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Effect of aggregate type on heated self-compacting concrete

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Abstract. In this study, two types of aggregate were used for making self-compacting concrete. Standard cubic specimens were exposed to different temperatures. Seventy-two standard cylindrical specimens (150×300 mm) and Seventy-two cubic specimens (150 mm) were tested. Compressive strengths of the manufactured specimens at 23℃ were about 33 MPa to 40 MPa. The variable parameters among the self-compacting concrete specimens were of sand stone type. The specimens were exposed to 23, 100, 200, 400, 600, and 800℃ and their mechanical specifications were controlled. The heated specimens were subjected to the unconfined compression test with a quasi-static loading rate. The corresponding stress-strain curves and modulus of elasticity were compared. The results showed that, at higher temperatures, Scoria aggregate showed less sensitivity than ordinary aggregate. The concrete made with Scoria aggregate exhibited less strain. The heated self-compacting concrete had similar slopes before and after the peak. In fact, increasing heat produced gradual symmetrical stress-strain diagram span.

Keywords: thermal effects; self-compacting concrete; elastic module; stress-strain curve; aggregate types

1. Introduction

Designing fire-resisting structures requires examining materials and behavior of a structure under high temperatures. The analysis and modeling of material behavior in these conditions are performed through software and complying with experimental results. The effect of temperature rise on the behavior of various materials varies. Therefore, the composite materials made of different materials exhibit complex behaviors and specific changes. Concrete is used for making various structures and is often used in combination with steel and steel rebar. Today, self-compacting concrete (SCC) is used increasingly and it is necessary to be familiar with its behavior at high temperatures for the analysis of structural behavior under fire. Aggregates play an effective role in transmitting compressive force in concrete. Heat also affects concrete by developing cracks in the concrete structure. Cracks in the concrete structure affect strain and lead to permanent deformation in concrete. These cracks are due to the different thermal contraction/expansion behaviors of concrete and the aggregates. Expansion and compression in the aggregates cause cracking and the cracks affect mechanical properties of the concrete (Shafigh *et al*. 2016).

Physical and chemical properties of the materials and concrete used in a structure are changed due to high temperatures. Compressive strength and the modulus of elasticity of concrete reduce due to heat (Sancak 2008, Mydin and Wang 2012, Petkovski 2010, Xiao and Konig 2004, Georgali and Tsakiridis 2005, Sanad *et al*. 2000, Poon *et al*. 2004, Sun *et al*. 2000, Ismail *et al*. 2011, Ali *et al*. 2004).

Some studies also discussed the effect of heat on tensile strength and stress-strain diagram. Due to changes of specifications of concrete, materials used, and differences in size of specimens, it is less likely to compare the obtained results accurately (Janotka and Nurnbergerova 2005, Chang *et al*. 2006, Youssef and Moftah 2006, Carreira and Chu 1985). Modeling, compressive strength analysis, the modulus of elasticity, and stress-strain relations of concrete are necessary for designing fire resistant structures (Hernández and Barluenga 2004, Tanyildizi and Cevilk 2010, Li and Purkiss 2005, Cui *et al*. 2012, Annerel and Taerwe 2009, Chandra *et al*. 1980, Khennane and Baker 1993, Terro 1998). The available models attempted to examine and predict concrete behavior under different temperatures with respect to mix type, aggregates type, concrete admixtures, and size of specimens.

With respect to the specifications of SCC, the demand to use it has been increased. Depending on the relevant conditions, admixtures and plasticizers are added to concrete. This concrete is compressed under the influence of its weight and there is no need to apply more vibration anymore. There are many studies on using SCC with respect to the type of lightweight and normal aggregates (Alghamri *et al*. 2016, Karamloo *et al*. 2016). The use of lightweight aggregates that float in a concrete mix may damage monotony of concrete and the effect of heat and mechanical specifications will be very different (Falade *et al*. 2010, Lo *et al*. 2009, Tanyildizi and Coskun 2008, Tanyildizi and Coskun 2008, Sengul *et al*. 2011, Othumn and Wang 2011, Choi *et al*. 2006). Some of the studies also offered models to study behavioral difference among the effects of aggregates on SCC.

