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The Effect of Initial Temperature of Self-Compacting Concrete on Its Long-Term Mechanical Properties

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Abstract:

One of the important issues in the production of concrete is environmental variability that affects the concrete and elements constructed from this material. Due to the importance of different characteristics of concrete in short- and long-term conditions, this article aims to investigate the influence of initial temperature conditions of self-compacting concrete on its long-term characteristics and determine the initial optimal temperature of concrete. For these purposes, several experiments under three temperature conditions of 5, 20, and 40 degree-of-Celsius were conducted to evaluate the rheology and mechanical properties of fresh concrete in the range of 7 and 28 days. In these experiments, alternative mineral admixtures of cement such as micro-silica, fly ash, and zeolite were used to build the concrete specimens. Results demonstrate that the mechanical properties of the specimens increase with increasing initial temperature in the short term, while such properties significantly decrease in the long term compared to the specimens constructed under lower initial temperature. Moreover, the fluidity of self-compacting concrete increases with increasing initial temperature.

Keywords:

Self-compacting concrete, Initial concrete temperature, Mechanical strength, Durability properties, Rheology, Optimal temperature.

1. Introduction

From the beginning of developing the application of reinforced concrete, insufficient fluidity and low ductility of concrete are always major challenges. Despite addressing these issues by increasing the level of water in the concrete mix, this procedure increases the ratio of water to cement and seriously decreases the strength and durability of concrete. Due to advances and emergence in new kinds of chemical admixtures called plasticizer and super plasticizer that increase the fluidity of concrete, some practical issues of concrete caused by the use of high quality concrete but low efficiency are dealt with. Based on recent developments in structural engineering and the design of complex concrete sections, the use of large amounts of these substances for constructing high fluidity and large strength of concrete leads to blockage, separation, and bleeding.

Self-compacting concrete is an innovative material that one does not require vibration for placement and compaction. This kind of concrete is able to flow under its own weight to fill the required space or formwork completely and to produce a dense and adequately homogenous material without a need for vibrating compaction. In recent years, the use of self-compacting concrete in urban projects has become very popular due to the ease of concreting and significant reduction of density noise and the possibility of creating smooth and visible surfaces and implementing different architectural designs. High ductility with filling ability, permeability, and resistance in separation

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are the three basic criteria for producing the self-compacting concrete (Mohan and Mini, 2018).

The study on the rheology of fresh concrete is based on the assumption that the behavior of fresh concrete can be considered as a liquid. Unlike an elastic solid that undergoes limited deformation and reversibility under a load, a fluid under constant shear is deformed constantly so that this deformation will be available as long as the load is applied. There are numerous rheological models that express the flow behavior of fresh concrete, which is a non-Newtonian fluid with yield strength. Bingham model is one of the most widely used model because of its simplicity and appropriate adaptation to the behavior of fresh concrete (Bu et al. 2018).

To formulate the Bingham model, it is necessary to determine two main parameters including the yield stress and plastic viscosity. The yield stress refers to the amount of force required to start the flow of a material. Furthermore, the plastic viscosity is defined as the internal strength of a material against flow freely. With these two parameters, the self-compacting concrete can be described as a material that has a great impact on its construction conditions, particularly temperature. Because the temperature of environment and concrete is dependent on time and location, it is essential to track the influence of its variations as an invariant parameter of concrete.

On the other hand, the chemical reaction between water and cement in concrete mixture is a factor that leads to the production of a homogeneous mixture owing to integrity of aggregates, water, and cement. In such a case, this reaction makes durable and high quality concrete by providing adhesion in concrete. The quality and form of these reactions, which are known as the weakest part of concrete, are influenced by various environmental factors, one of which is temperature. The following are related recent works.

