Scientific Research and Essays Vol. 5(15), pp. 2055-2064, 4 August, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2010 Academic Journals

Full Length Research Paper

Characteristics of workability, strength, and ultrasonic pulse velocity of SCC containing zeolite and slag

Ibrahim Türkmen, Ali Öz and Abdulkadir Cüneyt Aydin*

Department of Civil Engineering, Faculty of Engineering, Atatürk University, 25240- Erzurum, Turkey.

Accepted 2 July, 2010

This paper reports the results of the study conducted to evaluate the influence of natural zeolite (NZ) and blast furnace slag (BFS) and both NZ + BFS on the ultrasonic pulse velocity (UPV), compressive strength, flexure strength and density of self-compacting concrete (SCC). In addition, the relationship between UPV and compressive strength was evaluated. NZ, BFS and both NZ+BFS were used as the mineral admixtures in replacement of Portland cement. It was possible to produce SCC using 10%NZ, 10%, 20%, 30% BFS and 10% NZ+20% BFS with a slump flow in the range of 500 to 700 mm. Compressive strength, flexure strength and UPV were determined at 3, 7, 28 and 90-day. Finally, it was observed that the specimens (with 10% BFS) for 90-day had the highest compressive strength and UPV. It was observed that the specimens (with 20% BFS) for 90-day had the highest flexure strength. The relationship between UPV and compressive strength was exponential for NZ, BFS and NZ+BFS. The relationship between flexure strength and compressive strength was logarithmic for NZ, BFS and NZ+BFS. However, the constants in the models were different for each mineral admixture and each level replacement of PC.

Key words: Self-compacting concrete, ultrasonic pulse velocity, strength, natural zeolite, blast furnace slag.

INTRODUCTION

Concrete is a multiphase, exceedingly complex heterogeneous material and one of the principal materials for structures. However, the heterogeneous structure of concrete results to some undesirable effects. The heterogeneity and properties of concrete is mostly concerned with the hydration. Hydration, the chemical reaction between water and ingredients of cement is one of the most important properties of its strength gain process. This property of hydration caused a change in volume of hydrated cement, varying hydration rate through the concrete and time dependency of strength gain. One of the main reasons of strength gain is the mechanical properties of concrete. The mechanical properties of cement based materials is needed by designers for stiffness and deflections evaluation and is a fundamental property required for the proper modeling of its constitutive behavior and for its proper use in various structural applications. For this reason, determination of mechanical properties of concrete has become very important from a design point of view. But, due to the economic considerations, there is strong demand on natural resource usage. Moreover, when weights of the structures are considered, not only natural light weight aggregates, but also, artificial light materials like gas concrete are used. Incorporation of natural/artificial resources in concrete leads to environmental, economic and/or technological benefits (Gül et al., 2007; Aydin et al., 2007; Aydin, 2007a; Aydin and Gül, 2007; Aydin et al., 2006; Düzgün et al., 2005; Tortum et al., 2005; Oguz and Aydin, 2003; Hasar et al., 2010; Hasar et al., 2009; Aydin et al., 2009; Aydin et al., 2008; Aydin, 2007b; Aydin et al., 2010).

Use of self-compacting concretes (SCC) lowered the noise level on the construction site and diminished the effect on the environment (Persson, 2001) and has improved the quality of concrete *in situ* (Xie et al., 2002). SCC is a new category of high-performance concrete (HPC), characterized by its ability to spread into place under its own weight without the need of vibration, and self-compact without any segregation and blocking. The introduction of SCC represents a major technological advance, which leads to a better quality of concrete

*Corresponding author. E-mail: acaydin@atauni.edu.tr.

produced and a faster and more economical concrete construction process (Sonebi, 2004). The use of SCC in civil engineering has gradually increased over the past few years, as reported by Persson (2001), Xie et al. (2002), Sonebi (2004), Sari et al. (1999), Persson (2003), Poon and Ho (2004), Lachemi et al. (2004), Jooss et al. (2002), Sahmaran et al. (2005), Nagataki and Fujiwara (1994) and Khayat (1999).

Zeolite is also used as a mineral admixture to produce high performance concrete in China. Natural zeolite (NZ) contains large quantities of reactive SiO_2 and Al_2O_3. Similar to other pozzolanic materials such as silica fume and fly ash, zeolite substitution can improve the strength of concrete by the pozzolanic reaction with $Ca(OH)_2$. In general, NZ, like other pozzolanic materials, contributes to the strength of concrete better than of strength of cement (Canpolat et al., 2004).

NZ also prevents the undesirable expansion due to alkali–aggregate reaction (Canpolat et al., 2004; Poon et al., 1999). According to Feng et al. (1998), partial replacement of cement by zeolite can improve the properties of concrete, by increasing concrete strength and preventing undesirable expansion due to alkali aggregate reactions. A number of research studies have been carried out on zeolite concrete (Canpolat et al., 2004; Poon et al., 1999; Feng et al., 1998; Feng and Peng, 2005; Sammy et al., 1999; Ding, 1999), including studies on the mechanical and microstructural properties and strengthening mechanism of zeolite on the blended concrete.

The ultrasonic method (Liang and Wu, 2002; Malhotra, 1984; Filipczynski et al., 1966; Krautkramer and Krautkramer, 1983) is one of the nondestructive testing techniques and is frequently adopted for evaluating the quality of *in situ* concrete structures. Ultrasonic non-destructive testing (NDT) technique is frequently used to estimate the quality of concrete. This method is typically based on the measurement of the propagation of velocity, which is closely related to mechanical properties and, more directly, to the modules of elasticity. Standard methods consider concrete as a homogeneous material (Krautkramer and Krautkramer, 1983). The measurement of the ultrasonic compressive wave velocity has been used for a long time to evaluate the setting and hardening of cementation systems (Krautkramer and Krautkramer, 1983; Boumiz et al., 1996; Goueygou et al., 2002; Herdnandez et al., 2002; Jeong and Hsu, 1996; Herdnandez et al., 2000; Tan et al., 1996; Ay and Topçu, 1995; Ould et al., 2002; Koehler et al., (1998) Elvery and Ibrahim, 1976; Sayers and Dahlin, 1993).

