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Full Length Research Paper

Assessment of high strength and light weight aggregate concrete properties using ultrasonic pulse velocity technique

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In this study, the ultrasonic pulse velocity technique as a non-destructive testing of concrete was used to assess the effect of some criteria on high strength and light weight aggregate concrete. The study included several concrete mix design with ages of 7, 28 and 90 days. The effect of age, cement content, water ratio and slump on two concrete types was studied and discussed. The use of ultrasonic pulse velocity technique to assess concrete strength and quality was a good choice for effects determination.

Key words: Non destructive testing (NDT), ultrasonic pulse velocity (UPV), compressive strength, regression analysis.

INTRODUCTION

The non-destructive testing of concrete has a great technical and useful importance. These techniques have been grown during recent years especially in the case of construction quality assessment. The main advantage of non-destructive testing method is to avoid the concrete damage and disturbing of the performance of structure components. Their application is simple and quick and test results can be achieved easily on the site. The possibility of concrete testing in structures is demanding in which the cores cannot be drilled and the use of less expensive equipment (Hobbs and Tchoketch, 2007). The use of ultrasonic pulse velocity (UPV) as a non-destructive testing of concrete for assessment of concrete quality, has been extensively investigated for decades. It is more likely to assess the quality and characteristics of at site concrete and composed of measuring the transit time of an ultrasonic pulse velocity through the concrete (Solís-Carcaño and Moreno, 2008). The velocity of the signals pass through in a concrete depends on the density and elasticity. According to the theory of the sound propagation in solids, the sound transmission velocity depends on the density and the elastic modulus of the concrete and it is independent of the excitation frequency that causes the agitation. The excitation may cause longitudinal (compression) waves and transverse (shear) waves in the concrete (Hobbs and Tchoketch, 2007). Numerous data and the correlation relationships between the strength and pulse velocity of concrete have been arranged previously. Galan (1967) reported a regression analysis to predict compressive strength of concrete based on sound characteristics similar to be UPV and estimated concrete strength and damping constant. A particular transducer must be used in the purpose of determining dynamic elastic modulus and Poisson’s ratio of concrete and based on the wave type (longitudinal or transverse). There is not any standard correlation between concrete compressive strength and the ultrasonic pulse velocity and this matter was controlled by many aspects (Turgut, 2004; Shariati et al., 2011). However, the value of this method to estimate the quality of concrete is based on the fact that the curve slope between the two variables is comparatively coherent. Consequently, a calibration curve between compressive strength and ultrasonic pulse velocity obtained for each concrete is needed, otherwise not enough dependability would be attained (Popovics and Popovics, 1997). The nature of the aggregates which is one of the major aspects that is generally more plentiful, rigid, and resistant part in concrete, influences this correlation and changes the elastic properties of the concrete (Sturrup et al., 1984; Ravari et al., 2011).

In this paper, ultrasonic pulse velocity technique is recognized as non-destructive evaluation test to qualitatively asses the homogeneity and integrity

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Figure 1. Pulse velocity testing equipment (PUNDIT).

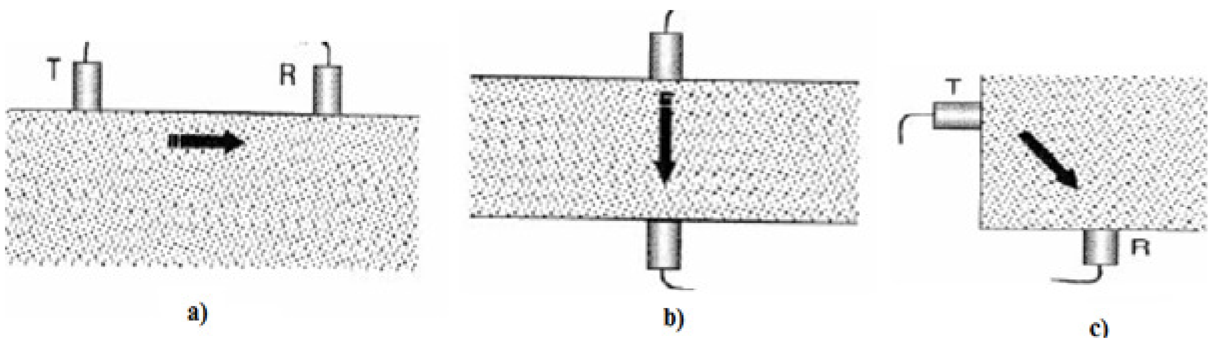


Figure 2. The arrangement of probe of pulse velocity measurement: Direct (a), semi-direct (b) indirect (surface) transmission

parallel to mechanical properties of high strength concrete (HSC) and light weight aggregate concrete (LWAC).

