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Research Article

Behavior improvement of self-compacting concrete in hot weather

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ABSTRACT

The main aim of this research is studying the effect of hot weather on the properties of self-compacting concrete and conventional concrete in both fresh and hardened state. Also, this research extends to improve the behavior of self-compacting concrete in hot weather. The main parameters were surrounding weather temperature (5°C, 20°C and 35°C), concrete materials temperatures' (25°C, 50°C), curing temperatures (25°C and 50°C) and admixtures (using a retarder). Two stages were carried out to achieve the research aim. The behavior of self-compacting concrete compared to conventional concrete was evaluated in the first stage. Based on the first stage, attempts to enhance the concrete properties were evaluated in the second stage. Precautions on mixing and placing concrete in these climates are considered. Results are a drive in terms of; workability tests, compressive strength, splitting tensile strength, and flexural strength. Test results showed that self-compacting concrete behavior and strengths were better than conventional concrete. Slump test, J-ring and V-funnel test were used to evaluate the fresh properties of the self-compacting concrete. Drying shrinkage of self-compacting concrete in hot weather were also evaluated.

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1. Introduction

Hot weather is the major reason of plastic shrinkage and cracks. Those cracks enhance bad chemicals as O_2, CL-, SO_4(-2) and CO_2 inside the concrete mix so that those cracks are determined the main reason of undesired strength results of concrete structures in hot weather (Nasir et al., 2016). Factors such as high temperature of the surrounding air, low relative humidity, the increase in wind speed and the continuous direct solar radiation affects badly on concrete at its fresh stage and during hardening processes (Al-Amoudi et al., 2007). Plastic shrinkage, cracks and strength reduction are results to exposing the structure to hot weather which led to the increase of concrete mix temperature and evaporation rate with a reduction in the structural safety (Ahmadi, 2000). Attempting to deal with such hard conditions, some important precautions must be taken. Self-compacting concrete is a concrete that flows under its own weight through restricted sections without segregation or bleeding. It's one of the highly workable types of concrete which also has high performance and suitable strength (EFNARC, 2005). Cooling concrete materials before use, the early concrete curing, and using suitable curing methods after concrete cast help overcoming such hard conditions. The results carried out by Al-Feel and Al-Saffar (2009) showed that Self-compacting concrete gives high early compressive strengths when taking previous precautions.

The nature of SCC is the increasing ratio of fine aggregates (F.A) to coarse ones (C.A) when comparing it to the conventional concrete as the ratio is (F.A/C.A = 1.22) so that, many practical applications have been discussed in researches to make sure that mechanical and durability properties are the same like conventional normally vibrated concrete especially in the hardened case. In hot weather conditions, the recommendations are clearly stated in the ACI 2010 (Mouret et al., 2003). The study of Park et al. (2017) showed that water contents, hydration products and the pore structures are the main affecting factors on strengths. The work was carried out under typical summer conditions, but the elevated hot temperatures didn't affect the early age strengths of concrete. On the long term, there was a strength loss because of the reduction of hydration and the porosity increase (EFNARC, 2005).

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2. Experimental Program

The innovation in this research is the comparative study of the properties and the behavior of the self-compacting concrete compared to conventional concrete at hot weather. Also, how to improve its performance under hot weather. The importance of this research is to provide sufficient data for the researchers and engineers that concerns in using self-compacting concrete in the desert sites or such places with hot weather. 13 mixes for each type of concrete were casted.

2.1. Materials

The type of used cement is the ordinary Portland cement CEM I 52.5 N from the Suez factory. The Egyptian Standard Specification (E.S.S. 4756-1, 2012) is satisfied. The fine aggregate is the natural siliceous sand which satisfies the (E.S.S 1109, 2008). The mechanical properties of fine aggregates are shown on Table 1. The coarse aggregate is natural crushed dolomite with a maximum size of 10 mm satisfying ASTM C33 (2018), the particles were angular and irregular. According to the Egyptian code of practice, clean drinking fresh water was used for mixing and curing procedures. A high range water reducer for self-compacting concrete as a third generation superplasticizer, is used as concrete additive that facilitates extreme water reduction, excellent flowability at the same time optimal cohesion and highest self-compacting behavior. It meets the requirements of ASTM C494 Types G and F and BS EN 934 (2012). A highly effective super plasticizer with a set retarding effect for producing free-flowing concrete in hot climates is used that complies with ASTM C494 (2017) Types G and F and BS 5075 (2012) part 3. Fly ash is also used for producing a proper self-compacting mix according to the (E.C.P. 203, 2017). The method used for the concrete mix design was the CBI. The concrete mixture is designed to give at 28-day a compressive strength of 400 kg/m^2. The suitable mix design has the following constituents as shown in Table 2.

Table 1. Physical and mechanical properties of sand used.

Description	Value
Volume weight (t/m^3)	1.73
Specific gravity	2.6
Absorption (%)	0.78
Voids ratio (%)	33.81
Fineness modulus	2.61

Table 2. Mix proportions.

Code	Water (kN/mm^3)	Cement (kN/mm^3)	Sand (kN/mm^3)	Dolomite (kN/mm^3)	F.A. (%)	S.P. (%)	R2004 (%)
NC	1.8	4.5	6	11.617	----	----	----
SCC	1.53	4.5	9.9	8.2	2	2	----
HNC	1.53	4.5	6.15	11.94	----	----	2
HSCC	1.53	4.5	9.78	8.1	2	2	2

NC: Normal concrete, SCC: Self-compacting concrete, HNC: Hot weather normal concrete,
HSCC: Hot weather self-compacting concrete,
F.A.: Fly ash; an additive for producing the self-compacting concrete,
S.P.: A high range water reducer for self-compacting concrete,
R2004: A highly effective super plasticizer with a set retarding effect

Fig. 1. Crushed ice used for cooling mixing water.

Fig. 2. Heating mixing materials in the oven.

Each material is weighted accrual for the required accuracy. The surface moisture and the effective absorption of aggregate especially sand greatly affect the amount of mixing water. It's very important to determine the properties of aggregate to keep the amount of water content. In order to obtain a uniform concrete mix, mixing was performed using a mixer with high efficiency by feeding the materials in the proper order. The materials were mixed for a proper periods for 2 minutes of normal weather mixes and heated in the laboratory oven for about 30 mins reaching more than 50°C for hot weather mixes.

Charging sequence is coarse aggregate, fine aggregate, and the cement. After 2 minutes from starting time, water of different temperatures (5°C, 20°C and 35°C) with any superplasticizer is added to the mix gradually the mixer is still rotate after adding water with the superplasticizer for 3 minutes to insure the full mixing of the concrete components. Water at 5°C were reached by using crushed ice and at 35°C were reached by using boiling water leaving it in the laboratory normal weather for about 10 mins as shown in Figs. 1 and 2.

The concrete was charged out from the mixer; the slump, j-ring and v-funnel tests were performed to evaluate the fresh properties of the self-compacting concrete according to Egyptian Standard Specifications (E.S.S.). The concrete was placed in the molds. All specimens of both normal and self-compacted concrete were kept at molds for 24 hours. After 24 hours they were removed from the molds and immerged in clean water of temperature of 25°C for curing at 25°C. Other specimens were immerged in clean water of 50°C temperature using a heater for curing at 50°C until taken out for tested.

2.2. Testing of hardened concrete

Three tests were conducted to obtain hardened concrete properties as follow:

1. Compressive strength test using 78 concrete cubes of 100*100*100 mm length for each type of concrete.
2. Splitting tensile strength test using 52 concrete cylinders of 200 mm length and 100 mm diameter for each type of concrete.
3. Flexural strength test using 26 concrete prisms of 500 mm length and a cross-section of 100 mm for each type of concrete.
4. Dry shrinkage test using 26 concrete prisms of 250 mm length and a cross-section of 70 mm for each type of concrete as shown in Table 3.

3. Results and Discussion

3.1. Fresh properties

As shown in Fig. 3 and Table 4, the results comply with Salhi et al. (2017). The properties of fresh self-compacting concrete are affected by the hot weather conditions. The concrete temperature rises and the setting time of concrete decreases resulting in increasing the hydration rate at early ages. The more the decreasing setting time, the more difficult of concrete compacting.

3.2. Compressive strength

The compressive strength of self-compacting concrete in hot weather has higher values at early ages as the structure of C-S-H gel is modified in the cement, but at later ones decreased values are noticed compared to normal conditions mortar as the results obtained by Madduru et al. (2016). In hot weather, the high temperatures accelerate the hydration products causing a hydration product shell that is more dense around the clinker particles that still anhydrite (Shuai et al., 2016).

