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EFFECT OF HOT WEATHER CONCRETING ON THE MECHANICAL AND DURABILITY PROPERTIES OF CONCRETE-A REVIEW

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1. INTRODUCTION

Hot weather or hot climate as defined according to ACI 305 R (Hills, 2010) is any combination of environmental conditions such as high temperature, low relative humidity, high wind speed as well as solar radiation. It tends to affect the quality of fresh and hardened concrete by enhancing the rate of cement hydration and moisture loss. As reported earlier, the best favorable fresh concrete temperature is between 50˚F and 60˚F (Steven et al 1981, Mindess and Young, 1981). During hot weather concreting, the hot weather temperature exceeds 100˚F. It has a significant influence on long term strength and durability. Hot weather problems are mainly encountered in the summer. However, the associated climate factors mentioned above can exist at any time, especially in tropical or arid climates. ACI committee – 305 (Hills, 2010) does not involve any limit for concrete temperature. However, ACI 301 "Specifications for Concrete Construction", states the temperature limits shall apply for mass concrete placements. Furthermore, in order to prevent hot weather problems, other standards require an extreme temperature limit. For example, as reported by British standard BS 8110, 1985, during placing time, the temperature of concrete must be higher than 30°C and the preferable temperature is usually 27˚C. Besides, according to ASTM C94, Daniel and Lobo, 2005 also provided a limit of concrete temperature between 29°C and 32°C. In southwestern USA, concreting is prevented in summer months. Besides, in Arabian gulf states, the annual temperature (between June and September) varies between 10°C and 50°C. Hence, the allowable highest concrete temperature is usually between 35°C and 38°C. Some authors (Malhotra, 2002; Kay, 2003) investigate that the climate in Arab gulf is extremely hot. In some Russian regions, the temperature in summer weather can attain more than 25˚C with low humidity (<50%) in daytime. These conditions have significant impact on the workability and consistency of concrete during its transportation and casting at construction site. In this case, if temperature rises and surpasses the permissible limit, a big amount of empty pores will occur due to water evaporation which leads to density and strength loss. In such conditions, cement is not well hydrated and leads to damage the porous structure of concrete. Cement hydration is the key element for making high quality of concrete in dry and hot weather (Temkin, 2001; Kkhoa, 2007; Magatte, 2009; Khatib et al, 2021; Khatib et al, 2022^{a}, Khatib et al, 2022^{b}, Khatib et al, 2022^{c}). For this reason, the utilization of waste offers an alternate solution to disposal for addressing environmental injustice, lowering dangers, and enhancing urban sustainability. There has been a lot of interest in the reuse and recycling of municipal solid waste incinerator (MSWI) ash in the construction sector (Charbaji et al, 2018; Ghanem et al, 2019; Machaka et al, 2019; Khatib et al, 2020). A potential solution to the environmental justice problems in waste management and the building industry is to include MSWI ash into the manufacturing of cement and concrete. The incorporation of this material leads to the reduction of cement hydration (Ghanem et al, 2020; Khatib et al, 2021).

This article discusses the main problems of hot weather concreting and its precautions based on key standards. Furthermore, a review is illustrated below to discuss about the effects of the hot weather on the mechanical and durability properties of concrete.

2. PROBLEMS OF HOT CLIMATE ON CONCRETE

The achievement of many hot-weather concrete placements depends on the steps taken to slow the hydration of cement reactions within the concrete and to reduce the rate of moisture evaporation from the freshly mixed concrete. Concrete problems in hot weather would include:

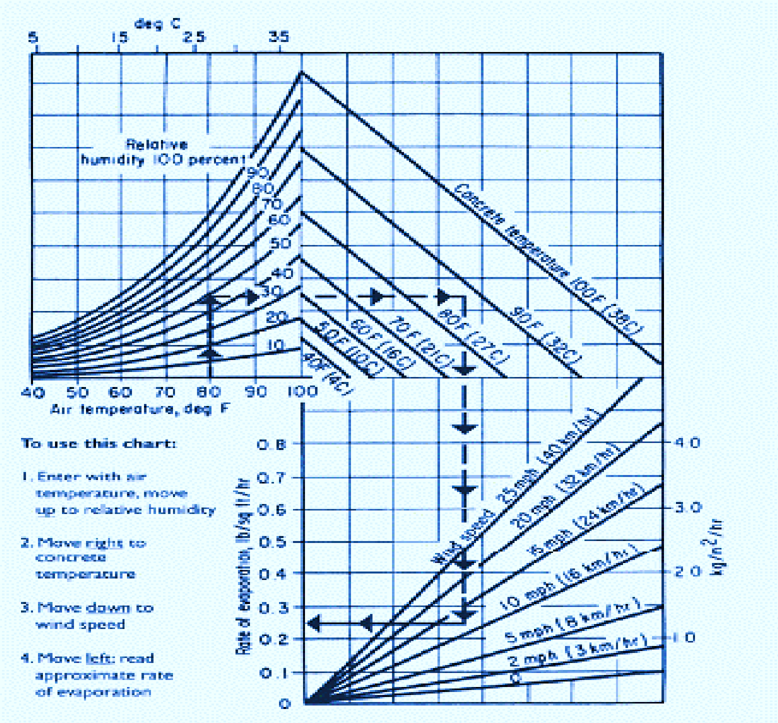
2.1. Increase in water demand

Loss of moisture take place in hot weather. In order to maintain the required workability, the demand of water goes up. The addition of water leads to a lack in the resistance and durability of concrete (Kulkarni and Prakash, 2013; Surahyo, 2019). However, other research display that rising the W/C ratio with a suitable cure could progress the resistance of concrete (Ait-Aider et al, 2007;

Zhutovsky and Kovler, 2014; Zhutovsky and Kovler, 2017). Usually, drying shrinkage increases as mixing water content goes up

2.2 Excessive evaporation

ACI 305 (Hills, 2010) elucidates that plastic shrinkage repairing must be taken into consideration if the rate of evaporation attains a value of 1 kg/m²/h. This value is evaluated from the ACI 305(Hills, 2010) monograph (Fig. 1). This plot has been discussed and new strategies have been proposed (Al-Fadhala et al, 2001; Mbemba, 2010a) because this monograph is related to the open surface evaporation of water and not for concrete surface. However, other researcher (Hover, 2006) confirmed that this monograph provides reasonable values when the climatic data are recorded precisely from construction site. Excessive water evaporation during hardening could provide plastic shrinkage and cracks formation (Selvamony et al, 2010; Zhutovsky et al, 2013). This process can be prevented by coating some materials. However, it is necessary to avoid loss of moisture during setting and delivery of concrete to jobsite (Aruova, 2006; Elsageer et al, 2009). For solving this problem, the inclusion of additives for production can be one of the efficient solution. It saves cement and avoids negative influence of high temperature and also saves the concrete mix performance during its delivery, setting and hardening (Shi et al, 2009; Pereira et al, 2012; Zhimin et al, 2012; Barabanshchikov and Komarinskiy, 2014; Solobay et al, 2014; Bong et al, 2019, Sokolava et al, 2021).



