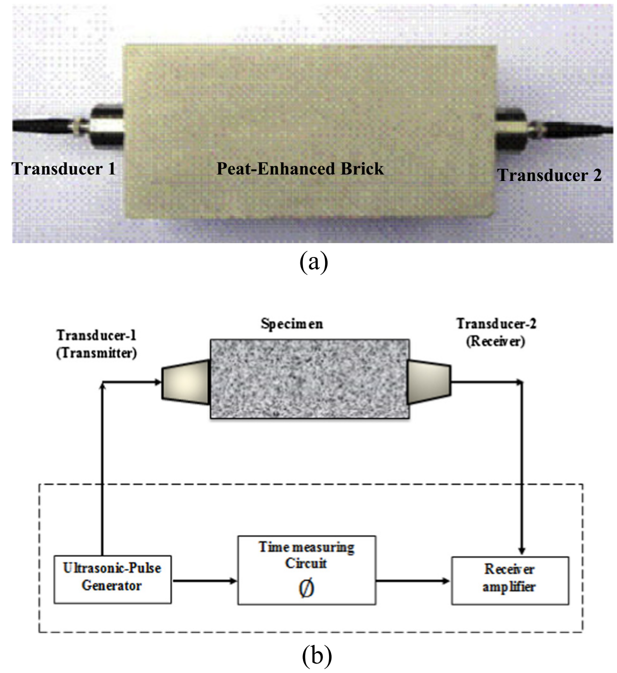

Fig. 1. (a) Setup of transducers and test specimen, (b) schematic diagram of pulse velocity testing circuit.

$$V = \frac{L}{t} \tag{2}$$

where L is the specimen length (peat–cement–sand brick with length of 22 cm), V is the pulse velocity (km/s) and t is the actual travel time through medium.

Investigators should ensure that the specimen has smooth surface at the point of contact with the transducers [24]. In addition, it is important that the surface is free of impurities, contamination or other heterogeneous particles. If impurities exit on the surface, they must be removed before the measurement.

2.1.2. Relationship between UPV and mechanical properties of cementitious materials

Density and elasticity of construction materials determine the velocity of ultrasonic pulses [25–27]. Thus, the velocity of ultrasonic pulse depends on the mechanical properties of the cementitious materials, such as cement type, mix proportions, type of aggregate, permeability, porosity, density, cement hydration, curing, water cement ratio, and manufacturing process [25,27–30]. The complexity in the inner structure of cementitious materials is governed by their constituents, such as (i) cement paste, (ii) mineral aggregates, and (iii) interfaces between aggregate particles and paste. This complexity leads to irregularity in ultrasonic waves, which interferes with non-destructive tests [26]. For example, the size of aggregate influences the ultrasonic pulse velocity. Probably, larger aggregates have higher pulse velocity, which depends on the mix design [29].

In addition to the mechanical properties, the production process also determines the behavior of UPV. For instance, increase in curing period amplifies the UPV values. Longer curing period increases the UPV due to alteration in the ratio of gel/space in longer curing period. This is because at the early stages of hydration, the air bubbles and the air/water phase in the cement paste in the water governing the UPV value [1,15,31,32]. On the other hand, increase of oxygen permeability and porosity decreases the UPV value. This indicates that the ultrasonic pulse travels faster through the solid than the void [17]. Recent efforts by Islam et al. [33] showed the