The effect of mixing water temperatures on the compressive strength of the different concrete mixes;

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 4 shows the relation between age and compressive strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 5°C. Fig. 4(a) illustrates that the compressive strength increases with the age. Mixes cured at 25°C and 50°C have a compressive strength slightly less than that of control mix. The compressive strength of the mixes cured at 50°C is greater than that at 25°C only at early ages (7-

days) by about 23.8%, but at later ages it was less than that at 25°C by about 9% at (28-days) and 4.6% at (56-days). That is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages. Fig. 4(b) has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The results of compressive strength at (7-days) for the cured mixes at 50°C are greater than that at 25 by about 20%, less than that at 25°C by about 10% at (28-days) and less than that at 25°C by about 12% at (56-days).

Second, the same curing temperature and different concrete types (NC, SCC):

At 7-days tests, the results of self-compacting concrete specimens are always greater than conventional ones. The average compressive strength of (SCC) increased by about 1.4% compared to that of the conventional concrete. At 28-days tests, the average compressive strength of (SCC) increased by about 1.75% compared to that of the conventional concrete. At 56-days tests, the average compressive strength of (SCC) increased by about 5% compared to that of the conventional concrete.

Table 3. Shrinkage of conventional and self-compacting concrete.

Mixes	Shrinkage (%)
NC. Materials at 25°C, Mixing water at 5°C	0.049
NC. Materials at 25°C, Mixing water at 20°C	0.051
NC. Materials at 25°C, Mixing water at 35°C	0.050
SCC. Materials at 25°C, Mixing water at 5°C	0.098
SCC. Materials at 25°C, Mixing water at 20°C	0.057
SCC. Materials at 25°C, Mixing water at 35°C	0.064
NC. Materials at 50°C, Mixing water at 5°C	0.072
NC. Materials at 50°C, Mixing water at 20°C	0.049
NC. Materials at 50°C, Mixing water at 35°C	0.010
SCC. Materials at 50°C, Mixing water at 5°C	0.067
SCC. Materials at 50°C, Mixing water at 20°C	0.153
SCC. Materials at 50°C, Mixing water at 35°C	0.105
NC. Materials at 50°C, Mixing water at 35°C and using a retarder	0.067
SCC. Materials at 50°C, Mixing water at 35°C and using a retarder	0.115

Table 4. Fresh properties of self-compacting concrete.

Mixes	Slump		J-Ring		V-Funnel	
	D_{avg} (cm)	T (50cm) (sec.)	D_{avg} (cm)	H (cm)	T_o (sec.)	T (after 5mins) (sec.)
Materials at 25°C, Mixing water at 5°C	70	4.5	53	1.4	8	11
Materials at 25°C, Mixing water at 20°C	75	3.5	75	2	7	10
Materials at 25°C, Mixing water at 35°C	72	2.5	71	1.8	6	9
Materials at 50°C, Mixing water at 5°C	69	4	52	1.7	10	12
Materials at 50°C, Mixing water at 20°C	70	3	63	1.75	6.5	8.5
Materials at 50°C, Mixing water at 35°C	67	2	65	2	6	7.5
Materials at 50°C, Mixing water at 35°C and using a retarder	74	2	72	1.85	5	7

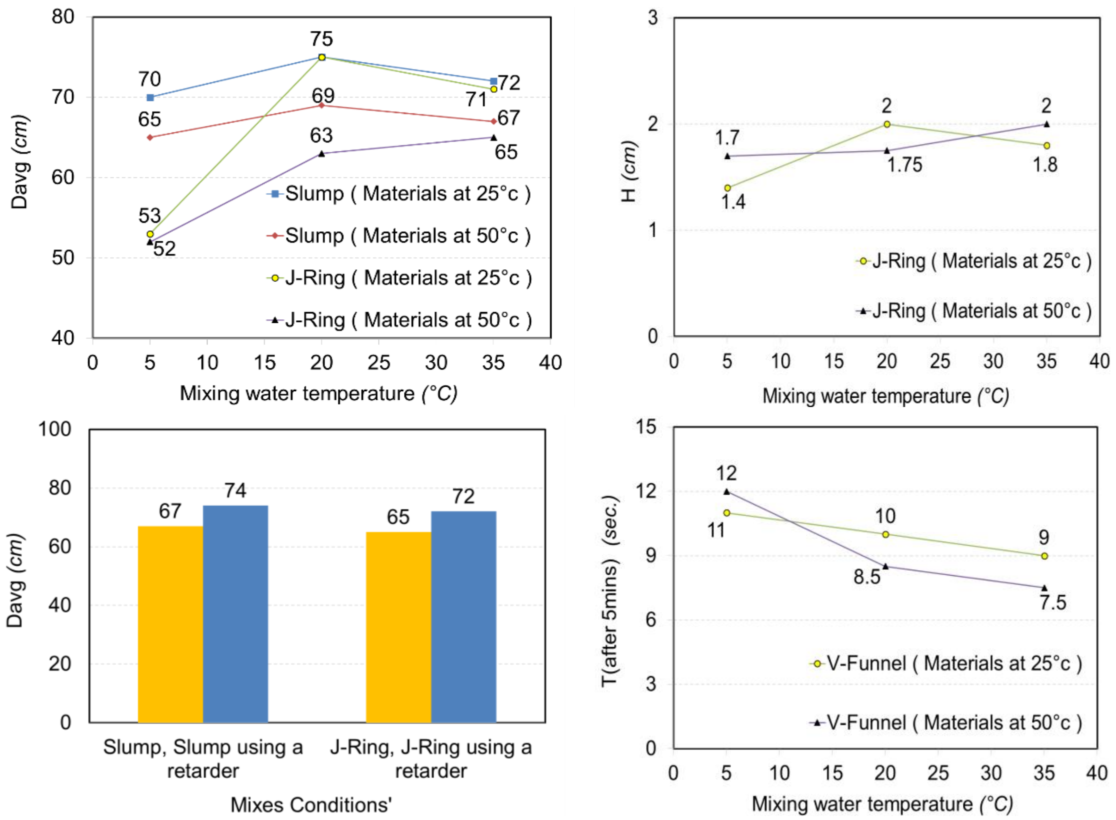

Fig. 3. Fresh properties of self-compacting concrete.

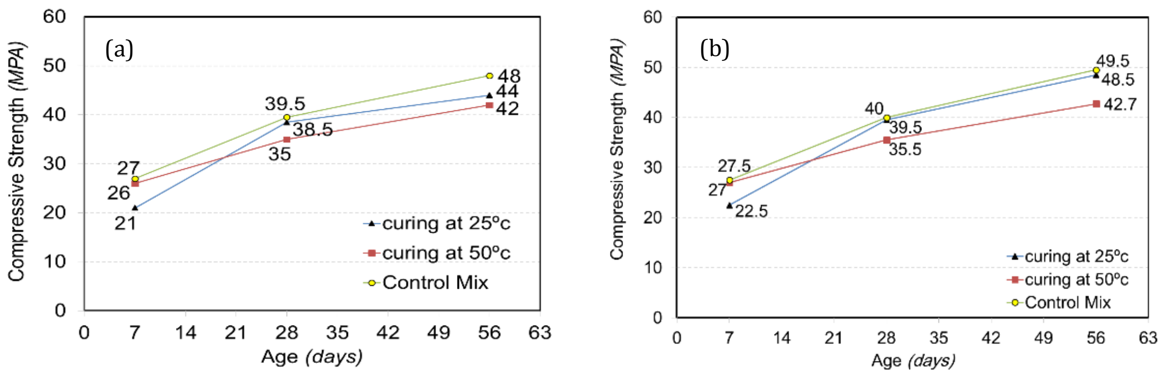

Fig. 4. Relationship between compressive strength and age using mixing materials at 25°C and mixing water at 5°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 5 shows the relation between age and compressive strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 20°C. Fig. 5(a) illustrates that the compressive strength increases with the age. Mixes cured at 25°C and 50°C have a compressive strength slightly less than that of control mix. The compressive strength of the mixes cured at 50°C is greater than that at 25°C only at early ages (7-days) by about 11%, but at later ages it was less than that at 25°C by about 5% at (28-days) and 7% at (56-days). That is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages. Fig. 5(b) has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The results of compressive strength at (7-days) for the cured mixes at 50°C are greater than that at 25 by about 13%, less than that at 25°C by about 6% at (28-days) and less than that at 25°C by about 8% at (56-days).

Second, the same curing temperature and different concrete types (NC, SCC):

At 7-days tests, the results of self-compacting concrete specimens are always greater than conventional ones. The average compressive strength of (SCC) increased by about 2.63% compared to that of the conventional concrete. At 28-days tests, the average compressive strength of (SCC) increased by about 1% compared to that of the conventional concrete. At 56-days tests, the average compressive strength of (SCC) increased by about 2.7% compared to that of the conventional concrete.

