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COMPRESSIVE STRENGTH EVALUATION OF LIGHTWEIGHT CONCRETE WITH EXPANDED GLASS AGGREGATE BY ULTRASONIC PULSE VELOCITY METHOD

CHRISTOPHER COLLINS and SAMAN HEDJAZI

Dept of Civil Engineering and Construction, Georgia Southern University, Statesboro, USA

In the present study, a non-destructive testing method was utilized to assess the mechanical properties of lightweight and normal-weight concrete specimens. The experiment program consisted of more than a hundred concrete specimens with the unit weight ranging from around 850 to 2250 kg/m^3. Compressive strength tests were performed at the age of seven and twenty eight days. Ultrasonic Pulse Velocity (UPV) was the NDT that was implemented in this study to investigate the significance of the correlation between UPV and compressive strength of lightweight concrete specimens. Water to cement ratio (w/c), mix designs, aggregate volume, and the amount of normal weight coarse and fine aggregates replaced with lightweight aggregate, are the variables in this work. The lightweight aggregate used in this study, Poraver®, is a product of recycled glass materials. Furthermore, the validity of the current prediction methods in the literature was investigated including comparison between this study and an available expression in the literature on similar materials, for calculation of mechanical properties of lightweight concrete based on pulse velocity. It was observed that the recently developed empirical equation would better predict the compressive strength of lightweight concrete specimens in terms of the pulse velocity.

Keywords: UPV, Lightweight aggregate concrete, Non-destructive testing, Expanded waste glass.

1 INTRODUCTION

Evaluation of the mechanical properties of concrete materials through non-destructive testing methods has been widely used in the litrature. Ultrasonic techniques are used to measure the velocity in concrete by sending a pulse generated from a piezoelectric transducer to explore the qualities of concrete and integrity of the material. It is also a useful technique for quality control and detection of defects and thickness measurements in existing structures. There appear to be reasonably good correlations between UPV and concrete compressive strength (CS) (AASHTO 2018). The relationship between UPV and compressive strength has been proven that can be affected by different factors including the aggregate's type and size, cement type and specifications, curing of specimens, mix design, age of concrete, voids/cracks and moisture content, (Chingalata *et al.* 2017). Standard testing methods must be used to investigate the relationships between UPV and CS of concrete specimens (ASTM C597-02 2002, Bogas *et al.* 2013). Equations for the f_c of lightweight concrete (LWC) using UPV were published in previous studies (Bogas *et al.* 2013, Mohamad-Ali, *et al.* 2016, Al-Nu'man *et al.* 2015, Chingalata *et al.*

2017). Therefore, due to the specificity of LWC built from EGA, a correlation between UPV and f_c of concrete must be established for each type of these Lightweight Aggregates (LWA). It is also emphasized in those works, that the utilization of EGA in lightweight concrete is a recent topic that requires more research. The main aggregate of focus in this study was an EGA and it meets the required American Standards for Testing and Mixing (ASTM) for LWA. Developing a new equation to better estimate the relationships between CS and UPV is the ultimate goal of the present work and can enhance the assessment of members made of LWC. Different size of EGA has been used in this study to better evaluated f_c and UPV relationship.

2 EXPERIMENTAL PROGRAM

2.1 Materials

The experimental program designed for the present study consists of several concrete mixes using lightweight EGA. The LWC mixes are designed to consider the gradual replacement of Normal-weight Aggregate (NWA) with LWA from zero to hundred percent. The grain sizes and properties of the LWA used are presented in Table 1.

Table 1. Aggregate properties.

Property	Normal weight aggregates		Lightweight aggregates		
	Gravel Mix (GM)	Coarse Sand (CS)	Poraver (0.25 -0.5 mm)	Poraver (1-2 mm)	Poraver (2-4 mm)
Specific Gravity (kg/m^3)	2.4	2.75	0.55	0.36	0.32
Absorption Capacity (%)	2.3	1.87	19	9	9
Moisture Content (%)	4.5	6.4	0.5	0.5	0.5
Fineness Modulus	3.64	2.9	1.92	3.81	4.7

2.2 Mix Proportions

The mix designs used in this work are shown in Table 2. The ACI 211.2-98 (1998) weight method was followed for mix designing. For comparability reasons, the mixes were designed with the same slump of 3-4 inches and the amount of cement content.

2.3 Test Methods

All procedures for making concrete specimen in the laboratory were followed by ASTM C192 (2006). The Poraver® (2019) aggregate was exposed to water an hour before mixing. The Gravel Mix and Coarse Sand were wetted with 50% of the water at the beginning of the mixing process and was mixed for 1 minute or until most of the material were wet. The LWA was then added to the mix and mixed for another thirty seconds to a minute. The cement and rest of the water were added to the mix and it was then mixed for 1-2 minutes or until the materials resembled a cementitious paste. The total mixing time for all of the samples was constant. 50.8

mm x 101.6 mm cylinder specimen was selected for the current study. Due to the specimen size, a correction factor was used to properly assess the amount of stress for a concrete sample that is not the standard size for testing Yi *et al.* 2006). UPV and f_c test was conducted at the ages of 7 and 28 days.

