Freeze-Thaw Resistance of Self Compacting Concrete Incorporating Basic Pumice

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Abstract: - In this study, an experimental study was conducted to investigate the effect of basic pumice on frost resistance of self-compacting concrete (SCC). A total of 6 SCCs with a water/binder ratio of 0.32 was produced in which crushed stone replaced with basic pumice in 5 different mixture ratios with increased 5% from 10% to 30% as well as control of self-compacting concrete (SCC-C) without basic pumice. Within the scope of this study, ultrasonic pulse velocity (UPV) and mass loss values were measured at every 50 cycles. Moreover, relative dynamic modulus of elasticity (RDME) and durability factor (DF) of all SCCs were calculated. At the end of 300 freeze-thaw cycles, compressive strength of all SCC mixtures was tested to obtain the freeze-thaw resistance of basic pumice. According to experiment results that carried out, using of basic pumice up to 20% increased the frost durability of SCC mixtures.

Key-Words: - Frost resistance, basic pumice, self-compacting concrete, ultrasonic pulse velocity, mass loss

1 Introduction

The production of self-compacting concrete (SCC) that settled under its own weight and quite easily fill densely reinforced intersects of formwork thanks to the high fluidity without the need of internal or external vibrations and segregation or bleeding during casting [1,2] is one of the most important technology improvements in construction industry [3,4]. Due to occupation of 60-70% of the concrete volume, aggregates play a main role in affecting workability, strength, dimensional stability, and durability as well as the cost of SCC [5,6].

Pumice is a natural, lightweight and puzzolanic material of volcanic origin [7,8]. Pumice, occurred with the result of sudden cooling, has acquired an extremely porous structure [7]. While basic pumice that main research topic of this study has a black or brown color, acidic pumice has a white and off-white [9,10]. Pumice, the most commonly found and the most used in the earth is acidic pumice. Namely, usage area of basic pumice is less than that of acidic pumice [7]. Approximately, 7.4 billion m^3 (40%) of total pumice reserve (18 billion m^3) of the world is located in Turkey [11].

The frost resistance is one of the most important durability parameters for concrete [12], especially significant in cold climates [13,14]. Considering concrete structures in cold environments, as water freezes to ice, it expands, exerting tensile forces on the material. If these forces exceeds material strength, cracks occurs as an irreversible damage on the structure. As a result of the continuation of thawing action, the water then moves through the cracks, expanding them further, and leads to more damage when freezing action occurs again. This can be result with the deterioration and failure of concrete structures. As the result of freezing and thawing, internal damage has gained more attention for concrete designed with low water/binder ratio (w/b) as well as external damage [15,16]. It is known that porous structure and water absorption capacity of aggregate, air content and water-cement ratio of concrete has a great importance in terms of freeze-thaw resistance of concrete [13,17]. Due to having more porous and permeable structure of aggregate, hydraulic pressures that generated in the porous structure of concrete can be more easily dissipated [18]. Therefore, it can be improved the durability of concrete against to freeze-thaw action [17].

It is known that pumice has high sound and heat insulation properties due to having connected and disconnected pores [8,19]. However, in studies carried out by R. Polat et al. [15] and M.B. Karakoc et al. [16], it have been identified the positive effects of pumice on freeze-thaw action of concrete.

Considering the literature studies, there is very few studies written to explain effects on freeze-thaw action of basic pumice aggregate, especially in the production of self-compacting concrete.

The main objective of the study presented herein is to investigate the effect of basic pumice on the frost resistance of self-compacting concrete (SCC) designed with w/b=0.32. First of all, control concrete of self-compacting concrete (SCC-C) without basic pumice was produced. Then, SCCB10, SCCB15, SCCB20, SCCB25 and SCCB30 were generated by using basic pumice instead of crushed stone in the ratios 10%, 15%, 20%, 25% and 30%, respectively. All of SCC mixtures were exposed to freeze-thaw cycles up to 300 cycles. The ultrasonic pulse velocity (UPV) values and mass losses at every 50 freeze-thaw cycles of all SCC mixtures were specified. Lastly, compressive strength of all SCC mixtures subjected to 300 freeze-thaw cycles and curing application were tested.