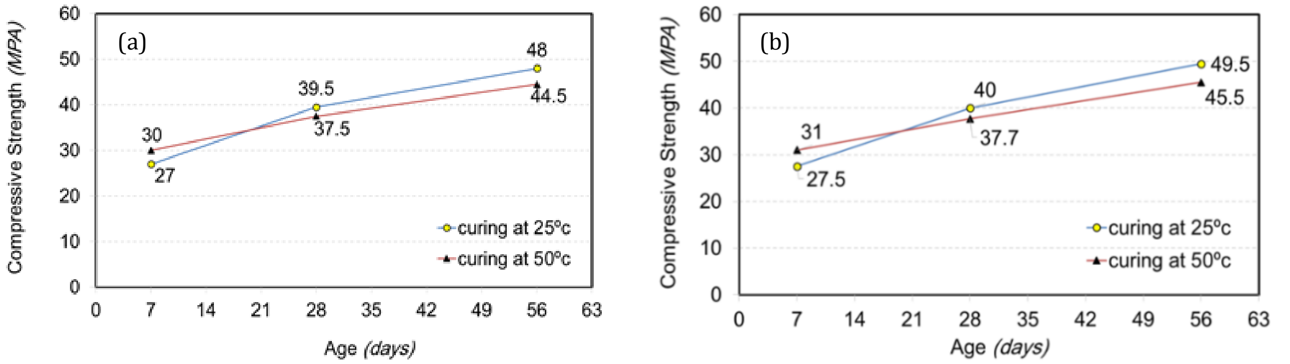

Fig. 5. Relationship between compressive strength and age using mixing materials at 25°C and mixing water at 20°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 6 shows the relation between age and compressive strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 35°C. Fig. 6(a) illustrates that the compressive strength increases with the age. Mixes cured at 25°C and 50°C have a compressive strength slightly less than that of control mix. The compressive strength of the mixes cured at 50°C is greater than that at 25°C only at early ages (7-days) by about 12%, but at later ages it was less than that at 25°C by about 13% at (28-days) and 14% at (56-days). That is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages. Fig. 6(b) has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The results of compressive strength at (7-days) for the cured mixes at 50°C are greater than that at 25°C by about 10%, less than that at 25°C by about 13% at (28-days) and less than that at 25°C by about 12% at (56-days).

Second, the same curing temperature and different concrete types (NC, SCC):

At 7-days tests, the results of self-compacting concrete specimens are always greater than conventional ones. The average compressive strength of (SCC) increased by about 2.3% compared to that of the conventional concrete. At 28-days tests, the average compressive strength of (SCC) increased by about 2.25% compared to that of the conventional concrete. At 56-days tests, the average compressive strength of (SCC) increased by about 4% compared to that of the conventional concrete.

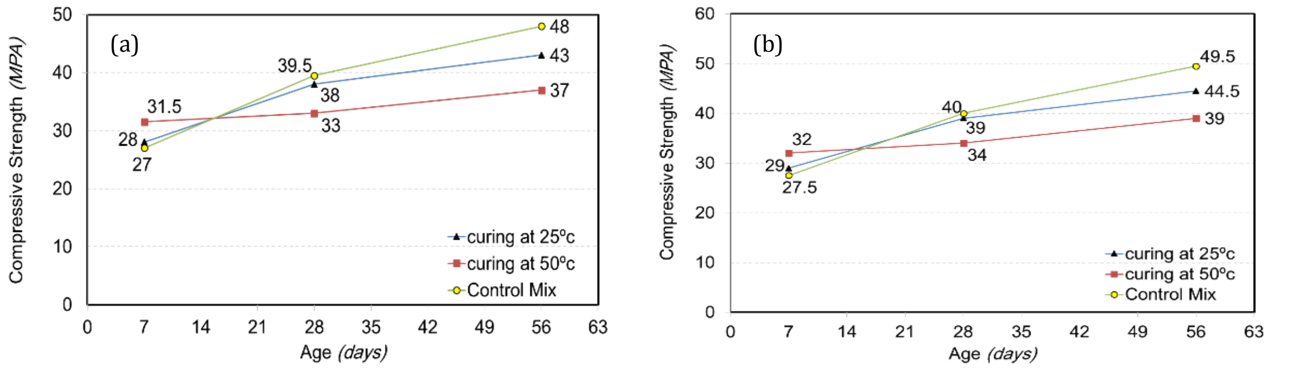

Fig. 6. Relationship between compressive strength and age using mixing materials at 25°C and mixing water at 35°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 7 shows the relation between age and compressive strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 5°C. Fig. 7(a) illustrates that the compressive strength increases with the age, mixes cured at 25°C and 50°C have a compressive strength slightly close to each other and the compressive strength of the control mix obviously is greater than other mixes. It's greater than the mixes cured at 25°C by about 237% at (7-days), 119% at (28-days) and 100% at (56-days) and also greater than mixes cured at 50°C by 145% about at (7-days), 139% at (28-days) and 113% at (56-days).

Fig. 7(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The control mix is greater than the mixes cured at 25°C by about 129% at (7-days), 81% at (28-days) and 65% at (56-days) and also greater than mixes cured at 50°C by about 128% at (7-days), 100% at (28-days) and 76% at (56-days).

Second, the same curing temperature and different concrete types (NC, SCC):

At 7-days tests, the results of self-compacting concrete specimens are always greater than conventional ones. The average compressive strength of (SCC) increased by about 12% compared to that of the conventional concrete. At 28-days tests, the average compressive strength of (SCC) increased by about 10.8% compared to that of the conventional concrete. At 56-days tests, the average compressive strength of (SCC) increased by about 13.75% compared to that of the conventional concrete.

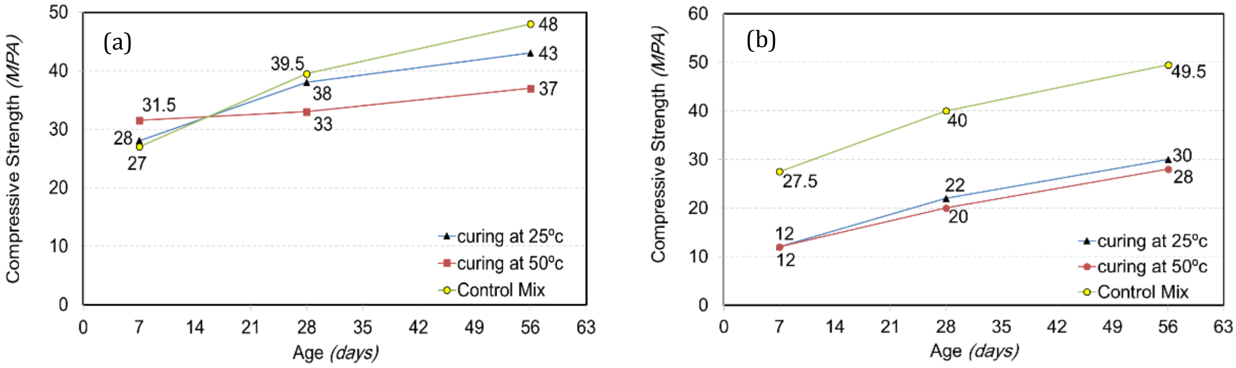

Fig. 7. Relationship between compressive strength and age using mixing materials at 50°C and mixing water at 5°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 8 shows the relation between age and compressive strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 20°C. Fig. 8(a) illustrates that the compressive strength increases with the age, mixes cured at 25°C and 50°C have a compressive strength slightly close to each other and the compressive strength of the control mix obviously is greater than other mixes. It's greater than the mixes cured at 25°C by about 200% at (7-days), 97% at (28-days) and 50% at (56-days) and also greater than mixes cured at 50°C by 125% about at (7-days), 132% at (28-days) and 62% at (56-days). Fig. 8(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The control mix is greater than the mixes cured at 25°C by about 111% at (7-days), 56% at (28-days) and 35% at (56-days) and also greater than mixes cured at 50°C by about 89% at (7-days), 66% at (28-days) and 55% at (56-days).

Second, the same curing temperature and different concrete types (NC, SCC):

At 7-days tests, the results of self-compacting concrete specimens are always greater than conventional ones. The average compressive strength of (SCC) increased by about 14.6% compared to that of the conventional concrete. At 28-days tests, the average compressive strength of (SCC) increased by about 17% compared to that of the conventional concrete. At 56-days tests, the average compressive strength of (SCC) increased by about 7.8% compared to that of the conventional concrete.

