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The Effect of Cement Type and the Atmospheric Steam Curing Cycles on the Properties of Variable Types of Self-Compacting Lightweight Concrete

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Abstract: With the steam curing technology, effective fast curing technique in prefabrication technology, the effect of atmospheric steam curing on the mechanical properties of variable types of self-compacting lightweight concretes and the combination of the properties of semi-lightweight self-compacting concrete are important engineering approaches, focused in this study, in terms of workable and lightweight concrete production that is easy to apply. The cement type (CEM I 42.5 and CEM II 32.5) and three types of aggregates (normal, pumice and raw perlite) were the parameters of the study, including three types of steam curing cycle. The manufactured concrete samples were not only tested for compressive strength and bending, but also for splitting tensile strength. The fresh and hardened unit weight, dimension check and ultrasonic pulse velocity observations were also obtained for all 108 concrete samples. The three steam curing cycles were about 36.5 hours for 65°C, 70°C and 75°C. These steam-curing cycles were designed according to predesign tests and literature. As a result, the cement type and aggregate effect on the steam curing regimes were obtained. The decrease in the compressive strength of lightweight pumice concretes by the curing temperature rise and the negative effects of CEM II 32.5 on the strength values were the other striking results of the tests.

Keywords: Self-Compacting Lightweight Concrete, Atmospheric Steam Curing, Pumice, Perlite, Compressive Strength

1. Introduction

Self-compacting concretes (SCC) are made using an innovative world-renowned technology widely used in the vast field of construction. SCC a new kind of High-Performance Concrete (HPC) with excellent deformability and segregation resistance was first developed in Japan in 1986. It is a special kind concrete that can flow through and fill the gaps of reinforcement and corners of moulds without any need for vibration and compaction during the placing process [1, 2].

Lightweight concrete application has recently become conventional in different forms including lightweight aggregate concrete, fine aggregate concrete and bubbled air concrete that has been replaced with ordinary concrete. Lightening process of ordinary concretes has been done in different cases and with various shapes. Thus, self-compacting concretes are the new generation of lightened concretes in concrete industry. Lightweight concrete is known for its advantage of reducing the self-weight of the structures, reducing the areas of sectional members as well as making the construction convenient [3, 4].

Structural lightweight aggregate concrete (SLWC) is usually produced by replacing the whole or a part of natural normal-weight aggregate by artificial or natural lightweight aggregate (LWA). Such aggregates, natural or artificial, are available in various parts of the world. Pumice is a type of natural lightweight aggregates of volcanic origin, and it is found abundantly in the volcanic area, e.g. countries such as Chile, Ethiopia, Greece, Spain, Turkey, the United States and Iran [5].

In order to ensure high fluidity, self-compacting concrete is a widely used method, limiting the amount of coarse aggregate and mortar. In addition, the increasing proportion of fine material is required. Fine grains of fine material should be considered smaller than 0.125 mm. For this purpose, fly ash, stone dust (limestone powder), slag (ground) and silica fume can be used [6, 7].

Components of self-compacting concrete are generally thin materials, and because of their better compression by filling out the better, they have unit weight greater than normal concretes. Therefore, while the structures are aimed to be of high strength, its weight is increased. Lightweight aggregate concrete has been in use for many years to reduce the inherent burden [8].

A significant decrease in the total weight of concrete structures is achieved by the use of lightweight concrete. As the positive effects of this, reductions in the load-bearing element's cross-sections become smaller. As a result, the cost structure is reduced. However, lightweight concretes are useful functions in terms of increasing earthquake resistance of the real reinforced concrete structures. In case of using lightweight concrete due to reduction of the entire weight of the building, smaller dynamic forces will occur during an earthquake.

In particular, the production of prefabricated building components, speeding up the increase of concrete strength to take advantage of the maximum number of possible patterns, saves time and labour. Temperature and humidity are effective in the development of mechanical properties of the concrete over time. Keeping humidity high, even when environment has saturated humid, the strength gain speed can be increased by decreasing the ambient temperature of 70-90 degrees. This process is named such as heat treatment, steam curing at atmospheric pressure and tunnel formwork system. In these methods, concrete reaches the desired strength in a short time of 1-2 days. These methods are used in the manufacturing of precast concrete structural elements.

