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Effect of initial exposure temperature on the fresh and hardened properties of cement mortar and concrete

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A B S T R A C T

The effects of the ambient temperature on the fresh and hardened properties of cement mortar and concrete with superplasticizers of different families were investigated over the range of 5-40°C. Normally a concrete mix is designed at a standard testing condition but is used in a totally different or varying site conditions. Such changes in ambient conditions, especially temperature, can affect the fresh as well as the hardened properties of concrete significantly. It is observed that fluidity of cement mortar and concrete decreases with an increase in the ambient temperature, both with and without superplasticizer. The compressive strengths of mortar and concrete increases initially with an increase in the initial exposure temperature and thereafter decrease. The flexural strength of mortar and splitting tensile strength of concrete were also found to decrease with an increase in initial temperature.

Keywords : *Concrete, Strength, Temperature, Workability*

1. Introduction

Concrete mixes designed at laboratory or certain testing condition are often used in totally different or varying site conditions (as even ambient conditions could vary with season to season or even with time within the same day). Such changes in ambient conditions, especially temperature, can affect the fresh as well as hardened properties of concrete significantly. In addition to this, the modern high-performance concrete invariably incorporates one or more admixtures (mineral admixtures as well as chemical admixtures) to get the desired properties. The ambient temperature to which the concrete is exposed can affect the performance of these admixtures in the cementitious system, which can make the scenario more complicated.

The objective of this work is to study the effect of temperature, superplasticizer type and their interaction on the fresh and hardened properties of cement mortar and concrete. The effectiveness of different types of superplasticizer with temperature are analysed. The fluidity of cement mortar is evaluated by determining the spread of mortar using flow table test. To study the influence of superplasticizer and temperature on the loss in fluidity of mortar with time, the spread is observed over an hour. The development of compressive and flexural strengths of cement mortar is also assessed. For concrete, the slump test using the Abram's cone, and tests for the compressive and splitting tensile strength are performed.

2. Experimental details

2.1 Materials

Ordinary portland cement of 53 grade, conforming to IS 12269 (2004), and de-ionized water were used for the study. The chemical composition and physical properties of the cement are given in Table 1 and Table 2. One commercially-available superplasticizer each from the polycarboxylate ether (PCE), sulphonated naphthalene formaldehyde (SNF), and sulphonated melamine formaldehyde (SMF) families was incorporated in the study of the effect of temperature and superplasticizer on cement mortar. The PCE and SNF based superplasticizers were used in the case of concrete, as these admixtures are commonly used in construction sites. The properties of the different superplasticizers used are given in Table 3. The superplasticizer dosages are given as the ratio of the solid content of the superplasticizer to cement by weight (sp/c). The liquid content in the superplasticizer has been accounted for as part of the water cement ratio (w/c). Standard sand confirming to IS 650 (1991) was used to prepare the cement mortar. All the three grades (Grade I, II and III) of sands were taken equally and mixed together to form the fine aggregate. A w/c of 0.35 was used for all mixes throughout the study.

2.2 Testing conditions

The effect of mixing temperature on cement mortar was studied at 5, 15, 25, 35 and 40°C whereas for concrete, the tests were performed at at 5, 25 and 40°C with a constant humidity of 65%, except in the case of 5°C, where the condensation of water raised the humidity slightly. A walk-in environmental chamber was used to maintain the temperature and humidity.

https://doi.org/10.70002/iitm.rdr.1.1.23
Received on 10 April 2025, Accepted on 21 May 2025, Available online 26 May 2025
Publisher: Centre of Excellence (CoE) on Technologies for Low Carbon and Lean Construction (TLC_2) at Indian Institute of Technology Madras

All the materials were maintained at the prescribed temperature for at least 48 hours prior to the mixing, for preconditioning. The temperature of each materials was checked and ascertained to be within ±2°C of the prescribed temperature. The mixing, casting and determination of spread of mortar and slump of concrete were done inside the chamber at the prescribed temperature. The specimens required for the determination of the mechanical properties of cement mortar and concrete were mixed and cast inside the chamber, and kept at the same temperatures for 24 hours. Thereafter, the specimens were demoulded and cured in a mist room for the desired ages of curing before testing.

Table 1 Chemical properties of the cement used

Composition	Percentage by mass (%)
Calcium oxide (CaO)	59.04
Silica (SiO_2)	20.61
Alumina (Al_2O_3)	6.17
Iron oxide (Fe_2O_3)	3.76
Magnesia (MgO)	2.36
Sulphuric anhydride (SO_3^{2-})	2.27
Sodium oxide (Na_2O)	0.16
Potassium oxide (K_2O)	0.28
Total chloride content (Cl^-)	0.03
Total loss on ignition	2.65
Total alkalies (Na_2O)eq	0.34
Insoluble residue	2.36

Table 2 Physical properties of cement

Property	Value
Water demand for normal consistency of cement paste	29%
Initial Setting time	197 minutes
Final setting time	299 minutes
Fineness	290 kg/m^2

Table 3 Properties of the superplasticizer used

Designation	Chemical type	Density kg/liter	Solid content (%)
PCE	Polycarboxylate ether	1.09	35
SNF	Sulphonated naphthalene formaldehyde	1.21	42
SMF	Sulphonated melamine formaldehyde	1.20	40