To use this chart:

1. Enter with air temperature, move up to relative humidity
2. Move right to concrete temperature
3. Move down to wind speed
4. Move left: read approximate rate of evaporation

Fig. 1. ACI monograph for estimating the evaporation rate from concrete surface (Hills, 2010)

2.3 Loss of workability

In hot weather situations, fresh concrete is exposed to a high rate of slump loss leading to a difficult placing. During hot climate, the rate of moisture loss as well as the rate of cement hydration is high and results in a rapid loss of concrete workability.

2.4 Decrease in the setting time of concrete

Weather conditions affect the setting time of concrete. Also wind is most significant parameter compared to the relative humidity action and temperature (Ahmadi, 2000; Kay, 2003). The initial setting time of concrete is usually decreased due to the high rate of cement hydration reaction which affects the time available for transmitting, placing as well as finishing.

2.5 Cracks due to shrinkage

Cracking related with hot climate concreting happens at early ages and may include plastic shrinkage, drying shrinkage, adhesive cracks as well as thermal cracks. Plastic cracking exists in fresh concrete. These cracks occur due to the rapid loss of moisture and are usually linear and exist at the surface of concrete. Besides, these cracks can have a length from 1 or 2 cm (small cracks) to 1 or 2 m (big cracks) and a depth of around 23 cm with a thicknesses of 0.1 to 3 mm (Belferrag et al, 2013). Adhesion cracks are perceived within the concrete and covered around aggregate particles, forming curved gaps between the paste and aggregate particles. Adhesion cracks is resulting from a combination of plastic shrinkage and external stresses when concrete is hardening (Belferrag et al, 2013). Besides, drying shrinkage cracks are more distinctive of an inelastic failure. These cracks may range from surficial cracks to a larger cracks and leads to reduce concrete strengthening. Drying shrinkage cracks tend to be more dangerous than plastic shrinkage cracks. Usually, under thermal constriction, the surfaces undergo contraction. Thus, the inside will be compressed. Besides, if the tensile stress on the surfaces is greater than the tensile strength, cracks will exist (Nabil et al, 2011). Furthermore, the high temperature inside the concrete involves self-desiccation cracking (Surahyo, 2019). Thermal cracks can have similar characteristics as drying shrinkage cracks. Factors such as cement content of the mixture, concrete temperature, size of aggregates, the location and size of steel reinforcement and form removal significantly affect the improvement of thermal cracks.

2.6 Loss in concrete strength

The rate of cement hydration reaction increases as the temperature goes up. This leads to a higher early strength, but, the long-term strength of concrete will drop. This occurs due to the loss of moisture and lack of concrete workability. Some researches display (Ortiz et al, 2005; Bella et al, 2011a; Bella et al, 2013) that as hydration process is accelerated, the long-term strength (28 days) is condensed. This is due to the high acceleration of hydrate products at high temperature compared to the one accelerated in regular temperature (20 ± 5°C).

2.7 Lack in concrete durability

As discussed above, the high temperature affects the initial workability of concrete. Thus, the addition of water in the mixer at the site is mandatory. Concrete in this case will be more vulnerable to sulfate attack, freeze-thaw, penetration of CO_2 leading to concrete carbonation. Also, low compaction may occur due to low workability which makes concrete more exposed to deterioration (Mbemba, 2010a; Mbemba, 2010b).

3. HOT WEATHER CONCRETING PRECAUTIONS

3.1.Cooling of concrete components

Cooling of concrete components with cold water is the cheapest way to diminish concrete temperature. Also, adding ice cube as a partial replacement of mixing water can provide in reducing the temperature of concrete. On site, it may be required to use at least two cement silos. In this case, the period between delivery and cast is extended to decrease the temperature of cement. The cement silo must be painted in white in order to decrease the temperature due to solar radiation.

Fresh concrete temperature can be calculated as follow:

$$T= \frac{0.22(TaWa+TcWc)+TwWw+TaWwa}{0.22(WaWc)+Ww+Wwa} \qquad (1) \quad \text{(Hills, 2010)}$$

Where:
T: fresh concrete temperature
Ta: Temperature of aggregates
Tc: Temperature of cement

Tw: Temperature of mixing water
Wa: weight of aggregates
Wc: weight of cement
Ww: weight of mixing water
Wwa: weight of free water

3.2. Production and deliverance

The best way for reducing concrete temperature is by painting the concrete mixing trucks in white color. From previous work, fresh concrete in a white mixing trucks can be around 1.45˚C cooler than concrete in black mixing truck based on a 1-hour transport time (Bella et al, 2017). The time between mixing and transport must be retained to a minimum. The mixing plant trucks delivery must be matched with the concrete rate placement to prevent extended stop at the construction site before the mixing trucks are discharged. Using nitrogen can achieve extremely low temperatures but the process is expensive (Abdullah et al, 2013).

3.3. Placement

The best time for the placement of concrete is at night because at this time the components have low temperature. Besides, the temperature of the previous cast concrete samples and molds can be condensed by covering it prior to the operation of placement. Fresh concrete must be covered by windbreaks or shades especially in hot weather.

3.4. Curing time

3.4.1. Initial curing

According to ACI 308 R, initial curing is defined as the time between the concrete placement and final curing time application. The proper time for the final curing application is at the beginning of concrete setting time. The initial curing is attained through the use of different evaporation reducers such as alcohol (Bella et al, 2011b; Bella et al, 2017) and precisely designed for extreme evaporation conditions. The technique is based on applying evaporative reducers in sufficient quantity after finishing. In this way, concrete will not lose its serious amounts of water via evaporation. Furthermore, we should apply a part of the curing product earlier after placement in order to assist as an efficient evaporative reducing agent.