Khayat (1999) reported that mineral admixture and fine filler content could improve the viscosity of SCC. Taşdemir et al. (1997) reported that blast furnace slag concretes tend to be weaker at early ages than ordinary Portland cement (PC) concretes, but at later ages, they may have the same or higher strength than the ordinary PC ones. Reeves (1986) has shown that in the use of blast furnace slag, the heat of hydration is generated more slowly than ordinary PC. Thus, the rate of gain of strength also increases gradual than that of ordinary PC (Orchard, 1979).

Two approaches used in defining strength properties will be considered in this paper: The first is that the conventional destructive test methods enable the strength of the concrete to be measured by way of cores or cubes cut from the concrete. However, this is not possible in all cases and especially, not for slender members. Alternatively, complete structural members can be load-tested to failure but the extent of the damage to the structure is considerable. The second is the ultrasonic pulse velocity (UPV) technique, which is based on the ability to measure the propagation velocity of a pulse of vibration energy, which has passed through a concrete medium. Knowing the direct path length between the transducers and the time of travel, the pulse velocity through the concrete can be obtained (Uzal et al., 2003).

The UPV method, also known as the transit time method, uses a detector to measure the time-of-flight it takes for an ultrasonic pulse to pass through a known thickness of solid material (Türkmen et al., 2003). The UPV can be written as:

$$V_c(x,t) = \frac{x}{t} \tag{1}$$

where V_c (x, t) is the UPV in concrete, x is the propagated path length and t is the transit time. Based on the experimental results, Tharmaratram and Tan (1990) gave the relationship between UPV in a concrete V_c and concrete compressive strength f_c' as:

$$f_c' = a e^{bV_c} \tag{2}$$

RESEARCH SIGNIFICANCE

There are many studies related to the effect of mineral admixtures on the mechanical properties of concrete, but the effect of NZ, BFS and both NZ+BFS on the relationship between ultrasonic pulse velocity and destructive method of SCC has not been reported previously. Thus, the effects of pozzolanic activity of NZ, BFS and both NZ+BFS admixtures on the mechanical properties of concrete, need to be investigated. Most authors, study ultrasonic pulse velocity (UPV) (Liang and Wu, 2002; Tharmaratnam and Tan, 1990; Ye et al., in press; Kenai and Bahar, 2002; Sahmaran et al., 2005). In this article, two different types of mineral admixtures are used, in combination, and the effect of mineral inclusion on the workability of SCC and normal concrete is also researched. Slump flow and slump tests are performed to assess workability. Moreover, the mechanical properties, namely the compressive strength, flexure strength and UPV of hardened concretes are also determined at

Table 1. Chemical analysis and physical properties of PC, NZ and BFS (%).

Component		PC (%)	NZ (%)	BFS (%)
SiO_2		20.06	65.72	39.56
Fe_2O_3		3.6	1,19	0.33
Al_2O_3		5.16	10,88	10.82
CaO		62.43	1.43	37.68
MgO		2.82	0.75	6.79
SO_3		2.32	0.07	0.33
Sulphide (S^{-2})		0.17	-	-
Chlor (Cl^-)		0.04	-	0.125
Undetermined		1.05	-	3.99
Free CaO		0.71	-	-
LOI		1.55	-	-
Specific gravity (g/cm^3)		3.13	2.22	2.86
Specific surface (cm^2/g)		3600	6350	4000
Compressive strength (MPa)	2 day	24.5	-	-
	7 day	42.0	-	18
	28 day	44.4	-	-

various ages.

EXPERIMENTALLY STUDY

ASTM Type I, PC, from Aşkale cement Factory in Erzurum, Turkey, was used in this study. Superplasticizer-ViscoCrete 3080 (SP), NZ, BFS, and aggregate were obtained from Sika Company in İstanbul, Manisa Gördes, Iskenderun Iron-Steel Factory in Hatay-Iskenderun, and Aras River in Erzurum in Turkey, respectively. A SP based on chains of modified polycarboxylic ether was used, compatible with ASTM C 494 F at a dosage of 2% of cement. In order to eliminate the variation of aggregate and cement, each was taken from the same batch throughout the investigation. The chemical composition and physical properties of the materials used in this study are summarized in Table 1.

First group

Separately, NZ mixtures were prepared by adding 10, 20 and 30% NZ replacement for PC.

Second group

Separately, BFS mixtures were prepared by adding 10, 20 and 30% NZ replacement for PC.

Third group

Separately, 20% NZ+10% BFS or 10% NZ+10% BFS concrete mixtures were prepared in replacement for PC.

For each mix, three specimens of 280 × 70 × 70 mm prisms and 100 × 200 mm cylinders were prepared, and cured in lime saturated water at 20 ± 3℃ during the test period. Cylinder specimens were tested for compressive strength in accordance with ASTM C 39 at 3, 7, 28 and 90 days curing periods. For each curing period, three specimens were used to determine compressive strength. Prism specimens were tested for flexure strength in accordance with ASTM C 78 at 3, 7, 28 and 90 days curing periods. For each curing period, three specimens were used to determine flexure strength. The ultrasonic pulse velocity (UPV) of the reference concrete and NZ-BFS-cement based concrete modified by SP were determined in accordance with ASTM C 597 at 3, 7, 28 and 90 days. The full details of these concrete mixes are given in Table 2. This test method covers the determination of the velocity of propagation of compressional waves in concrete.

The workability methods used in this study are given and standardized by the SCC Committee of EFNARC (2002) and it measures the free and restricted deformability (slump flow) of an SCC mix. This test procedure is thus described.

The slump flow is used to evaluate the horizontal free flow (deformability) of SCC in the absence of obstructions. The test method is very similar to the test method for determining the slump of concrete. The difference is that, instead of the loss in height, the diameter of the spread concrete is measured in two perpendicular directions and recorded as slump flow. The higher the slump flow, the greater the concrete's ability to fill form works (Tan et al., 1996). During the slump flow test, the time required for the concrete to reach a diameter of 500 mm is also measured and recorded as t_{500} and t_{end}.

RESULTS AND DISCUSSION

The results obtained in the test are shown in Figures 1 - 7 and Table 3. They are presented to some extent in graphical form in the figures and table, and are thus evaluated and discussed.