Concrete is an important material in civil engineering due to some remarkable merits such as tolerating high temperature and fire, and low thermal conductivity and specific heat (Mohan and Mini, 2018). This does not mean that the temperature does not any effect on concrete. On the contrary, high temperatures can cause severe discoloration, and changes in the compressive strength, the modulus of elasticity, and the appearance of concrete (Bu et. al. 2018). Phan and Carino (2002) demonstrated that the engineering behavior and properties of high-strength concrete are entirely different from ordinary concrete under the same conditions against high temperatures. The main reasons for this difference include: (i) the loss of relative strength at 100-400°C, and (ii) crushing and weight loss at 200-400°C. Regarding the first reason, they observed that the compressive strength of high-strength concrete roughly decreased by 40%, while this type of reduction with the same conditions in the ordinary concrete corresponded to 20-30%. Tanyildizi and Coskun (2008) constructed lightweight concrete specimens under 200, 400, 600, and 800°C. Their results showed that the increase in temperature reduces the concrete strength owing to volatilization and dewatering of concrete. These reasons led to decreases in the strength and modulus of elasticity increases in the coefficient of thermal expansion and thermal conductivity, and concrete weakness. On the other hand, the research of Othuman and Wang (2011) on the thermal properties of lightweight foam concrete demonstrated that high temperature degrees affect free water in concrete blowhole and chemical bonding water in hydrated cement. Bastami et. al. (2011) investigated the performance of high-strength concrete under high temperatures. They concluded that the reduction in the compressive strength is one of the main changes in the materials that occurs during applying high temperature. They reached the worst performance of their high-strength concrete by the reduction in the strength by 80% at 800°C. Andic-Cakır and Hızal (2012) assessed the effect of temperature on lightweight self-compacting concrete. In that research, the amounts of the modulus of elasticity of specimens were considerably affected by the types of aggregates. They observed that the permeability of concrete specimens was controlled by decreasing the ratio of water-to-cement in the presence of porous aggregates. Their results also showed that the increase in temperature, for all specimens, led to the weight loss as a result of the formation of stream inside the aggregates and cavities. Siddique and Kaur (2012) conducted a research on concrete using ground granulated blast furnace slag (GGBFS). They observed that the loss of weight up to 100°C is roughly inconsiderable; however, the weight of concrete significantly decreased from temperature more than 100°C leading to the impact of temperature on the modulus of elasticity. Among all specimens, the one with 20% GGBFS yielded the largest compressive strength at 27°C and 350°C at the end of the experiment. For these temperatures, the specimens without GGBFS indicated more compressive strength. Morsy et. al. (2012) investigated the effects of high temperatures up to 800°C on the mechanical properties and microstructure of nano-metakaolin cement mortars. They concluded that after an initial increase in compressive strength at 250°C for the mortar specimens, the strength decreased considerably at higher temperatures.

In another study, Prem et. al. (2013) assessed the influence of curing temperature on high strength concrete and the achievement of compressive strength of more than 150 MPa. They initially placed concrete specimens at 90, 150, and

200 °C for 3 and 7 days and then stored them at normal laboratory temperature for 28 days. Once the experiment was accomplished, the results showed that the compressive strength of concrete changes from 152 MPa to 217 Mpa by altering the curing state. To investigate the sensitivity of the ratio of micro-silica to temperature to self-compacting concrete, Aydin et al. (2015) built four mixing design plans by applying 0, 5, 7.5, and 10% of micro-silica instead of concrete. After constructing the concrete specimens for 24 hours and storing them at 65, 70, and 75 °C, they conducted the mechanical and durability experiments on time. The experimental results demonstrated that the compressive strength of the specimens mixed by the micro-silica at 70 °C is more that the corresponding strength values at the other temperature degrees. However, the specimen without the micro-silica reached the maximum compressive strength at 65 °C. Also, Different strength grades of concrete and exposure temperatures are the main variables considered in the investigations (Mathews et. al, 2020)

The secondary gel formation nature of the SCM delays the initial setting time, thus enhancing the mechanical properties of the mix. Perlite aggregate formed by the rapid cooling of lava spews from volcanoes when exposed to high temperatures results in further particle expansion. EPA is a lightweight material widely used as aggregate in blended concrete to reduce the weight of elements. EPA used in optimum quantity as a primary component in SCC may enhance the strength gain capacity to take up pozzolanic reactions. The performance of EPA is evident when SCC is exposed to elevated temperatures by resisting the heat flux into the concrete core (Abed and Brito, 2020).

Because the hydration reaction of cement is a relatively slow chemical reaction, the temperature of concrete at any stage of its lifetime (e.g., the periods of concrete production, curing, and operation) can affect the properties of concrete. Therefore, the temperature in concrete is a general and vast issue that includes the environment temperature during concrete placing, temperature of fresh concrete mix, temperature in concrete processing, hydration temperature, etc. On the other hand, because self-compacting concrete involves complex and sensitive mixing design and minor variations in the proportions and types of materials may cause serious changes in the concrete, it is crucial to consider the initial temperature effects. Therefore, the major contribution of this article is to study the effects of initial material temperature before construction on the performance of fresh concrete and its mechanical properties along with the durability of self-compacting concrete.