This method is applied with heat in order to accelerate the cement hydration reactions with saturated steam under atmospheric pressure. Application of steam curing, material properties, concrete composition (cement type, dose, water/cement ratio, additives, etc.), concrete placement and compression facilities, geometric features of the construction components, steam curing cycle (application time) and storage conditions (post-cure temperature and humidity) are effective factors.

To evaluate more strength gain of concrete, the environment has to be saturated with enough moisture, and the temperature has to be increased, as well. Heat required to heat the media is achieved by steam curing. This process occurs under 100°C and at atmospheric pressure, it is considered as a special case of humidity curing [9].

In practice, steam-curing cycles are collected in three groups. These are called as fast (stiff) cycles, the total cycle time is 6-7 hours and heat treatment temperature is 80-90°C, moderate (modest) cycles, the total cycle time is 9-11 hours and heat treatment temperature around is 70°C, and slow (soft) cycles, the total cycle time is 20-22 hours and heat treatment temperature does not exceed 55-60°C [10].

Although maximum temperature limit values in curing locations should be within the range from 40 to 100°C, the temperature is applied between 65-80°C. While the maximum temperature applied to the circuit of steam curing increases, the compressive strength of the concrete will increase.

The most effective and most important parameter on the degree of economic efficiency and successful application of steam curing is the steam curing cycle and cement [11].

The curing method used for precast concrete products differs from the normal curing method where steam curing is usually employed because it accelerates the rate of strength development. However, this curing method alters the properties of the resulting concrete [12, 13]. Heat treatment is widely used to accelerate the strength-gaining rate of the concrete; the ultimate strengths of the heated-treated concrete are lower than those of the standard cured specimens.

Steam curing at the atmospheric pressure is an important technique for obtaining high and early strength values in concrete production. Cement type is an important parameter in steam curing process as well as curing period and temperature. CEM I 42.5 is the type of cement that is most commonly used in Turkish precast concrete plants, and its behaviour is well known.

In this study, normal, pumice and perlite were used as the aggregate. Three different Atmospheric Steam Curing cycles were applied to investigate the effect on the properties of SCLWC. The used cement types were CEM I 42.5 and CEM II 32.5. We investigated the properties of SCLWC with two different cement under different atmospheric Steam Curing Cycles, i.e. the compressive strength, the flexural strength, the splitting tensile and the Ultrasonic pulse velocity (UPV). In addition to slump flow, V-funnel, J-ring, and L-box tests are performed to assess workability.

It was concluded that performance of concrete containing metakaolin (MK) is better than that of reference without MK under steam-cured conditions (50–70°C). The improvement can be explained by the occurrence of the pozzolanic reaction of MK and thermo-activated under steam curing conditions [14].

In last years, the use of steam-cured concrete at ambient pressure in pre-cast concrete elements is improving rapidly due to its advantages such as high production efficiency, low labor costs, high quality, and little negative effects on environment. The key parameters of steam-cured concrete are pre-curing time (typically no more than 4 hours, maximum steam temperature (usually limited to 60 ± 5 C and duration at the maximum steam temperature (usually 6–18 hours) [15].

2. Experimental Program

2.1. Materials

In this study, the coarse and fine aggregates were obtained from Aras River in Erzurum, Turkey. The maximum size of coarse aggregates used was 16 mm where the smallest particles used as fine aggregate were 0–2 mm. All the natural aggregates used for this study were in the dry form.

In this research, lightweight pumice and perlite aggregates were used to decrease the overall weight of the final self-compacting concrete. Pumice Aggregate is a low-density highly-vesicular volcanic glass consisting mainly of silica SiO2. The maximum size of pumice coarse aggregate used was 16 mm where the smallest particles used as fine aggregate were 0–2 mm. The maximum size of perlite coarse aggregates used was 8 mm where the smallest particles used as fine aggregate were 0–2 mm. The chemical compositions of this pumice and perlite aggregates are shown in Table 1.

Portland cement (PC) from Aşkale, Erzurum, Turkey was used in this study. The Silica Fume was obtained from the Plant in Etibank of Antalya. Silica Fume (SF) was considered as an additive in order to improve the bonding between the aggregates and cement paste, and to ensure proper resistance to segregation. The cement dosage and water of the mixture were kept constant at 400 kg/m^3 and 308 kg/m^3 throughout this study, respectively. The chemical composition, physical and mechanical properties of the two type cement (CEM I 42.5 and CEM II 32.5) and Silica Fume used in this study are summarized in Table 1.