2 Materials and Methods

2.1 Materials

CEM I 42,5R type Ordinary Portland cement conforming to TS EN 197 [20] (mainly based on the European EN 197-1) was utilized in preparing the concrete specimens. Fly ash (FA) was utilized as mineral additive material in the production of SCC. Physical and chemical properties of these materials are listed in Table 1. High-Range-Water-Reducing-Admixture (HRWRA) with a specific gravity of 1.07 as plasticizer additive material was utilized to provide the desired workability.

To determine aggregate properties, specific gravity and water absorption tests were performed as per ASTM C127 [21]. It was found that water absorption capacity for basic pumice of 4-8 mm diameter was obtained as %9.42 and that of basic pumice of 8-16 mm diameter was identified as %8.15 while specific gravity in saturated surface dry condition of basic pumice for 4-8 and 8-16 mm grain size used as coarse aggregate were determined as 2.17 and 2.09, respectively. However, natural fine aggregate was a mixture of crushed and natural river sands with specific gravities of 2.63 and 2.67, respectively. Crushed stone aggregate with a maximum size of 16 mm and with a specific gravity of 2.65 was also used. A photograph of basic pumice in 4-8 and 8-16 mm grain size is shown in Fig. 1.

Table 1. Physical and chemical properties of Portland cement and fly ash

Chemical Analysis (%)	Cement	Fly Ash
CaO	62,58	2,24
SiO_2	20,25	57,2
Al_2O_3	5,31	24,4
Fe_2O_3	4,04	7,1
MgO	2,82	2,4
SO_3	2,73	0,29
K_20	0,92	3,37
Na_2O	0,22	0,38
Loss of Ignition	2,96	1,52
Specific Gravity	3,15	2,04
Blaine Fineness (m^2/kg)	326	379

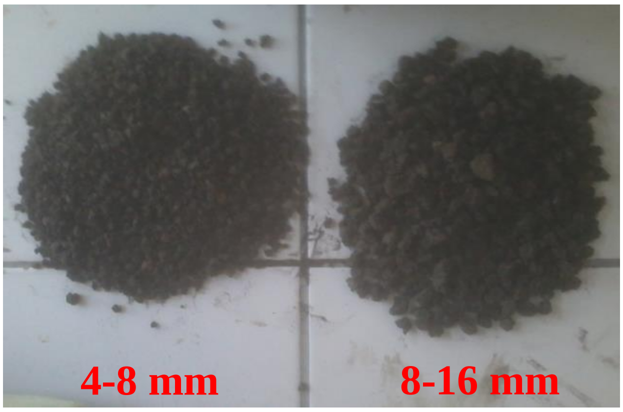

Fig. 1. View of basic pumice in 4-8 and 8-16 mm grain size

2.2 Preparation of the concrete mixtures

Batching and mixing procedures were applied according to ASTM C192/C192M [22]. A total of 6 SCC mixtures were designed with a constant w/b ratio of 0.32 and a total cementitious material content of 550 kg/m^3 incorporating binary cementitious blends of 20% FA and 80% Portland cement. The mixes were all the same except the natural aggregate being replaced by pumice aggregate at different proportions as illustrated in Table 2. At first, the control mixture (SCC-C) included 100% natural aggregates were produced. Then, the process of replacement was conducted in volume fractions from 10% to 30% at 5% increments by volume of pumice coarse aggregate. Before mixing, basic pumice was exposed in water for 24 hours to provide adequate saturation and then by wiping with the towel just before the mixture have saturated surface dry condition.

Table 2. Mixture ratios SCC-C and SCCBs

Code Number	Water/Binder	Cement + Fly Ash	Coarse Aggregate (kg/m^3)			Fine Aggregate (kg/m3)		HRWRA
			Crushed Stone	Basic Pumice		Crushed Stone	Natural Sand	
		kg/m^3	4-16 mm	4-8 mm	8-16 mm	0-2 mm	0-4 mm	(gr)
SCC-C	0,32	550	822	0	0	244,7	579,8	210
SCCB10	0,32	550	657,6	67,3	64,8	244,7	579,8	195
SCCB15	0,32	550	575,4	101	97,2	244,7	579,8	180
SCCB20	0,32	550	493,2	134,6	129,7	244,7	579,8	170
SCCB25	0,32	550	411	168,3	162,1	244,7	579,8	160
SCCB30	0,32	550	328,8	201,9	194,5	244,7	579,8	150

SCCBs were designed with a slump flow diameter of 690±20 mm, by adjusting the amount of HRWRA. At the end of the trial batching procedure, it was obtained that the process of basic pumice replacement in the SCC was performed up to 30% due to EFNARC limitations [23]. Basic pumice reduced workability of SCC by increasing of T_{500} time and V-funnel flow time, by decreasing of slump flow diameter and L-box height-ratio. The basic reason can be explained that basic pumice has too much surface roughness as well as the irregular shape.