3.4.2. Final curing

Final curing is the period between the initial curing application and the programmed cure end. Final curing methods are categorized into 3 types: a) curing product method, b) water curing method and c) curing with plastic sheet cover. Curing product method is usually the best method for curing due to the relatively low labor costs specially for large surface. Additionally, the features of this curing methods are described by ASTM C1315 and ASTM C309. Regarding the water curing method, it includes vaporization, immersion, burlap and other wet absorbent materials. It is usually considered as the only efficient curing method for resisting drying cracking for concrete with low W/C ratio. Additionally, applying plastic sheet method is generally considered as simple and practical for smaller surfaces.

4. EFFECT OF HOT WEATHER CONDITIONS ON THE MECHANICAL AND DURABILITY PROPERTIES OF CONCRETE

As mentioned previously, Hot weather conditions affects the mechanical and durability properties of concrete. Various researchers investigated that substituting cement by supplementary cementitious materials SCMs could enhance the overall performance of concrete. Besides, other researchers have focused on the role of w/c ratio, curing methods and chemical additives in reducing the heat of concrete during hot weather. The section below discussed the effects of using such agents on the mechanical and durability performance of concrete.

4.1. Fresh concrete properties

4.1.1. Workability and setting time

Long time ago, the effects of hot temperature on the workability and strength of concrete have been reported by many authors (Price, 1951; Klieger, 1958; Powers, 1958; Barnes et al, 1977; Dodson and Rajagopalan, 1979; Zawde, 1983). These studies reported that high temperature affected the degree of evaporation from fresh concrete surface (Sayahi, 2016) so that addition mix water is required to maintain concrete slump. One way for reducing hot - weather problems and controlling the temperature of the fresh concrete is the use of chemical admixtures. Additionally, chemical admixtures can control the effects of hot climate conditions (Otoko and Chinwah, 1991; Sahoo and Dash, 2009; Aydin and Gul, 2007; Alsadey, 2013; Erniati et al, 2014; Mbugua et al, 2016; Kandhari, 2017; Hazarika et al, 2018; Rizzuto et al, 2020) and at the same time, it doesn't change the composition of hydrate products (Lea 1988; Neville 2006). Retarding admixtures like sugar, salts and some carbohydrate derivatives have been positively used (Ramachandran, 1993; Jumadurdiyer et al, 2005; Naghoj and Abdel-Rahmna, 2005; Aburawi and Swamy, 2008; Abd et al, 2016; Afroz et al, 2018; Shetty and Jain, 2019; Devi et al, 2020; Afroz et al, 2021). For example, Selezneva et al, 2019 studied the effects of adding additives in hot climate conditions. Results showed that MC- Power Flow 2695 and Centrament Air 202 didn't save the workability of concrete in dry hot weather conditions. However, Centrament N 101 additive saved the workability almost completely and MC- Techniflow 70 saved the workability most efficiently (slump decreased only 1cm). Besides, the use of Cassava powder as a retarder (0.05%) in hot weather conditions has the ability to increase the workability, retard the setting time and also increase both the early and long term strength of concrete (Otoko, 2014) as shown in Table 1 and 2.

Table 1. Effect of temperature on the strength of concrete (Otoka, 2014)

S/NO	Temperature	Average Compressive strength (MPa)			
		3 days	7 days	14 days	28 days
1	Ambient	28.3	35.5	38.4	40.7
2	48˚C	29.6	38.9	41.8	43.4
3	60˚C	30.8	27.5	25.2	24.6

Table 2. Effect of sugar and cassava powder on the strength of concrete (Otoka, 2014)

S/NO	Test specimen	Average compressive strength (MPa)			
		3 days	7 days	14 days	28 days
1.	A- 0.05% S	23.1	30.9	31.8	38.4
2.	B-0.05%- CP	24.5	29.1	30.0	36.8
3.	C- 0.15% S	14.2	17.5	30.8	34.3
4.	D-control	22.0	25.3	27.6	28.7
5.	E-0.15% CP	20.1	21.4	22.7	23.5

S: sugar; CP: cassava powder

4.2. Mechanical properties

4.2.1. strength of concrete

Some studies revealed that the use of tested additives may help to regulate concrete strength specially in hot weather climate. For example, Selezneva and Shustov, (2019) reported the impact of using different type of additives on the compressive strength of concrete. It was reported that adding strongly plasticizing additive (Mc- Techniflow 70) was considered as the best effective additive. Its compressive strength attains a value of 35 MPa with 1.2% of additive compared to the control sample. On the other hand, some researches showed the effect W/C ratio on the strength of concrete in hot weather. For example, Awall et al, 2019 exhibited the effect of normal concrete with fly ash (FA) and with 8 different W/C ratio as well as normal concrete with admixture and also with 8 different W/C ratio. As shown in Fig. 2, the highest compressive strength is observed at 0.6 W/C ratio (37.8˚C, 67% RH) and 0.65 W/C ratio (39.2˚C, 51% RH). The concrete including admixture has the maximum compressive strength compared to the other samples. Furthermore, curing the concrete in hot weather could enhance its strength. This finding is elucidated Kaleta-Jurowska and Jurowski, 2020. They indicated that as concrete curing temperature increased, the early compressive strength definitely increased. After 3 days of curing, an increase in compressive strength was perceived at 40˚C compared to concrete cured at 20˚C. However, concrete cured at 12˚C had a lower compressive strength (11% lower than concrete curing at 40˚C). After a period longer than 28 days, it was observed that as temperature increased, the compressive strength definitely dropped. After 2 years of curing, samples cured at 12˚C attained a compressive strength 13% higher than those cured at 40˚C. Besides, Chen et al, 2009 investigated the effect of hot spring environments on the strength and durability of concrete. Three types of hot springs existed in the range of 40 to 90˚C. The data indicated that compressive strength of concrete compromising pozzolanic materials cured by a hot spring with high temperature increased rapidly in the early ages. This is due to the high temperature and chloride ions. In the later ages, the trend of strength development decreased obviously and the strength was even lower than that of the standard cured one.