TEST PROGRAMME

Theory of the ultrasonic pulse velocity (UPV)

The UPV equipment (e.g. PUNDIT) includes a transducer, a receiver and an indicator for showing the time of travel from the transducer to the receiver (Figure 1) (Manual, 1994).Ultrasonic pulse uses fast potential changes to create vibration that leads to its basic frequency. The transducer is firmly attached to concrete surface to vibrate the concrete. The pulses go through the concrete and reach the receiver (ASTM, 2002). UPV tests are also performed to predict strength of early age concrete. The UPV methodology relies on direct arrival of compressional waves, which are generated by sources with resonant frequencies rang of sound and can be considered as energy in motion. The sound can vibrate in air or in molecular solids around a fix point. The test is performed by positioning the source and receiver on either side of the area in question, then the source sends a compressional wave through the region, and the receiver records the full waveform on the other side. The arrangement of probe of pulse velocity measurements are categorized in: (a) Opposite faces (direct transmission); (b) Adjacent faces (semi-direct transmission), or (c) Same face (indirect or surface transmission) which are shown in Figure 2.

The pulse velocity can be determined from the following equation:

$$V=L/T \quad (1)$$

where, V = pulse velocity (km/s), L = path length (cm), and T = transit time (μs).

Receptor probe, found that part of the pulse arrives earlier. The progressive longitudinal vibrations reach faster. However, along the perpendicular to the plane transmitter probe, maximum energy is transferred to the concrete, but it is possible to receive pulses in the other direction. Figure 2 shows how a productive form of the aforementioned is possible (Galan, 1967).

In this study, direct method was used. Five reading on the surface of the concrete cube and two reading on the concrete cylinder were selected on five areas. Lots of the volumes of concrete cube and cylinder specimens were tested. The location of probe placement in forms the cubic and cylindrical samples is shown in Figure 3.

RESULTS AND DISCUSSION

Effect of concrete age on the pulse velocity rates

Results of UPV test on concrete cube samples of both

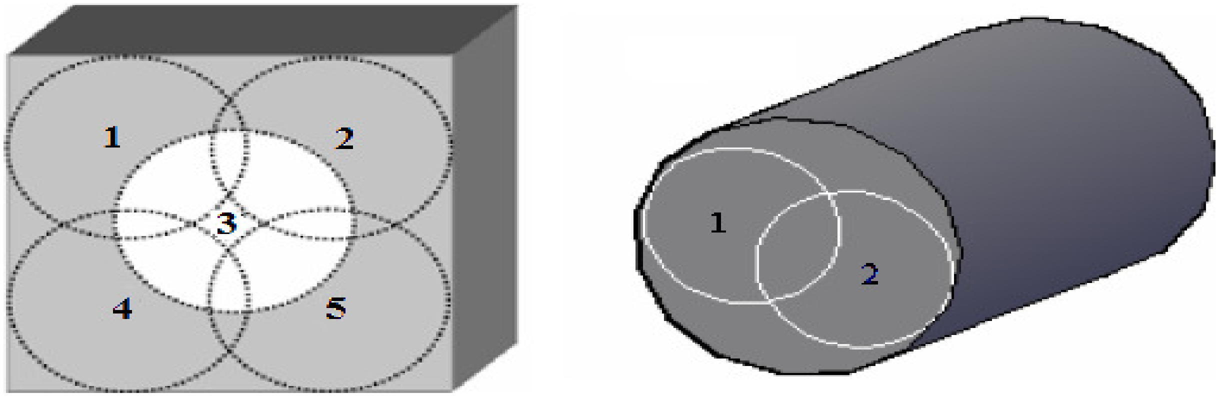


Figure 3. Location of probe placement.

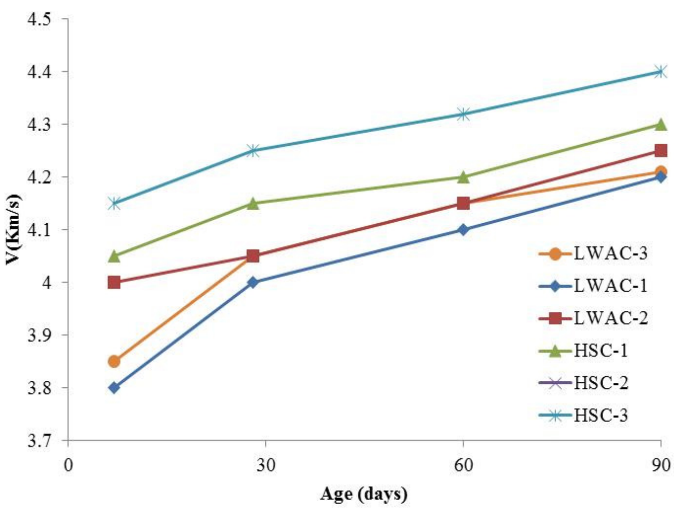


Figure 4. The effect of age on UPV rates for HSC and LWAC.