2.3 Test procedures

Freeze-thaw durability tests were conducted as 300 cycles on three 100x100x100 mm cubic specimens for every SCC mixture. According to ASTM C666 – Procedure A [24], specimens were exposed to freeze-thaw cycles with a machine provided temperature conditions, raising from -18 °C to + 4 °C and reducing from +4 °C to -18 °C. Thanks to the specified these degrees, freezing for 3.5 hours, and then thawing for 1.5 hours of specimens were allowed. This procedure applied to specimens throughout 300 freeze-thaw cycles.

Deterioration was determined by means of UPV measurements which given preliminary idea about some properties of concrete such as compressive strength, relative dynamic modulus of elasticity (RDME) and durability factor (DF). Measurements were made at every 50 cycles up to 300 freeze-thaw cycles. Nevertheless, changes of weight for specimens were measured at every 50 cycles. RDME and DF values computed according to ASTM C666 – Procedure A [24] thanks to UPV measures identified for all mixtures at the end of freeze-thaw cycles have been determined by the Eq. 1 and Eq. 2, respectively, [25]. The equations and meanings of abbreviations used in the equations are shown in Table 3.

At the end of 300 cycles, compressive strength measurements of 100x100x100 mm cubic specimens that exposed to both of freeze-thaw (three cube samples) and permanent cure application (three cube samples) were carried out according to ASTM C 39 [26]. The compressive strength of specimens was determined by averaging of the test results for three cubic specimens.

Mass loss of three cubic specimens for all SCC mixtures at every 50 freeze-thaw cycles was specified. Measurement process has been performed through a normal weighing.

3 Results and Discussion

3.1 Ultrasonic pulse velocity

The values of UPV for control concrete and SCCBs at every 50 freeze-thaw cycles are shown in Table 4. In addition, percentage change of UPV values at every 50 freeze-thaw cycles is presented in Fig. 2. Considering the results measured after 300 freeze-thaw cycles, the best result was obtained for SCCB10. UPV values specified at the end of 300 freeze-thaw cycles with respect to first reading, declined in the ratios of 6.67%, 3.29%, 4.39%, 5.74%, 6.24% and 7.01% for SCC-C, SCCB10, SCCB15, SCCB20, SCCB25 and SCCB30, respectively.

Table 3. The equations and meanings of abbreviations used in the equations

RDME = $(v_c^2 / v_0^2)*100$ Eqn. (1)	DF = (RDME)*(N)/M Eqn. (2)
RDME	Relative dynamic modulus of elasticity at N cycles, %
v_c	Ultrasonic pulse velocity measured in c freeze-thaw cycles
v_0	Ultrasonic pulse velocity measured without exposed to the freeze-thaw cycles
DF	Durability factor of the test specimen
N	Number of cycles at which RDME reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less
M	Specified number of cycles at which the exposure is to be terminated

Table 4. UPV values at every 50 freeze-thaw cycles

Code	Freeze-Thaw Cycles						
	First reading	50 Cycles	100 Cycles	150 Cycles	200 Cycles	250 Cycles	300 Cycles
SCC-C	5155	5100	5061	4995	4941	4847	4811
SCCB10	4958	4941	4910	4896	4864	4815	4795
SCCB15	4946	4916	4893	4847	4795	4753	4729
SCCB20	4928	4885	4862	4802	4743	4690	4645
SCCB25	4901	4848	4808	4755	4704	4627	4595
SCCB30	4895	4800	4736	4687	4630	4586	4552

While basic pumice used up to 20% increased freeze-thaw resistance of SCC, SCC incorporating 30% basic pumice decreased. The freeze-thaw resistance of SCC containing 25% pumice was close to the control concrete. The main reason for this, pumice that a permeable aggregate has porous structure ranging from fully closed to fully open [18,27]. As a matter of fact, the frost resistance of concrete is dependent mainly upon its permeability, amount of freezable water and rate of freezing and degree of saturation [28]. Moreover, UPV values decreased with increased the number of freeze-thaw cycles [29].