Table 2. Mix proportions.

	Mix Label:	w/c	Cement (g)	Water (g)	GM (g)	CS (g)	LWA (0.25-0.5 mm) (g)	LWA (1-2 mm) (g)	LWA (2-4 mm) (g)
NWC	1*	0.3	685	203	1374	2200	-	-	-
	2*	0.29	685	201	916	2372	-	-	-
	3*	0.29	685	199	458	2545	-	-	-
	4*	0.3	685	205	1833	2028	-	-	-
	5*	0.3	685	208	2595	1737	-	-	-
	6*	0.31	653	202	3488	1343	-	-	-
	7*	0.32	653	208	4536	916	-	-	-
	8*	0.29	685	199	458	2545	-	-	-
	5a	0.31	576	177	3284	1275	-	-	-
	12a	0.47	576	272	3284	1275	-	-	-
LWC	9*	0.29	685	199	304	2545	-	-	154
	4e	1.88	576	1084	658	1275	-	-	2631
	5d	0.31	576	177	3284	508	-	-	767
	7b	0.47	576	272	2631	1021	-	658	254
	8e	0.47	576	272	658	1021	254	658	-
	9f	0.7	576	404	1973	767	508	329	-
	10f	0.7	576	404	658	1021	254	658	-
	12b	0.47	576	272	3284	1021	181	-	-
	12c	0.47	576	272	3284	767	167	-	-
	12d	0.47	576	272	3284	508	253	-	-
	12e	0.47	576	272	3284	254	340	-	-
	12f	0.47	576	272	3284	340	421	-	-

3 RESULTS AND DISCUSSION

To calculate UPV, Eq. (1) from ASTM C597-02, (2002) was used to measure the ultrasonic pulse velocity (V) of the concrete specimen. V was measured in meters per second, T was the transit time, measured in seconds, of the pulse, and L was the distances between the center faces of the transducers. The UPV instrument recorded T in microseconds. An available expression from previous works on similar materials, for calculation of CS of lightweight concrete based on pulse velocity is presented in Eq. (2) (Bogas *et al.* 2013), Where, the CS of concrete, f_c, is in MPa, UPV is in m/s, KUPV, is a constant, and the dry density, ρ, is in kg/m^3. This equation was used for the comparison between the UPV and fc values obtained from the CTM.

$$V = \frac{L}{T} \tag{1}$$

$$f_c = \left(\frac{V}{K_{UPV} \cdot \rho^{0.5}} \right)^{\left(\frac{2}{3}\right)} \tag{2}$$

3.1 Compressive Strength

In Table 3, the concrete mixes, their densities, UPV and f_c evaluated at the 7th and 28th day are presented. These densities, UPV, and f_c were the average values recorded for each mixture. The test values for each individual specimen in each composition and testing age are portrayed in Figure 1. All f_c and UPV values were measured in MPa and km/s. Figure 1 summarizes all of the measurements for the UPV and CS of different mixtures at the age of 7 and 28 days. More than 140 data points were considered to take into account the CS of specimens ranging from 0.3 to 60 MPa and UPV values of 50 to 4500 m/s. The average f_c at the 28th day for each concrete composition used in this study exhibited exponential increases as UPV increased, as seen in Figure 2. Also presented in Figure 2, the f_c estimated by Eq. (2) (Bogas *et al.* 2013), was evaluated using the UPV values measured in this study. This comparison proved that the type of relationship between UPV and f_c was specific to the material's property utilized in a mixture. From this research, it was proven that the relationship between CS and UPV must be studies for each type and size of LWA used in the mixture.

Table 3. Mix proportion, dry density, ultrasonic pulse velocity, compressive strength, and water to cement ratio.

Mixes	Dry Density	Ultrasonic Pulse Velocity		Compressive Strength		w/c
	(kg/m^3)	UPV, 7d (km/s)	UPV, 28d (km/s)	f_c, 7d (MPa)	f_c, 28d (MPa)	
1*	2119	-	3.96	-	28.2	0.30
2*	2069	-	3.22	-	24.0	0.29
3*	2027	-	3.23	-	20.0	0.29
4*	2078	-	3.53	-	26.6	0.30
5*	1973	-	3.13	-	21.6	0.30
6*	1875	-	3.41	-	15.2	0.31
7*	1679	-	2.58	-	4.4	0.32
8*	1916	-	1.88	-	5.2	0.29
9*	1520	-	1.92	-	3.1	0.29
5a	2104	1.88	1.75	0.83	1.0	0.31
5d	1827	1.55	2.21	1.4	1.7	0.31
7b	1938	1.36	3.62	1.0	1.1	0.47
8e	1799	1.11	1.11	0.5	1.6	0.47
9f	1882	1.38	1.38	0.97	2.6	0.70
10f	1882	1.47	1.47	0.93	1.0	0.70
12a	1930	2.68	2.45	3.0	3.6	0.47
12b	1797	1.98	2.36	1.97	3.3	0.47
12c	1800	2.16	2.4	2.16	2.78	0.47
12d	1827	2.96	2.1	2.96	2.2	0.47
12e	1907	2.8	1.95	3.61	1.8	0.47
12f	1550	1.48	1.59	1.03	1.1	0.47