Fresh concrete and workability

The data on the slump flow test and slump test of specimens

Table 2. Mixture proportions.

Mixtures		PC (%)	NZ (%)			BFS (%)			NZ+BFS (%)	
		100	10	20	30	10	20	30	10 + 20	20 + 10
w/c		0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Water (kg/m^3)		195	195	195	195	195	195	195	195	195
Cement (kg/m^3)		400	360	320	280	360	320	280	280	280
Natural zeolite (kg/m^3)		-	40	80	120	-	-	-	40	80
Blast furnace slag (kg/m^3)		-	-	-	-	40	80	120	80	40
Aggregates sizes (mm)	0 – 4 kg/m^3	783	783	783	783	783	783	783	783	783
	4 – 8 kg/m^3	418	418	418	418	418	418	418	418	418
	8 – 16 kg/m^3	427	427	427	427	427	427	427	427	427
Super plasticizer (%)		2	2	2	2	2	2	2	2	2

made using NZ, BFS and NZ+BFS are given in Table 3. As it can be seen from Table 3, concretes made with 20 and 30% NZ shows that flow diameter is lower than 500 mm. Nagataki and Fujiwara (1994) suggested a slump flow value ranging from 500 - 700 mm for a concrete to be SCC. At more than 700 mm, the concrete might segregate, and at less than 500 mm, the concrete might have insufficient flow to pass though highly congested reinforcement. Therefore, normal slump test on the concretes made with 20 and 30% NZ was measured. However, all other concrete specimens are self-compacting concrete which shows that slump flow diameter is higher than 500 mm. Flow diameter values changed up to 600, 540, 600, 660, 700 and 560 mm for 0 and 10% NZ, 10, 20 and 30% BFS and 10%NZ+20%BFS replacement of PC, respectively (Table 3). NZ reduced the workability of concrete specimens, while BFS increased workability of fresh concrete specimens. Khayat (1999) reported that an SCC often contains high-volume replacements of fly ash or BFS enhanced fluidity and cohesiveness and limit heat generation. Such materials are generally less reactive than cement and can reduce problems resulting from fluidity loss of rich concrete.

Strength and UPV

Effect of NZ

NZ reduced compressive strength, flexure strength and UPV of concrete at all levels of replacement at 3, 7, 28 and 90 days (Table 4). Reductions were very high at early ages, but with increasing curing period, the reduction percent decreased. Reductions in compressive strength, flexure strength and UPV at 3-day curing period were 28, 39, 68%, 8, 22, 39% and 2, 4, 12% for 10, 20 and 30% NZ replacement of PC, respectively. Reduction rates in compressive strength, flexure strength and UPV decreased significantly with increasing curing period. Thus, at 28-days curing period for compressive strength, these values reduced to 5, 12 and 49% for 10, 20 and 30% NZ replacement of PC, respectively (Table 4). At 90-days curing periods for compressive strength, reductions were 19, 23 and 43% for 10, 20 and 30% NZ replacement of PC, respectively. Results of numerous studies have indicated that NZ slows the rate of hardening and reduces compressive strength of concrete (Sahmaran et al., 2005; Ay and Topçu, 1995). The reduction value increased with increasing NZ content in the mixtures. Uzal et al. (2003) reported that the addition of NZ (15, 25 and 35% by weight of cement) decreased the compressive strength for 3 day up to 7, 30 and 57%, respectively. Thus, it can be said that cement paste containing NZ showed a steady reduction in compressive strength, UPV and flexure strength at 3, 7, 28 and 90 days as a function of replacement percentage (Figure 1). This can be directly related to the properties of NZ that decrease the heat of hydration of concrete and required long curing period.

Effect of BFS

The data on the compressive, flexure strength and UPV of specimens made using BFS are given in Table 4. Relationship between UPV and curing time of concrete containing BFS are shown in Figure 2. The 3-day compressive strength of concrete made with 10, 20 and 30% BFS were 17.1, 16.9, and to 16.6 MPa, respectively. The 3-day both compressive and flexure strength of concrete decreased with increasing BFS replacement of PC. Reductions for 3-day compressive strength, flexure strength and UPV were 21, 22, 23%, 4, 12, 21% and 1, 2, 2% for 10, 20 and 30% BFS, respectively. The 7-day compressive strength decreased 9, 7 and 23% for 10, 20 and 30% BFS, respectively. Increasing the curing period resulted in a decrease of reduction values of compressive strength due to BFS compared to the 3-day compressive strength. For 10, 20 and 30% BFS replacement of PC at 28 days was approximately similar or higher than the control sample’s compressive strength, flexure strength

Table 3. Fresh concrete properties.

Samples		PC (%)	NZ (%)			BFS (%)			NZ+BFS (%)	
		100	10	20	30	10	20	30	20 + 10	10 + 20
Slump flow time (t_{sudden}) (s)	t_{500}	5	5	*	*	5	4	4	*	6
	t_{end}	46	40	*	*	36	40	48	*	48
Slump flow (mm)	t_{end}	600	540	*	*	600	660	700	*	560
Slump (mm)		*	*	45	30	*	*	*	50	*

Table 4. Hardened concrete properties.