Polycarboxylic ether based high range water reducer (HRWR) Grace Exp 1028 with density between 1.07 and 1.10 g/cm^3 (at 20°C) was used to enhance the flowability of all the mixtures.

Table 1. *Chemical Analysis and Physical Properties of PC, Silica Fume, Pumice, Perlite, (%).*

s		CEM I 42.5	CEM II 32.5	Silica Fume	Pumice	Perlite
SiO_2		20.79	18.44	79.77	69.78	70.7
Fe_2O_3		3.43	3.21	1.43	2.11	0.842
Al_2O_3		5.17	4.50	1.25	11.16	16.6
CaO		60.29	56.5	2.06	2.47	0.871
MgO		3.03	2.57	3.7	0.60	1.11
SO_3		3.12	2.14	1.54	0.06	0.0280
Sulphide (S^{-2})		0.17	0.18	-	-	-
Chlor (Cl^-)		0.0251	0.0086	-	0.0496	0.0946
Undetermined		0.32	0.28	3.99	-	-
Free CaO		0.34	0.54	-	-	-
LOI		1.55	1.21	-	-	-
Specific gravity (g/cm^3)		3.13	2.86	-	-	-
Specific surface (cm^2/g)		3751	4630	14400	-	-
	2 day	23.6	14.9	-	-	-
Compressive strength (MPa)	7 day	37.9	27.4	-	-	-
	28 day	48.0	38.5	-	-	-

2.2. Methods

In this study, three different atmospheric steam curing degrees, 65°C, 70°C and 75°C, and two different cement types were used. Hence, totally 6 different mixtures were cast in this study. The full details of these concrete mixes are given in Table 2.

The self-compacting lightweight concrete mixtures were prepared in a laboratory mixer. The fine and coarse aggregate was initially dry mixed for about 30 sec. This was followed by the addition of cement, silica fume and 1/3 of total mixing water. After 1.5 min of mixing, the rest of the mixing water together with the SP was added. All batches were mixed for a total mixing time of 5 min. Specimens for the testing of the hardened properties were prepared by direct pouring of concrete into moulds without compaction. The self-compactibility of the mixtures was examined according to standards of Self Compacting Concrete Committee of EFNARC [16]. Four types of workability tests were performed on fresh concrete mixture, slump flow, J-ring, L-box, and V-funnel. Slump flow test is primarily used to assess the filling ability of the concrete without any obstructions. As a result, the total time for 500 mm spreading (t_{500}) of concrete is measured. The second test, J-ring test, is an extension of slump flow test and indicates the passing ability of the concrete. It can also be used to investigate the resistance of SCC to segregation. The L-box test aims at investigating the passing ability of SCC. The reached height of fresh SCC defines the blocking behaviour of steel bars with specified gaps. The V-funnel test is an alternative method, which indicates the period of a defined volume of SCC that needs to pass a narrow opening. The V-funnel test is to some degree related to the plastic viscosity. All the above-mentioned tests are defined in detail elsewhere [16, 19-29].

For each mixture, three samples of 100x200 mm cylinders and three 70x70x280 mm prisms (totally 108 specimens) were prepared and cured for 36.5 hours under the atmospheric steam cure at 65°C, 70°C and 75°C until the testing time. The atmospheric steam curing cycles and characteristics, applied to samples were presented in Table 3.

At 36.5 hours, samples were tested for compressive strength, splitting-tensile strength and flexural strength (centre point loading) in accordance with ASTM C-192, ASTM C-496, and ASTM C-293, respectively. The results for the workability and hardened properties of the mixes are presented in Table 4 and 5, respectively.

Table 2. *Mixture proportions.*

Mixtures		Normal Aggregate		Perlite		Pumice	
		CEM I 42.5	CEM II 32.5	CEM I 42.5	CEM II 32.5	CEM I 42.5	CEM II 32.5
w/binder (cement and SF)		0.56	0.56	0.69	0.69	0.91	0.91
Water, kg/m^3		308	308	379	379	503	503
Cement, kg/m^3		400	400	400	400	400	400
Silica Fume, kg/m^3		150	150	150	150	150	150
Aggregate Size (mm)	0-2 kg/m^3	643	643	646	646	290	290
	2-4 kg/m^3	256	256	328	328	81	81
	4-8 kg/m^3	196	196	155	155	51	51
	8-16 kg/m^3	196	196	-	-	48	48
Superplasticizer % (1.5)		8.25	8.25	8.25	8.25	8.25	8.25