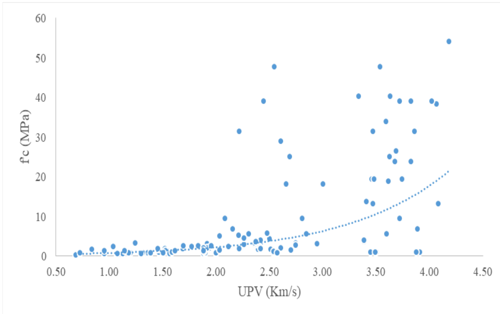

Figure 1. f_c vs. UPV for NWC and LWC at 7 and 28 days.

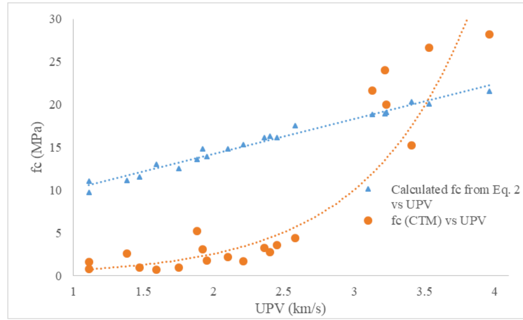

Figure 2. UPV vs. the calculated f_c and f_c obtained from the CTM at 28 days.

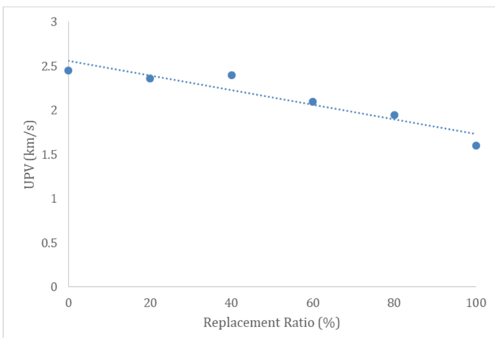

Figure 3. UPV vs. RR.

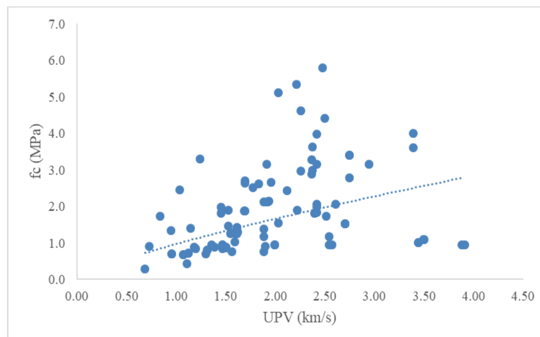

Figure 4. f_c vs. UPV for LWC at 7 and 28 days.

In Figure 3, the relationships of the LWA content and UPV for the mix proportions 12a, 12b, 12c, 12d, 12e are presented here. This plot was created for investigating the effects of the LWA content in a composition by employing a replacement ratio (RR). In Figure 3, these individual compositions and their RR were used to correlate UPV. From these figures, it was depicted that for the present LWC, as the EGA content increased, UPV decreased. In Figure 4, UPV versus f_c for all of the LWC specimens was demonstrated. This figure exhibited specimens with different compositions and sizes of aggregate with concrete ages of 7 and 28 days.

4 CONCLUSION

Lightweight aggregates, such as EGA, have been utilized in recent structural and non-structural members. In the present article, the compressive strength of lightweight concrete composed of lightweight Expanded Glass Aggregate was evaluated using UPV. The expectations from previous studies was confirmed for the material used in this study such as 1) LWA is a good replacement for normal aggregate to achieve smaller bulk densities while keeping the desired properties 2) For the mixtures presented, UPV increased as the f_c increased 3) For LWC containing larger amounts of LWA, UPV decreased with more LWA content. 4) UPV and CS decrease when the dry density decreases, 5) it was observed that the available equations in the literature cannot be used to estimate the CS in term of UPV for the aggregates used in this study. For future research, more experimental specimen including different sizes of Poraver EGA and improved gradations of the mixture compositions, are needed to properly assess and validate the relationship between UPV and CS for the LWA used in here.

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