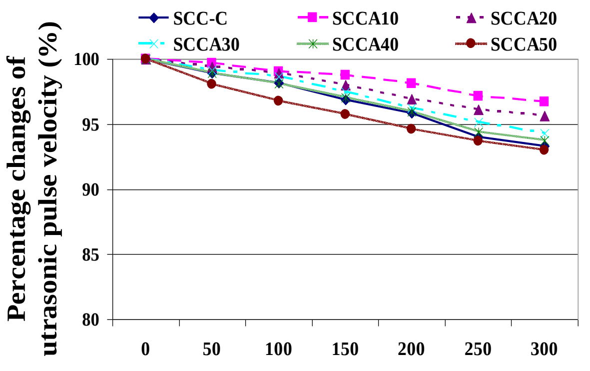

Fig. 2. UPV as percentage at every 50 freeze-thaw cycles

3.2 Relative dynamic modulus of elasticity and durability factor

The graphical view of RDME is generally used to identify the frost resistance of concrete and DF calculated depending on RDME are listed in Fig. 3 and Fig. 4, respectively. Also, the variation in the value of RDME over the entire duration of freezing and thawing cycles gives pre-understanding about the strength of the concrete. As it is seen in Fig. 3, RDME value calculated with Eqn. (1) at the end of 300 freeze-thaw cycles was found as 87.10%, 93.53%, 91.42%, 88.84%, 87.90% and 86.48% for SCCs incorporating basic pumice aggregate in the ratios of 0%, 10%, 15%, 20%, 25% and 30%, respectively. However, as seen Fig. 4, the test results for DF values were similar with that of the RDME value. Considering the test results of RDME and DF values, it can be concluded that the best data determined for SCCB10. Nevertheless, the frost resistance of SCC-C and SCCB25 were close to each other. The reason of this, pumice has a porous and permeable structure [18,27]. Moreover, RDME and DF data obtained from the SCCB30 were lower than that of SCC-C. The main reason for reduction of frost resistance in concrete incorporating 30% basic pumice is creation extra spaces and weak aggregate phase in concrete [30].