HSC and LWAC showed that with increasing of concrete age in cylindrical and cubic samples, the velocity speed increase accordingly. This increase was slightly higher in HSC. Figure 4 shows the increasing of pulse rates for some samples of HSC and LWAC. From the Figure 4, it can be seen that the increasing rate of pulses are higher in the age of 7 days than 28 days but on the other hand, it increases with slower rate in age of 28 to 90 days. This matter is consistent with the function of the compressive strength of concrete with age.

Effect of cement content on the transmission speed of ultrasound pulses in concrete

From previous research, it is verified that with increasing of cement content in concrete (up to 600 kg m^{-3}), its compressive strength increases (Ravindrarajah, 1997). The results of ultrasonic pulse velocity of cylinder and cubic samples on HSC and LWAC also showed that increasing the cement content caused a rapid pulse in pundit readings. The increasing rates of pulse are almost same in both HSC and LWAC when the cement content was increased simultaneously. The effect of cement content on pulse rates are shown in Figure 5 for both HSC and LWAC.

Effect of water cement ratio on transmission rate of pulses in ultrasonic pulse velocity

Compressive strength of concrete increases with reduction of W/C ratio and this matter was verified using pundit machine to test the compression strength of concrete. The results showed that by reducing the w/c ratio, the pulse rate increased in most cases. This rate of reduction was almost same for both the HSC and LWAC as well (Figure 6).

The effect of slump on concrete strength and ultrasonic pulses estimation

Large slump of concrete is one of the factors that make differences in compressive strength and pulse velocity of concrete. With high concrete slump, the aggregates with different density separate easily and cause heterogeneity in the sample and consequently affect the concrete compression strength and ultrasonic pulse rates. To prove this matter, the relationship between compressive strength and ultrasonic pulse velocity was checked when the slump is less than or equal to 12 cm and again when the concrete mix has a slump greater than 12 cm. Based on this assessment the former statements was verified as well (Figure 7).

The relationship between ultrasonic pulse velocity and compressive strength of HSC and LWAC

Compression strength tests along with ultrasonic pulse

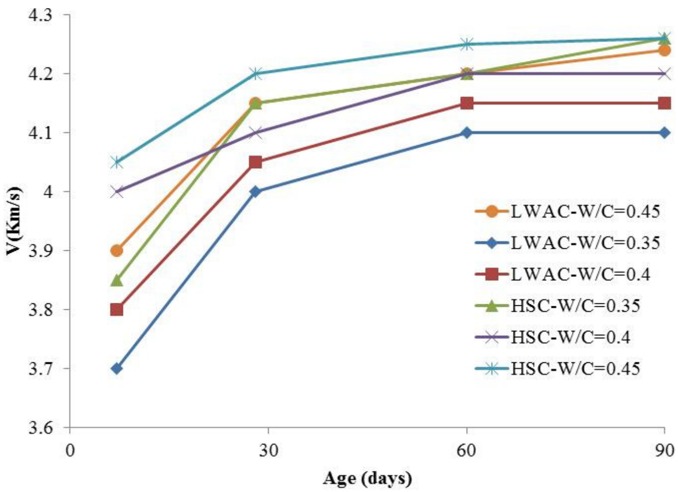
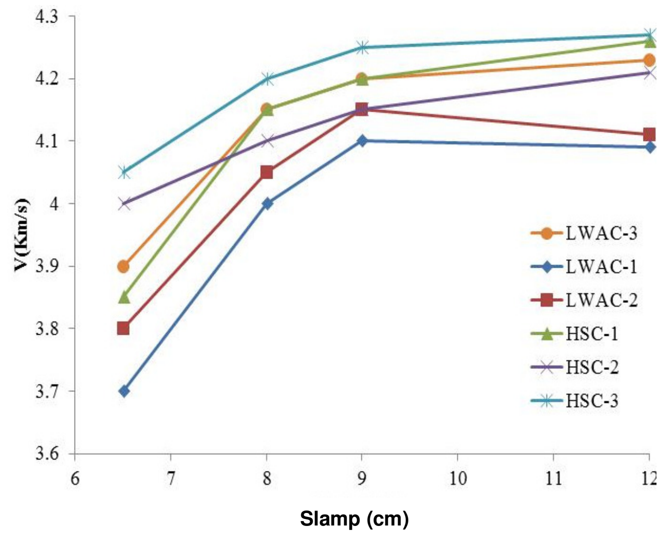


Figure 5. The effect of cement content on UPV.