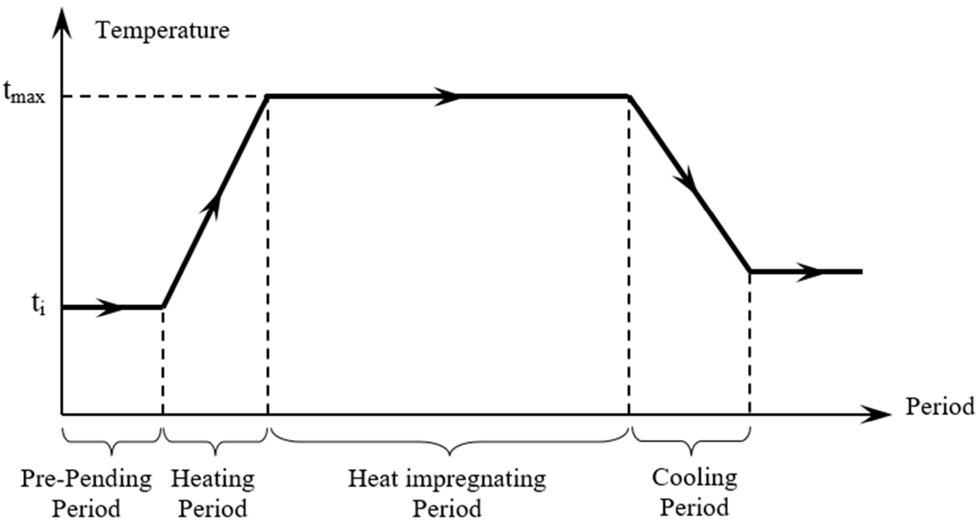

Figure 1. *The schematic representation of a typical atmospheric steam curing cycle.*

Table 3. *Atmospheric steam curing cycles and characteristics.*

Steam Curing Cycles	Pre-Pending Period		Heating Period		Heat impregnating Period		Cooling Period		Total Period
	Temperature (°C)	Time (h)	Temperature (°C)	Time (h)	Temperature (°C)	Time (h)	Temperature (°C)	Time (h)	Time (h)
65°C - 24 h	25	4	25-70	4	70	24	70-32	4.5	36.5
70°C - 24 h	27	4	27-75	4	75	24	75-32	4.5	36.5
75°C - 24 h	29	4	29-80	4.5	80	24	80-32	5	37.5

3. Results and Discussions

The results obtained in the test are shown in Table 4-5 and Figures 2-4. They are presented to some extent in graphical form in the figures and table, and evaluated and discussed below.

3.1. Fresh Concrete and Workability

The data on the slump flow test and slump test of specimens performed using normal aggregate, perlite and pumice are given in Table 4. As it can be seen in Table 4, concretes made with normal aggregate, perlite and pumice have shown flow diameter higher than 500 mm. Nagataki and Fujiwara [17] 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 through highly congested reinforcement. All concrete specimens are self-compacting for shown slump flow diameter higher than 500mm. Flow diameter values changed up to 740, 700, 720, 710, 720 and 750 mm for normal aggregate, perlite and pumice, respectively (see Table 3). Concrete containing CEM II cement made with normal aggregate reduced the workability of concrete specimens. However, concrete containing CEM II cement made with pumice increased the workability of fresh concrete specimens. Khayat [18, 19] reported that an SCC often contains high-volume replacements of fly ash or blast furnace slag to enhance the fluidity and cohesiveness and limit heat generation. Such materials are generally less reactive than cement and can reduce the problems resulting from fluidity loss of rich concrete.

Table 4. *Fresh concrete properties.*

Properties		Normal Aggregate		Perlite		Pumice	
		CEM I 42.5	CEM II 32.5	CEM I 42.5	CEM II 32.5	CEM I 42.5	CEM II 32.5
Slump flow time (t_{sudden}) (s)	t_{50}	3	5	4	5	5	4
	t_{end}	30	41	30	35	45	46
Slump flow (mm)	d_f	740	700	720	710	720	750
V-Funnel time (s)	t_v	11	11.5	5	5	7	9
J-Ring (cm) (in-out of ring)	h_{i-o}	10 - 11	10.5 - 11.5	8 - 9	8.5 - 9.5	10 - 11.5	8.5 - 9.5
L-Box (h_2/h_1)	r	0.93	0.93	0.93	0.93	0.87	0.88

3.2. Strength and UPV

Effect of Pumice: Pumice reduced the compressive strength, splitting tensile strength, flexure strength and UPV of concrete at all levels of the atmospheric steam curing at 65°C, 70°C and 75°C (Table 5).