Moreover, it is well known that concrete properties including SF and FA are significantly influenced by cuing methods compared to plain concrete. Long time ago, Maage, 1986 reported the effect of different curing temperature (5˚C, 20˚C and 35˚C) on concrete with FA and SF. It was observed that samples with SF and FA were more vulnerable to curing at high temperature compare to plain concrete. Besides, the influences of curing temperature on SF content to replace cement was reported by wild et al, 1995. It was perceived that at 50˚C curing temperature, the development of strength is motivated at an early age. On the other hand, concretes with 12% and 16% SF cured at a temperature of 20˚C attained their highest strength at 28 days. Though, concrete samples with 20% and 28% SF achieved their highest strength after 28 days. It is well noted that concrete adding FA is more susceptible to disturb curing compared to control concrete mix. To elucidate this finding, khan and Ayers, 1995 reported the influences of curing on strength at 23˚C and with 95% RH of concrete with SF and FA. It was found that the shortest curing period applied by analytical model for concrete with SF was 3 days. The use of copper slag in concrete has been investigated by Boakye et al, 2014. It was detected that compressive strength declined as the copper slag content went up for all curing methods. Additionally, Khatib et al, 2010 investigated that substituting 30% of cement with Metakaolin (MK) has a clear effect on the relative concrete strength cured at 5˚C and 20˚C specifically at the early stages of hydration. Another research conducted by Khatib et al, 2009 studied the effect of adding MK as a replacement of cement in low temperature curing (5˚C). Results showed that adding up 20%MK causes an improvement in concrete strength up to 7 days of curing. Also, Nasir et al, 2016 reported the effect of casting temperature at different temperature (25, 32, 38 or 45˚C) on the compressive and tensile strength of concrete incorporating VFFA (very fine fly ash), SF, FA, natural pozzolan (NP) or ground granulated blast furnace slag (GGBS). Concrete samples were cured in natural air via wet - burlap. They concluded that the best casting temperature for concrete with SF was 32˚C and for concrete incorporating VFFA, GGBS, FA and NP was 38˚C. Similarly, Al- Amoudi et al, 2007 investigated the effect of concrete incorporating SF and the influence of curing methods on its strength. The values of compressive and tensile strength as well as pulse velocity were more in the SF cement concrete than the control sample. As shown in Table 3 and 4, samples cured by water-ponding were more effective than those cured with wet-burlap. Zhao et al, 2012 studied the influences of initial water curing at 3, 7 and 14 days on SCC incorporating FA. It was found that the initial water curing was achieved at 7 days. This is due to the pozzolanic reaction. SCC under full room (FR) curing condition had a higher compressive and flexural strength than SCC under full standard (FS) and full water (FW) curing condition. On the other hand, the strength of SCC mixed at high temperature (50˚C) was similar or higher than that mixed at the control temperature (20˚C) (Le et al, 2021). Another study on the effect of curing methods in hot weather on the properties of High –strength concrete (HSC) and high-strength concrete with polypropylene fibers (HSCF) was conducted by Zeyad, 2019. In this study three curing methods were used (i: water immersion method, w: wet gunny method and s: water spraying method). As displayed in Fig. 3, for compressive strength, HSC and HSCF cured via water immersion method attained high values than those cured with other methods and the maximum compressive strength was achieved for HSCF concrete samples (74MPa) at 90 days. Similarly, for indirect tensile strength (Fig. 4), the water immersion methods attained the best results among other treatment methods. Also, the addition of fiber to concrete mixtures improved the results. At 90 days, HSCF concrete samples attained the highest value (6.31 MPa). Same trend was observed for flexural strength and the highest value recorded for HSCFi concrete samples was 7.34 MPa (Fig. 5).

Table 3. Compressive, tensile strength and UPV of samples with SF cured by water-ponding (AL-Amoudi et al, 2007)

Curing age (days)	Compressive strength (MPa)	Split tensile strength (MPa)	Pulse velocity (m/s)
3	28.7	2.03	4266
7	34.2	2.92	4410
14	37.6	3.89	4568
28	48.5	4.65	4746
90	52.8	4.84	4822
180	53.4	4.9	4830

Table 4. Compressive and tensile strength of samples with SF cured by covering with wet-burlap (Al-Amoudi et al, 2007)

Curing age (days)	Compressive strength (MPa)	Split tensile strength (MPa)	Pulse velocity (m/s)
3	26.8	2.01	4293
7	33.4	2.71	4420
14	39.1	3.69	4530
28	49.3	4.64	4688
90	51.1	4.75	4769
180	52.4	4.76	4798

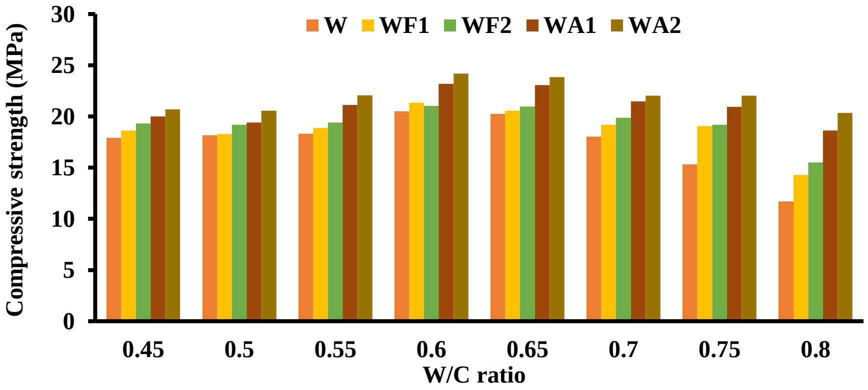


Fig. 2. W/C ratio versus compressive strength for different types of concrete (Awall et al, 2019)

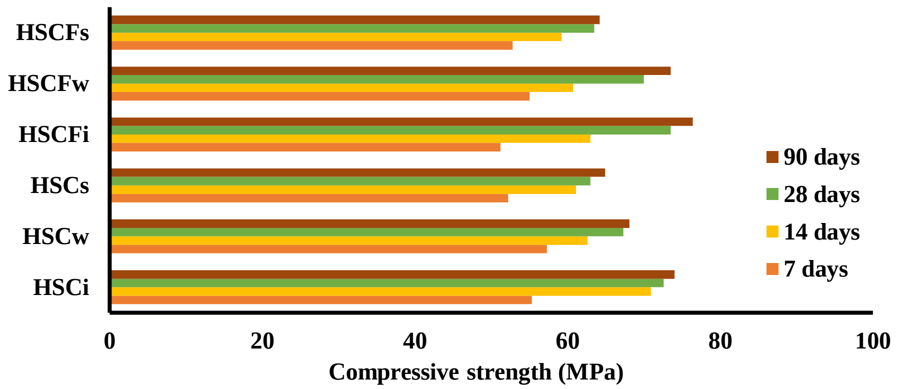


Fig. 3. Results of compressive strength for different types of concrete (Zeyad, 2019)