	Samples	PC (%)	NZ (%)			BFS (%)			NZ+BFS (%)	
		100	10	20	30	10	20	30	20 + 10	10 + 20
3-Day	Density of cylinders (kg/m^3) (± 0.02)	2268	2232	2192	2035	2257	2225	2206	2224	2249
3-Day	Compressive strength (MPa)	21.6	15.6	13.2	6.9	17.1	16.9	16.6	12.8	13.2
	Red. (-) or Inc. (+) (%)	0	-28	-39	-68	-21	-22	-23	-41	-39
	UPV (m/s)	3690	3620	3540	3260	3640	3630	3630	3510	3540
	Red. (-) or Inc. (+) (%)	0	-2	-4	-12	-1	-2	-2	-5	-4
	Flexure strength (Mpa)	5.11	4.69	4.00	3.14	4.92	4.50	4.05	4.16	4.51
	Red. (-) or Inc. (+) (%)	0	-8	-22	-39	-4	-12	-21	-19	-12
7-Day	Compressive strength (MPa)	32.5	26.5	19.7	13.2	29.7	30.1	24.9	19.8	21.4
	Red. (-) or Inc. (+) (%)	0	-18	-39	-59	-9	-7	-23	-39	-34
	UPV (m/s)	3990	3930	3790	3730	3950	3950	3910	3720	3890
	Red. (-) or Inc. (+) (%)	0	-2	-5	-7	-1	-1	-2	-7	-3
	Flexure strength (Mpa)	5.84	5.13	4.37	4.08	5.50	5.29	5.02	5.05	5.14
	Red. (-) or Inc. (+) (%)	0	-12	-25	-30	-6	-9	-14	-14	-12
28-Day	Compressive strength (MPa)	34.7	32.8	30.4	17.7	35.4	36.5	35.5	21.3	31.1
	Red. (-) or Inc. (+) (%)	0	-5	-12	-49	+2	+5	+2	-39	-10
	UPV (m/s)	4100	4050	3940	3850	4170	4180	4170	3900	4070
	Red. (-) or Inc. (+) (%)	0	-1	-4	-6	+2	+2	+2	-5	-1
	Flexure Strength (Mpa)	6.10	5.23	5.10	4.19	6.13	6.26	6.16	5.27	5.82
	Red. (-) or Inc. (+) (%)	0	-14	-16	-31	0	+3	+1	-14	-5
90-Day	Compressive strength (MPa)	47.7	38.4	36.5	27	50.2	49.7	47.8	36.7	43.8
	Red. (-) or Inc. (+) (%)	0	-19	-23	-43	+5	+4	0	-23	-8
	UPV (m/s)	4260	4240	4180	3900	4290	4280	4270	4120	4210
	Red. (-) or Inc. (+) (%)	0	0	-2	-8	+1	0	0	-3	-1
	Flexure strength (Mpa)	6.33	5.59	5.42	5.04	6.45	6.71	6.40	6.02	6.26
	Red. (-) or Inc. (+) (%)	0	-12	-14	-20	+2	+6	+1	-5	-1

and UPV. For 28-day, compressive strength was increased up to 2, 5 and 2% at 10, 20 and 30% BFS replacement levels, respectively. As for 90-days compressive strength, increases in compressive strength were increased up to 5, 4 and 0% for 10, 20 and 30% BFS replacement of PC, respectively. However, reductions were decreased with increasing curing period. The reduction value increased with increasing BFS content in the mixtures at early curing period. Turkmen et al. (2003) reported the same results for BFS. Demirboğa et al. (2004) reported the same results for mortar. Taşdemir et al. (1997) reported that BFS concretes tend to have lower strengths at early ages than PC concretes, but at later ages, they may have the same or greater strength than the PC ones. Reeves (1986) has shown that in the use of blast furnace slag, the heat of hydration

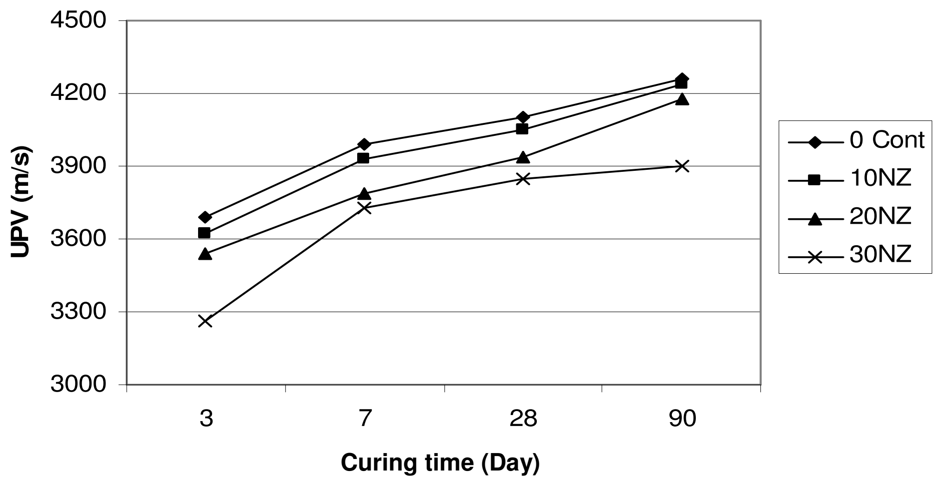

Figure 1. Relationship between ultrasonic pulse velocity and different curing periods for NZ.

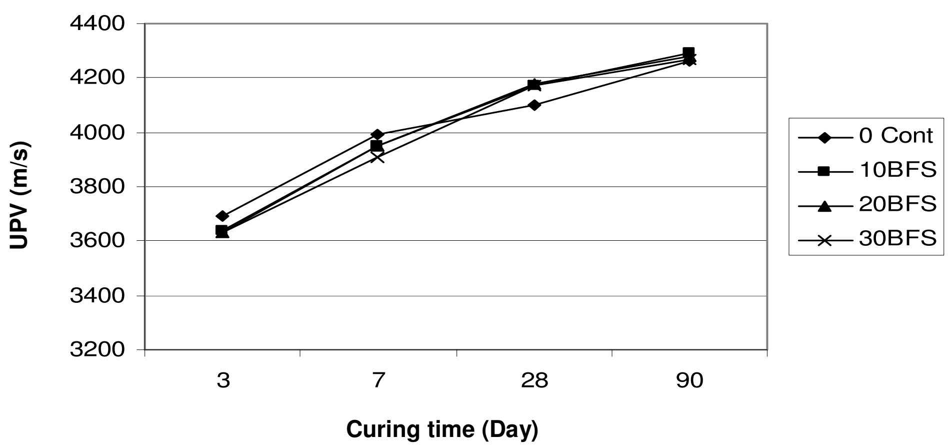

Figure 2. Relationship between ultrasonic pulse velocity and different curing periods for BFS.

is more slowly generated than that of ordinary PC. Thus, the rate of gain of strength increases gradually than that of PC (Orchard, 1979). The UPV of BFS for 3, 7, 28 and 90-day is shown in Table 4 and Figure 2. UPV changed between 3630 to 4290 m/s at 3, 7, 28 and 120-day curing periods. 10, 20 and 30% BFS replacement of PC for 3 and 7-day were lower than that of control sample, but the increasing curing period, decreased the reduction in UPV due to BFS (Figure 2). Maximum UPV value was determined for 10% BFS sample at 90 days.