This study examines the behavior of self-compacting concrete made with two aggregates, namely, lightweight

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Table 1 Materials qualifications

Materials name	Materials type	Qualifications
Aggregates	Scoria	Bulk: 750 kg/m^3
	Crashed stone	Bulk: 1650 kg/m^3
Water	Normal	PH: 7
Cement	Type 1	Setting time: 135 min, compressive strength: 325 kg/cm^2
Additives	Calcium silicate	Density: 1600 kg/m^3
	Plasticizer	-----

Table 2 Self-compact concretes mixes

Groups name	Aggregate type	Cement percentage			Slump flow cm	Compressive strength (cube) MPa
		Plasticizer	Calcium Silicate	water		
SCC 1	Scoria	3%	4%	35%	63	33
SCC 2	Crashed stone	3%	4%	35%	66	36
SCC 3	Scoria	6%	8%	35%	63	36
SCC 4	Crashed stone	6%	8%	35%	65	39

aggregate (Scoria) and ordinary aggregate (sand). The corresponding modulus of elasticity and stress-strain diagrams were compared. The obtained results were compared with those of the previous models, and a new model was proposed for stress-strain diagram variations and elasticity model.

2. Experimental work

The experimental studies discuss the SCC behavior made of stone sand and scoria at high temperatures. The study of concrete behavior is carried out by comparing the changes made in experimental results and considering variable factors in a test.

2.1 Materials

The manufactured SCC contained calcium silicate. The manufactured SCC contained calcium silicate. Plasticizer was used for improving slump flow (Table 1). Type I Portland cement, two types of stone sands, and scoria were used for making the concrete. Scoria aggregate was used for reducing concrete weight and it was only used within the range of coarse aggregate (sand) of the mix.

2.2 Specimens

Seventy-two (section diameter: 150 mm, high: 300 mm) standard cylindrical specimens and one hundred and eight (150 mm) cubic specimens were tested. The concrete mix was made of the water-to-cement ratio of 35% (Table 2). An equal ratio of gravel-sand was used in the mix. The weights of normal concrete mix and lightweight concrete were estimated to be 2440 kg/m^3 and 1730 kg/m^3, respectively.

Fig. 1 The specimens were taken out of the molds and kept for 26 days in a pool

Fig. 2 Test machine (A: heater, B: compressive test, C: V funnel test, D: L test)

2.3 Curing

First, aggregates were poured in a mixer as saturated surface dry (SSD) and cement and micro silica were added to it. After mixing for one minute, a mixture of water and plasticizer was added to it. The mixtures were poured in cylindrical and cubic molds and kept in the molds for 24 hours. The specimens were taken out of the molds and kept for 26 days in a pool containing a mixture of water and some lime for reducing alkaline condition. The specimens were kept at laboratory temperature (23°C) for one day (Fig. 1). They were subjected to heating, loading and testing. Actually, the air holes in the specimens were not dry but the effects of that water is negligible (Lo *et al*. 2009, Arioz 2007, Tanyildizi and Cevik 2010, Lo *et al*. 2009, Fathi and Farhang 2014). The specimens were allowed to cool naturally to room temperature.

2.4 Test machine

The constructed specimens had four different compressive strengths, and were heated and tested at six