2.3 Test Procedures

2.3.1 Cement Mortar

The cement mortar was prepared using a 5-litre 1/6hp Hobart-type blender with a B flat beater. The cement to sand ratio of the mortar adopted was 1:1.6 with a water to cement ratio of 0.35 for the study. The mixing procedure carried out for preparing the mortar for this study is as follows: the cement and sand were dry mixed for one minute; then, 70% of the mixing water is added to the mix and mixed with low speed (with a shaft speed of 139 rpm and planetary speed of 61 rpm) for one minute, and later the superplasticizer and remaining water were added and mixed for two minutes. The mixing was then stopped, and sides of the bowl and blades were scraped (15-20 seconds). The mortar was again mixed for two minutes at medium speed (with a shaft speed of 285 rpm and planetary speed of 125 rpm). The flow table test confirming to ASTM C230/C230 M - 08 and C1437 - 07 were used to study the fluidity of cement mortar. In order to account for the higher fluidity of superplasticized cement mortar, the standard flow table was modified by increasing its diameter using a polycarbonate plate, as shown in Figure 1. The spread of the cement mortar was measured in two orthogonal directions, and the average of the spread diameter is expressed as the spread of mortar. In order to study the effect of time on the loss in fluidity, the spread was determined immediately after mixing, and subsequently at 30 and 60 minutes after the addition of water to cement. The mortar was kept in air-tight containers at a constant temperature in between measurements and mixed for 30 seconds at medium speed (with a shaft speed of 285 rpm and planetary speed of 125 rpm) before each measurement. To study the effect of temperature on the fluidity and loss in fluidity with time for superplasticized cement mortar, the mortar was prepared and tested at different temperatures, with the saturation dosage of superplasticizer (using Marsh cone test) determined for cement paste at 25°C. Mortar cubes of 50×50×50 mm and prisms of 160×40×40 mm were used to study the compressive and flexural strength. The mortar was filled in the mould in two layers. For cubes, each layer was tamped with 32 strokes with a tamping rod. For the prisms, each layer was compacted with a jolting apparatus (confirming to IS: 10078-1982) with sixty jolts in 60 seconds. After casting, the specimens were kept in the controlled condition for 24 hours, then demoulded, and placed in mist room for curing till the respective days of testing. The strength after 3, 7 and 28 days of curing were determined. Three specimens were tested at surface dry condition for each age, and the average is taken as the strength of mortar. The specimens were tested with a Controls Advantest 9 mortar testing machine for the determination of compressive strength and flexural strength. The compressive strength test was carried out as per ASTM C109/C109M - 11a with a loading rate of 900 N/s. The flexural strength of mortar was determined as per ASTM C348 (2002) with a loading rate of 40 N/s.

Figure 1 Modified Flow Table apparatus

2.3.2 Concrete

The materials were batched and mixed in a pan type AIMIL mixer. The water needed for saturating the aggregates was added according to the absorption coefficients at 25°C. The cement, fine aggregate and coarse aggregate were mixed first for one minute to get a uniform distribution of the materials. Then, 70% of the mixing water was added and mixed for a minute. The remaining water and superplasticizer were added to the above mixture and blended again for four more minutes.

The flow behaviour has been characterised in this study using the slump test, as per IS 1199 (2004). For the study of the influence of temperature, concrete was prepared and tested with the saturation dosage of superplasticizer (as determined from Marsh cone test for cement paste at 25°C) for all temperatures.The compressive and splitting tensile strength of concrete were determined to study the influence of ambient temperature on strength of concrete. The tests were done with a Controls Advantest 9 testing machine. Compressive strength of concrete was determined on concrete cube specimens of dimension 150×150×150 mm as per IS 516 (1959 – Reaffirmed on 2004). The splitting tensile strength of concrete was determined on concrete cylinders of size 150×300 mm as per IS 5816 (1999 – Reaffirmed on 2004). Two packing strips of hardboard of nominal thickness of 4mm conforming to IS1658 (2006) of width approximately15mm and length greater than the length of the line of contact of the test specimen were employed. The loading rate used was 1.2 N/mm^2/min.

Table 4 Saturation dosages of superplasticizer at 25°C

Superplasticizer	Dosage (%)
PCE	0.13%
SNF	0.25%
SMF	0.25%

3. Test results and Discussions

3.1 Determination of saturation dosage of superplasticizer

The Marsh cone test was used to determine the saturation dosage of superplasticizer. Many researchers have been previously used Marsh cone test to evaluate the fluidity and the saturation dosage of superplasticizer (Aitcin 1998; Agullo et al. 1999; Roncero et al. 1999; Gomes et al. 2001, Jayasree and Gettu 2008, Jayasree et al. 2011). Marsh cone is a metallic cone with an opening of 8 mm at one the end. The cement paste was prepared and 1000 ml was poured into the Marsh cone and the time required for 500 ml to flow out was measured with different dosages of superplasticizer. Saturation dosage of superplasticizer is the dosage beyond which the addition of superplasticizer will not increase the fluidity considerably. In the present study the saturation dosage is selected as the dosage corresponding to the point where the log flow time versus superplasticizer curve takes an angle of 140±10˚ as suggested by Gomes et al. (2001). The Marsh cone flow time curve for the PCE, SNF and SMF based superplasticizer at 25˚C is given in Figure 2 and the corresponding saturation dosages are given in Table 4.