Effect of NZ+BFS

The compressive strength, flexure strength and UPV of concrete made with both NZ+BFS in replacement of PC are presented in Table 4 and relationship between UPV and curing periods of concrete containing NZ+BFS are shown in Figure 3. As can be seen from Table 4, 3-day compressive strength, flexure strength and UPV of specimens is less than those obtained for control specimens. The difference in reductions of strength percent due to NZ+BFS, decreased with increasing curing period as it occurred for NZ and BFS separately replacement for PC. Reductions in compressive strength at 3, 7, 28 and 90-day for 20% NZ+10%BFS and 10% NZ+20%BFS were 41 and 39%; 39 and 34%; 39 and 10% and 23 and 8%, respectively. Curing period affected the decrease in reduction of compressive strength to a large extent. Türkmen et al. (2003) reported that BFS concretes tend to have lower strengths at early ages than PC concretes, but at later ages, they may have the same or greater strength than the PC ones. However, after about 28 day curing period, the UPV reached a certain value and thereafter increased only slightly. In other words, the UPV took a shorter time to reach a plateau

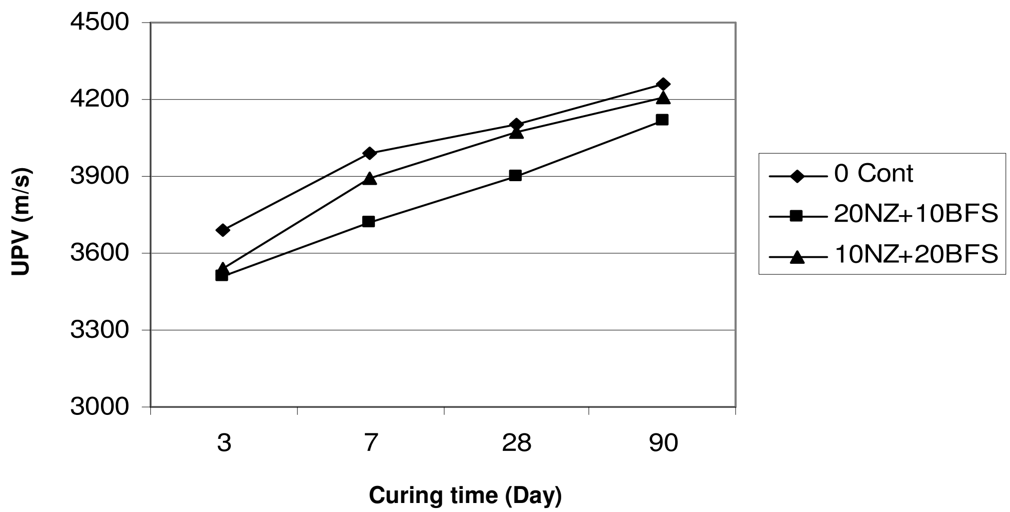

Figure 3. Relationship between ultrasonic pulse velocity and different curing periods for NZ++BFS.

value for mineral admixtured concretes when compared to the compressive strength. The increment in UPV due to BFS was higher than that of NZ for curing period (Table 4). Increasing age decreases the gap between the strength of control sample and the other samples. This is due to the pozzolanic activity of minerals that it may be effective only in the long term. It can be seen from Table 4 that concretes which are made up of NZ, BFS, and NZ+BFS can be used for C 25 (Strength Class, MPa) replacement of PC. Its disadvantage is to decrease the long term.

Relationship between compressive strength and flexure strength

Figures 5 - 7 show the results of the concrete with the mineral admixtures of NZ, BFS and NZ+BFS, separately. For the NZ, BFS and NZ+BFS, the following models were found, respectively:

$$y = 1.5766Ln(x)-0.0047 \quad (1)$$

$$y = 1.9476Ln(x)-1.0128 \quad (2)$$

$$y = 1.6Ln(x)+0.2645 \quad (3)$$

NZ, BFS and NZ+ BFS models justify the general model of Equation 1, 2 and 3 and their determination coefficients were 0.89, 0.91 and 0.98, respectively. When the models of control and samples containing NZ, BFS and NZ+BFS were separately pooled, we found that the relationships were also logarithmic (Figures 5 - 7). As it can be seen from Equation 1, 2 and 3, their constants are also similar but the equation's constants are different from each other.

Relationship between compressive strength and UPV

Taking into account the heterogeneous nature of concrete, the general relationship between UPV and compressive strength is pooled together for all results in Figure 4; for concretes at ages between 3 and 90 days. A determination coefficient (R^2) of 0.94 indicates a very good exponential relationship between UPV and compressive strength. A determination coefficient (R^2) of 0.94 indicates a very good exponential relationship between UPV and compressive strength when results were pooled together (Figure 4). For all results, the following law relating compressive strength was found to be (f_c' in MPa) to UPV (Vc in m/s):

$$f_c' = 0.0301e^{0.0017Vc} \quad (4)$$

The relationship determined in this study, between f_c' and V_c, fitting the general Equation (2) is reported by Tharmaratram and Tan (1990), and Demirboğa et al. (2004) reported the similar relationship for high volume mineral admixtured concrete.

As it can be seen from Equations 2 and 4 in which their constants are also similar but the Equation's constants are different from each other. It can be concluded that this study corroborated that the general Equation (2) reported by Tharmaratram and Tan (1990) are also fitted for mineral admixtured concretes.

Conclusions

It is possible to produce SCC using 10% NZ, 10% BFS, 20% BFS, 30% BFS and 10% NZ+20% BFS with a slump flow in the range of 500 - 700 mm, end flow time ranging from 36 - 48 s.