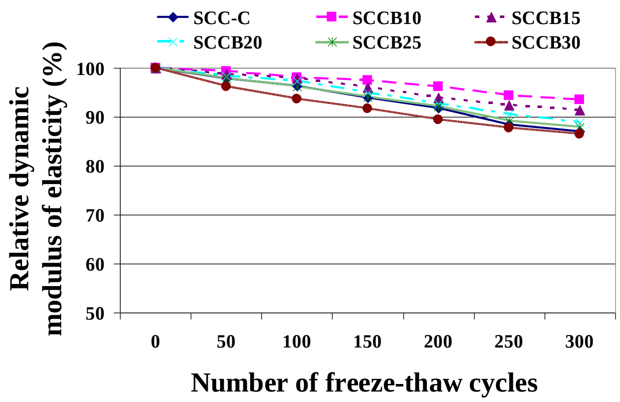

Fig. 3. RDME as percentage at every 50 freeze-thaw cycles

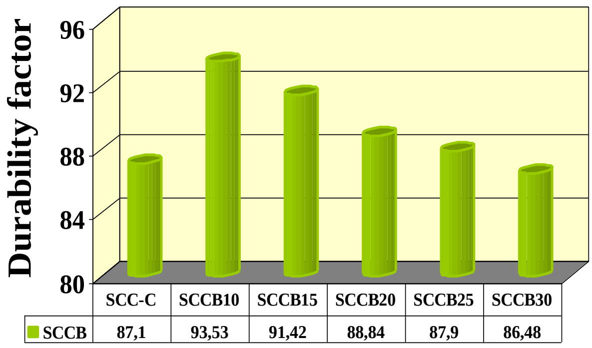

Fig. 4. DF of all SCC mixtures

3.3 Compressive strength

Compressive strength changes of specimens exposed to 300 freeze-thaw cycles and continuous cure application throughout 300 cycles are listed in Table 5. The results of the compressive strength of specimens for each SCC mixture are graphically presented in Fig. 5. Compressive strength of SCC-C, SCCB10, SCCB15, SCCB20, SCCB25 and SCCB30 mixtures decreased as 16.06%, 13.49%, 14.37%, 15.02%, 16.15% and 16.96%, respectively, with respect to mixtures subjected to continuous cure application throughout 300 cycles. As it is known, the strength variation reflects the degree of the resistance to freezing and thawing [31]. It can be concluded that SCCB10 showed the best freeze-thaw resistance. However, the main reason for the less reduction occurred strength up to 20% is improvement of the interfacial transition zone of SCC [17]. As given in study by Karakoç et al. [16], pore structure is the most significant parameter stating durability of concrete, especially concrete subjected to cycles of freezing and thawing. Additionally, the using of porous and permeable aggregate in SCC can improve hydration due to absence of shrinkage-induced microcracking and continuous internal curing [30]. The percentage reduction occurred in compressive strength of SCC-C and SCCB25 were almost equal while it was higher for SCCB30 than that of SCC-C. Because, excessive air voids and weak aggregate phase are creation extra spaces in concrete. As a result of this, the compressive strength of concrete reduced [30].

Table 5. The percentage compressive strength of specimens

Mixtures	Exposed to Continuous Cure Application	Exposed to 300 Freeze-Thaw Cycles
SCC-C	100	83,94
SCCB10	100	86,51
SCCB15	100	85,63
SCCB20	100	84,98
SCCB25	100	83,85
SCCB30	100	83,04

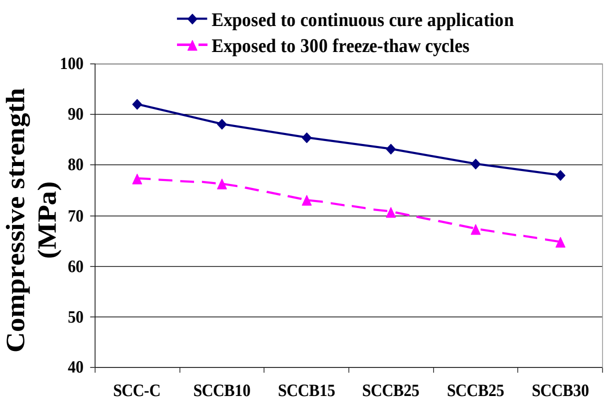

Fig. 5. Compressive strength of specimens

3.4 Mass loss

Specimen weights at every 50 cycles are given in Table 6 and the variations of these values are also graphically shown in Fig. 6. As it is seen in Fig. 6, while the percentage mass loss of control concrete was found 0.42%, that of SCC mixtures incorporating basic pumice in the ratios of 10%, 15%, 20%, 25% and 30% were calculated as 0.26%, 0.30%, 0.34%, 0.41% and 0.48%. In comparison with SCC-C, the best results were obtained for SCCB10, SCCB15 and SCCB20. The reason of this situation is high water degree holding capacity of pumice. The percentage mass loss of SCC-C and SCCB25 gave similar results. However, the main reason of greater percentage mass loss of SCCB30 is the spalling effect and weak aggregate phase of pumice [30].

Table 6. Specimen Weights

Code	Specimen Weights (gr)						
	First Reading	50 Cycles	100 Cycles	150 Cycles	200 Cycles	250 Cycles	300 Cycles
SCC-C	2387	2386,5	2384,5	2382,5	2380,5	2379	2377
SCCB10	2316	2315,7	2314	2313	2312	2311,5	2310
SCCB15	2332	2331,7	2329,4	2328,7	2327,4	2327	2325
SCCB20	2323	2322,6	2320	2319	2318	2317	2315
SCCB25	2309	2308,5	2307	2305	2302,4	2300,6	2299,5
SCCB30	2293	2292,2	2289	2287	2285,5	2284,5	2282