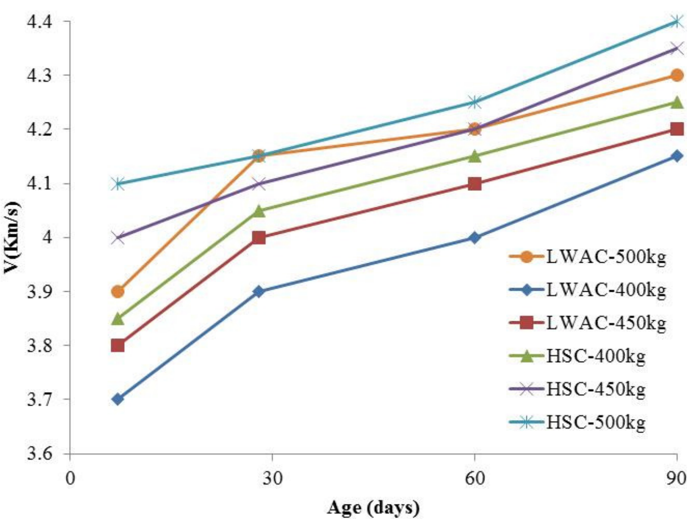


Figure 6. The effect water cement ratio on UPV.

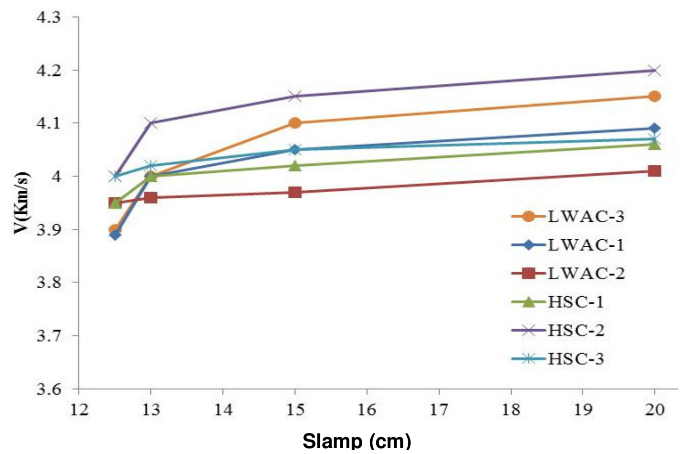


Figure 7. The effect of concrete slump on UPV (for slum less and more than 12 cm).

velocity test were done for many cylinder and cubic samples of 28-day age. Calibration curves for laboratory tests and UPV readings were drawn using regression analysis. The correlation relation between pundit readings and compression strength of concrete are represented by plotting the averages of ultrasonic pulse velocity against the compressive strength of each member. The best fit line, which represents the relationship between pundit reading and the compressive strength of concrete, is a straight line which has an equation with curve fit. A view of the data, correlations between pulse velocity and compressive strength were obtained with reasonable approximation. For each category of concrete mix (HSC and LWAC), the relationship between pulse velocity and compressive strength of concrete, a fitted exponential curve was obtained (Figure 8).

The results show that, obtained R2 from the correlation curve of comparisons between pundit readings and selected concrete mix design is much more than obtained R2 from comparison of all pundit readings against all compression strengths. It means that with the initial calibration of pundit, only one concrete mix design can be tested and for other concrete mixes, the pundit must calibrate again. On the other hand, one defined equation for strength estimation of wide range of concrete samples cannot be used.