Table 5. *Hardened Concrete Properties.*

SAMPLES			Unit Weight (kg/m3)	Compressive Strength (MPa)	Flexure Strength (Mpa)	Splitting Tensile Str. (Mpa)	UPV (m/s)
Normal Aggregate	CEM I 42.5	65°C	2130	32.1	5.6	3.0	3608
		70°C	2070	32.1	6.1	3.5	3550
		75°C	2110	33.6	6.2	3.4	3540
	CEM II 32.5	65°C	2040	26.5	4.9	1.9	3459
		70°C	2060	27.7	5.2	3.3	3448
		75°C	2080	23.2	4.8	2.6	3351
Perlite	CEM I 42.5	65°C	1790	19.9	4.2	2.7	2505
		70°C	1810	24.2	4.6	1.7	2596
		75°C	1780	22.2	4.0	1.6	2547
	CEM II 32.5	65°C	1770	17.3	4.1	1.3	2224
		70°C	1780	17.2	3.8	1.2	2371
		75°C	1760	14.2	3.7	1.5	1942
Pumice	CEM I 42.5	65°C	1180	4.9	2.1	1.2	1895
		70°C	1140	5.9	1.2	1.2	2119
		75°C	1160	5.3	1.9	0.9	1864
	CEM II 32.5	65°C	1150	6.2	1.8	0.8	1709
		70°C	1130	4.4	1.4	0.9	1706
		75°C	1140	3.6	1.4	1.0	1347