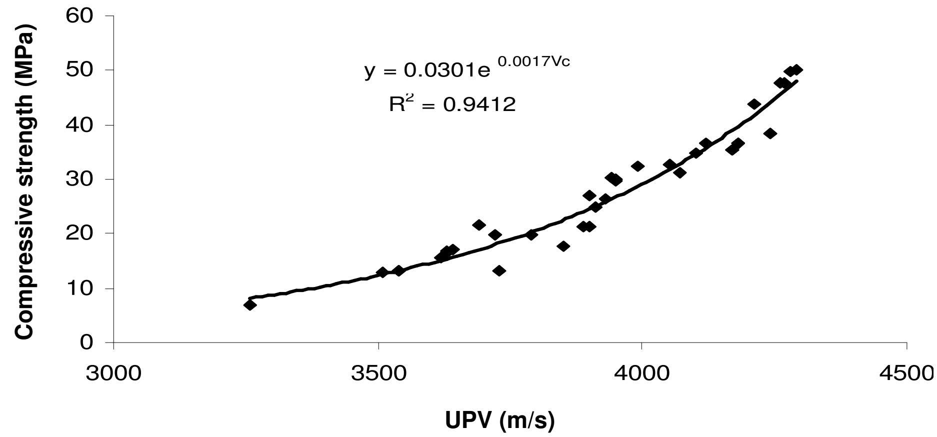

Figure 4. Relationship between compressive strength and UPV for all results between 3 and 90 days of curing periods for PC, NZ, BFS and NZ+BFS.

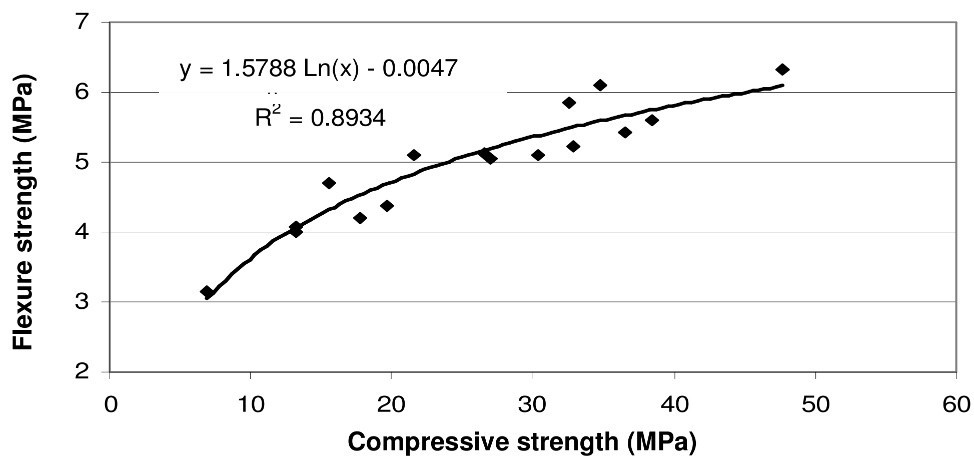

Figure 5. Relationship between flexure strength and compressive strength for control and samples contain NZ.

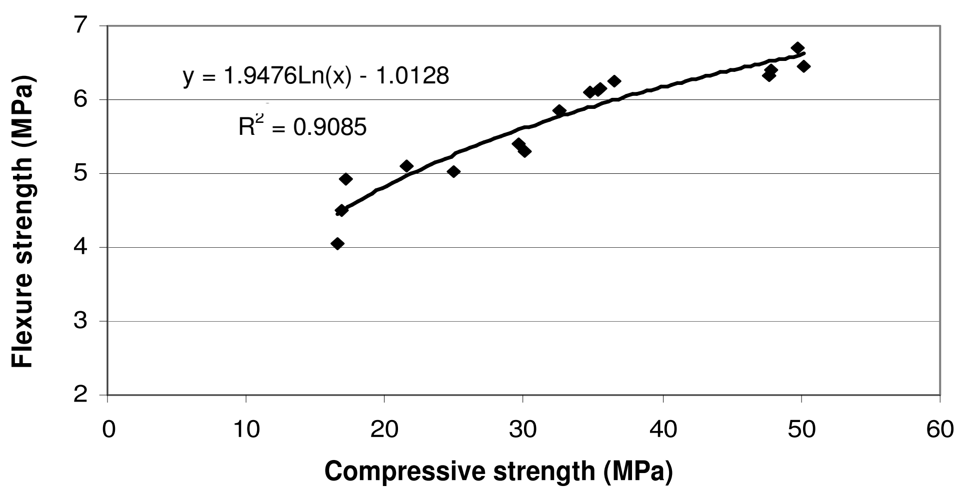

Figure 6. Relationship between flexure strength and Compressive strength for control and samples contain BFS.

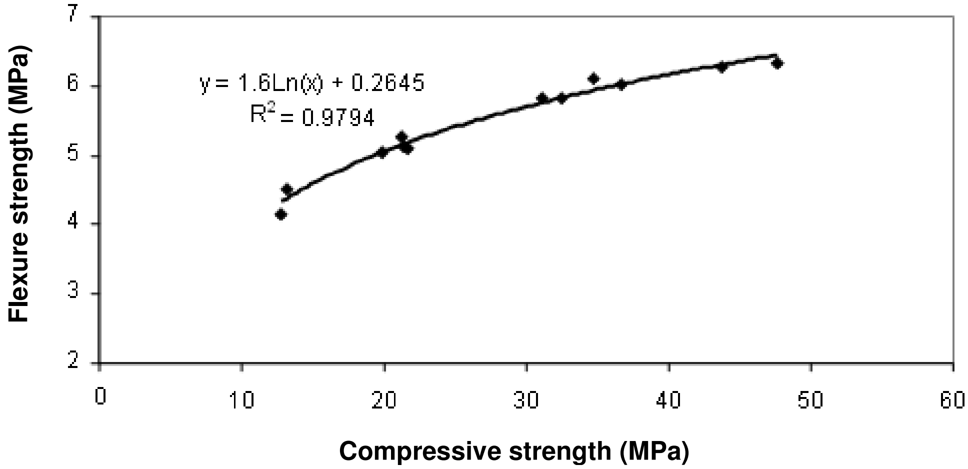

Figure 7. Relationship between flexure strength and compressive strength for samples control and containing NZ + BFS.