Conclusion

In this study, the ultrasonic pulse velocity technique as a non destructive testing of concrete was used to assess the effect of some criteria on high strength and light weight aggregate concrete. The study included several concrete mix design with age of 7, 28 and 90 days. The

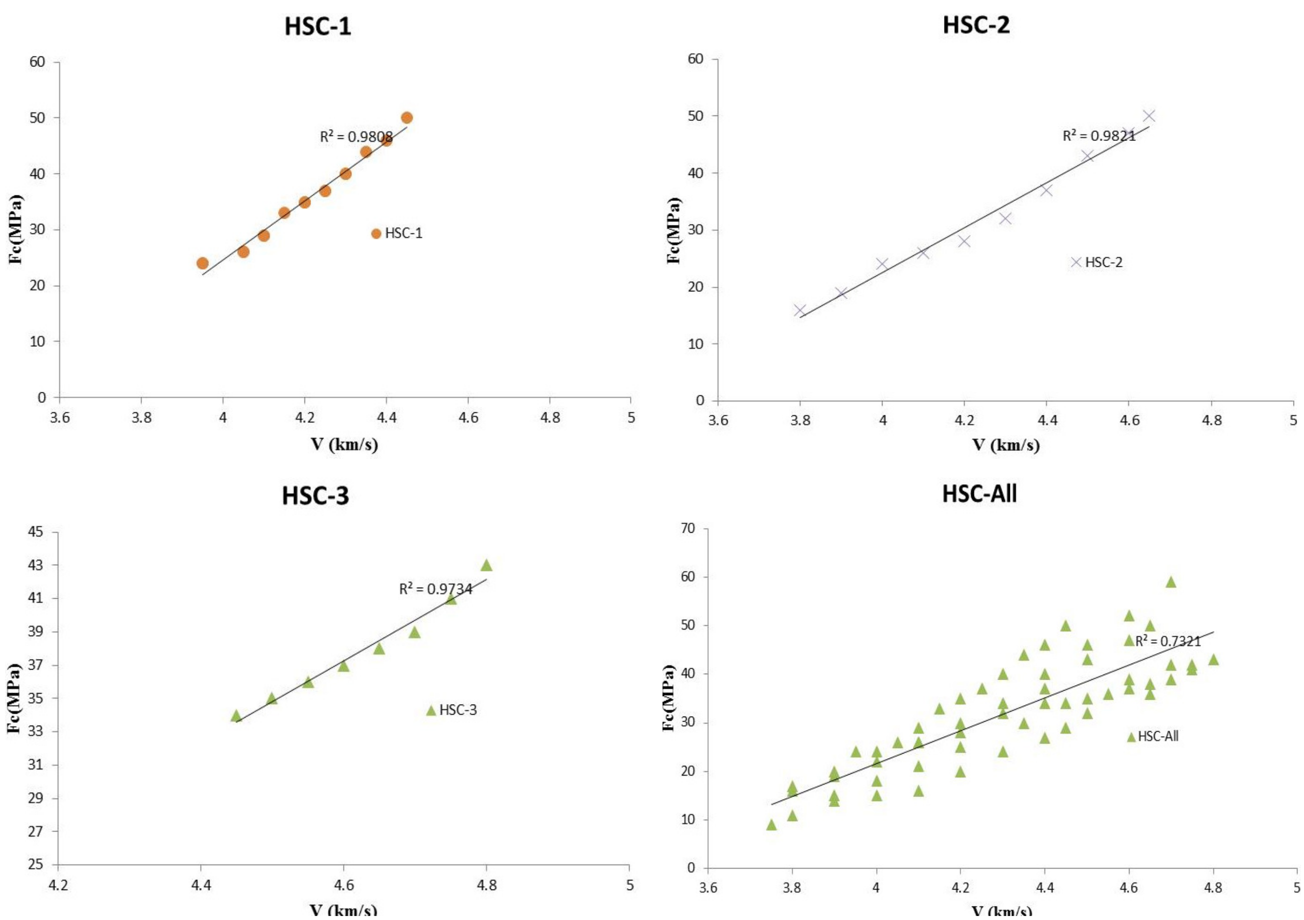


Figure 8. The effect of choosing selected concrete mix and all concrete mix on UPV.

effect of age, cement content, water ratio and slump on both concrete types was studied and discussed. The results show that with increasing of concrete age, the velocity speed increase accordingly and this increase was slightly higher in HSC compare to LWAC. Also it was concluded that increasing the cement content caused a rapid pulse in pundit readings and reducing the w/c ratio, the pulse rate increased in most cases. The rate of reduction was almost same for both the HSC and LWAC as well. It was also confirmed that with high concrete slump, the aggregates with different density affect the concrete compression strength and ultrasonic pulse rates. Calibration curves for laboratory tests and UPV readings were drawn using regression analysis. The results show that, obtained R2 from the correlation curve of comparisons between pundit readings and selected concrete mix design is much more than obtained R2 from comparison of all pundit readings versa all compression strengths.

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