3.2 Effect of temperature and superplasticizer on the fluidity of cement mortar

The fluidity of cement mortar was analysed in terms of the spread of mortar using flow table test as explained earlier. The spread was determined for the cement mortar without superplasticizer and with the superplasticizer dosage corresponding to the saturation dosage at 25°C (determined from Marsh cone test) for each type of superplasticizer. The saturation dosages of the different superplasticizers used are given in Table 3. The initial spread (i.e., the spread of mortar immediately after mixing) obtained from the flow table test is plotted against temperature in Figure 3.

All the mortars studied (Figure 3) showed decreasing initial spread with an increase in temperature, which can be attributed to the increasing water demand at higher temperatures. The higher water adsorption of the cement leads to the decrease in the availability of free water, and hence

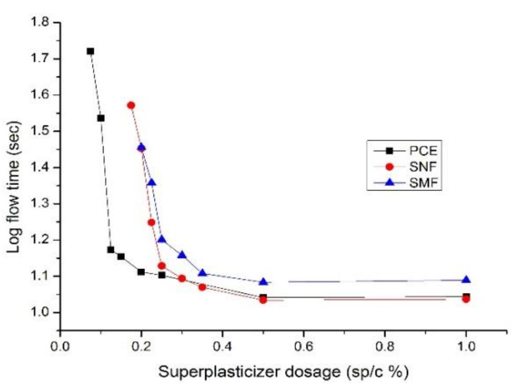


Figure 2 Marsh cone flow time curve for PCE, SNF and SMF based superplasticizer at 25˚C

the aggregates can also play a key role in the fluidity of mortar. Ortiz et al. (2009) attributed the decrease in workability of mortar at higher temperature to the higher water absorption of the aggregates at higher temperatures. When the aggregates are exposed to higher temperature, its pore structure expands and the size of the pores will increase, which results in more absorption of water by the aggregates in less time. Since the properties of water, such as viscosity, density and surface tension, vary with increase in temperature, there is a higher rate of penetration of water into the pore structure of aggregate at higher temperatures (Ortiz et al. 2009). The effect of temperature on the fluidity of cement mortar has been studied earlier in terms of rheological parameters (i.e., yield stress and plastic viscosity). Gołaszewski and Szwabowski (2004) observed

decreases the fluidity of mortar. Furthermore, the water absorption of

an increase in yield stress and a decrease in plastic viscosity with an increase in ambient temperature for cement mortar. The increase in yield stress at higher temperature indicates a decrease in the fluidity of mortar, confirming the trend seen in the present study.

It is also observed from the test results (Figure 3) that the fluidity increases with the addition of superplasticizer, as expected. The PCE-based superplasticizers gave better spread compared to the SNF- and SMF-based superplasticizers, at the corresponding saturation dosage of superplasticizer determined for cement paste at 25°C. As expected, the better efficiency of the PCE-based superplasticizer leads to higher fluidity of the PCE-based mortar, even at low dosages.

3.3 Effect of temperature on the evolution of fluidity with saturation dosage of superplasticizer at 25°C

The loss in fluidity with time is an important property of cement mortar and concrete as it needs to be workable during transporting, placing, compacting and finishing. The loss in fluidity with time is studied here with the help of flow table test. The spread of cement mortar was measured immediately after mixing, and subsequently at 30 and 60 minutes after adding the water to the cement, as explained earlier. The spread of mortar obtained from the flow table test with the saturation dosage of superplasticizer for cement paste at 25°C (given in Table 3) is plotted against time for different superplasticizers in Figure 4a-d.

Figure 4 Spread of mortar with time at different temperatures for superplasticizer dosage corresponding to the saturation dosage at 25°C for the (a) Control, (b) PCE, (c) SNF, and (d) SMF mixes.

All the mortars studied (Figures 4a-d) show higher spread at lower temperatures (5 and 15°C) than at the higher temperatures (25-40°C), during the entire period of measurement (i.e., one hour). As expected, the spread of mortar decreases with time and with an increase in temperature, at all ages. It is generally observed that the loss in fluidity is higher in the first 30 minutes compared to the second half an hour, especially at higher temperatures. The loss in fluidity with time depends upon the initial fluidity of the mortar to a large extent, which could be the reason for lower loss in fluidity at higher temperatures value within just 30 minutes.

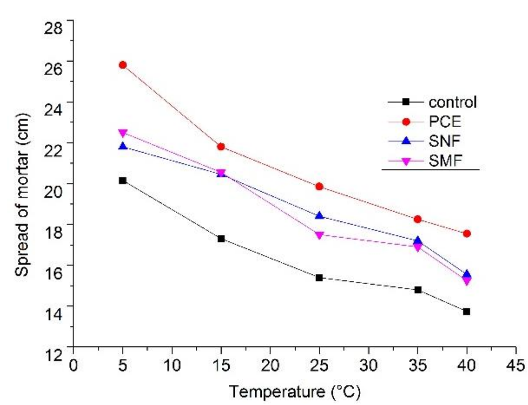


Figure 3 Initial spread of cement mortar in the flow table test for different temperatures

3.4 Effect of temperature on the compressive strength of cement mortar

The effects of ambient temperature can also be seen on the mechanical properties of superplasticized cement mortar due to the alteration of the hydration reactions of cement. The compressive strength was determined as explained earlier, and the results are plotted against age for cement mortar with and without superplasticizer, in Figure 5a-d.