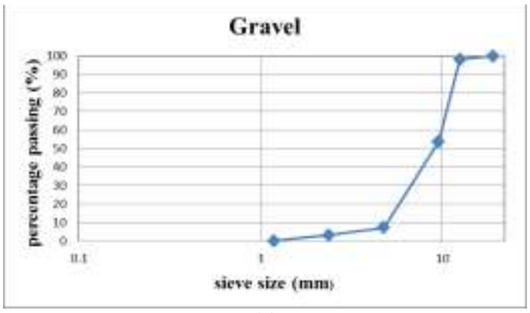
2. Experimental work

2.1. Material and mixing design

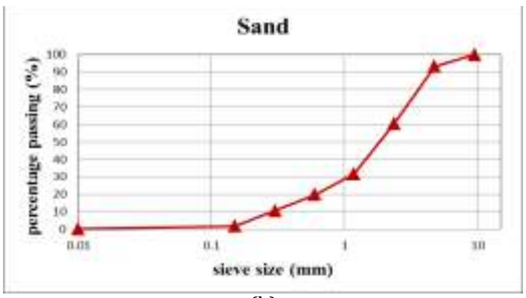
The accurate selection of materials is a necessity for optimizing the mixing design of self-compacting concrete. Because this type of concrete is more sensitive to variations in material properties in comparison with ordinary concrete (Koehler and Fowler, 2007), it is important to further emphasize this issue and identify different parameters of the components of self-compacting concrete that may affect the rheology of fresh concrete. In order to decrease the hazard of separation and bleeding in concrete and increase the ratio of the fine to coarse aggregates, this research utilizes filler in concrete. Furthermore, three types of mineral admixtures including micro-silica, zeolite and ash in the amount of 15% by weight of cement have been applied to control the hydration temperature of cement and increase the water absorption and the volume of cement paste.

2.1.1. Aggregates and fillers

In this research, the main components of self-compacting concrete consist of pea gravel with uniform gradation and river sand (i.e. the soft modulus equal to 3.8) in accordance with the seventh category of Standard No. 302 of the National Standards Organization of the Zanjan Housing Foundation. Additionally, the limestone powder of the maximum size of 125 μm is considered as fine grain and filler. Table 1 lists the main properties of the gravel and sand aggregates. Fig. 1 shows the gradation curves of the gravel and sand used in constructing the self-compacting concrete.



(a)



(b)

Fig. 1. Gradation curves of the gravel and sand

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Table 1. The main properties of the aggregates applied to self-compacting concrete analytical

Aggregate	Maximum nominal size (mm)	Water absorption (%)	Density (gr/cm³)
Pea gravel	12.5	1.2	2.69
River sand	4.75	1.8	2.64

2.1.2. Cement

Cement is one of the most important and effective components in durability and mechanical properties of concrete that undertakes the adhesion in concrete for producing a homogeneous substance. Although the EFNARC guideline (EFNARC 2002) permits civil engineers to utilize different Portland cements in making the self-compacting concrete, the majority of researches regarding this kind of concrete applied the ordinary Portland cements (ACI 237R 2007). The cement used in this study is the Kurdistan Type 2 of the density of 3.15 gr/cm^3, which was approved by Standard No. 389 of the Iran national standards organization. The chemical analysis of this cement was confirmed by its manufacturer factory report as presented in Table 2.

Table 2. The chemical properties of the basic cement substances and their percentages

Ingredients	Kurdistan cement	Micro-silica	Zeolite	Fly Ash
Sio_2	21.54	94.6	67.79	55
Al_2O_3	4.95	1.32	13.66	26
CaO	63.24	0.87	1.24	9
Fe_2O_3	3.82	0.49	1.68	7
MgO	1.55	0.97	1.20	2
SO_3	2.43	0.05	0.5	1
Na_2O	0.48	0.31	2.04	-
K_2O	0.75	-	-	-

2.1.3. Mineral and chemical admixtures

The mineral admixtures usually have the average sizes of aggregates and specific weight and surface area less than cement (Turanli et al. 2005). In self-compacting concrete, cement admixtures, depending on their properties, can bring benefits such as reducing production costs and hydration heat and improving the rheology and concrete durability (Saleh Ahari et. al. 2015). Nowadays, it is feasible to use various admixtures as alternatives to cement such as micro-silica, metakaolin, ash, blast furnace slag, zeolite, etc. This study considers three different kinds of admixtures including micro-silica from Semnan's mines, zeolite produced by Aria-Beton-Arg Company[1] and low-calcium South African fly ash from Rayehe-Beton-Sabz Company[2]. Table 2 lists the chemical and physical characteristics of micro-silica and zeolite according to the relevant company reports.