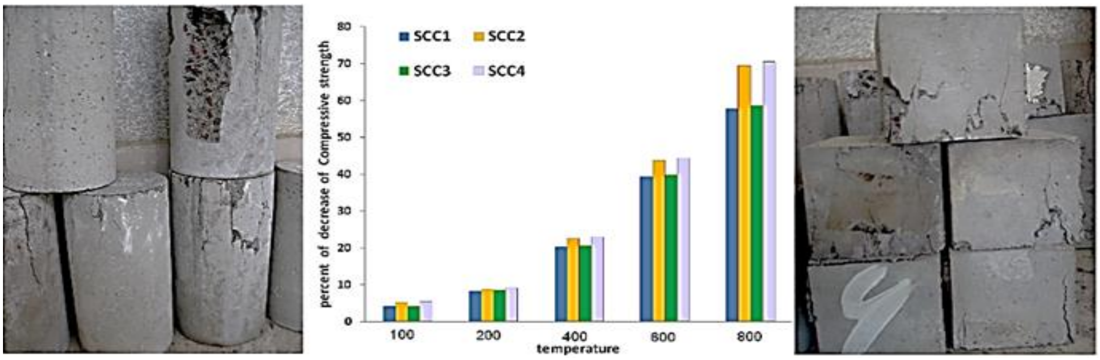

Fig. 3 Compressive strength of specimens at different temperatures

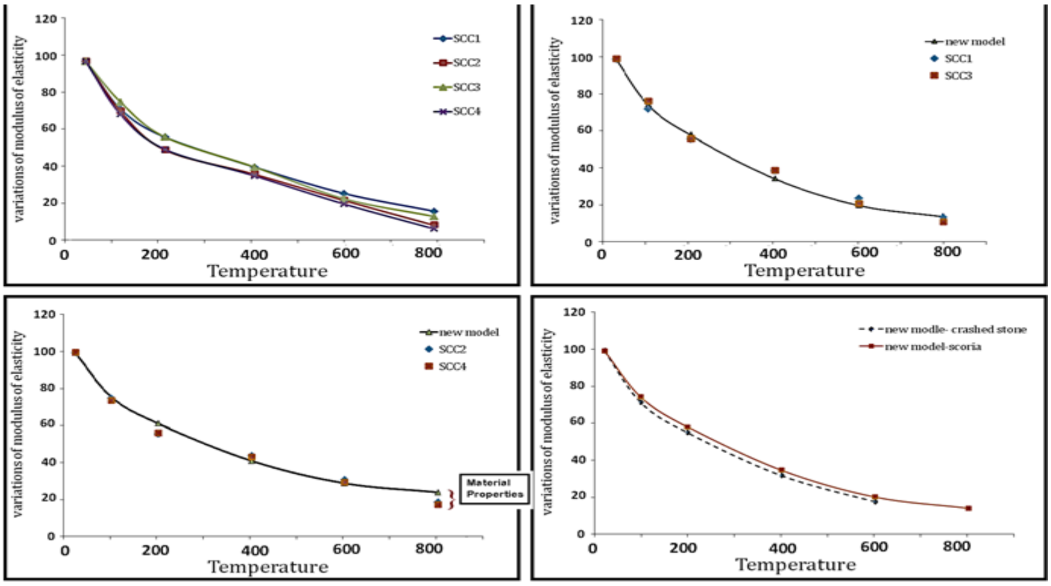

Fig. 4 Elastic moduli of concrete at the high temperatures

Table 3 Some available models for elastic moduli

Concrete type	E_{ct} / E_{ci}	T	Reference
Normal concrete	1-0.0015 T	20<T<300	Hu *et al*. (1994)
	0.8–0.0084 T	200<T≤700	
	0.28	700<T	
	1	20≤T≤60	Jia and Xiao (1996)
	0.83–0.0011 T	60<T≤700	
	(-0.001552 T+1.03104) g	20≤T≤600	Schneider (1986)
	(-0.0025 T+0.25) g	600≤T≤100	
Lightweight concrete	(-0.00102 T+1.0204) g	20≤T≤1000	

$g=1+\frac{f\ ci}{f'c}*\frac{T-20}{100};\frac{f\ ci}{f'c}\leq 3$

E_{ct}:Elastic moduli of concrete at t temperature
E_{ci}:Elastic moduli of concrete

different temperatures (23℃, 100℃, 200℃, 400℃, 600℃ and 800℃). The heating rate was 10˚C/min. The cylindrical specimens were tested under uniform compressive uniaxial loading. The concrete beams were placed under uniaxial loading at the center and the flexure applied to the beams was controlled. A loading rate of about 5KN/s was deployed

Table 4 Proposed models for elastic modules the different temperatures

Concrete type	Proposed models for elastic module	Temperature	α - factor
SCC normal weight	$100*((T-T_o)*(0.0045+\frac{1}{2\,T}))*23*\alpha*E_o$	23≤T≤800	$\alpha=1.75-\frac{T}{1000}$
SCC light weight	$100*((T-T_o)*(0.0045+\frac{1}{2.5\,T}))*23*\alpha*E_o$	23≤T≤ 800	

T_o=primary temperature, E_o=primary elastic module at T_o

within the quasi-static range (Fig. 2).

3. Results and discussion

This research discussed the effect of heat on compressive strength and strain changes with respect to stress and elastic module (gradient of stress-strain diagram) in SCC. NSC and LSC were compared and the results of this comparison were used for modeling the mechanical behavior of concrete at different temperatures.