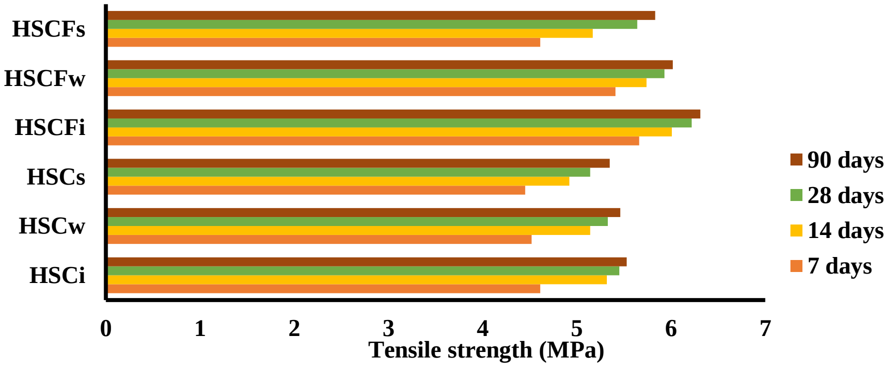


Fig. 4. Results of indirect tensile strength for different types of concrete (Zeyad, 2019)

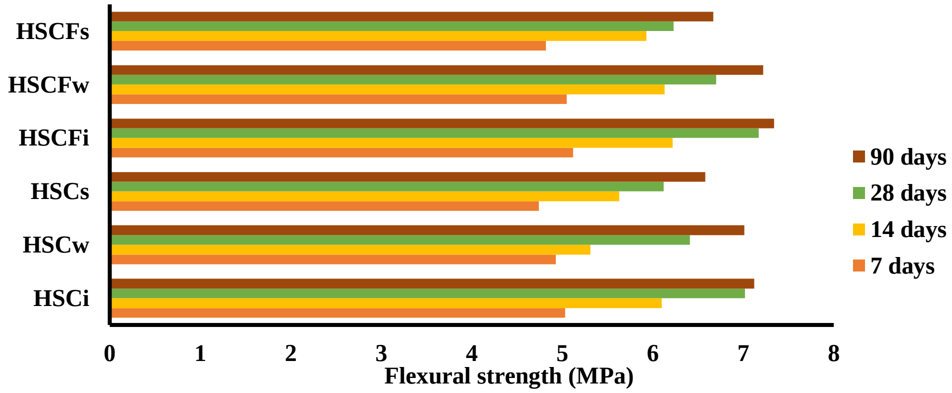


Fig. 5. Results of flexural strength for different types of concrete (Zeyad, 2019)

4.3. Durability properties

4.3.1. Permeability and porosity of concrete

The permeability test is a non-destructive technique used to estimate the durability of concrete.

Tang et al, 2017 reported the influence of curing temperature on the mechanical and durability of concrete under highly environment temperature. In this experiment, the temperature varied from 40˚C, 60˚C, 75˚C and 90˚C and a humidity of 90%. It was shown that above 60˚C, the strength of concrete and its resistance to chloride ion penetration dropped. Besides, Chen et al, 2009 reported the effect of hot spring environments on the durability performance of concrete. The hot springs temperature ranged from 40 to 90˚C. The results of permeability and electric resistance tests showed that concrete cured in hot spring had higher durability than samples cured in air. The effect of different curing methods on the permeability of concrete with and without SF in hot weather conditions was investigated. In this study, authors used five different curing methods: burlap method and four chemical compounds methods (acrylic-, bitumen-, water-based compounds, coal tar epoxy). They informed that applying chemical compounds method with its different application in hot weather had better concrete permeability performance than the other method (burlap). Besides, the inclusion of water curing before using compound curing had a positive influence on concrete durability. The influences of curing on the porosity, permeability and strength of concrete with SF and FA under various curing methods (underwater, at room temperature after two days of underwater curing, at room temperature after demolding and indoor natural air at 38˚C) were conducted by Ramezanianpour and Malhotra, 1995. The results showed that a drop in underwater curing caused an increase in the permeability and porosity of concrete. A research about the curing optimization for durability and strength of SF and FA concretes under hot climate conditions was established by Khan and Abbas, 2017. Results showed that concretes with binary and ternary mixes and standard curing scheme I had lesser permeability compared to concretes treated with other curing schemes. FA and SF have a significant role in improving the durability of concrete. As shown in Fig. 6, the least permeability for all curing schemes was achieved for concrete incorporating 10% SF and the highest permeability was observed for curing scheme II for concrete with 20% FA. Le et al, 2021 studied the water porosity of SCC in hot weather. Results exhibited that the total porosity in the SCC hardened concrete does not increase with the rising in the initial temperature of the mixture. Mangat and Khatib, 1992 studied the effect of initial curing on sulfate resistance of combined cement concrete. Three different initial curing conditions were carried out: wet/ air cured at 45°C, 25% RH; air cured at 45°C, 25% RH; air cured at 20°C, 55% RH. Results showed that the sulfate resistance of concrete rises with the substitution of cement with 9% silica fume, 22% pfa and 80% GGBS. Also, Mangat and Khatib, 1993 investigated the effect of adding fly ash, slag and silica fume on sulfate resistance. The samples were cured initially for 14 days after casting under different temperatures (20 and 45˚C) and humidity (25, 55 and ˷100%) before immersion in a sulfate solution. The results displayed that cement replacement by 22 and 32% FA produced maximum sulfate resistance. The sulfate resistance is high in initially air-cured samples compared with initially wet/air-cured samples. Also, the addition of 5 to 15% SF resulted in a great enhancement in sulfate resistance. An 80% GGBS increases the sulfate resistance of concrete. However, adding 40% GGBS under initial wet/air-curing at 45˚ C and 25 % relative humidity didn’t show a higher sulfate resistance compared with the control mix. Besides, Khatib and Mangat, 1999 studied the effect of superplasticizer (SP) and curing on the porosity of cement paste. Samples were subjected to a high temperature of 45°C and normal temperature curing (20°C) and also exposed to different relative humidities (25%, 55% and ∼100%). Data showed that the addition of SP dropped the total interrupted pore volume of paste. The percentage of pores < 100 nm rises in the existence of SP. The effect of high-temperature (37˚C) and low-humidity (25%) curing on chloride penetration in concrete containing cement replaced by 20% FA and 9% SF was investigated. Results showed that the chloride penetration at early ages of exposure is directly associated to the porosity of the binder phase and the absorption rate of concrete. Higher chloride penetration resistance was perceived when cement is partially substituted with either FA or SF (Khatib and Mangat, 2002; Khatin and Mangat, 2003, Yahiaoui et al, 2017).