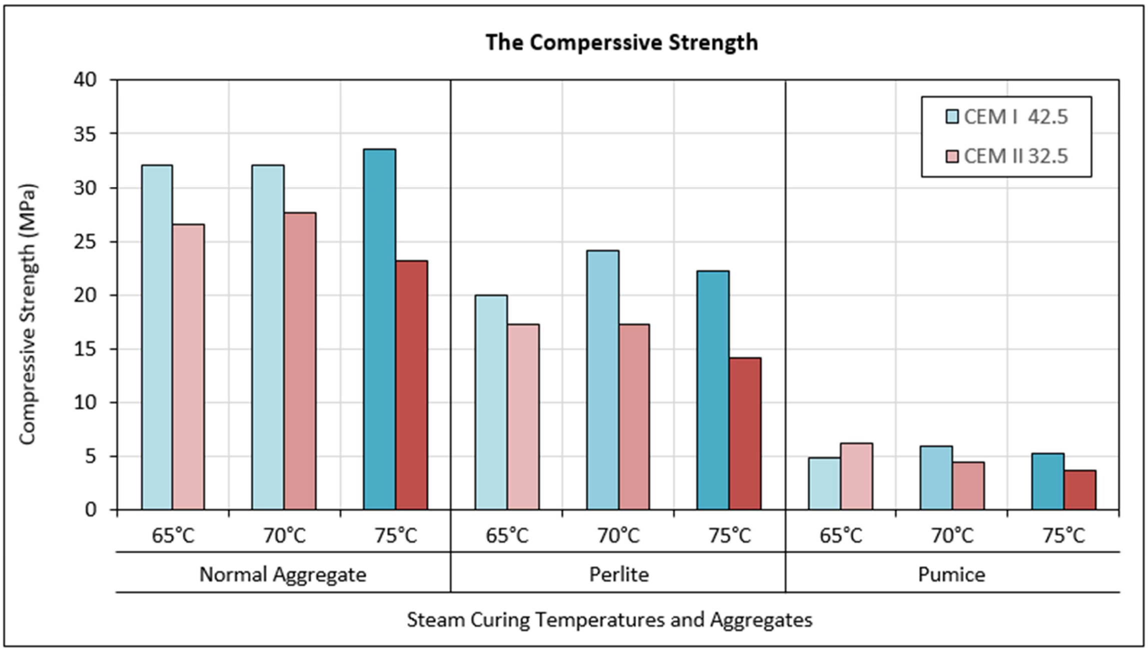

Figure 2. *The effect of steam curing conditions on the compressive strength.*

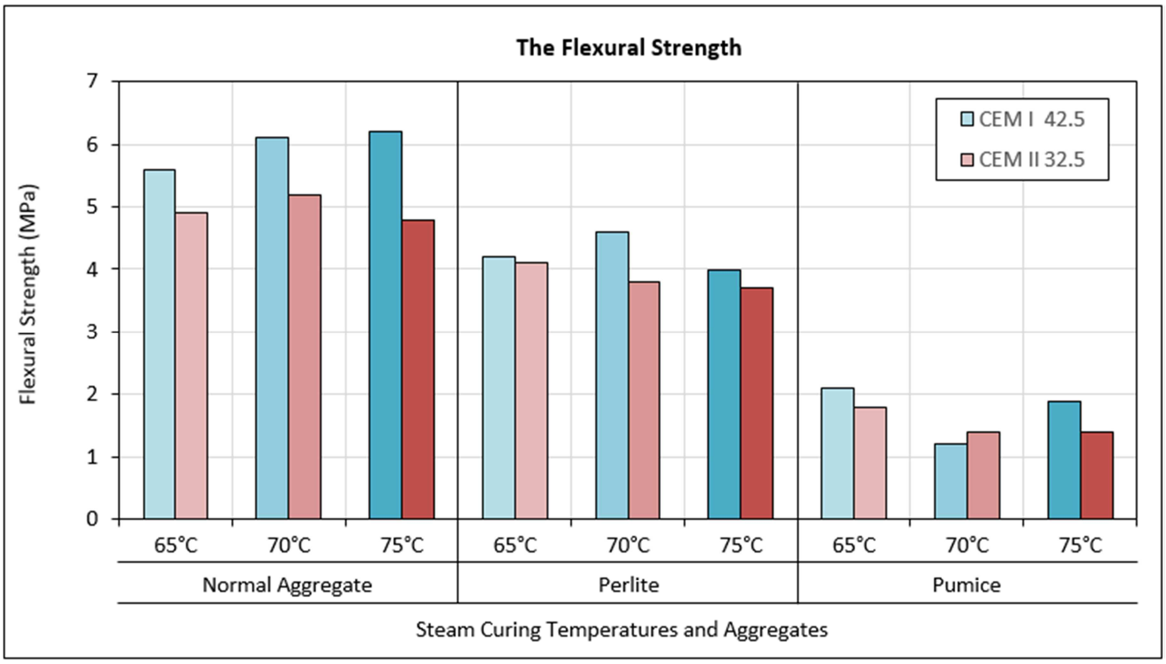

Figure 3. *The effect of steam curing conditions on the flexural strength.*

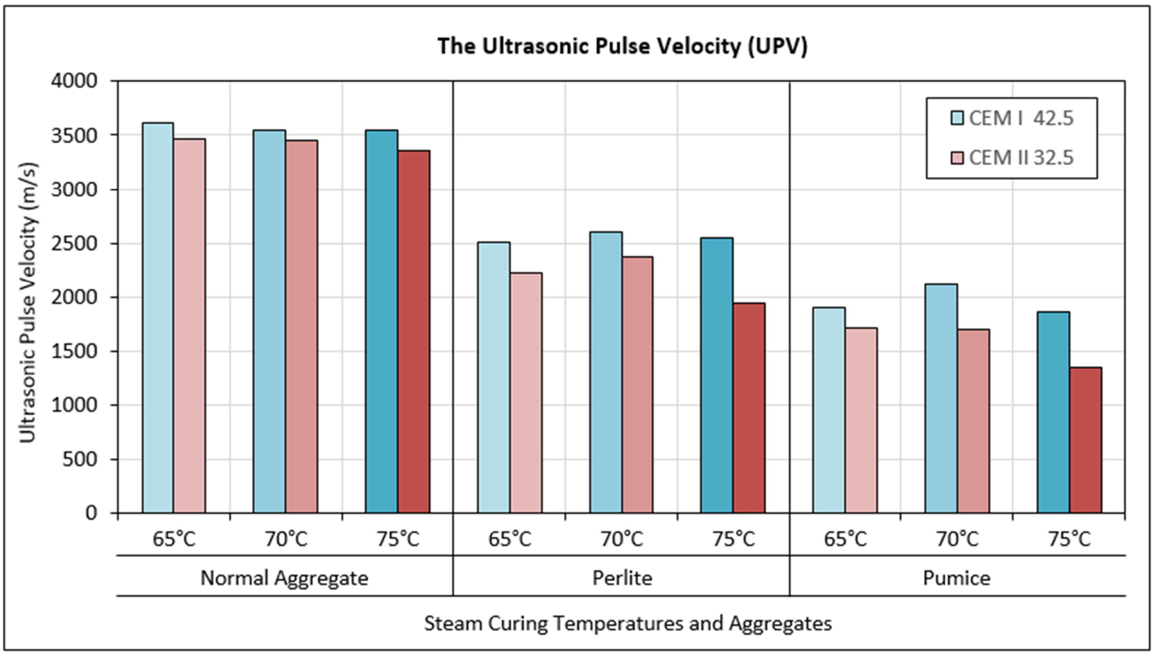

Figure 4. *The effect of steam curing conditions on the ultrasonic pulse velocity.*

4. Conclusion

This study exhibits the effects of different steam curing cycles and cement types on some mechanical properties of SCC produced with normal, perlite and pumice aggregates. For this reason, the concrete specimens were produced with CEM I 42.5 and CEM II 32.5 type cements and were subjected to steam curing at the temperatures of 65°C, 70°C and 75°C. Their fresh concrete properties such as flow time, flow diameter, V-funnel, J-ring and L-box, and hardened concrete properties such as compressive strength, flexural strength, splitting tensile strength and UPV were investigated. According to the obtained experimental results, some of the following points may be considered:

It is possible to produce SCC using lightweight aggregate such as perlite and pumice, with a slump flow higher than 700 mm and end flow time ranging from 30 to 46 s. The compressive strength, flexural strength and UPV values of concrete samples made with pumice were lower than the other two cement types. When the steam curing temperature increase from 65°C to 75°C, while the compressive strength of CEM I 42.5 samples showed an increase, that of CEM II 32.5 samples showed a decrease for all three aggregate types. Thus, the increase of steam curing temperature showed an improving effect on the compressive strength for CEM I 42.5 cement type.