3.1 Compressive strength

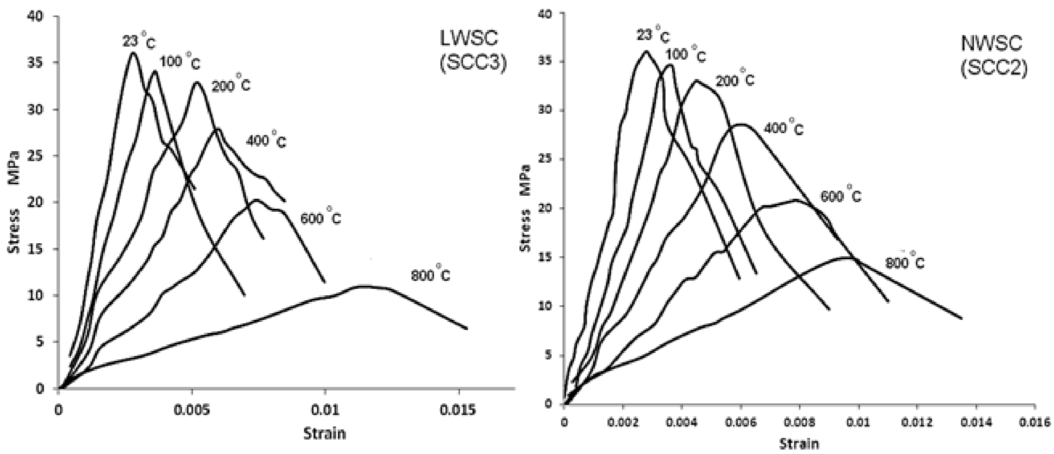

Fig. 5 Compressive stress–strain curves for NWSC and LWSC after heating

Compressive strength of normal concrete reduces with increasing temperature (Cui *et al*. 2012, Annerel and Taerwe 2009, Chandra *et al*. 1980, Khennane and Baker 1993, Terro 1998). The strength reduction occurs with respect to temperature intensity and is more considerable at higher temperatures (Falade *et al*. 2010, Lo *et al*. 2009, Tanyildizi and Coskun 2008, Tanyildizi and Coskun 2008, Sengul *et al*. 2011). The SCC specimens were tested at 23, 100, 200, 400, 600, and 800℃ temperatures and uniaxial compressive strengths of the specimens were calculated using the quasi-static loading speed (Fig. 3).

The rate of compressive strength reduction (percentage) with respect to the test temperature showed that SCC's compressive strength reduction with normal aggregates exceeded that of the LSC. The difference between NSC and LSC compression strengths at 600℃ and 800℃ was considerable. In fact, the difference became greater at higher temperatures. Table 2 shows SCC compressive strength at 23℃ and Fig. 3 shows its reduction in percent.

3.2 Modulus of elasticity

Heat reduces SCC elastic module. Elastic module reduction results in considerable changes in the 23℃-200℃ temperature range. The intensity of changes reduces past this range. In fact, elastic module changes become milder in 400℃-800℃ temperature range as compared with lower temperatures. The studies show that the SCC with further compressive strength encounters more severe changes in the elastic module due to being heated. The higher the SCC compressive strength, the higher the elastic module reduction caused by temperature rise (Fig. 4).

Various models have been proposed for predicting heated concrete behavior and determining concrete elastic module with respect to temperature variations (Table 3). They are classified with respect to concrete type and are often in the form of a combination of discontinuous linear equations. Table 4 presents some models for predicting heated SCC behavior. This model is for determining NSC and LSC elastic module and the two models are different as far as the effect of temperature coefficient is concerned.

With respect to the different effects of temperature on the behavior and elastic modules of NSC and LSC, the two behavioral models display further differences at higher temperatures (Fig. 4). The proposed models have appropriate compatibility with the experimental results.

However, with respect to the specimen’s compressive strength and the effect of compressive strength on elastic module changes in reaction to temperature rise, these models will be slightly different with the experimental results at a high temperature. Of course, simplicity, continuity, and accuracy of the model demonstrate its superiority. The model predicts heated SCC behavior through a continuous relationship using the initial temperature and the initial elastic module depending on that temperature.