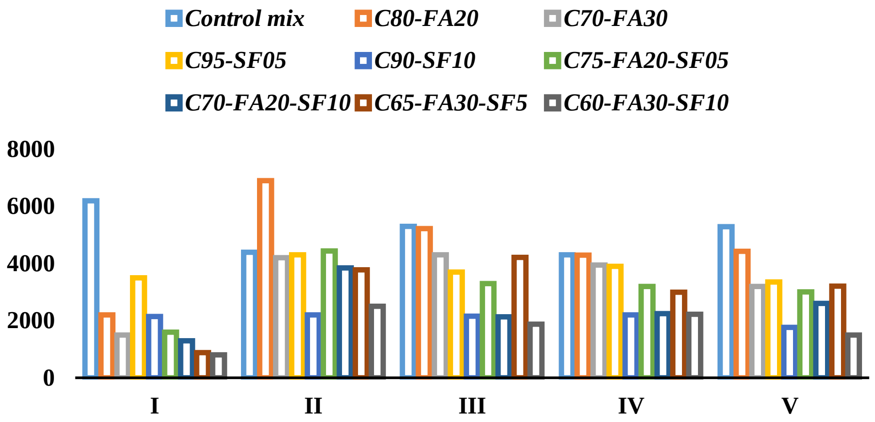


Fig. 6. Results of the permeability of concretes at different curing schemes at 90 days (Khan et al, 2017)

4.4. Shrinkage

4.4.1. Plastic shrinkage

Some researches specified that under hot weather temperature, concrete has the ability to crack by plastic shrinkage even at low rate of evaporation. For example, Almusallam et al, 2001 and Berhane et al, 1992 perceived the plastic shrinkage cracks at an evaporating rate of 0.2-0.7 and 0.4 kg/m^2/hr, respectively. On the other hand, other studies reported the effect of plastic shrinkage on cement concrete containing SF in hot climate conditions (Al Amoudi et al, 2004; Lofgren and Esping, 2006; Tao and Weizu, 2006, Fontana et al, 2012; Ghourchian et al, 2018; Ghourchian et al, 2019). Al –Amoudi et al, 2004 evaluated the impact of silica fume on plastic shrinkage of concrete exposed to hot climate conditions. Results exhibited that plastic shrinkage strain raised with the addition of different percentages of SF (5%, 7.5% and 10% by cement weight). This was recognized to the lower SF bulk density and its higher specific surface area. Similarly, the plastic shrinkage values in SF cement concrete samples was greater than that in the control mix samples (Al Amoudi et al, 2007). It achieved an average of 70% more than that in the plain cement concrete samples. Besides, the plastic shrinkage strain was almost equal in small and big samples. Al-Gahtani, 2010 investigated the shrinkage results for VFFA, FA and SF concrete cured by wrapping in damp burlap, acrylic-, and water-based compounds. The concrete samples were mold with 100% type I, 10% VFFA, 30% FA and 7% SF. It was shown that plastic and drying shrinkage of concretes cured with chemical mixtures were lower than those cured with other methods. Another study conducted by Sonebi et al, 2007 revealed that plastic shrinkage of concrete is affected by the addition of polypropylene fibers. Samples were tested at different mix temperature (16-25˚C) and air temperature (20, 30 and 40˚C). Results showed that a reduction in plastic shrinkage strain occurred with the increase in fibers content. For example, the addition of 0.2% and 0.4% of fibers in concrete dropped the plastic shrinkage by 43% and 9% compared to the reference mix respectively.