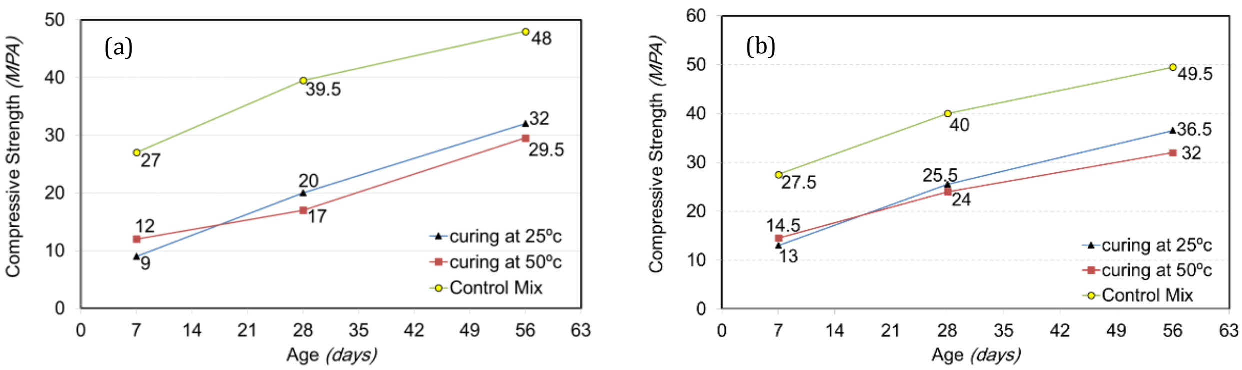

Fig. 8. Relationship between compressive strength and age using mixing materials at 50°C and mixing water at 20°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 9 shows the relation between age and compressive strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 35°C. Fig. 9(a) illustrates that the compressive strength increases with the age, mixes cured at 25°C and 50°C have a compressive strength slightly close to each other and the compressive strength of the control mix obviously is greater than other mixes. It's greater than the mixes cured at 25°C by about 134% at (7-days), 163% at (28-days) and 118% at (56-days) and also greater than mixes cured at 50°C by 110% about at (7-days), 192% at (28-days) and 140% at (56-days). Fig. 9(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The control mix is greater than the mixes cured at 25°C by about 77% at (7-days), 116% at (28-days) and 76% at (56-days) and also greater than mixes cured at 50°C by about 66% at (7-days), 128% at (28-days) and 102% at (56-days).

Second, the same curing temperature and different concrete types (NC, SCC):

At 7-days tests, the results of self-compacting concrete specimens are always greater than conventional ones. The average compressive strength of (SCC) increased by about 16% compared to that of the conventional concrete. At 28-days tests, the average compressive strength of (SCC) increased by about 11.7% compared to that of the conventional concrete. At 56-days tests, the average compressive strength of (SCC) increased by about 13.3% compared to that of the conventional concrete.

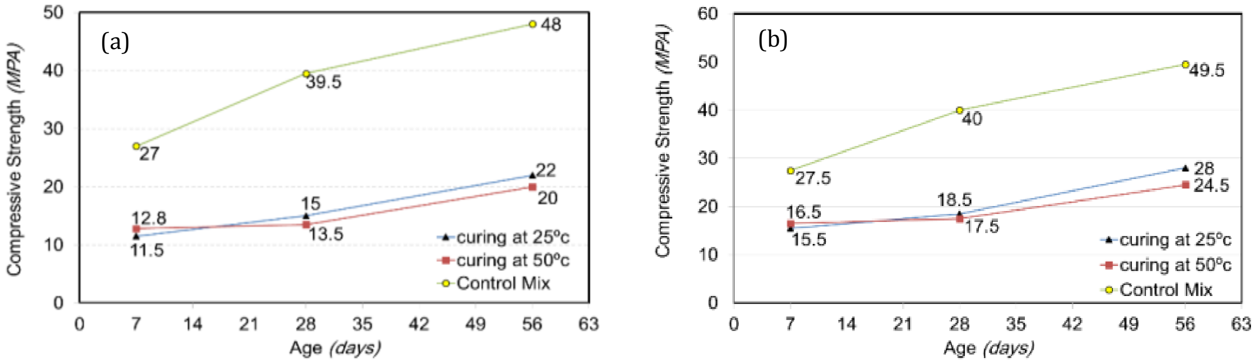

Fig. 9. Relationship between compressive strength and age using mixing materials at 50°C and mixing water at 35°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 10 shows the relation between age and compressive strength for the (NC) and (SCC) mixes cured at 50°C not using a retarder, mixes cured at 50°C using a retarder and control mix using mixing water temperature at 35°C. Fig. 10(a) illustrates that the compressive strength increases with the age, mixes cured at 50°C using a retarder have a compressive strength better than that not using a retarder and the compressive strength of the control mix obviously is greater than other mixes. It's greater than the mixes not using a retarder by about 111% at (7-days), 192% at (28-days) and 140% at (56-days) and also greater than mixes using a retarder by 92% about at (7-days), 108% at (28-days) and 118% at (56-days). Fig. 10(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The control mix is greater than the mixes not using a retarder by about 66% at (7-days), 128% at (28-days) and 101% at (56-days) and also greater than mixes using a retarder by about 61% at (7-days), 81% at (28-days) and 90% at (56-days).

Second, the same curing temperature and different concrete types (NC, SCC):

At 7-days tests, the results of self-compacting concrete specimens are always greater than conventional ones. The average compressive strength of (SCC) increased by about 13% compared to that of the conventional concrete. At 28-days tests, the average compressive strength of (SCC) increased by about 10.4% compared to that of the conventional concrete. At 56-days tests, the average compressive strength of (SCC) increased by about 9.9% compared to that of the conventional concrete.

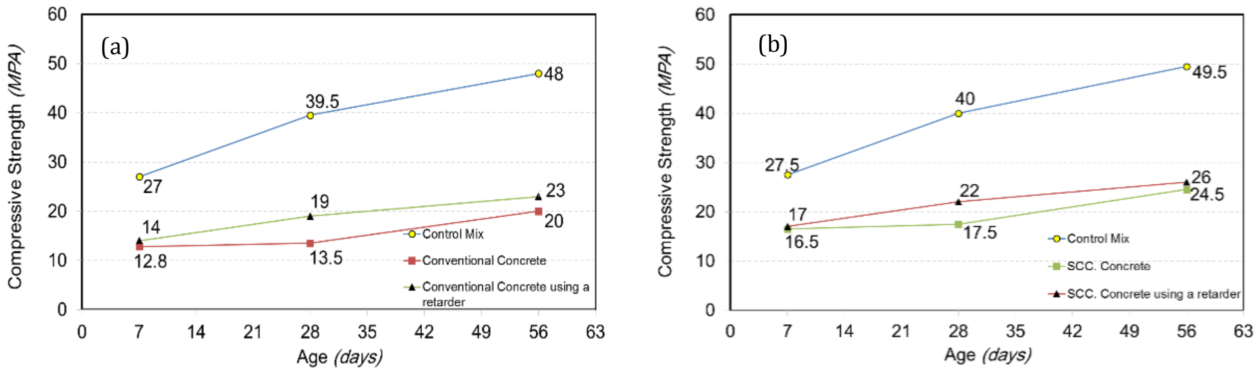

Fig. 10. Relationship between compressive strength and age using mixing materials at 50°C and mixing water at 35°C in addition to a retarder: (a) Normal concrete; (b) Self-compacting concrete.

Using a retarder had a significant effect on the results as shown in Fig. 10, there was an increase by about 9.4% and 3% for NC and SCC respectively after 7-days. After 28-days the increase was by about 40.75% and 25.71% for NC and SCC respectively. Finally, when testing after 56-days, results increased by about 15% and 6.12% for NC and SCC respectively.

3.3. Splitting tensile strength

Hot weather has the same influences of compressive strength results on splitting tensile strength results. Low tensile strength results compared to compressive strength results are also obtained. The irregular shape of crushed aggregates is very important as because of that shape water bleeding collects under the pieces of aggregates in an easy way decreasing the bond around that irregular surface and when the tensile force is applied in a zone of that irregular shape, cracks immediately develop in that zone before the other zones of concrete causing the low value of tensile strength. These results were complied with the study of (Sampebulu, 2008).

The effect of mixing water temperatures on the splitting tensile strength of the different concrete mixes;

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 11 shows the relation between age and splitting tensile strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 5°C. Fig. 11(a) illustrates that the splitting tensile strength increases with the age. Mixes cured at 25°C and 50°C have a splitting tensile strength slightly less than that of control mix. The splitting tensile of cured mixes at 50°C was less than that at 25°C by about 14% at (28-days) and 13% at (56-days). That is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages. Fig. 11(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The results of splitting tensile strength at (28-days) for the cured mixes at 50°C, are less than that at 25°C by about 11% and by about 11.4% at (56-days). The results of self-compacting concrete specimens are always greater than conventional ones.