Chemical admixtures are one of the most important components of self-compacting concrete. This is because it is often difficult to provide the efficiency and stability of this type of concrete through the only materials used in the ordinary concrete. These additives improve the mechanical and physical properties of concrete by affecting the water-cement collection and creating chemical reactions between water and cement from several minutes to several hours after adding to concrete. In this research, a polycarboxylate-based superplasticizer admixture from Aria-Beton-Arg Company has been used to provide the required efficiency. Due to the difference in the quality of products, the determination of the consumption of super-lubricants is only possible by conducting tests.

2.2. Mixing design

To determine the standard mixing ratio based on the proposed assumptions and principles, several mixing schemes in standard experimental conditions under fine-to-coarse and water-to-powder ratios were constructed in the first step. Subsequently, fresh concrete tests including L-shaped box and V-shaped funnel on the above-mentioned ratios were conducted to determine criteria for rejecting or approving the schemes. Eventually, after constructing five mixtures, the final mix design was prepared. In this regard, Table 3 lists the final mixing design of the three final schemes, where the abbreviations SF, ZE, and FA refer to the schemes based on micro-silica, zeolite, and fly ash, respectively.

In order to better assess the effect of the type of mineral admixtures on consistency and mechanical properties of concrete, this study utilized three kinds of similar mineral substances equal to 10% of the cement weight of the mixing design (450 kg/m^3) as the alternative of the cement. Moreover, the amount of superplasticizer needed for the mixing design was equal to 1% of the weight of cement. This choice was due to providing the compatibility of the ratio of the consistency of the fresh concrete with the standard defined for self-compacting concrete.

1. Aria-Beton-Arg Company, 3rd unit, 5th floor, Gold Building, Southwest side of Sadeghieh second square, Tehran, Iran, Tel: +98-21-44061450, Email: Contact@aryabetonarg.com

2. Rayehe-Beton-Sabz Company, 1ST unit, Building 25, Heydari Moghadam St. Ashrafi Esfahani Blvd., Tehran, Iran, Tel: +98-21-44618379, Email: clinic_beton@yahoo.com

Table 3. The final mixing designs

Components	Scheme		
	SCC-SF	SCC-FA	SCC-ZE
Cement (kg/m³)	405	405	405
Water-to-cement ratio	0.47	0.47	0.47
Gravel (kg/m³)	621	621	621
Sand (kg/m³)	908	908	908
Stone powder (kg/m³)	120	120	120
Super lubricant (kg/m³)	4.5	4.5	4.5
Micro-silica (kg/m³)	45	0	0
Fly ash (kg/m³)	0	45	0
Zeolite (kg/m³)	0	0	45

3. Concrete construction process

As mentioned earlier, the process of construction of fresh concrete is based on three temperature degrees (i.e. 5, 20, and 40°C). There are different approaches to reaching these degrees such as keeping all components of concrete before construction in temperature control containers and using equilibrium equations for estimating the concrete temperature and reaching the mentioned degrees.

Since the specific heat capacity of water is five times of the corresponding capacity of cement and aggregates (Schindler and McCullough, 2002), the water temperature is incorporated to estimate the concrete temperature. Using the proposed formulation in ACI 306 R (ACI 306R-16, 2017) and Iran national building regulation No. 9, the temperature T in the unit of °C is estimated as follows:

$$T(^\circ\mathrm{C}) = \frac{0.22(G_d T_G + C T_c + S_d T_s) + T_w W_w + T_G W_G + T_s W_s}{0.22(G_d + C + S_d) + W_w + W_G + W_s} \quad (1)$$

Where C, G_d, and S_d denote the weight of the cement, gravel, and sand under the dry condition in the unit of kg/m³, respectively. Moreover, W_w, W_G, and W_s are the volumes of water used in concrete construction, the gravel moisture, and the sand moisture in the unit of L/m³, respectively. Eventually, T_c, T_G, T_s, and T_w refer to the temperature degrees of the cement, the gravel, the sand, and the water in the unit of degree-of-Celsius (°C), respectively. In case of using ice instead of water for cooling the concrete, Eq. 1 can be rewritten as:

$$T(^\circ\mathrm{C}) = \frac{0.22(G_d T_G + C T_c + S_d T_s) + (W_w - W_i)T_w + W_i(0.5T_i - 80) + T_G W_G + T_s W_s}{0.22(G_d + C + S_d) + W_w + W_G + W_s} \quad (2)$$

In this equation, *Wi* and *Ti* represent the ice mass in the unit of kilograms the ice temperature in degrees Celsius, respectively.