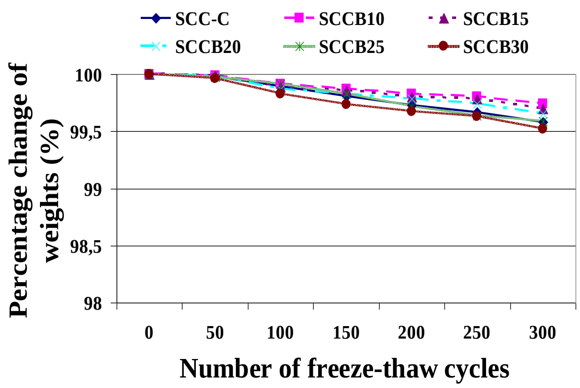

Fig. 6. Percentage change values of weights

4 Conclusions

It can be concluded the following results from this study;

- UPV, RDME and DF values decreased by using basic pumice. However, considering the percentage changes of them at the end of 300 freeze-thaw cycles, it can be concluded that basic pumice up to 20% in SCC can be used for the resistance of freezing and thawing. Utilization of pumice in the ratio 30% declined the frost resistance of SCC.
- Compressive strength of SCCs decreased by the increasing of basic pumice at the end of 300 freezing and thawing cycles. However, considering the percentage changes of compressive strength test results, the best results for the resistance of freezing and thawing were obtained from SCCB10, SCCB15 and SCCB20, respectively. This conclusion can be explained by the positive effect for pumice aggregate with porous and permeable structure since the frost resistance of concrete can be affected its permeability, amount of freezable water and rate of freezing and degree of saturation. Nevertheless, using of pumice in the ratio of 30% causes extra spaces and decreases the freeze-thaw resistance of SCC.
- Increasing number of freeze-thaw cycles increased mass loss for all mixtures. While the best result was obtained for SCCB10, SCCB30 had the worst result. The percentage mass loss measured for SCCB30 can be explained the spalling effect and the weak aggregate phase of pumice.

References:

[1] E. Güneyisi, M. Gesoglu, E. Booya, K. Mermerdas, Strength and Permeability Properties of Self-Compacting Concrete with Cold Bonded Fly Ash Lightweight Aggregate, *Construction and Building Materials*, Vol.74, 2015, pp. 17-24.

[2] H. Zhao, W. Sun, X. Wu, B. Gao, ‘‘The Properties of the Self-Compacting Concrete with Fly Ash and Ground Granulated Blast Furnace Slag Mineral Admixtures, *Journal of Cleaner Production*, Vol.95, 2015, pp. 66-74.

[3] P.C. Ryan, A. O'Connor, Comparing the Durability of Self-Compacting Concretes and Conventionally Vibrated Concretes in Chloride Rich Environments, *Construction and Building Materials*, Vol.120, 2016, pp. 504-513.

[4] M. Sonebi, S. Nanukuttan, Transport Properties of Self-Consolidating Concrete, *ACI Materials Journal*, Vol.106, No.2, 2009, 161-166.

[5] O. R. Khaleel, S.A. Al-Mishhadan, H.A. Razak, The Effect of Coarse Aggregate on Fresh and Hardened Properties of Self-Compacting Concrete (SCC), *Procedia Engineering*, Vol.14, 2011, pp. 805-813.

[6] M.D. Safiuddin, M.A. Salam, M. Z. Jumaat, Effects of Recycled Concrete Aggregate on the Fresh Properties of Self-Consolidating Concrete, *Archives of Civil and Mechanical Engineering*, Vol.11, No.4, 2011, pp. 1023-1041.

[7] A. Tolgay, E. Yasar, Y. Erdogan, Nevşehir Pomzasının Agrega Olarak Betonda Kullanılabilirliğinin Araştırılması, *5. Endüstriyel Hammaddeler Sempozyumu*, Izmir, Turkey, 13-14 May 2004.

[8] O. Gencel, Characteristics of Fired Clay Bricks with Pumice Additive, *Energy and Buildings*, Vol.102, 2015, pp. 217-224.

[9] M. Duman, A. Şekeroğlu, Pomza Taşı için Alternatif Bir Kullanım Alanı: Etlik Piliç Yetiştiriciliği, *Niğde İli Endüstriyel Hammaddeler Sempozyumu*, Nigde, Turkey, 20 April 2016.

[10] H. Köse, Ç. Pamukçu, N. Yalçın, T. Seçer, Pomza ve Yapı Malzemesi Olarak Kullanım Olanakları, *2. Endüstriyel Hammaddeler Sempozyumu*, Izmir, Turkey, 16-17 October 1997.