Second, the same curing temperature and different concrete types (NC, SCC):

The average splitting tensile strength of (SCC) control mix increased by about 3% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 25°C increased by about 4.3% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 50°C increased by about 7.5% compared to that of the conventional concrete.

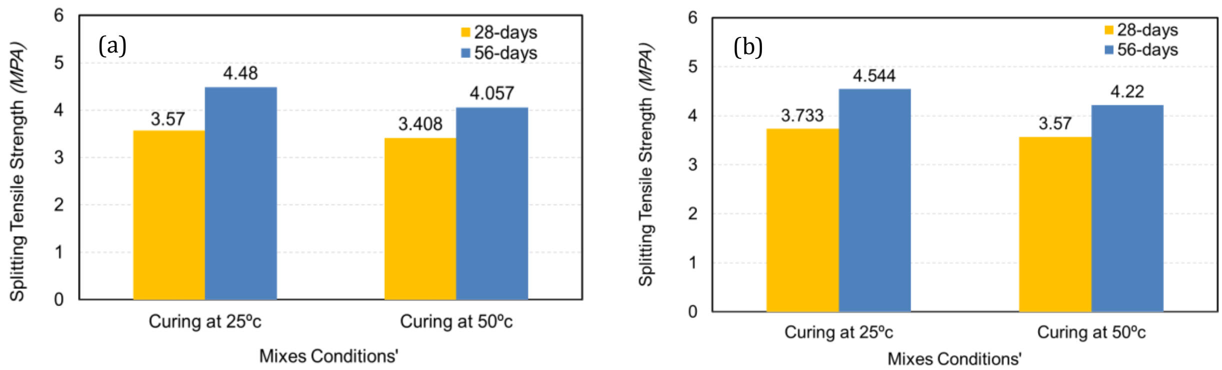

Fig. 11. Relationship between tensile strength and age using mixing materials at 25°C and mixing water at 5°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 12 shows the relation between age and splitting tensile strength for the (NC) and (SCC) mixes cured at 25°C (control mix) and cured at 50°C using mixing water temperature at 20°C. Fig. 12(a) illustrates that the splitting tensile strength increases with the age. The splitting tensile of cured mixes at 50°C was less than that at 25°C by about 4.5% at (28-days) and 9% at (56-days). That is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages. Fig. 12(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The results of splitting tensile strength at (28-days) for the cured mixes at 50°C, are less than that at 25°C by about 4% and by about 7% at (56-days).

Second, the same curing temperature and different concrete types (NC, SCC):

The average splitting tensile strength of (SCC) cured at 25°C increased by about 4% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 50°C increased by about 4.3% compared to that of the conventional concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 13 shows the relation between age and splitting tensile strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 35°C. Fig. 13(a) illustrates that the splitting tensile strength increases with the age. Mixes cured at 25°C and 50°C have a splitting tensile strength slightly less than that of control mix. The splitting tensile of cured mixes at 50°C was less than that at 25°C by about 13.2% at (28-days) and

13% at (56-days). That is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages. Fig. 13(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The results of splitting tensile strength at (28-days) for the cured mixes at 50°C, are less than that at 25°C by about 17% and by about 10% at (56-days). The results of self-compacting concrete specimens are always greater than conventional ones.

Second, the same curing temperature and different concrete types (NC, SCC):

The average splitting tensile strength of (SCC) control mix increased by about 3% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 25°C increased by about 8.3% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 50°C increased by about 7% compared to that of the conventional concrete.

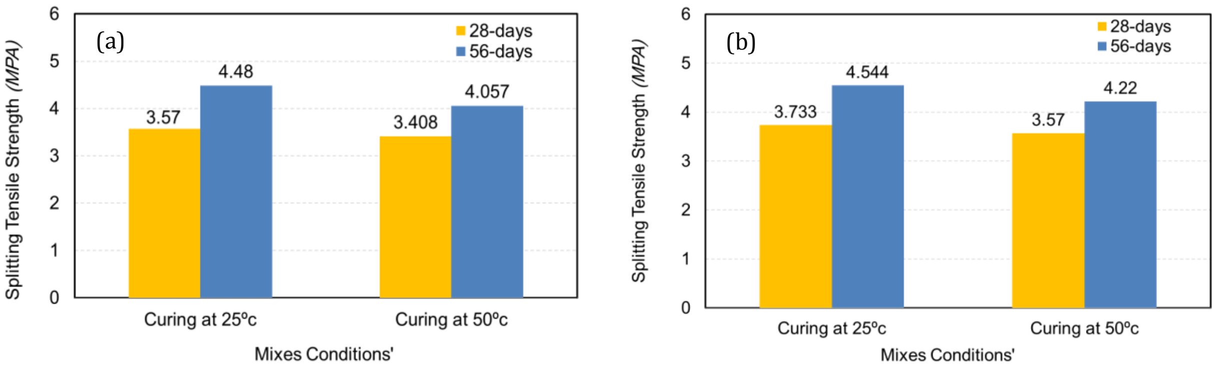

Fig. 12. Relationship between tensile strength and age using mixing materials at 25°C and mixing water at 20°C: (a) Normal concrete; (b) Self-compacting concrete.

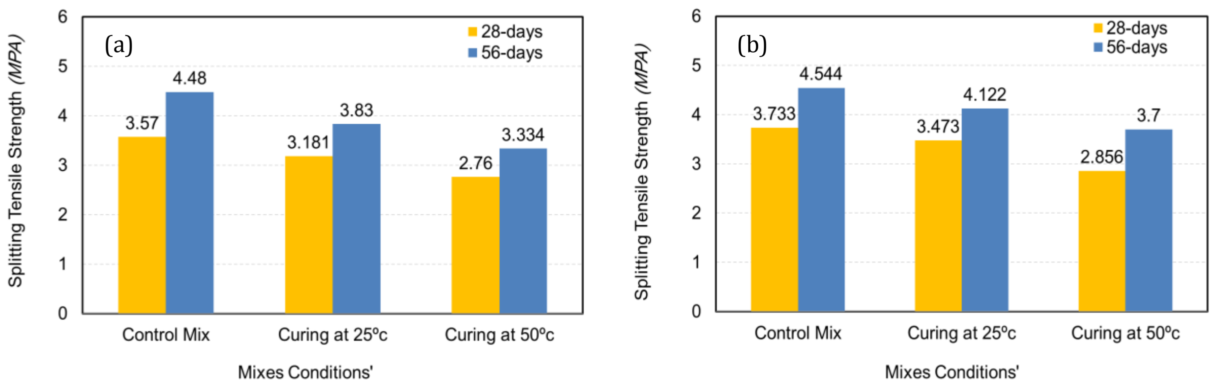

Fig. 13. Relationship between tensile strength and age using mixing materials at 25°C and mixing water at 35°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 14 shows the relation between age and splitting tensile strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 5°C. Fig. 14(a) illustrates that the splitting tensile strength increases with the age, mixes cured at 25°C and 50°C have a splitting tensile strength slightly close to each other and the splitting tensile strength of the control mix obviously is greater than other mixes. It's greater than the mixes cured at 25°C by about 42% at (28-days) and 44% at (56-days) and also greater than mixes cured at 50°C by about 83% at (28-days) and 91% at (56-days). This is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages.

Fig. 14(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The control mix is greater than the mixes cured at 25°C by about 28% at (28-days) and 31% at (56-days) and also greater than mixes cured at 50°C by about 53% at (28-days) and 63% at (56-days). The results of self-compacting concrete specimens are always greater than conventional ones.

Second, the same curing temperature and different concrete types (NC, SCC):

The average splitting tensile strength of (SCC) control mix increased by about 3% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 25°C increased by about 14% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 50°C increased by about 22% compared to that of the conventional concrete.