The investigations indicate that the aggregate type directly affects thermal resistance and the degree to which heat affects concrete behaviour. The behavioural variations of the concrete did not depend on a specific temperature and the concrete showed different responses depending on aggregate type in different temperatures. The change in concrete behavior at temperatures above 400℃ did not merely depend on aggregate type. This temperature also affected the behaviour of cement mortar.

3.3 Strain-stress curve

Concrete strain can be determined with respect to the imposed stress, thermal-caused initial cracks, absorbed energy, and persistent strains caused by high temperatures through studying stress-strain diagram. Fig. 5 shows an SCC compressive stress-strain curve under a uniaxial uniform loading for NSC and LSC. As the stress-strain curve of the heated concrete shows, the dependent strains on a fixed stress increase with rising temperatures, which is due to the extension of initial thermal micro cracks. The stress-strain curve takes an extended form with the thermal SCC compressive strength reducing. Studies show that the level below the stress-strain diagram has slight changes due to increase in temperature.

Studying the stress-strain curve proves that the changes of stress-strain curve up to the temperatures below 400℃ is different from concrete behavior at the temperature above

Table 5 Stress-strain relation unloaded concrete at high temperatures

Stress	Limitation	Stress-Strain relation	Temperature	Reference
σ_{ct}	$\varepsilon_{ct}>\varepsilon_{max}$	$f_c.[1-(\frac{\varepsilon ct-\varepsilon max}{3 .\varepsilon max})^2]$	$T\leq 800$	Lie *et al.* (1985)
	$\varepsilon_{ct}\leq\varepsilon_{max}$	$f_c.[1-(\frac{\varepsilon max - \varepsilon ct}{\varepsilon max})^2]$		
σ_{ct}	$\varepsilon_{ct}>\varepsilon_{max}$	$f_c.[1-(\frac{30 (\varepsilon ct - \varepsilon max)}{(130-f'c).\varepsilon max})^2]$		Kodur *et al.* (2004)
	$\varepsilon_{ct}\leq\varepsilon_{max}$	$f_c.[1-(\frac{\varepsilon max - \varepsilon ct}{\varepsilon max})^H]$		
$\frac{\sigma ct}{f'ct}$	--------	$\sigma_{uo}[0.00165(\frac{T}{100})^3- 0.03(\frac{T}{100})^2+0.025(\frac{T}{100})+1.002$		Chang *et al.* (2006)
σ_{ut}	$E_T=E_o$	$M(\frac{\varepsilon ct}{\varepsilon cr}) / [1+(m-\frac{n}{n-1})(\frac{\varepsilon ct}{\varepsilon cr}) + (\frac{1}{n-1})(\frac{\varepsilon ct}{\varepsilon cr})^n]$	$T\leq 60$	Eurocode2 (2003)
	$E_T=\frac{800-T}{740}E_o$		$60<T\leq 800$	

$M=\frac{E r}{E'cr}$, $M_o=\frac{E c}{E'c}$, $E_c=5000\sqrt{f'c}$, $n_o=[\frac{f'c}{12}]+0.77>1 n=n_o(\frac{M}{Mo})^{1.014-0.0007T}$, σ=Stress, ε=Strain, E=Elastic Module, T=Temperature, f'_c=Maximum Compressive Strength, ε_{max}=Strain at Maximum Stress

Table 6 Proposed new model

Concert type	Strain	Temperature	Stress-Strain relations	*B*-factor
SCC normal weight	$\varepsilon\leq\varepsilon_o$	$23\leq T\leq 300$	$(\frac{\sigma*\sqrt{f'c}}{E.})*B+(\frac{\sigma*\sqrt{f'c}*T}{80*E.})$	$B=0.0014\ T+0.34$
		$300\leq T\leq 800$		$B=0.0044\ T-0.91$
	$\varepsilon_o\leq\varepsilon$	$23\leq T\leq 300$	$(\frac{\sigma*\sqrt{f'c}}{E.})^{-1}*(\frac{\sqrt{f'c}}{6BE.})$	$B=-0.0031\ T+1.68$
		$300\leq T\leq 800$		$B=0.0005\ T+0.733$
SCC light weight	$\varepsilon\leq\varepsilon_o$	$23\leq T\leq 300$	$(\frac{\sigma*\sqrt{f'c}}{E.})*B+(\frac{\sigma*\sqrt{f'c}*T}{80*E.})$	$B=0.0022\ T+0.31$
		$300\leq T\leq 800$		$B=0.001\ T-1.6*10^{-5}\ T+2.5*10^{-8}+1.3$
	$\varepsilon_o\leq\varepsilon$	$23\leq T\leq 300$	$(\frac{\sigma*\sqrt{f'c}}{E.})^{-1}*(\frac{\sqrt{f'c}}{6BE.})$	$B=0.0037\ T+1.7$
		$300\leq T\leq 800$		$B=0.0008\ T+0.643$