From the test results (Figure 5a-d), it is observed that the compressive strength is affected by the temperature to which the cement mortar is exposed initially. The initial compressive strength (3 day) of cement mortar increases with an increase in ambient temperature. However, at later ages, the strength decreases significantly with an increase in initial exposure temperature.

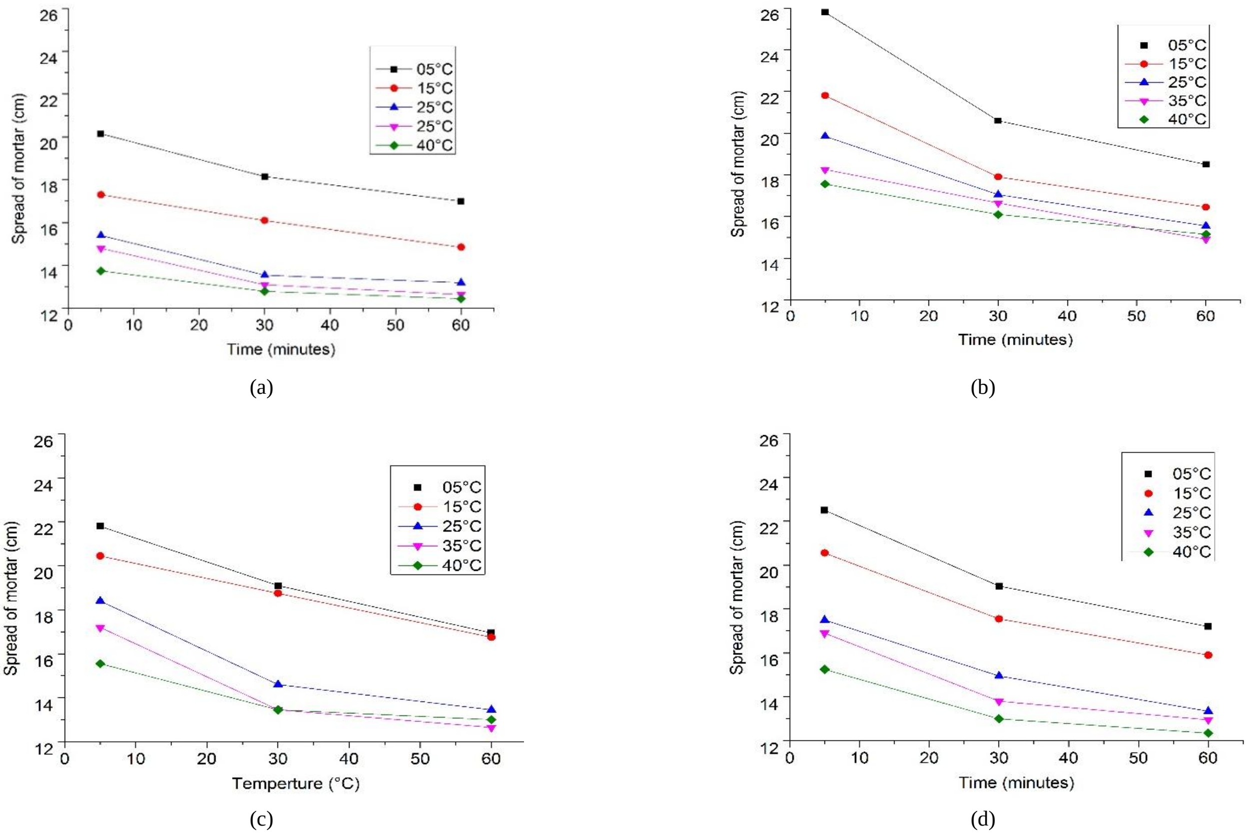


Figure 4 Spread of mortar with time at different temperatures for superplasticizer dosage corresponding to the saturation dosage at 25°C for the (a) Control, (b) PCE, (c) SNF, and (d) SMF mixes