NZ+ BFS reduced both compressive strength and UPV values. However, reductions were lower than that of NZ and higher than that of BFS.

NZ instead of cement reduced compressive strength at all level of replacement. The decrease in the compressive strength was very high at early age but with increasing curing period decreased. UPV increased with the increasing curing period for NZ samples. Maximum reductions occurred for 30% replacement of NZ.

The maximum compressive strength and UPV were observed with the 10% BFS replacement of PC at 90 day. Compressive strength, flexure strength and UPV were very low for all levels of mineral admixture at early age curing period, especially for samples containing BFS. However, with the increase of curing period, both compressive strength and UPV of all samples increased. NZ, BFS and NZ+BFS reduced compressive strength, flexure strength and UPV values at 3 and 7 day curing periods. However, BFS replacement of PC increased the compressive strength, flexure strength and UPV values at 28 and 120 day cure periods.

A determination coefficient (R^2) of 0.94 indicates a very good exponential relationship between UPV and compressive strength when all results were pooled together.

When Compressive strength and flexure strength of NZ, BFS and NZ+BFS results were pooled together separately, the relationships were logarithmic and only constants were different for each mineral additive.

REFERENCES

Aydin AC, Düzgün OA, Tortum A (2008).Determination of the Optimum Conditions for Steel Fibers on the Mechanical Properties of Natural Lightweight Aggregate Concrete, Pollack Perodika, 2008, 3(1): 101-112. (SCI değil).

Aydin AC (2007). Prediction of concrete elastic modulus using adaptive neuro-fuzzy inference system - Rejoinder, Civil Engineering and Environmental Systems, 24: 301-302

Aydin AC (2007). Self Compactability of High Volume Hybrid Fiber Reinforced Concrete, Construction and Building Materials, 21: 1146-1151.

Aydin AC, Arslan A, Gül R (2007). Mesoscale Simulation of Cement

Aydin AC, Gül R (2007). Influence of Volcanic Originated Natural Materials as Additives on the Setting Time and Some Mechanical Properties of Concrete, Construction and Building Materials, 21: 1274-1278.

Aydin AC, Karakoç MB, Düzgün OA, Bayraktutan MS (2010). Effect of low quality aggregates on the mechanical properties of lightweight concrete, Sci. Res. Essays 5(10): 1133-1140.

Aydin AC, Tortum A, Yavuz M (2006). Prediction of concrete elastic modulus using adaptive neuro-fuzzy inference system, Civil Engineering and Environmental Systems, 23: 295-309.

Aydin AC, Tortum A, Yavuz M (2009). Prediction of concrete elastic modulus using adaptive neuro-fuzzy inference system - Rejoinder, Civil Engineering and Environmental Systems, 6: 157-158.

Based Materials' Time Dependent Behavior, Comput. Mater. Sci, 41/1: 20-26.

Boumiz A, Vernet C, Cohen TF (1996). Mechanical properties of cement pastes and mortars, Adv. Cement Based Mater. 3: 94-106.

Canpolat F, Yilmaz K, Köse MM, Sümer M, Yurdusev MA (2004). Use of zeolite, coal bottom ash and fly ash as replacement materials in cement production, Cement Concrete Res. 34: 731-735.

construction and building materials in China, Constr. Build. Mater. 19: 579-584.

Demirboğa R, Türkmen İ, Karakoç MB (2004). Relationship between ultrasonic velocity and compressive strength for high-volume mineral-admixtured concrete ,Cement Concrete Res. 34: 2329-2336.

Ding JT, Yan PY, Liu SL, Zhu JQ (1999). Extreme vertices design of concrete with combined mineral admixtures, Cement Concrete Res. 29: 957-960.

Düzgün OA, Gül R, Aydin AC (2005). Effect of steel fibers on the mechanical properties of natural lightweight aggregate concrete, Mater. Lett. 59: 3357-3363.

EFNARC. Specification and guidelines for self-compacting concrete. English ed. Norfolk, UK: European Federation for Specialist Construction Chemicals and Concrete Systems; 2002.

Elvery RH, Ibrahim LAM (1976). Ultrasonic assessment of concrete strength at early ages, Mag. Concr. Res., 28: 181-190.

Feng N-Q, Peng G-F (2005). Applications of natural zeolite to construction and building materials in China, Construction and