The decrease in the compressive strength of lightweight pumice concretes by the curing temperature rise and the negative effect of CEM II 32.5 on the strength values were the striking results of the tests. Besides, the expanding property of self-compacting pumice aggregate concrete was one of the other striking results for the atmospheric steam curing. The maximum compressive strength and flexural strength were observed in the samples produced with normal aggregate and CEM I 42.5 type cement for 75°C steam curing temperature.

When the increase of steam curing temperature from 65°C to 75°C, the UPV values of the specimens with perlite and pumice aggregates showed increase for CEM I cement type, but they more clearly decreased in CEM II cement type. In the SCC specimens with perlite and pumice lightweight aggregate, the maximum compressive strengths were obtained at the steam curing temperature of 70°C for the CEM I cement type. Their UPV results also support this situation.

References

[1] Okamura H. Self-compacting high performance concrete. Concr Int 19 (7): 50–4.

[2] Okamura H, Maekawa K, Ozawa K. High performance concrete. Gihoudou Pub, Tokyo (1993) [in Japanese].

[3] Yasar E, Atis CD, Kilic A, Gulsen H. Strength properties of lightweight concrete made with basaltic pumice and fly-ash. Materials Letters 2003; 57: 2267–70.

[4] Rossignolo JA, Agnesini MVC, Morais JA. Properties of high-performance LWAC for precast structures with Brazilian lightweight aggregate. Cement and Concrete Composites 2003; 25: 77–82.

[5] United States Geological Survey. Pumice and pumicite, statics and information. In: Mineral commodity summaries; 2008; 130–1.

[6] Bonavetti V, Donza H, Menééndez G, Cabrera O, Irassar EF. Limestone filler cement in low w/c concrete: A rational use of energy. Cement Concrete Res 2003; 33: 865–71.

[7] Bosiljkov VB. SCC mixes with poorly graded aggregate and high volume of limestone filler. Cement Concrete Res 2003; 33: 1279–86.

[8] Demirboga R, Örüng İ, Gül R. Effects of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concretes. Cem. Concr. Res. 2001; 31: 1627–32.

[9] Neville AM. Properties of concrete. 4th edition, London: Pitman Publishing Limited 1997.