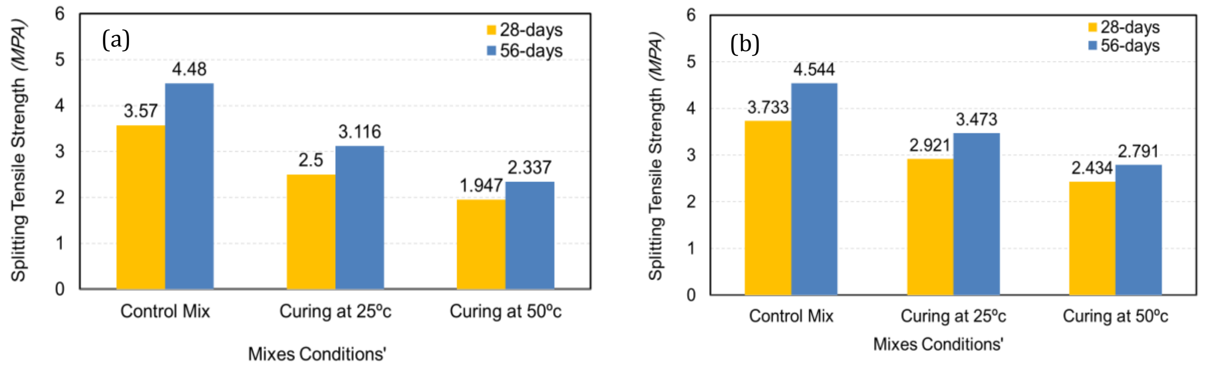

Fig. 14. Relationship between tensile strength and age using mixing materials at 50°C and mixing water at 5°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 15 shows the relation between age and splitting tensile strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 20°C. Fig. 15(a) illustrates that the splitting tensile strength increases with the age, mixes cured at 25°C and 50°C have a splitting tensile strength slightly close to each other and the splitting tensile strength of the control mix obviously is greater than other mixes. It's greater than the mixes cured at 25°C by about 25% at (28-days) and 33% at (56-days) and also greater than mixes cured at 50°C by about 65% at (28-days) and 67% at (56-days). This is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages.

Fig. 15(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The control mix is greater than the mixes cured at 25°C by about 12% at (28-days) and 21% at (56-days) and also greater than mixes cured at 50°C by about 40% at (28-days) and 49% at (56-days). The results of self-compacting concrete specimens are always greater than conventional ones. The average splitting tensile strength of (SCC) control mix increased by about 3% compared to that of the conventional concrete.

Second, the same curing temperature and different concrete types (NC, SCC):

The average splitting tensile strength of (SCC) cured at 25°C increased by about 13.7% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 50°C increased by about 17.8% compared to that of the conventional concrete.

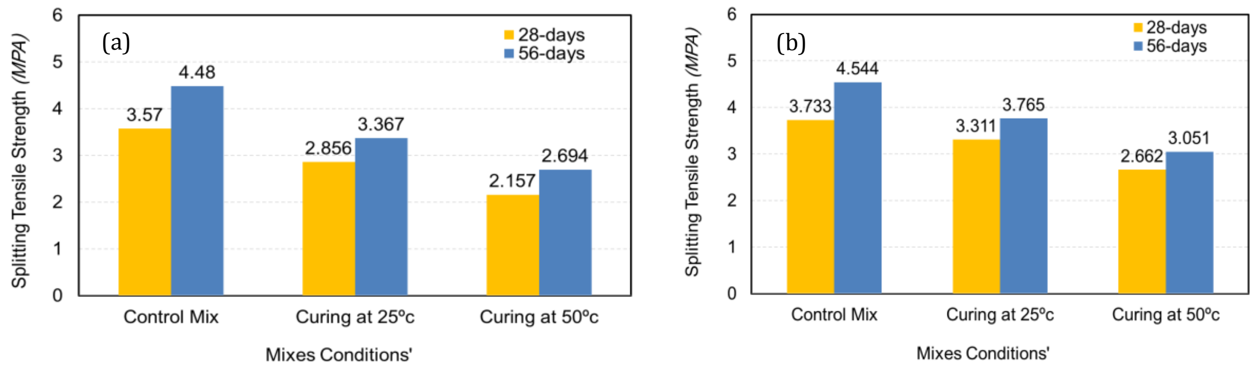

Fig. 15. Relationship between tensile strength and age using mixing materials at 50°C and mixing water at 20°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 16 shows the relation between age and splitting tensile strength for the (NC) and (SCC) mixes cured at 25°C, 50°C and control mix using mixing water temperature at 35°C. Fig. 16(a) illustrates that the splitting tensile strength increases with the age, mixes cured at 25°C and 50°C have a splitting tensile strength slightly close to each other and the splitting tensile strength of the control mix obviously is greater than other mixes. It's greater than the mixes cured at 25°C by about 57% at (28-days) and 64% at (56-days) and also greater than mixes cured at 50°C by about 100% at (28-days) and 112% at (56-days). This is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages.

Fig. 16(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The control mix is greater than the mixes cured at 25°C by about 44% at (28-days) and 46% at (56-days) and also greater than mixes cured at 50°C by about 65% at (28-days) and 75% at (56-days). The results of self-compacting concrete specimens are always greater than conventional ones. The average splitting tensile strength of (SCC) control mix increased by 3% compared to that of the conventional concrete.

Second, the same curing temperature and different concrete types (NC, SCC):

The average splitting tensile strength of (SCC) cured at 25°C increased by about 14.3% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 50°C increased by about 25% compared to that of the conventional concrete.

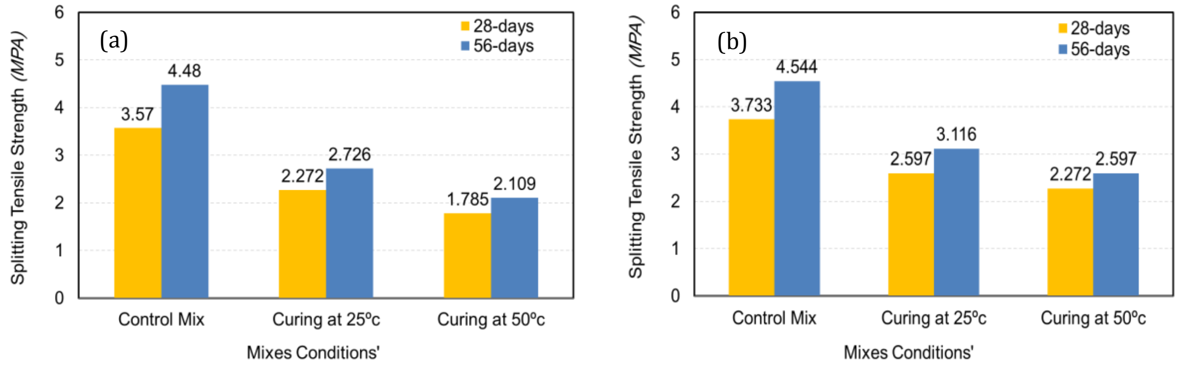

Fig. 16. Relationship between tensile strength and age using mixing materials at 50°C and mixing water at 35°C: (a) Normal concrete; (b) Self-compacting concrete.

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 17 shows the relation between age and splitting tensile strength for the (NC) and (SCC) mixes cured at 50°C not using a retarder, mixes cured at 50°C using a retarder and control mix using mixing water temperature at 35°C. Fig. 17(a) illustrates that the splitting tensile strength increases with the age, mixes cured at 50°C using a retarder have a splitting tensile strength better than that not using a retarder and the splitting tensile strength of the control mix obviously is greater than other mixes. It's greater than the mixes not using a retarder by about 100% at (28-days) and 112% at (56-days) and also greater than mixes using a retarder by 70% at (28-days) and 71.5% at (56-days).

Fig. 17(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The control mix is greater than the mixes not using a retarder by about 66% at 64% at (28-days) and 75% at (56-days) and also greater than mixes using a retarder by about 44% at (28-days) and 56% at (56-days).

Second, the same curing temperature and different concrete types (NC, SCC):

The average splitting tensile strength of (SCC) control mix increased by about 3% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) using a retarder increased by about 16.5% compared to that of the conventional concrete. The average splitting tensile strength of (SCC) cured at 50°C increased by about 25% compared to that of the conventional concrete.

Using a retarder to improve the obtained results made its job as shown in Fig. 17. There was an increase by about 18.15% for NC and 14.31% for SCC after 28-days. Also when testing after 56-days, there was an increase by about 24% for NC and 11.86% for SCC. The results of self-compacting concrete specimens are always greater than conventional ones.

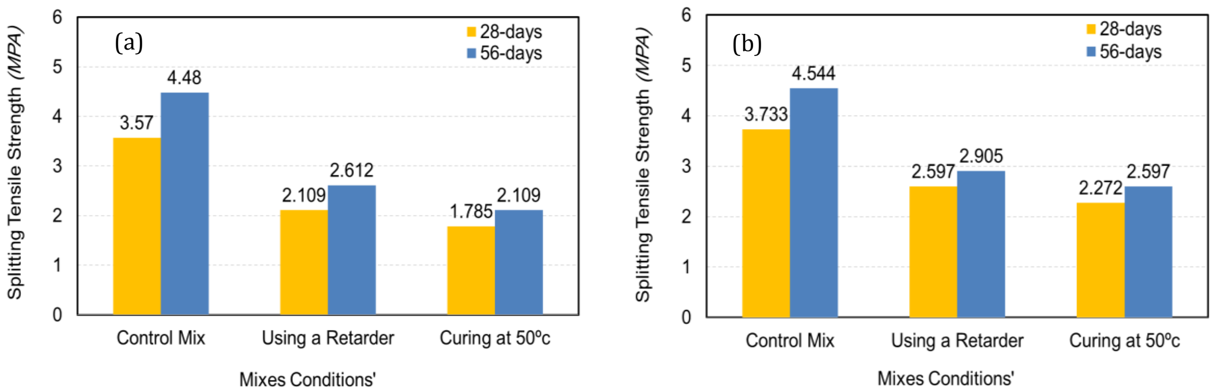

Fig. 17. Relationship between tensile strength and age using mixing materials at 50°C and mixing water at 35°C in addition to a retarder: (a) Normal concrete; (b) Self-compacting concrete.