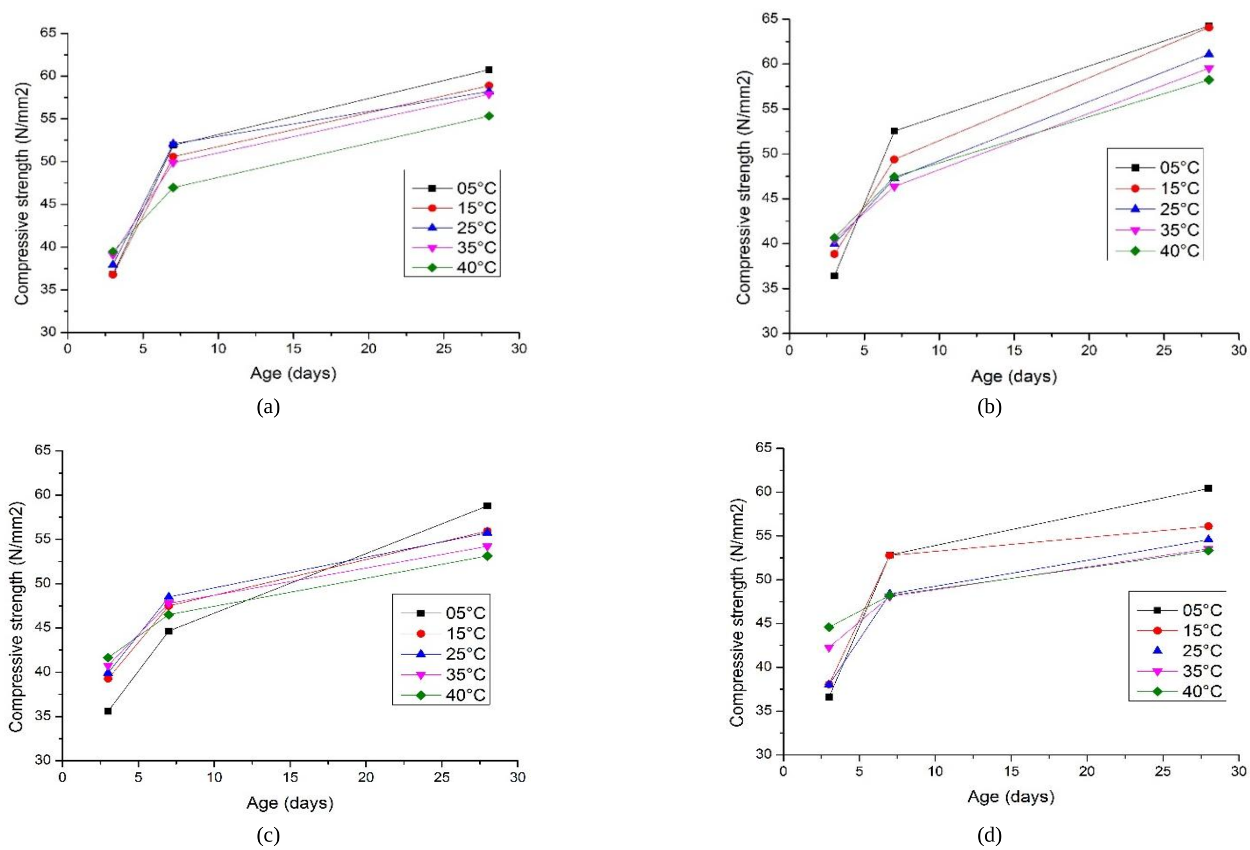


Figure 5 Compressive strength of mortar for the (a) Control, (b) PCE, (c) SNF, and (d) SMF mixes

From the test results, it is clearly observed that the 3-day compressive strength increases with an increase in temperature for cement mortar with and without superplasticizer. At 7 days, the control mortar and PCE- and SMF-based superplasticized cement mortar show a decrease in compressive strength at higher temperature. At 28 days, the control, as well as the superplasticized cement mortar, gave lower compressive strength as the temperature increased.

There seem to be two competing mechanisms involved in the effect of temperature, and the strength of mortar at an age depends on whichever mechanism is predominates at that time (Mirza et al. 1991). At early ages, the hydration of cement will be more due to the increased rate of reactions due to the higher temperature (up to 24 hours), which leads to higher strength initially. However, at later ages, the beneficial effects of the increased rate of hydration become equal to the detrimental effects of exposure to higher temperature and then the detrimental effects become dominant, which lead to reduction in strength. Kjellsen (1991) observed that the cement paste exposed to higher temperature can lead to a weaker, porous and non-uniform microstructure. It is evident that as porosity increases, the strength decreases (Sereda et al. 1980). Therefore, the more porous microstructure formed at higher temperature leads to a decrease in strength possibly due to the more porous hydrated cement paste or due to a weakened cement paste-aggregate bond. The lower strength at higher temperature can also be due to the incomplete hydration of cement particles due to the initial faster rate of moisture loss from the mortar (Mirza et al. 1991).

Earlier researchers also found an increase in early strength of mortar with increase in curing temperature and a reduction in later age strength (Aziz 2012; Mirza et al. 1991; Maltais and Marchand 1997; Elkhadiri et al. 2009). Kjellsen and Detwiler (1992) also observed that the effect of temperature is important only at the early ages and becomes less significant at later ages. A dense zone of hydration products is believed to form around the hydrating grains of cement at higher temperatures, and this formation of hydration shells would limit or even prevent further diffusion of ions, thereby reducing the ultimate degree of hydration (Kjellsen and Detwiler 1991; 1992). Sajedi (2011) also observed an increase in the initial compressive strength of mortar heated at 60°C for 24 hours immediately after demoulding, followed by a drop in strength, for mortar having almost same fluidity.