σ=Stress, ε=Strain, E=Elastic Module , T=Temperature, $30\leq f'_c\leq 40$ MPa

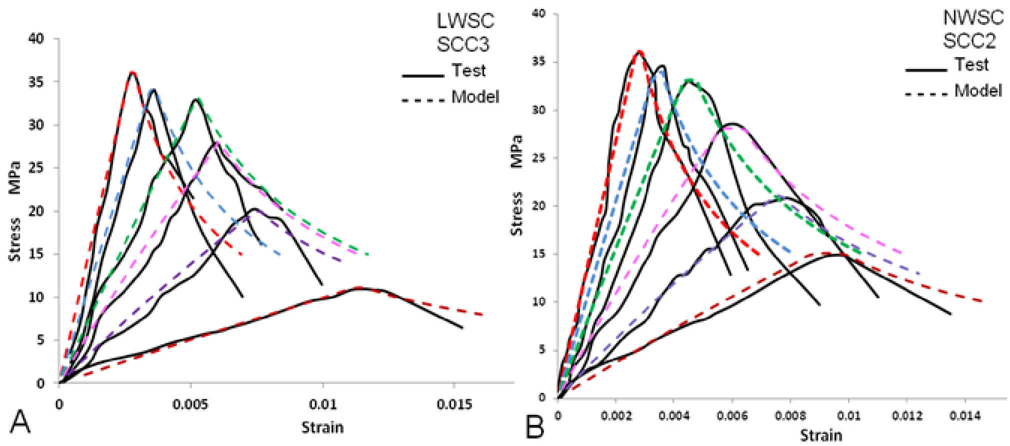

Fig. 6 Stress-strain carves of NWSC and LWSC after heating and new models

400°C. These changes follow the changes of loading curve gradient. LSC stress-strain curve behavior shows that the use of lightweight aggregates with lower compressive strength makes the concrete behave in a more brittle way. Moreover, the absorbed rate of energy and the level below stress-strain diagram are lower.

Various models attempted to predict concrete behavior and draw the stress-strain curve, most of which are related to below 800°C temperatures (Table 5). Stress-strain relationship was proposed with respect to temperature variations for the strains lower or higher than a peak point.

These relationships depend on elastic module and/or concrete's maximum strain at room temperature (23°C). Table 6 proposes some models for predicting stress-strain relationship in SCC. With respect to the changes of SCC behavior at 400°C or higher temperatures, which may be due to change of materials, the model is classified for the temperature range lower or higher than 300°C and the results are appropriately compatible with the studies (Fig. 6).

Fig. 4 shows NSC and LSC stress-strain curve and the predictive model. The proposed model is capable of determining post-peak concrete behaviour appropriately and accurately. The two types of concrete have an identical compressive strength within the temperature range of 23℃.

4. Conclusions

This research discusses SCC behavior under 23℃-800℃ temperature variations. The tested SCC was made of two types of broken and light-weight aggregates. NSC and LSC densities were about 2400 kg/m^3 and 1700 kg/m^3, respectively. Compressive strength, elastic module, and stress-strain relationship under a uniform compressive loading were studied within a quasi-static loading speed. The results show that SCC compressive strength decreases with rising temperatures. The higher the concrete compressive strength and/or the higher the temperature variation, the higher the compressive strength reduction will be. Given the aggregate type and the thermal resistance of the natural lightweight aggregate, heat affects light concrete at high temperatures less than it does concrete with normal aggregate. In fact, the thermal resistance of the light concrete made with natural lightweight aggregate at high temperatures is more than that of concrete with normal aggregate. The separate effect of heat on the aggregates also suggests this fact. This relationship is also true for concrete elastic module; however, the effect of aggregate types used in SCC should not be overlooked. Scoria aggregates exhibits lower reaction and changes to high temperatures as compared with normal aggregates. This makes LSC exhibit a brittle behavior at an equal temperature to NSC. It also makes the level below stress-strain diagram have a smaller area, and lowers energy absorption rate. The proposed models predict SCC behavior under temperature variations. Continuity and accuracy in predicting post-breakage concrete behavior are among the capabilities of the proposed models.