3.4. Flexural strength

The effect of hot weather on the flexural strength of self-compacting concrete is clear as discussed in the following figures. These results comply with the work of Madi. et al. (2017).

The effect of mixing water temperatures on the flexural strength of the different concrete mixes;

First, the same concrete type and different curing temperatures (25°C, 50°C):

Fig. 18 shows the relation between mixing water temperatures and flexural strength after 28-days for the (NC) and (SCC) mixes. Fig. 18(a) shows the flexural strength results after 28-days of conventional concrete (control mix) at different mixing water temperatures. The Figure illustrates that the flexural strength increases at mixing water temperature of 20°C by 14% compared to that at 5°C. It also shows that the flexural strength decreases at mixing water temperature of 35°C by 26% compared to that at 20°C.

Fig. 18(b) shows the flexural strength results after 28-days of self-compacting concrete (control mix) at different mixing water temperatures. The figure illustrates that the flexural strength increases at mixing water temperature of 20°C by 4.7% compared to that at 5°C. It also shows that the flexural strength decreases at mixing water temperature of 35°C by 21.3% compared to that at 20°C.

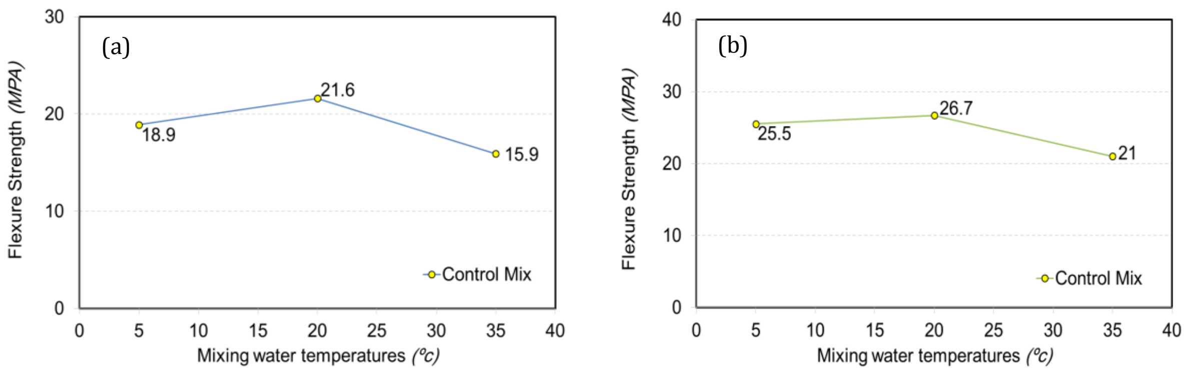

Fig. 18. Relationship between flexural strength and age using mixing materials at 25°C and mixing water at 25°C: (a) Normal concrete; (b) Self-compacting concrete.

Fig. 19 shows the relation between mixing water temperatures and flexural strength after 28-days for the (NC) and (SCC) mixes whose materials are at 25°C and cured at 50°C and control mix at different mixing water temperatures. Fig. 19(a) illustrates that the flexural strength increases at mixing water temperature of 20°C by 16.7% compared to that at 5°C. It also shows that the flexural strength decreases at mixing water temperature of 35°C by 28.6% compared to that at 20°C. The flexural strength of the control mix obviously is greater than the other mix as it's greater by about 5% at (5°C) of mixing water temperature, 3% at (20°C) and 6% at (35°C). This is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at later ages.

Fig. 19(b) has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The Figure illustrates that the flexural strength increases at mixing water temperature of 20°C by 13% compared to that at 5°C. It also shows that the flexural strength decreases at mixing water temperature of 35°C by 18% compared to that at 20°C. The control mix is greater than the other mix by about 16% (5°C), 7% at (20°C) and 3% at (35°C).

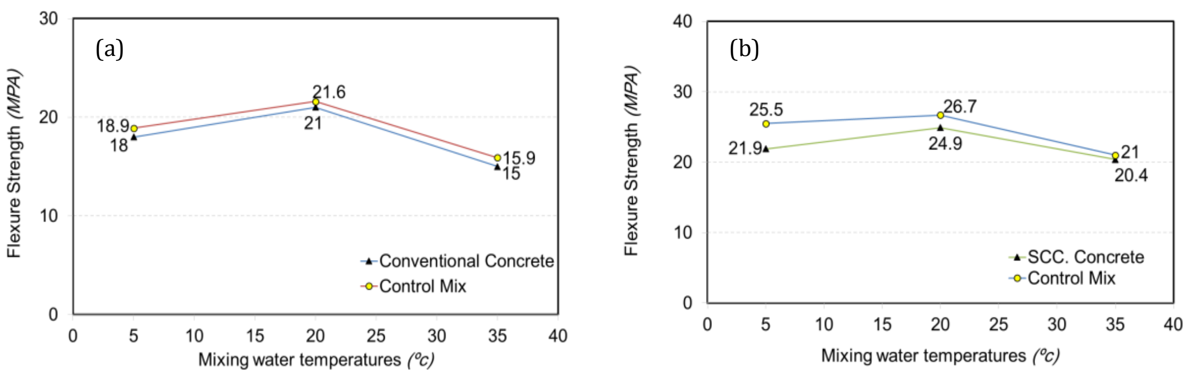

Fig. 19. Relationship between flexural strength and age using mixing materials at 25°C and mixing water at 50°C: (a) Normal concrete; (b) Self-compacting concrete.

Fig. 20 shows the relation between mixing water temperatures and flexural strength after 28-days for the (NC) and (SCC) mixes whose materials are at 50°C and cured at 25°C and control mix at different mixing water temperatures. Fig. 20(a) illustrates that the flexural strength increases at mixing water temperature of 20°C by 9% compared to that at 5°C. It also shows that the flexural strength decreases at mixing water temperature of 35°C by 12.5% compared to that at 20°C. The flexural strength of the control mix obviously is greater than the other mix as it's greater by about 43.18% at (5°C) of mixing water temperature, 50% at (20°C) and 66% at (35°C).

Fig. 20(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The figure illustrates that the flexural strength increases at mixing water temperature of 20°C by 12% compared to that at 5°C. It also shows that the flexural strength decreases at mixing water temperature of 35°C by 13.3% compared to that at 20°C. The control mix is greater than the other mix by about 26.8% at (5°C), 18.7% at (20°C) and 7.7% at (35°C).

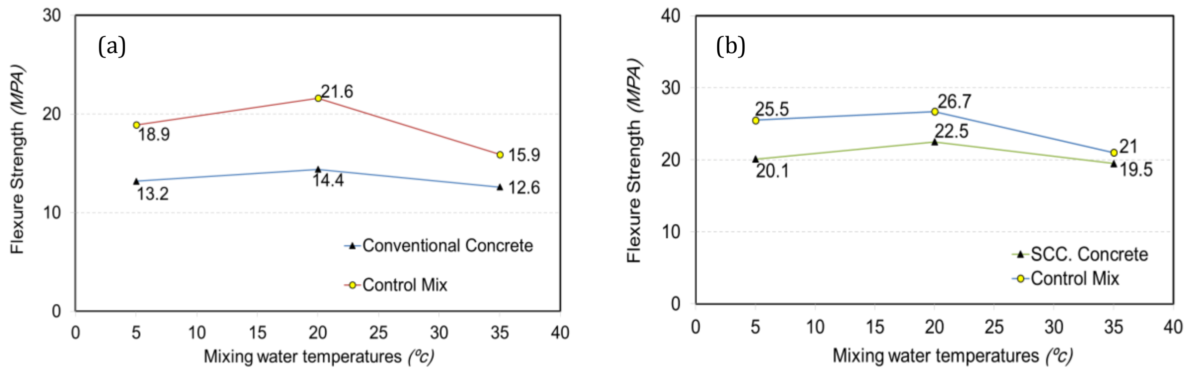

Fig. 20. Relationship between flexural strength and age using mixing materials at 50°C and mixing water at 25°C: (a) Normal concrete; (b) Self-compacting concrete.