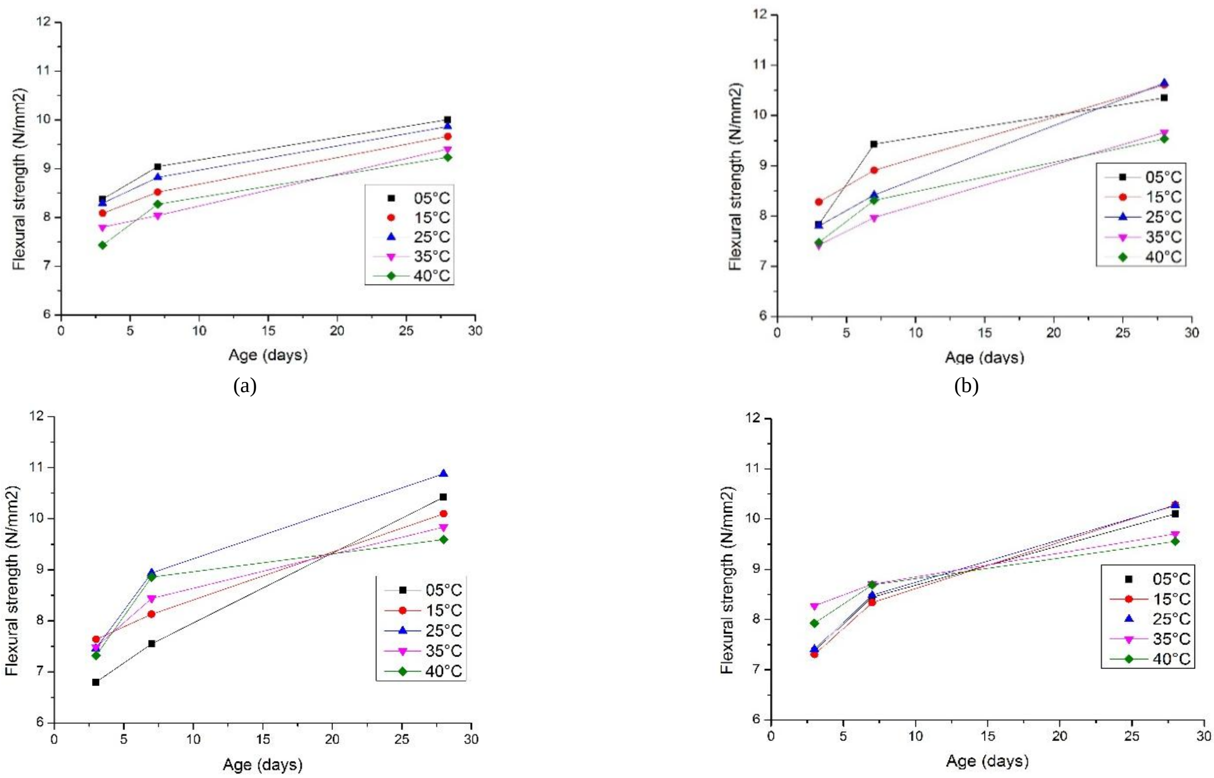
In the present study, the initial spread of mortar decreases at higher temperature, which may also contribute to the decrease in the compressive strength, since the initial fluidity of mortar will influence the level of compaction of the mortar. It is observed from Figures 5a-d that the influence of temperature is more predominant in the case of superplasticized cement mortars. The cement mortar without superplasticizer (Figure 5a) showed only a marginal variation in 3-day compressive strength with temperature. However, the superplasticized mortars (Figure 5b-d) exhibited significant increases in the 3-day compressive strength when exposed to higher initial temperatures.

3.5 The effect of temperature on the flexural strength of cement mortar

The flexural strength of cement mortar was determined as explained earlier and is plotted against age for different temperatures in Figure 6.

It is observed from the test results (Figure 6a-d) that even though the compressive strength of mortar shows an increase in strength with temperature at early ages, the flexural strength does not show such a trend. It appears that the 28-day flexural strength is always lower for high initial temperatures. At higher temperatures (i.e., 35 and 40°C), the SMF-based superplasticized cement mortar shows an increase in flexural strength at early ages, whereas the control and PCE based superplasticized cement mortar gave lower flexural strengths when exposed to higher temperature initially.

The results show that after 3 days of curing, the Control and SMF based superplasticized cement mortars had almost the same flexural strength from 5°C to 25°C, and thereafter, the flexural strength increases with temperature for SMF-based mortar and decreases for the control mortar. The PCE- and SNF-based superplasticized cement pastes show an increase in flexural strength from 5°C to 15°C and thereafter a decrease with increase in temperature after 3 days. The control mortar and the PCE-based cement mortar show a marginal decrease in flexural strength at 7 Sajedi (2011) also observed an increase in the initial compressive strength of mortar heated at 60°C for days, whereas the SNF- and SMF-based superplasticizers yield a marginal increase in flexural strength with increase in initial temperature. At 28 days, all the cement mortars gave a decrease in flexural strength at higher temperature but did not change much over the range of 5 to 25°C.



(a) (b) (c) (d)

Figure 6 Flexural strength of cement mortar for the (a) Control, (b) PCE, (c) SNF and (d) SMF

3.7 Effect of temperature on the fluidity of concrete

To study the effect of ambient temperature, concrete was prepared as explained earlier using the mix proportions given in Table 5. The fluidity of concrete was assessed with the slump test using the Abram's cone. Only the PCE- and SNF-based superplasticizers were used in this part of the study as these are the most common types of superplasticizers in the Indian context. The measured slump of concrete is plotted against temperature in Figure 7 (Note that two trials were conducted in each case).

Table 5 Mix proportion for concrete

Description	Quantity (kg/m^3)
Cement	440
Water	154
20 mm down aggregate	698
10 mm down aggregate	465
Sand	704

From Figure 7, it is observed that the slump of concrete decreases considerably with an increase in ambient temperature. Both the PCE- and SNF-based superplasticizers showed the same trend; as temperature increases, the slump decreases. It is also seen that the concrete prepared with both PCE- and SNF-based superplasticizers with the saturation dosage (for cement paste at 25°C) yielded almost the same slump at all temperatures studied, which reaffirms the usefulness of the Marsh cone test as a guideline for determining the saturation dosage of superplasticizer in concrete. The dosage of superplasticizer corresponding to the saturation dosage (of cement paste at 25°C), gave a slump of 75 and 80 mm for the PCE and SNF based superplasticizer, respectively, at 25°C, whereas the slump increases to 165 and 180 mm when the same mix was prepared at 5°C. When the temperature increased to 40°C, the slump reduced to 45 and 40 mm for the concrete with PCE- and SNF-based superplasticizer, respectively.