References

Alghamri, R., Kanellopoulos, A. and Al-Tabbaa, A. (2016), "Impregnation and encapsulation of lightweight aggregates for self-healing concrete", *Constr. Build. Mater.*, **124**, 910-921.

Ali, F., Nadjai, A., Silcock, G. and Abu-Tair, A. (2004), "Outcomes of a major research on fire resistance of concrete columns", *Fire Saf. J.*, **39**(6), 433-445.

Annerel, E. and Taerwe, L. (2009), "Revealing the temperature history in concrete after fire exposure by microscopic analysis", *Cement Concrete Res.*, **39**(12), 1239-1249.

Arioz, O. (2007), "Effects of elevated temperatures on properties of concrete", *Fire Saf. J.*, **42**(8), 516-522.

Carreira, D.J. and Chu, K. (1985), "Stress-strain relationship for plain concrete in compression", *ACI J.*, **82**(6), 797-804.

Chandra, S., Berntsson, L. and Anderberg, Y. (1980), "Some effects of polymer addition on the fire resistance of concrete", *Cement Concrete Res.*, **10**(3), 367-375.

Chang, Y.F., Chen, Y.H., Sheu, M.S. and Yao, G.C. (2006), "Residual stress-strain Relationship for concrete after exposure to high temperatures", *Cement Concrete Res.*, **36**(10), 1999-2005.

Choi, Y.W., Kim, Y.J., Shin, H.C. and Moon, H.Y. (2006), "An experimental research on the fluidity and mechanical properties of high-strength lightweight self-compacting concrete", *Cement Concrete Res.*, **36**(9), 1595-1602.

Cui, H.Z., Lo, T.Y., Memon, S.A., Xing, F. and Shi, X. (2012), "Experimental investigation and development of analytical model for pre-peak stress-strain curve of structural lightweight aggregate concrete", *Constr. Build. Mater.* **36**, 845-859.

Eurocode2 (2003), *Design of concrete structures Part 1&2, general rules, structural fire design*, European Committee for Standardization, EN 1992-1-2, Brussels.

Falade, F., Ikponmwosa, E. and Ojediran, N.I. (2010), "Behavior of lightweight concrete containing periwinkle shells at elevated temperature", *J. Eng. Sci. Technol.*, **5**(4), 379-390.

Fathi, H. and Farhang, K. (2014), "Effect of cyclic loadings on heated self-compacting concrete", *Constr. Build. Mater.*, **69**, 26-31.

Georgali, B. and Tsakiridis, P.E. (2005), "Microstructure of fire-damaged concrete", *Cement Concrete Compos.*, **27**(2), 255-263.

Hernández, O.F. and Barluenga, G. (2004), "Fire performance of recycled rubber-filled high-strength concrete", *Cement Concrete Res.*, **34**(1), 109-117.

Hu, B.L., Song, Y.P. and Zhao, G. (1994), "Test on strength and deformation of concrete under complex stress at elevated temperature", *Build. Sci. Res.*, **20**(1), 47-50.

Ismail, M., Ismail, S. and Muhammad B. (2011), "Influence of elevated temperatures on physical and compressive strength properties of concrete containing palm oil fuel ash", *Constr. Build. Mater.*, **25**(5), 2358-2364.

Janotka, I. and Nurnbergerova, T. (2005), "Effect of temperature on structural quality of the cement paste and high-strength concrete with silica fume", *Nucl. Eng. Des.*, **235**(17), 2019-2032.

Jia, F. and Xiao, J.Z.H. (1996), "Strength inspection on heated concrete with impact device", *Chin. Ind. Constr.*, **26**(6), 51-55.

Karamloo, M., Mazloom, M. and Payganeh, G. (2016), "Effects of maximum aggregate size on fracture behaviors of self-compacting lightweight concrete", *Constr. Build. Mater.*, **123**, 508-515.

Khennane, A. and Baker, G. (1993), "Uniaxial model for concrete under variable temperature and stress", *J. Eng. Mech.*, ASCE, **119**(8), 1507-1525.