4.4.2. Drying shrinkage

Drying shrinkage is defined as the rapid loss on concrete moisture. Several studies have been reported on the influence of hot temperature on the Drying shrinkage of concrete. Long time ago, Parrot, 1977^a and Parrot, 1977^b investigated that the curing temperature raised quickly from room temperature to a high temperature which normally induce drying and creep behavior. Besides, Thomas and Jemings, 2002 reported the shrinkage strain of OPC samples after heat curing temperature for a period of 24 h. data showed that shrinkage of heat-treated specimens was 15% lesser than that for untreated specimens cured at 20˚C at 12 days. Li et al, 2017 reported that the ultimate early-age shrinkage for a high performance cement paste was 450 με at a heat curing temperature of 90˚C after 48h. Previous researches (Pan et al, 2006; Mounanga et al, 2006; Bouziadi et al, 2016) recognized that the addition of SCMs such as FA, GGBS, SF and natural pozzolana could decrease the interior elevated temperature which lead to reduce the drying shrinkage of concrete. Yang et al, 2014 reported the influence of hot temperature on the drying shrinkage of concrete, Concrete was subjected to various temperature of 20±1˚C, 35±1˚C, 50±1˚C, and 60% ± 5 RH and to different W/C ratio of 0.3, 0.4 and 0.5. Results exhibited that as the temperature increased from 20˚C to 50˚C, the effect of W.C ratio on the drying shrinkage of concrete was progressively weakened. The replacement of cement by 20% of GGBS, 10% of SF and 20% FA was also investigated. Results showed that GGBS had a little effect on the drying shrinkage of concrete. Regarding the silica fume, it could enhance the drying shrinkage of concrete in the early and later ages specially in high temperature. However, the addition of 20% FA reduced the drying shrinkage of concrete in early ages and increased it in later ages. As reported by Al Amoudi et al, 2007, the drying shrinkage of samples with SF cement concretes achieved more strain than plain concrete specimens. Also, the drying shrinkage strain in both SF cement concretes and plain concretes in big samples was greater than that in small ones (Figures 7 and 8). Additionally, the study on cracking and drying shrinkage of SF cement concretes was investigated. Results exhibited that SF encouraged concrete cracks especially when concrete was improperly cured (Whiting et al, 2000). However, El Hindy et al, 1994 investigated that the drying shrinkage of cement concrete with SF dropped at log curing age period. Besides, Hooton, 1993 informed that drying shrinkage of SF cement concrete was 10-22% higher than that in OPC concrete for same w/b ratio. Khatri and Sirivivatnanon, 1995 informed that the early drying shrinkage of concrete with SCMs was more than control mix. Many researches are focus on the shrinkage of cement or concrete incorporating MK curing at normal temperature. Test results exhibited that the early age autogenous shrinkage can be dropped with the addition of MK content, and the long-term autogenous shrinkage increased with the inclusion of MK replacement level (Gleize et al, 2007; Brooks and Johari, 2001). Also, the drying shrinkage is remarkably dropped (Guneyisi et al, 2008). Though, the influence of MK on the autogenous shrinkage and expansion of concrete curing at high temperature (> 60˚C) is hardly reported. Khatib, 2009 showed that the addition of 15% MK caused an increase in linear shrinkage. Beyond 20% MK, the shrinkage is dropped. The influence of MK on the hydration, microstructure and volume stability of steam cured HSC with a low w/b of 0.25 cured at 80˚C was investigated. Results displayed that the cracks caused by steam curing was moderated after incorporating MK. The MK dropped the volume expansion and the drying shrinkage of steam cured by heat treatment leading to a better volume stability (Shen et al, 2017). A research was conducted by Jiang et al, 2018 about the effect of heat curing treatment on drying shrinkage of mortars containing GGBS. The results showed that drying shrinkage of untreated ad heat-treated mortar specimens dropped with the rise of the substitution amount of GGBS. As shown in Fig. 9, for untreated mortar samples, the drying shrinkage attained a value of 0.0733% at 28 days for plain sample. However, the incorporation of 20% and 40% GGBS reached a value of 0.068% and 0.05% respectively. This means that GGBS act as a filler and refines the pores structure which leads to decrease the drying shrinkage of mortars (Zhuang et al, 2012; Zhao et al, 2017). However, the addition of 60% GGBS achieved a value of 0.0561% and 0.0630% at 28 days for untreated and heat-treated mortar samples. This indicates that the optimal replacement level to restrain drying shrinkage is about 40% GGBS. Actually in this research, the measured drying shrinkage includes autogenous shrinkage and real drying shrinkage of mortars. This has been confirmed in earlier similar studies (Kristiawan and Aditya, 2015; Zhao et al, 2017). The real drying shrinkage drops with the increasing in GGBS content due to its filler effect. As reported by Lee et al, 2006, the addition of slag enhanced the autogenous shrinkage compared to plain concrete and it increased with the rise of GGBS content. Similarly, Tazawa and Miyazawa, 1997 revealed that the autogenous shrinkage was relative to the content of slag with specific surface area over approximately 400 m^2/kg. The addition of 50-70% GGBS increased rapidly the autogenous shrinkage of mortar. Besides, the incorporation of 0 and 20% GGBS for heat –treated mortar achieved lower drying shrinkage than un-treated mortar at all ages. This is in agreement with other studies (Parrot, 1977; Thomas, 2007; Han et al, 2016). Additionally, Deb et al, 2015 found that drying shrinkage dropped with the increase in GGBFS (slag blended with fly ash) content and decrease of sodium silicate to sodium hydroxide ratio(SS/SH) in GGBFS concrete samples cured at room temperature (20±2 ˚C and

70±10% RH). For example, at 180 days, the drying shrinkage values for R2.5S10 and R2.5S20 concrete mixtures are 722 and 675 με respectively. However, for R1.5S10 and R1.5S20 concrete mixtures, the drying shrinkage values are 660 and 482 με respectively as shown in Fig 10-a and 10-b.

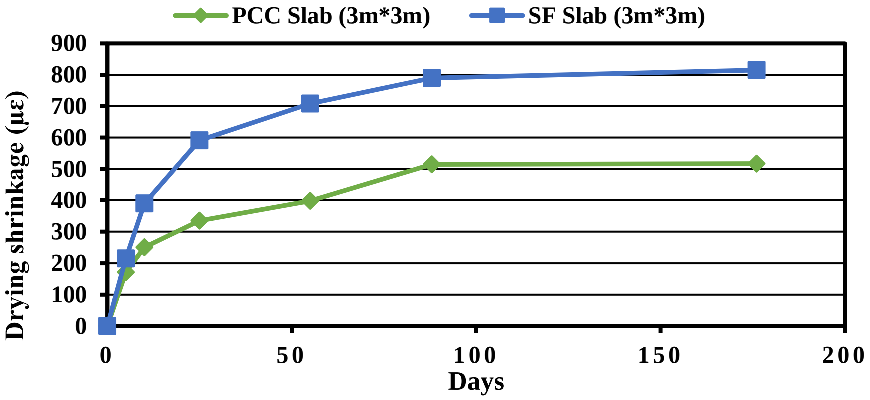


Fig. 7. Results of drying shrinkage strain for small (3x3 m) plain and silica fume concrete samples cured by coating them with wet-burlap (Al Amoudi et al, 2007)

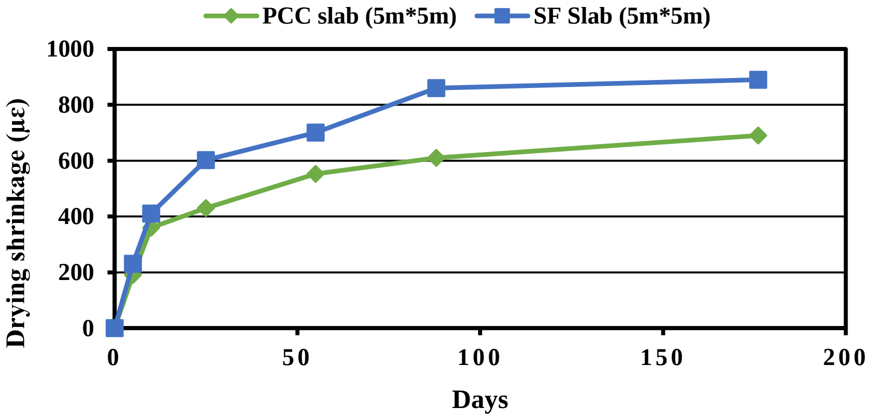


Fig. 8. Results of drying shrinkage strain for big (5x5 m) plain and silica fume concrete samples cured by coating them with wet-burlap (Al Amoudi et al, 2007)