[11] M. Kurt, M.S. Gul, R. Gul, A.C. Aydin, T. Kotan, The Effect of Pumice Powder on the Self-Compactability of Pumice Aggregate Lightweight Concret, *Construction and Building Materials*, Vol.103, 2016, pp. 36-46.

[12] O. Pospichal, B. Kucharczykova, P. Misak, T. Vymazal, Freeze-Thaw Resistance of Concrete with Porous Aggregate, *Procedia Engineering*, Vol.2, 2010, pp. 521-529.

[13] Y. Wu, B. Wu, Residual Compressive Strength and Freeze-Thaw Resistance of Ordinary Concrete After High Temperature, *Construction and Building Materials*, Vol.54, 2014, pp. 596-604.

[14] M. Tuyan, A. Mardani-Aghabaglou, K. Ramyar, Freeze-Thaw Resistance, Mechanical and Transport Properties of Self-Consolidating Concrete Incorporating Coarse Recycled Concrete Aggregate, *Materials and Design*, Vol.53, 2014, pp. 983-991.

[15] R. Polat, R. Demirboga, M.B. Karakoc, I. Turkmen, The Influence of Lightweight Aggregate on the Physic-Mechanical Properties of Concrete Exposed to Freeze-Thaw Cycles", *Cold Regions Science and Technology*, Vol.60, 2010, pp. 51-56.

[16] M.B. Karakoc, R. Demirboga, I. Turkmen, I. Can, Modeling with ANN and effect of pumice aggregate and air entrainment on the freeze-thaw durabilities of HSC, *Construction and Building Materials*, Vol.25, 2011, pp. 4241-4249.

[17] J.A. Bogas, J. De Brito, D. Ramos, Freeze-Thaw Resistance of Concrete Produced with Fine Recycled Concrete Aggregates, *Journal of Cleaner Production*, Vol.115, 2016, pp. 294-306.

[18] G. Verbeck, R. Landgren, Influence of Physical Characteristics of Aggregates on Frost Resistance of Concrete, *Portland Cement Association*, 1960.

[19] M. Sarıdemir, Alkali ile Aktive Edilmiş Öğütülmüş Pomzalı Harçların Dayanım Özellikleri, *Nigde İli Endüstriyel Hammaddeler Sempozyumu, Nigde*, Turkey, 20 April 2016.

[20] TS EN 197-1, *Cement-Part 1: Composition, Specifications and Conformity Criteria for Common Cements*, Turkish Standards, 2002.

[21] ASTM C 127, *Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate*, Annual Book of ASTM Standards, 2007.

[22] ASTM C192/C192M, *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*, Annual Book of ASTM Standards, 2007.

[23] EFNARC, *European Guidelines for Self-Compacting Concrete, Specification and Production and Use*, Association House, UK, 2005.

[24] ASTM C666/C666M-15, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*, Annual Book of ASTM Standards, 2015.

[25] M. Piegon, R. Pleau, Durability of Concrete in Cold Climates, *Modern Concrete Technology 4*, E&FN SPON, London, 1995.

[26] ASTM C39, *American Society for Testing and Materials, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, Annual Book of ASTM Standards, vol. 04.02. West Conshohocken, PA: ASTM, 2012.

[27] H. Cai, X. Liu, Freeze-thaw durability of concrete: ice formation process in pores, *Cement and Concrete Research*, Vol.28, No.9, 1998, pp. 1281-1287.

[28] M.D. Cohen, Y. Zhou, W.L. Dolch, Non-air-entrained high strength concrete – is it frost resistant? *ACI Materials Journal*, Vol.89, No.4, 1992, pp. 406–415.

[29] S. Mönnig, P. Lura, Superabsorbent polymers-an additive to increase the freeze– thaw resistance of high strength concrete, *Advances in Construction Materials*, 2007, pp.351–358.

[30] P. Lura, P.D. Bentz, D.A. Lange, K. Kovler, A. Bentur, Pumice aggregates for internal water curing, *In: Proceedings international RILEM symposium*, Evanston, IL, March Vol.22-24, 2004, pp. 137-151.

[31] R.H. Salem, E.G. Burdette, N.M. Jackson, Resistance to freezing and thawing of recycled agregate concrete, *ACI Materials Journal*, Vol.100, No.3, 2003, pp. 216–221.