Kodur, V.K.R, Wang, T.C. and Cheng, F.P. (2004), "Predicting the fire resistance behavior of high strength concrete columns", *Cement Concrete Compos.*, **26**(2), 141-153.

Li, L. and Purkiss, L. (2005), "Stress-strain constitutive equations of concrete material at elevated temperatures", *Fire Saf. J.*, **40**(7), 669-686.

Lie, T.T. and Lin, T.D. (1985), "Fire performance of reinforced concrete columns", *Fire Saf. Sci. Eng.*, 176-205.

Lo, T.Y., Nadeem, A., Tang, W.C.P. and Yu, P.C. (2009), "The effect of high temperature curing on strength and carbonation of pozzolanic structural lightweight concretes", *Constr. Build. Mater.*, **23**(3), 1306-1310.

Mirza, F.A. and Soroushian, P. (2002), "Effects of alkali-resistant glass fiber reinforcement on crack and temperature resistance of lightweight concrete", *Cement Concrete Compo.*, **24**(2), 223-227.

Mydin, M.A. and Wang, Y.C. (2012), "Mechanical properties of foamed concrete exposed to high temperatures", *Constr. Build. Mater.*, **26**(1), 638-654.

Othumn, M.A. and Wang, Y.C. (2011), "Elevated-temperature thermal properties of light weight foamed concrete", *Constr. Build. Mater.*, **25**(2), 705-716.

Petkovski, M. (2010), "Effects of stress during heating on strength and stiffness of concrete at elevated temperature", *Cement Concrete Res*., **40**(12), 1744-1755.

Poon, C.S., Shui, Z.H. and Lam, L. (2004), "Compressive behavior of fiber reinforced high-performance concrete subjected to elevated temperatures", *Cement Concrete Res*., **34**(12), 2215-2222.

Sanad, A.M., Lamont, S., Usmani, A.S. and Rotter, J.M. (2000), "Structural behavior in fire compartment under different heating regimes-Part 1 (slab thermal gradients)", *Fire Saf. J*., **35**(2), 99-116.

Sancak, E., Sari, Y.D. and Simsek, O. (2008), "Effects of elevated temperature on compressive strength and weight loss of the light-weight concrete with silica fume and superplasticizer", *Cement Concrete Compo*., **30**(8), 715-721.

Schneider, U. (1986), "Modelling of concrete behavior at high temperatures", *Proceedings of the International Conference of design of structures against fire*, 53-69.

Sengul, O., Azizi, S., Karaosmanoglu, F. and Tasdemir, M. (2011), "Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete", *Energy Build*., **43**(2), 671-676.

Shafigh, P., Nomeli, M.A., Alengaram, U.J., Mahmud, H.B. and Jumaat, M.Z. (2016), "Engineering properties of lightweight aggregate concrete containing limestone powder and high volume fly ash", *J. Clean. Produc*., **135**, 148-157.

Sun, W., Luo, X. and Chan, Y.N. (2000), "Compressive strength and pore structure of high-performance concrete after exposure to high temperature up to 800°C", *Cement Concrete Res*., **30**(2), 247-251.

Tanyildizi, H. and Cevilk, A. (2010), "Molding mechanical performance of lightweight concrete containing silica fume exposed to high temperature using genetic programming", *Constr. Build. Mater*., **24**(12), 2612-2618.

Tanyildizi, H. and Coskun, A. (2008), "Performance of lightweight concrete with silica fume after high temperature", *Constr. Build. Mater*., **22**(10), 2124-2129.

Tanyildizi, H. and Coskun, A. (2008), "The effect of high temperature on compressive strength and splitting tensile strength of structural lightweight concrete containing fly ash", *Constr. Build. Mater*., **22**(11), 2169-2175.

Terro, M.J. (1998), "Numerical modeling of the behavior of concrete structures in fire", *ACI Struct. J*. **95**(2), 183-193.

Xiao, J. and Konig, G. (2004), "Study on concrete at high temperature in China an overview", *Fire Saf. J*., **39**(1), 89-103.

Youssef, M.A. and Moftah, M. (2006), "General Stress-strain relationship for concrete at elevated temperatures", *J. Eng. Struct*., **29**(20), 2618-2634.

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