To reach the temperature of 5°C, ice was used a substitute for some of the required water. In addition to preheating gravel, sand, and cement, high temperature water was applied to achieve the temperature of 40°C. The temperature values of concrete materials and components can be observed in Table 4 to obtain the temperatures expressed based on Equations 1 and 2.

Table 4. The amounts and temperature of water and ice used in the concrete mixtures

Outputs	Temperature (°C)		
	5	20	40
Cementations material temperature (°C)	25	25	30
Gravel, sand, and stone powder temperature (°C)	25	25	30
Ice temperature (°C)	-5	-	-
Water temperature (°C)	3	7.8	64.1
Ice (Kg)	122	0	0
Water (lit)	89	211	211
Nominal temperature (°C)	3	21	41

Once the calculations have been finalized, the amount of 0.5m³ concrete in accordance with the approved mixing design under the estimated degrees of equilibrium temperature during 7 days was constructed.

After molding, the samples were kept at a constant temperature of 5, 20 and 40°C for 6 hours to reach the final setting time of the concrete. This process was performed to hold the concrete at the temperature under evaluation from the construction time to the final setting time. Subsequently, the concrete temperature returned to the standard laboratory temperature degrees after 6 hours.

It worth remarking that this process was conducted in the laboratory environment at the University of Zanjan. After implementing the experiments of fresh concrete, the total number of 108 specimens including 36 cubic specimens (10×10x10cm) and 75 standard cylinder molds (15x30cm) were molded to perform the experiments of the constructed concrete specimens.

3.1. Experiments

In the experiments, slump flow and v-shaped funnel tests were used to evaluate the rheological behavior of mixtures. Moreover, the compressive and tensile strength tests were conducted indirectly. On the other hand, static elastic modulus of 7 and 28 days and the ultrasonic plus velocity test were considered to assess the mechanical and durability properties of concrete, respectively. After 24 hours, the molds of the cubic specimens for the strength test and the cylinder specimens associated with the tensile strength test and static elasticity modulus were removed to immerse the concrete specimens in a water basin under 23°C. Table 5 shows the standard method for performing each test.

4. Analysis of results

4.1. Tests of rheology assessment

The slump flow test is used to measure the flow capacity of the mixture of fresh self-compacting concrete. In this test, the mixture diffusion time in a certain diameter is indicative of the mixture viscosity. As the time and diameter of diffusion increase, the mixture viscosity and flowability increase as well (ASTM C1611/C1611M-14, 2014).

The V-shaped funnel test, which evaluates the filling capacity of self-compacting concrete, is representative of the time (i.e. in the unit of seconds) of complete discharge of self-compacting concrete from the V-shaped funnel machine. As this time to be shorter, the concrete mixture is smoother. Moreover, the increase in discharge time indicates the reduction in the concrete flow. Fig. 2 and 3 illustrate the results of the slump flow and V-shaped funnel tests, respectively. It can be observed in these figures that the concrete consistency increases with increasing the initial temperature of the self-compacting concrete increases from 5ºC to 40ºC. Furthermore, this increase leads to reductions in the concrete viscosity. From the slops of the lines in Fig. 2, it is seen that the concrete consistency is more sensitive to low temperature conditions compared to high conditions.