Fig. 21 shows the relation between mixing water temperatures and flexural strength after 28-days for the (NC) and (SCC) mixes whose materials are at 50°C and cured at 50°C and control mix at different mixing water temperatures. Fig. 21(a) illustrates that the flexural strength increases at mixing water temperature of 20°C by 7.3% compared to that at 5°C. It also shows that the flexural strength decreases at mixing water temperature of 35°C by 13.6% compared to that at 20°C. The flexural strength of the control mix obviously is greater than the other mix as it's greater by about 53.7% at (5°C) of mixing water temperature, 63% at (20°C) and 39.47% at (35°C). This is due to the difference of concrete temperature, mixing water temperature and the surrounding temperature making cracks in concrete appear in the results at late ages. Fig. 21(b) also has the same trending conditions, but the concrete type is different as the self-compacting concrete is the case of study. The figure illustrates that the flexural strength increases at mixing water temperature of 20°C by 6.45% compared to that at 5°C. It also shows that the flexural strength decreases at mixing water temperature of 35°C by 16% compared to that at 20°C. The control mix is greater than the other mix by about 37% (5°C), 34.8% at (20°C) and 27.3% at (35°C).

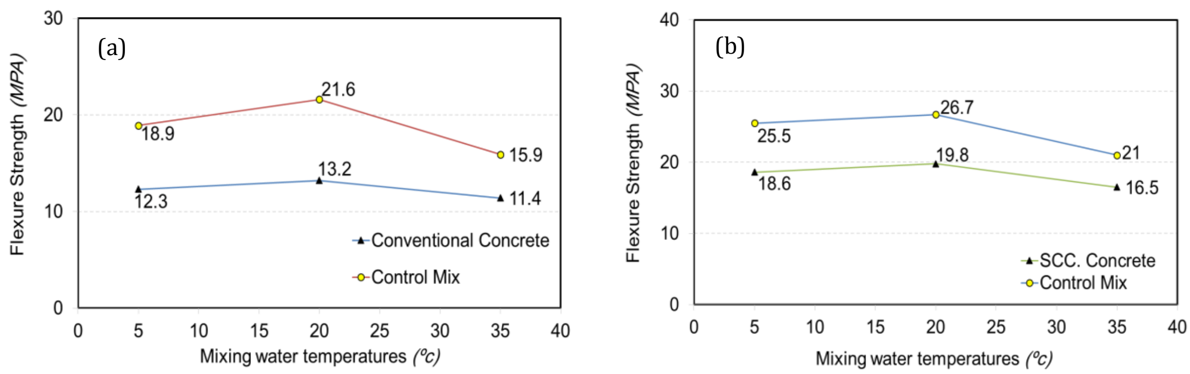

Fig. 21. Relationship between flexural strength and age using mixing materials at 50°C and mixing water at 50°C: (a) Normal concrete; (b) Self-compacting concrete.

Second, the same curing temperature and different concrete types (NC, SCC):

The previous results of flexural strength was conducted out of four stages, first one having the best results due to its ideal conditions was when the mixing materials at 25°C and the curing also at 25°C as shown in Fig. 18. Comparing the second stage (mixing materials at 25°C and the curing at 50°C) as shown in Fig. 19 to the first stage; the flexural strength of (SCC) decreased by about 14% when mixing water was at 5°C, by about 6.75% when mixing water was at 20°C and by about 2.3% when mixing water was at 35°C, The flexural strength of (NC) decreased by about 4.7% when mixing water at 5°C, by about 2.8% when mixing water was at 20°C and by about 5.7% when mixing water was at 35°C.

Comparing the third stage (mixing materials at 50°C and the curing at 25°C) as shown in Fig. 20 to the second stage shown in Fig. 19; the flexural strength of (SCC) decreased by about 8.2% when mixing water was at 5°C, by about 9.6% when mixing water was at 20°C and by about 4.4% when mixing water was at 35°C, The flexural strength of (NC) decreased by about 2.7% when mixing water at 5°C, by about 7.6% when mixing water was at 20°C and by about 16% when mixing water was at 35°C.

Comparing the fourth stage having the worst results because of its aggressive conditions (both the mixing materials and curing at 50°C) as shown in Fig. 21 to the third stage as shown in Fig. 20; the flexural strength of (SCC) decreased by about 7.5% when mixing water was at 5°C, by about 12% when mixing water was at 20°C and by about 15.4% when mixing water was at 35°C, The flexural strength of (NC) decreased by about 6.8% when mixing water at 5°C, by about 8% when mixing water was at 20°C and by about 9.5% when mixing water was at 35°C.

Using the retarder had significant increase on the flexural strength results by about 6.78% for (NC) and 13.33% for (SCC) as shown in Fig. 22. The average flexural strength of the (SCC) is higher than that of the (NC) by 39%.

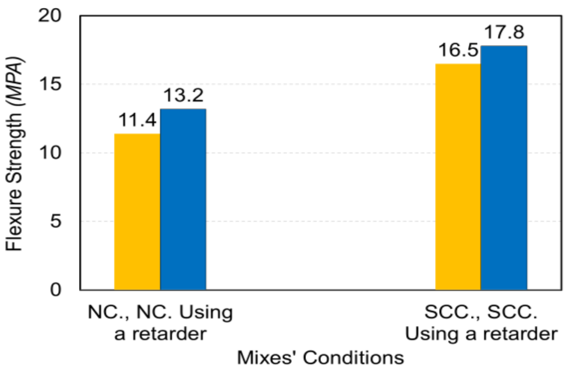

Fig. 22. Relationship between flexural strength and concrete mixes (conventional concrete and self-compacting) using mixing materials at 50°C and curing temperature of 50°C in addition to a retarder.

3.5. Concrete drying shrinkage

The curing time for concrete has a little significant effect on concrete drying shrinkage (Neville, 1996). The process of concrete drying shrinkage continues for years (Troxel et al., 1958). The results of the concrete drying shrinkage were obtained according to ASTM C157/C157M (2008). The results are shown in Table 3. There are many factors affecting the drying shrinkage which are the properties of the mixing materials, the environmental influences and the construction practices. It was found that the problem of losing moisture from the fresh concrete in hot weather because of evaporation. This problem leading to drying shrinkage cracking especially at early-ages can be minimized using shrinkage reducing admixtures (Bentz, 2006).

Studies made by Lura et al. (2011) have concluded that curing temperature plays an important role affecting the shrinkage of concrete. After 6-days of pouring, the shrinkage was 10μm/m when the curing temperature was 40°C and at 30°C, the shrinkage value was lower.

Mounanga et al. (2006) have found from their studies that shrinkage increases with temperature to a limit as when they measured it at curing temperature of 50°C was less than that at curing temperature of 40°C, they have stated that was because of structural, physical and chemical change of hydrates that are different from those measured at lower temperatures.

The tendency of both micro and macro cracks to increase occurs at elevated temperatures and this pays an important role in the increase of the total shrinkage of concrete (Maruyama and Teramoto, 2013)

The total shrinkage of concrete at curing temperature of 25 °C was more than that at curing temperature of 50 °C and that is because the potential of different reactions of cement and their relationships with cement and also the hydration mechanism (Jiang et al., 2014).

Test results showed that (SCC) concrete had better shrinkage average values compared to (NC) concrete when concrete materials were at 25°C and also when the concrete materials were at 50°C. At elevated ambient temperatures concrete shrinkage values were less than those at normal temperatures for (NC). In such hot weather conditions, concrete setting time is decreased and the hardening process occurs fast minimizing the probability of shrinkage compared to that at normal weather conditions. (SCC) shrinkage values were a little bit higher than those at normal temperatures. The retarder had a high effect increasing the shrinkage values of (NC) at hot weather while a significant increase on (SCC) shrinkage values.

4. Conclusions

The results present:

- The best performance of the two types of concrete even under high temperatures of either materials or curing are self-compacting concrete and conventional concrete respectively.
- The early curing of the specimens and covering them by burlap that also kept as wet as possible improves the properties of concrete.
- The compressive strength, splitting tensile strength and flexural strength at later ages shows that the curing compound is better than normal way of curing (water curing).
- Most un-desired results are those that were cured at 50°C and mixed of materials at 50°C, too.
- A retarder effect is very important to improve the properties of concrete especially in the most critical case of (materials temperature is at 50°C and curing temperature is also at 50°C).

The recommendations are:

- It should be clear that hot weather conditions have severe effects on both conventional and self-compacting concrete properties. As a result avoiding casting and curing at morning especially noon times in hot climates is a must.
- Using admixtures is the most helpful solution to overcome these undesired results of concrete properties.
- Types and dosages of admixtures especially retarders are the most important recommendations for any further work.
- New techniques or mixing more than a method for curing concrete in these hard conditions are also a remarkable cases of study.

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