Building Materials, 19 (2005): 579-584.
Feng NQ., Li ZG, Zang XW (2005). Study on the suppression effect of natural zeolite on expansion of concrete due to the alkali-aggregate reaction, Magaz. Concrete Res. 50(1998): 17-24.
Filipczynski L, Pawlowski Z (1966). Wehr J, Ultrasonic Methods of Testing Materials, Butterworth, London, 1966.
Goueygou M, Piwakowski B, Ould Naffa S, Buyle-Bodin F (2002). Assessment of Broadband ultrasonic attenuation measurements in inhomogeneous media, Ultrasonics, 40: 77-82.
Gül R, Okuyucu E, Türkmen I, Aydin AC (2007). Thermo-mechanical properties of fiber reinforced raw perlite concrete, Mater. Lett, 61/29: 5145-5149.
Handoo SK, Agarwal S, Agarwal SK, Physicochemical, mineralogical and, morphological characteristics of concrete exposed to elevated temperatures, Cement Concrete Res. 32: 1009–1018.
Hasar UC, Akkaya G, Aktan M, Gozu C, Aydin AC (2009). Water-To-Cement Ratio Prediction Using ANNs From Non-Destructive And Contactless Microwave Measurements, Progress In Electromagnetic Research, PIER 94, 2009, pp. 311-325.
Hasar UC, Simsek O, Aydin AC (2010). Application Of Varying-Frequency Amplitude-Only Technique For Electrical Characterization Of Hardened Cement-Based Materials, Microwave and Optical Technology Letters / 52(4): 801-805. April 2010.
Herdnandez MG, Anaya JJ, Izquierdo MAG, Ullate LG (2002). Application of micromechanicsto the characterization of mortar by ultrason, *Ultrasonics*, 40: 217-221.
Herdnandez MG, Izquierdo MAG, Ibanez A, Anaya JJ, Ullate LG (2000). Porosityestimation of concrete by ultrasonic NDE, Ultrasonics, 38: 531-533.
Improvement of concrete durability," Thomas Telford-Limited, pp. 59-95.
Jeong H, Hsu DK (1996). Quantitative estimation of material properties, of porous ceramics by means of composite micromechanics and ultrasonic velocity, NDT&E International, 29(2): 95-101.
Jooss M, Hans WR (2002). Permeability and diffusivity of concrete as function of temperature, Cement Concrete Res. 32: 1497-1504.
Kenai S, Bahar R (2003). Evaluation and repair of Algiers new airport building, Cement Concrete Composites 25: 633-641.
Khayat KH (1999). Workability, testing, and performance of self-consolidating concrete, ACI Mater. J., May-June, 1999, pp. 346-353.
Koehler B, Hentges G, Mueller W (1998). Improvement of ultrasonic testing of concrete by combining signal conditioning methods, scanning laser micrometer and space averaging techniques, NDT&E Int., 31(4): 281-287.
Krautkramer J, Krautkramer H (1996). Ultrasonic Testing of Material, Springer-Verlag, New York, 1983.
Lachemi MK Hossain MA, Lambros V, Nkinamubanzi PC, Bouzoubaa N (2004). Performance of new viscosity modifying admixtures in enhancing the rheological Properties of cement paste, Cement Concrete Res. 34: 185-193.
Liang MT, Wu J (1984). Theoretical elucidation on the empirical formulate for the ultrasonic testing method for concrete structures, Cement Concrete Res. 32(2002): 1763-1769.
Malhotra VM (1984). In Situ/Nondestructive Testing of Concrete, SP-82, American Concrete Institute, Detroit 1: 1-16.
Nagataki S, Fujiwara H (1994). Self compacting property of highly flowable concrete, Advances in Technology, Proceeding from the Second CANMET/ACI International Symposium, SP-154, V.M. Malhotra, ed., American Concrete Institute, Farmington Hills, Mich., 1994, pp. 209-226.
Oğuz E, Aydin AC (2003). Prediction Of Adsorption Velocity Of Phosphate Removal From Wastewater With Gas Concrete, Including Ph, Temperature, And Agitation Speed, Int. J. Environ. Poll. 19: 603-614.
Orchard DF (1979). Concrete technology. Applied Science Publishers Ltd., Vol. 1, Fourth Edition, London, p. 487.
Ould NS, Goueygou M, Piwakowski B, Buyle-Bodin F (2002). Detection of chemical damage in concrete using ultrasound, Ultrasonics, 40: 247-251.
Persson B (2001). A comparison between mechanical properties of self-compacting concrete and the corresponding properties of normal concrete, Cement Concrete Res. 31: 193-198.
Persson B (2003). Sulphate resistance of self-compacting concrete, Cement Concrete Res. 33: 1933-1938.
Poon CS, Ho DWS (2004). A feasibility study on the utilization of r-FA in SCC, Cement Concrete Res. 34: 2337-2339.
Poon CS, Lam L, Kou SC, Lin ZS (1999). A study on the hydration rate of natural zeolite blended cement pastes, Constr. Build. Mater. 13: 427-432.
Reeves CM (1986). "The Use of GGBS to produce durable concrete.
Sahmaran M, Yurtseven A, Yaman IO (2005). Workability of hybrid fiber reinforced self-compacting concrete, Build. Environ. 40: 1672-1677.
Sahmaran M, Yurtseven A, Yaman IO (2005). Workability of hybrid fiber reinforced self-compacting concrete, Build. Environ. 40: 1672-1677.
Sammy YNC, Xihuang J (1999). Comparative study of the initial surface absorption and chloride diffusion of high performance zeolite, silica fume and PFA concretes, Cement Concrete Composites 21: 293-300.
Sari M, Prat E, Labastire JF (1999). High strength self-compacting concrete original solutions associating organic and inorganic admixtures, Cement Concrete Res. 29: 813-818.
Sayers CM, Dahlin A (1993). Propagation of ultrasound trough hydrating cement pastes at early ages, Adv. Cem. Based Mater. (1): 12-21.
Sonebi M (2004). Medium strength self-compacting concrete containing fly ash: modeling using factorial experimental plans, Cement Concrete Res. 34: 1199-1208.
Tan KS, Chan KC, Wong BS, Guan LW (1996). Ultrasonic evaluation of cement adhesion in wall tiles, Cement Concrete Composite 18: 119-124.
Taşdemir MA, Taşdemir C, Özbek E, Altay B (1997). "Fineness Effect of GGBS on the Properties and microstructure of Concrete," 1st International Symposium on Mineral Admixtures in Cement., Istanbul, Turkey, pp. 198-215.
Tharmaratnam K , Tan BS (1990). Attenuation of ultrasonic pulse in cement mortar. Cement Concrete Res. 20: 335-345.
Topçu IB, Ay N (1995). The influence of ilicoferrochromium fume on concrete properties, Cement Concrete Res. 25(2): 387-394.
Tortum A, Celik C, Aydin AC (2005). Determination of the Optimum Conditions for Tire Rubber In Asphalt Concrete, Build. Environ. 40: 1492-1504.
Türkmen I, Gül R, Çelik C, Demirboğa R (2003). Determination by the Taguchi method of optimum conditions for mechanical properties of high strength concrete with admixtures of silica fume and blast furnace slag, Civil Engineering and Environmental Systems, 2003, 20(2): 105-118.
Uzal B, Bektaş F, Turanli L (2003). Investigation of expansion due to alkali-silica reaction and sulfate attack of granulated natural zeolite (Öğütülmüş doğal zeolitin alkali-silika reaksiyonu ve sülfat etkisi ile genleşmesinin incelenmesi), 5th National concrete congress, TMMOB, 1-3 October, 2003, İstanbul, Turkey, pp. 403-409.
Xie Y, Liu B, Yin J, Zhou S (2002). Optimum mix parameters of high-strength self-compacting concrete with ultrapulverized fly ash, Cement Concrete Res .32: 477-480.
Ye G, Lura P, van Breugel K, Fraaij ALA. Study on the development of the microstructure in cement-based materials by means of numerical simulation and ultrasonic pulse velocity measurement, Cement Concrete Composites (in press).