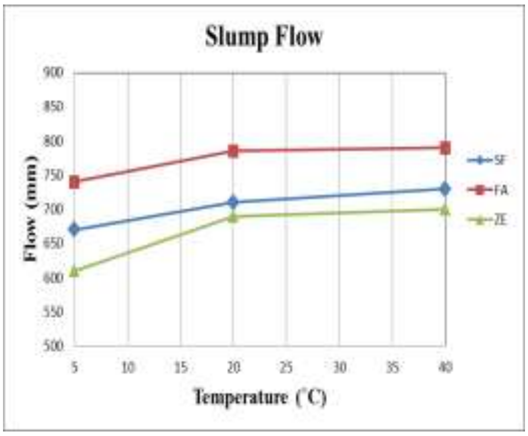


Fig. 2. The slump flow test

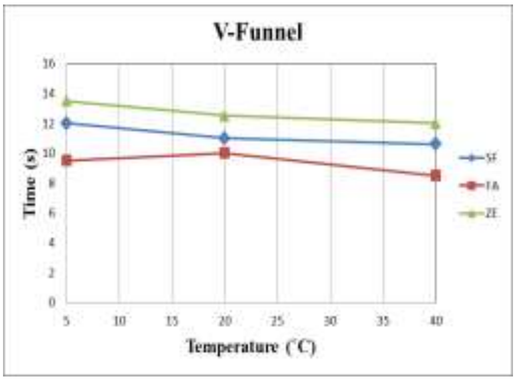
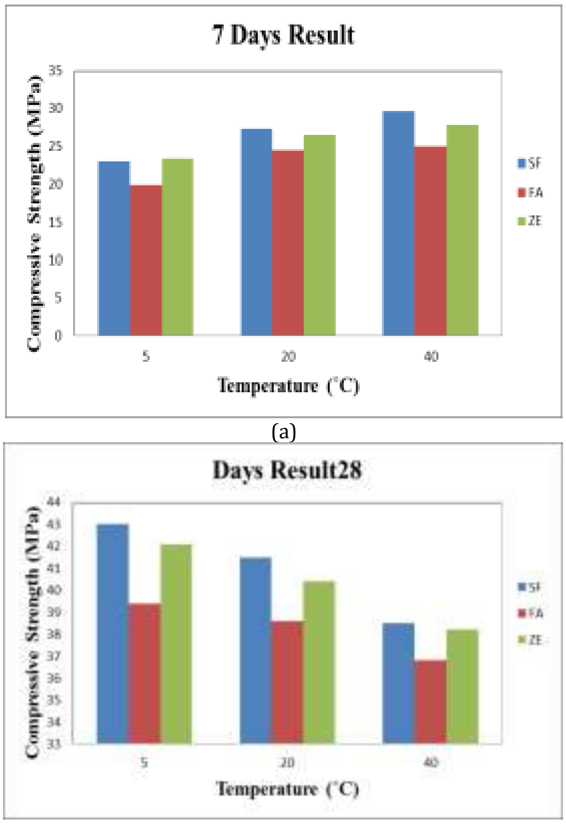


Fig. 3. The V-shaped funnel test

On the other hand, when the diameter of the powder substances decreases, the concrete consistency decreases. This phenomenon is due to the increases in the specific area of the powder substances and the amount of water absorption. In such cases, the filling and crossing capacities of self-compacting concrete decrease. Therefore, it is important to keep a balance between these criteria. During constructing the self-compacting concrete in cold areas or using low-temperature materials, one needs to increase the amount of super lubricant admixture in order to achieve the same concrete consistency.

4.2. Tests of mechanical properties

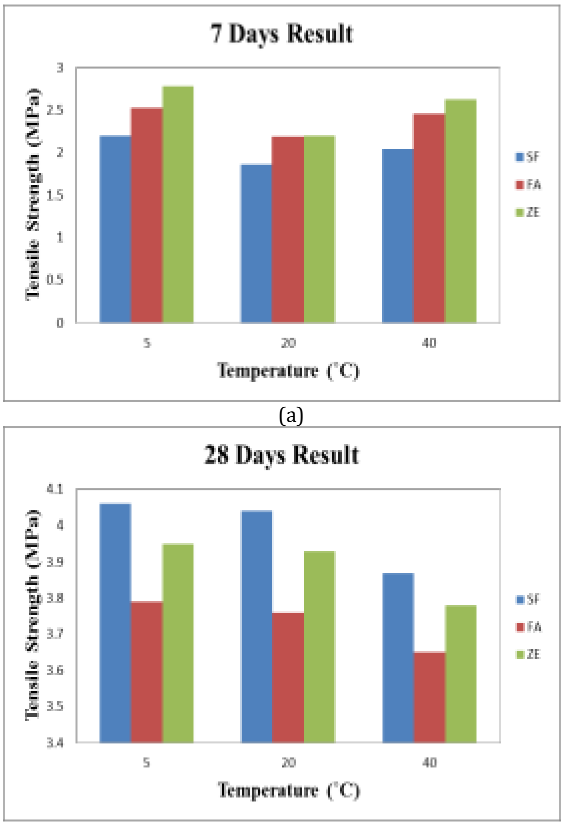
The results of the compressive strength (in the unit of MPa) tests regarding the cubic specimens are shown in Fig. 4. According to the compressive strength results in Fig. 4, the increase in the initial temperature of concrete expediates the hydration process of cement and increases the short-term compressive strength of self-compacting concrete. As can be seen in Fig. 4(a), the maximum value of the compressive strength of 7 days relates to the initial temperature of 40ºC. From the age of 7 to 28 days, one can observe that this process is reversed so that the concrete of the initial temperature of 5ºC gives the most quantity of the compressive strength. This means that due to high compact formation in small spaces of concrete in the initial low temperature, the long-term conditions provide higher strength values. Moreover, as the diameter of powder substances in the self-compacting concrete decreases, one can reach more sensitive conditions to the changes in the initial temperature. On the other hand, it can be realized that the micro-silica has smaller diameter against the other schemes and its compressive strength changes are more than the fly ash and zeolite when the temperature increases from 5ºC to 40ºC. This means that the use of smaller substances as alternative to cement in self-compacting concrete leads to more sensitive concrete specimen to initial temperature, in which case this application makes further changes in the concrete compressive strength. Hence, one can observe that the slop of the diagram of micro-silica changes is steeper than the corresponding slopes regarding the fly ash and zeolite. By increasing the age of concrete up to 90 days, therefore, it can be concluded that the initial temperature significantly affects the self-compacting concrete.