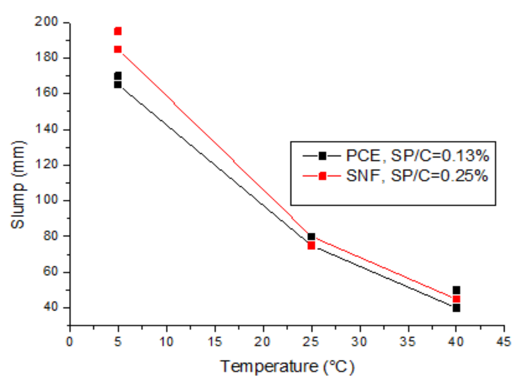


Figure 7 Change in slump of concrete with temperature

Ghafoori and Diawara (2010) also observed a loss in flow at hot weather conditions (i.e., 21°C to 43°C) and an increase in flow with cold weather conditions (i.e., -0.5°C to 21°C) for self compacting concrete. They attributed this to the higher adsorption of the superplasticizer by the cement, the increase in absorption of water by the aggregates, and the higher evaporation rate of water at higher temperatures. Mouret et al. (1997) also observed an increase in water demand for a required consistency increases with an increase in aggregate temperature. An increase of water demand with increase in temperature was reported by earlier researchers for concrete (Ravina and Soroko 1994; Soroko and Ravina 1998). The higher rate of hydration reactions and water demand at higher temperature will consume more water, and the consequent reduction in water increases the friction between the cement and aggregate particles leading to the stiffening of the fresh mix (Ravina and Soroko 1994).

3.8 Effect of temperature on the mechanical properties of concrete

The compressive strength of concrete was determined as per the procedure explained and the results are shown in Figure 8 (as mean values and scatter bars). It should be noted that the exposure temperature was maintained for 24 hours after casting the specimen. After that, the specimens were demoulded and kept in a mist room for curing. The age of specimen discussed here is given as the number of days after casting the specimen, which includes the 24 hours in the mould.

Figure 8 shows that the concrete exposed to a higher temperature initially (24 hours) attains higher early-age strength but develops lower strength at later ages compared to the specimens exposed to initial lower temperature.

Kim et al. (1998) also observed a similar trend in strength for concrete exposed to different temperature initially. Earlier studies have shown that concrete cured at higher temperature yield higher initial strength and lower long-term strength compared to concrete cured at lower temperatures (Mirza et al. 1991; Kim et al. 1998; Topçu and Toprak 2005). Shoukry et al. 2011 also observed a decrease in the 28-day compressive strength with an increase in exposure temperature.

The influence of temperature on cement hydration reactions and the strength development is still not completely clear. The increased rate of hydration of cement at higher temperature can form a layer of hydration products in the form of a ''shell'' on the surface of cement particles, which hinders the diffusion of hydration products further into the matrix (Kim et al. 1998; Ortiz et al. 2005).

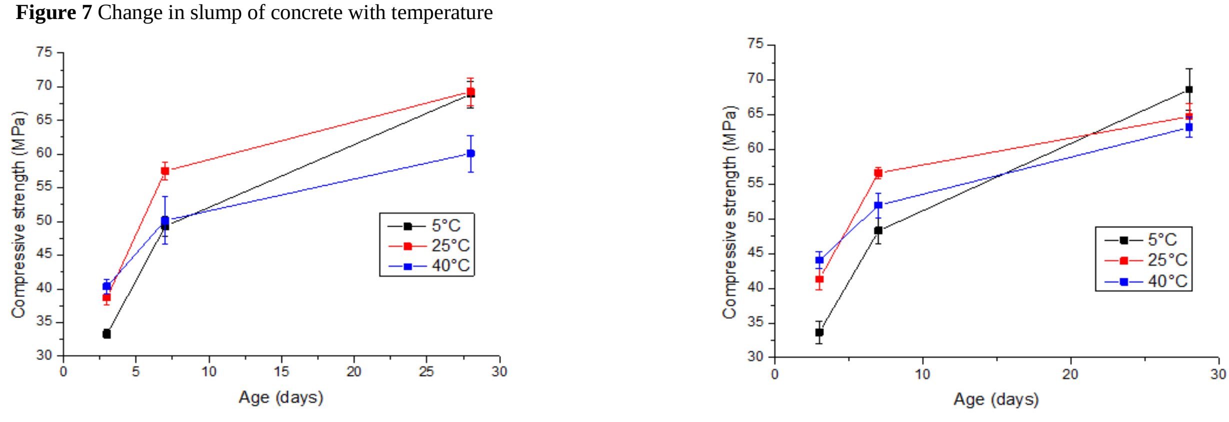


Figure 8 Compressive strength of concrete with temperature for the (a) PCE and (b) SNF mixes

It is also reported that the porosity of the cement paste subjected to higher temperature increases as a result of the non-uniform diffusion and precipitation of the hydration products. The increase in early curing temperature increases the hydration rate of cement initially and the strength increases rapidly. However, the difference in expansion coefficients of various ingredients of concrete and the non-uniform distribution of hydration products lead to more porosity and formation of micro cracks, eventually leading to a decrease in strength at later ages (Kim et al. 1998; Ortiz et al. 2005). In the present study, the concrete was exposed to higher temperature initially (i.e., till 24 hours after casting) and then cured at room temperature, therefore the difference in thermal contraction of different constituents of concrete due to the variation in thermal expansion coefficients of different ingredients of concrete may lead to the formation of microcracks, which in turn can reduce the long-term strength of concrete.