[10] Hwang, S., Khatib, R. H., Lee, S., Khayat, K., Optimization of steam-curing regime for high-strength, self-consolidating concrete for precast, prestressed concrete applications, PCI Journal, Vol: 57, Issue: 3, 2012, pp. 48–62.

[11] Öztekin E. Beton Sertleşmesinin Hızlandırılmasında Isıl İşlem Çevrimi ve Çimento Seçimi, Tübitak Kurumu Bilgi Profili No: 31, 1980, Ankara, Turkey.

[12] American Concrete Institute, Pressure steam curing, ACI Journal, Vol. 60, No 8, August 1963, pp 953-986.

[13] Erdem TK, Turanli L, Erdogan TY. 'Setting time: An important criterion to determine the length of the delay period before steam curing of concrete'. Cement and Concrete Research 2003; 33: 741-45.

[14] A. Ramezanianpour et al., Influence of initial steam curing and different types of mineral additives on mechanical and durability properties of selfcompacting concrete, Construction. Building Materials. 73 2014:187–194.

[15] Gonzalez-Corominas A, Etxeberria M, Poon CS. Influence of steam curing on the pore structures and mechanical properties of fly-ash high performance concrete prepared with recycled aggregates. Cement Concrete Composite. 2016:71:77–84.

[16] EFNARC 2002 Specifications and guidelines for self-compacting concrete. EFNARC, Association House, 99 West Street, Farnham, UK, www.efnarc.org, ISBN 0 953973344, 32pp.

[17] 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, MI, 209–226.

[18] Khayat KH. Workability, testing, and performance of self-consolidating concrete. ACI Mater J 1999; 346–53.

[19] Khayat KH. Workability, testing, and performance of self-consolidating concrete. ACI Mater J 1999; 96: 346–54.

[20] Li V, Kong HJ, Chan YW. Development of self-compacting engineered cementitious composites. In: Proceedings, International Workshop on Self-Compacting Concrete, Kochi, Japan, August, 1998.

[21] Okamura H, Ouchi M. Self-compacting concrete. J Adv Concr Technol 2003; 1: 5–15.

[22] De Schutter G. Guidelines for testing fresh self-compacting concrete, European Research Project, Testing SCC, Growth Contract No. GRD2-2000-30024, 2001–2004.

[23] Sahmaran M, Yurtseven A, Yaman IO. Workability of hybrid fiber reinforced self-compacting concrete. Build Environ 2005; 40: 1672–7.

[24] Aydin, A. C., Oz, A., Polat, R., Mindivan, H., Effects of the Different Atmospheric Steam Curing Processes on the Properties of Self-Compacting-Concrete Containing Microsilica SADHANA Academy Proceedings in Engineering Sciences, Vol. 40, Part 4, June 2015, pp. 1361–1371.

[25] Kurt M, Aydin, A. C., Gül, M. S., Gül, R., Kotan, T., The Effect Of Fly Ash To Self-Compactibility Of Pumice Aggregate Lightweight Concrete, SADHANA Academy Proceedings in Engineering Sciences, Vol. 40, Part 4, June 2015, pp. 1343–1359.

[26] Hasar, U. C., Simsek, O., Aydın, A. C., Application Of Varying-Frequency Amplitude-Only Technique For Electrical Characterization Of Hardened Cement-Based Materials, Microwave And Optical Technology Letters/ Vol. 52, No. 4, April 2010, pp. 801-805.

[27] Hasar, U. C., Akkaya, G., Aktan, M., Gozu, C., Aydın, A. C., Water-To-Cement Ratio Prediction Using ANNs From Non-Destructive And Contactless Microwave Measurements, Progress In Electromagnetics Research, PIER 94, 2009, pp. 311-325.

[28] Kurt M, Kotan, T., Gül, M. S., Gül, R., Aydin, A. C., The Effect of Blast Furnace Slag to Self-Compactability of Pumice Aggregate Lightweight Concrete, SADHANA Academy Proceedings in Engineering Sciences, 41(2), February 2016, pp. 253-264.

[29] Kurt M, Gül, M. S., Gül, R., Aydin, A. C., Kotan, T., The effect of pumice powder on the self-compactability of pumice aggregate lightweight concrete,, Construction and Building Materials, Vol. 103, 30 January 2016, pp. 36–46.