(a) (b)

Fig. 4. The compressive strength tests: (a) 7 days, (b) 28 days

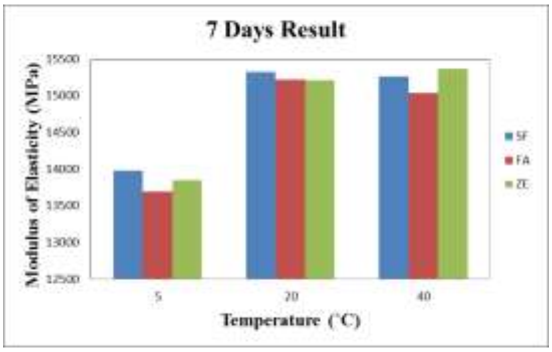
Fig. 5 demonstrates the results of tensile strength (in the unit of MPa) tests regarding the standard cylinder specimens. The effect of initial temperature on the process of obtaining strength and hydration rate of cement in the tensile strength test similar to the compressive strength increases with increasing the initial temperature in the short term; however, those decrease in the long-term conditions. According to Fig. 4, the amount of tensile strength of the constructed concrete mixture at 20°C for the age of 7 and 28 days is very close to the maximum value obtained from the temperature 40°C in 7 days and 5°C in 28 days. In some cases, the tensile strength amounts correspond to the maximum value. This is because of the high sensitivity of tensile strength to the internal texture of concrete, the effects of non-uniform shrinkage and the importance of the temperature of construction and curing on the tensile strength of self-compacting concrete. Due to the formation of denser microstructure, the self-compacting concrete mixtures constructed under 5°C and 20°C have a stronger internal texture and better durability properties than the concrete under 40°C. Approximately, the increase in the initial temperature of the self-compacting concrete from 5°C to 40°C increases the tensile strength by 24% for the age of 7 days and decreases the same strength by 4% for the age of 28 days.



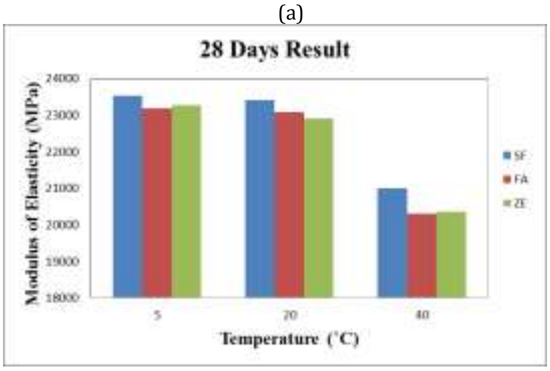
(a) (b)