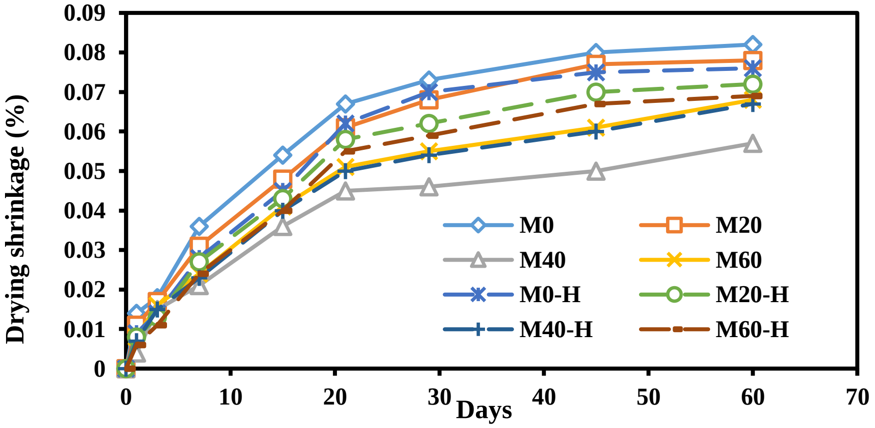


Fig. 9. Drying shrinkage results of heat-treated and untreated mortar samples (Jiang et al, 2018)

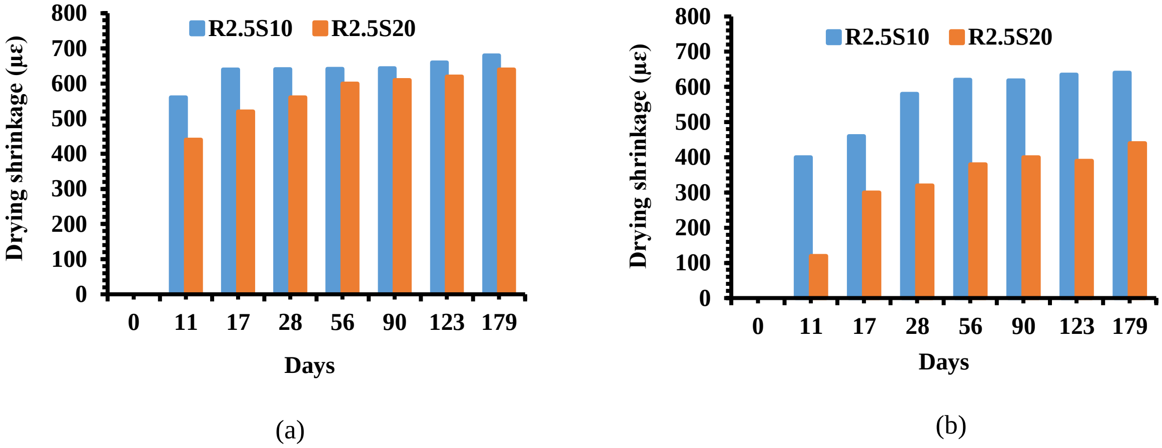


Fig. 10. Drying shrinkage values of geopolymer concrete with various slag content: (a) SS/SH ratio = 2.5, (b) SS/SH ratio = 1.5 (Deb et al, 2015)

4.4.3. Carbonation

Atmospheric carbonation includes a reaction between carbon dioxide (CO_2) and cementitious materials. The presence of CO_2 in the atmosphere disperses through the pores present in concrete surface and then reacts with calcium ions to form calcium carbonate ($CaCO_3$). Several studies illustrated the effect of temperature on the rate of carbonation in concrete (Osborne, 1989; John et al, 1990; Papadakis et al, 1991; Uomoto and Takada, 1992; Loo et al, 1994; Ruixia, 2010; Li et al, 2013; Chen et al, 2018). In these researches, the authors estimated the carbonation rate by using the phenolphthalein projection. Long time ago, Papadakis et al, 1991 perceived a small increase in the carbonation kinetics (about 15-20%) between 22 and 42°C in their study using concrete samples with w/c = 0.65. Same trend was obtained by Ruixia, 2010; John et al, 1990 and Loo et al, 1994 over small temperature ranges (between 15°C and 40°C). Mori et al, 1972 stated that the carbonated depth at 40 °C was double that obtained at 20°C. In the same way, Uomoto and Takada, 1992 informed a multiplication factor of 1.7 between 10 and 30°C, Matsuzawa et al, 2010 obtained a factor of 2 between 20 and 60°C, and Li et al, 2013 found a factor of 3 between 10 and 60°C. Recently, the effect of temperature on carbonation was reported in laboratory conditions using a new device developed. In this study, two hardened cement pastes (CEM I and CEM V/A) were tested between 20°C and 80°C at different relative humidity levels (RH). Results showed that the carbonation rate of the CEM I increased as temperature went up. However, the rate of carbonation of CEM V/A attained the maximum at around 50°C (Drouet et al, 2019).

5. KNOWLEDGE GAPS

In the framework of this article, the use of SCMs such as FA, SF, GGBS, etc… have a significant role in enhancing the mechanical and durability properties of concrete specially with using different curing methods. However, there is hardly any study focus on the role of natural fibers in reducing the temperature of concrete. For future plan, early age cracking of hot weather concreting may be modified by adding natural fibers in concrete. Besides, new experiments should be made on chemical, autogenous and drying shrinkage as well as expansion in hot weather concreting.

6. CONCLUSIONS

- Hot weather concreting according to ACI 305 is any combination of this conditions (high ambient temperature, high wind speed, solar radiation, low humidity and high concrete temperature) that tends to affect concrete properties.

- Main problems for fresh concrete in hot weather are plastic shrinkage and excessive evaporation. However, for hardened concrete, the most important problems are the drop in long-term strength and the decrease in concrete durability.
- Using adequate cuing method may help in reducing the temperature of concrete.
- One way of reducing hot - weather problems and controlling the workability of fresh concrete is the use of chemical admixtures.
- Incorporating SCMs such as FA, SF, VFFA and GGBS could enhance the long term strength and durability and they are affected by different curing methods.
- The addition of different SCMs could improve the plastic shrinkage of concrete. Besides, plastic shrinkage cracks can be controlled by using curing methods. The inclusion of VFFA, FA, SF and GGBS concrete samples cured with chemical compounds reduced plastic shrinkage cracks more than samples cured with other curing methods.
- Previous studies reported that the inclusion of SCMs such as VFFA, FA, SF, GGBFS could decrease the interior elevated temperature of concrete and led to reduce the drying shrinkage of concrete. However other studies showed that the addition of SF increased the tendency of drying shrinkage cracks special when concrete was improper cured.
- The high temperature had a significant impact on the carbonation rate of concrete. It was noticed that as temperature increased, the carbonation rate went up.

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