Fig. 5. The tensile strength tests: (a) 7 days, (b) 28 days

The results of the tests associated with the static modulus of elasticity for determining the influence of the initial temperature on the ductility of the self-compacting concrete (i.e. in the unit of MPa) are shown in Fig. 6. To determine the static elasticity modulus of concrete, various regulations have proposed formulas based on the amount of the concrete compressive strength, which have been validated in many experimental studies in such a way that the observations obtained from the test or the results calculated from formulas are non-conservative. Furthermore, the use of such formulas for estimating the value of the static elasticity modulus may arise the amount error owing to the main difference between the ordinary and self-compacting concrete. The influence of the initial temperature of the self-compacting concrete on the static modulus of elasticity is similar to the effect on the compressive and tensile strength; that as, the increase in the short time and decrease in the long time by increasing the temperature. However, the amount of elasticity modulus for the age of 7 days at 20°C is larger than the corresponding value at 40°C. The reason of this conclusion pertains to the dependency of the amount of modulus of elasticity on the quality of the internal texture of concrete and the quality of hydration of cement. Hence, these are the main factors for the occurrence of thermal cracks, particularly in the transition region at higher temperature values, the reduction in the amount of the static modulus of elasticity. On the other hand, since the modulus of elasticity is inversely related to the amount of the porosity in concrete and due to the low porosity of self-compacting concrete caused by high consistency, it is necessary to further control the amount of elastic modulus of the structure during the use of self-compacting concrete.



(a)



(b)

Fig. 6. The static elasticity modulus: (a) 7 days, (b) 28 days

4.3. Tests of measuring durability properties

Durability in concrete involves a wide range of different tests. Since the sending and receiving waves in ultrasound testing depend entirely on internal elements and texture of concrete, these are considered to measure the durability properties.

Having considered the velocity of ultrasonic waves in concrete through relationships and tables and diagrams proposed by various sources, it is possible to estimate important mechanical and durability properties such as the dynamic modulus of elasticity, the compressive strength, etc. The velocity of ultrasonic waves is directly related to the durability and mechanical properties of concrete so that the emergence of the high velocity of interest in indicative of homogeneity of the internal texture of concrete and the improvement on these properties. The results of the ultrasonic wave velocity test, which is one of the non-destructive tests in concrete, by an ultrasonic device (i.e. in the unit of m/s) along the straight line at the age of 28 days are presented in Table 6. As the data in this data reveals, one can perceive that the initial temperature of concrete does not have significant effect on the velocity of waves in the self-compacting concrete. As the same results regarding the tests of static elasticity modulus, it can be realized that the velocity of waves decreases at the initial temperature 20°C owing to an appropriate quality of hydration products.

Table 6. Standard experiment numbers

Scheme	Temperature (°C)		
	5	20	40
SF	4629	4688	4604
FA	4640	4672	4632
ZE	4633	4646	4611

A slight decrease in the velocity of ultrasonic waves with an increase in temperature from 20 to 40°C in the samples is probably related to the formation of more thermal microcracks due to the higher rate of hydration, especially in the transition zone.

5. Conclusions

The main conclusions of this research are drawn as follows. (1) The consistency of the self-compacting concrete increases by increasing the temperature of the concrete mixture. (2) Since the use of super lubricant in the self-compacting concrete is inevitable, the increase in the consistency of self-compacting concrete increases the probability of occurrences of the separation and dehydration phenomena increases as well. The results showed that the increase in the initial temperature of the concrete specimen leads to the increase in the concrete consistency. Therefore, it is important to pay more attention on the amount of super lubricant. (3) When the temperature of the mixture of the self-compacting concrete in the short time up to 7 days increased from 5°C to 40°C, the mechanical properties of the concrete significantly increased. This conclusion was due to the increase in the cement hydration rate. However, this procedure was reversed for 7-28 days as a result of the formation of more compact microstructures in the concrete mixture. (4) The durability properties in concrete were affected by the quality of the internal texture, the porosity of concrete, the quality and degree of hydration, the quality of the transfer area, the quality of materials, and the amount of air confined in the concrete. Therefore, the concrete mixtures under lower or higher temperatures than normal conditions are weak in the internal textures and are more heterogeneity compared to the normal and standard temperature. For these reasons, this study demonstrated that the mixture under the temperature of 20°C has better durability properties than other temperature conditions. (5) Among the mixing designs for constructing the self-compacting concrete, the micro-silica, zeolite, and fly ash had the moderate, high, and low water absorptions and high, moderate, and low cement properties, respectively. In this regard, it is recommended to utilize micro-silicas to construct self-compacting concrete for improving the fresh properties of self-compacting concrete, increasing the durability and strength of concrete, reducing the destructive effects of cement hydration temperature and environmental pollutions caused by cement productions. (6) To achieve a high-quality concrete specimen, it is necessary to consider appropriate durability and high strength. Due to the influence of different initial temperature conditions on the durability and mechanical properties of self-compacting concrete, therefore, the uses of an average temperature of 15 to 25°C for the fresh concrete mixture and appropriate admixtures and fillers for self-compacting concrete improve the total quality of the fresh self-compacting concrete.

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