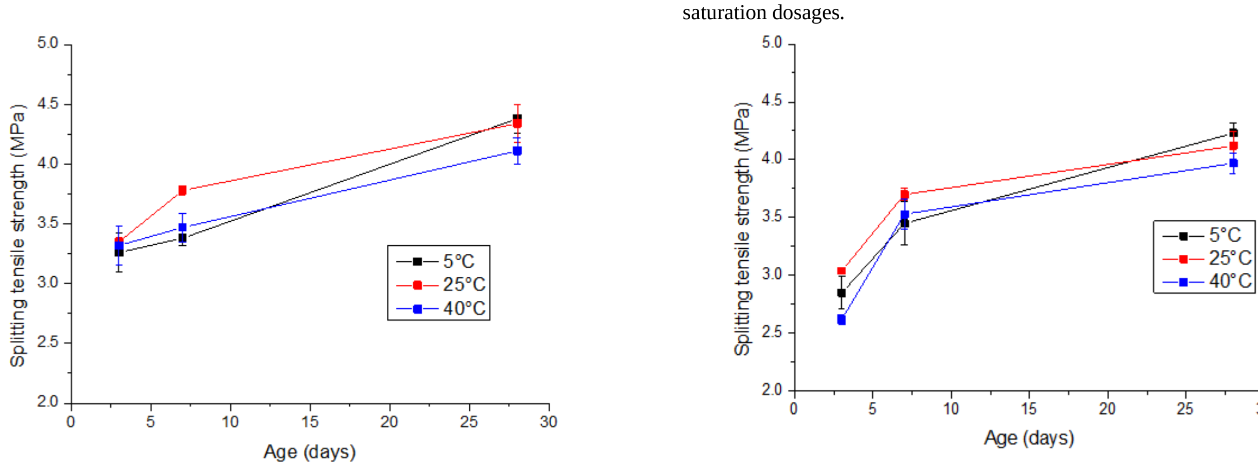
Verbeck and Helmuth (as cited in Ortiz et al. 2005) and Kjellsen and Detwiler (1991) observed that the rate of hydration is initially high at higher temperatures and slows down at the later ages, resulting in a non-uniform distribution of the hydration products within the paste. They explained this to be as a result of insufficient time for the diffusion products of hydration in the interstitial space to precipitate away from the cement particles due to increased rate of hydration at higher temperatures, whereas at lower temperatures, the hydration products will get sufficient time in the interstitial space for diffusion and precipitation which results in a more uniform and homogeneous distribution of hydration products at lower temperature. Kjellsen and Detwiler (1991) and Kjellsen et al. (1989) found a more uniform microstructure at lower temperatures compared to specimen exposed to high curing temperature. They also observed the dense hydration shells formed around the cement particles and an increased porosity at higher temperatures. Elkhadiri et al. (2009) concluded that the higher rate of hydration at the early ages (at higher initial temperatures) leads to the formation of dense hydration products near the hydration cement particles.

The splitting tensile strength of concrete was determined as explained earlier and results are plotted in Figure 9, showing a decrease in the tensile strength with an increase in temperature. This can be due to the higher amount of porosity and non-uniform microstructure of concrete exposed to initial higher temperature. As the defects are more, there will be a higher possibility of larger defects to develop into cracks, causing failure to occur at lower stresses. The drop in splitting tensile strength of the concrete with a rise in temperature may be partly attributed to more pronounced weakness of the transition zone (Mouret et al. 1997). The present results are in accordance with the results of Abbasi and Al-Tayyib (1985) and Shoukry et al. (2011), who have observed a decrease in splitting tensile strength of concrete with an increase in the preparation and curing temperature of concrete.

3.9 Correlation between initial fluidity of mortar and concrete

The previous sections described the effect of temperature on different properties of cement mortar and concrete. It would be useful to correlate the fluidity of cement mortar and concrete, in order to predict the fluidity of concrete from the simple tests on the cement mortar. In this study, the paste composition was maintained in the mortar and concrete for comparison. Also, a fine aggregate to cement ratio of 1.6 was used for both cement mortar and concrete. The results from the flow table test of mortar and slump test of concrete were plotted as a function of ambient temperature for PCE- and SNF-based superplasticizers in Figures 10a&b.

A good correlation can be observed between the spread of mortar and the slump of concrete with temperature; as temperature increases both these parameters decrease in a similar manner. Both the PCE-and SNF-based superplasticizers gave the same trend and correlation between cement mortar and concrete as the dosages in both cases were the corresponding saturation dosages.



(a) (b)

Figure 9 Split tensile strength of concrete with temperature for (a) PCE and (b) SNF mixes.

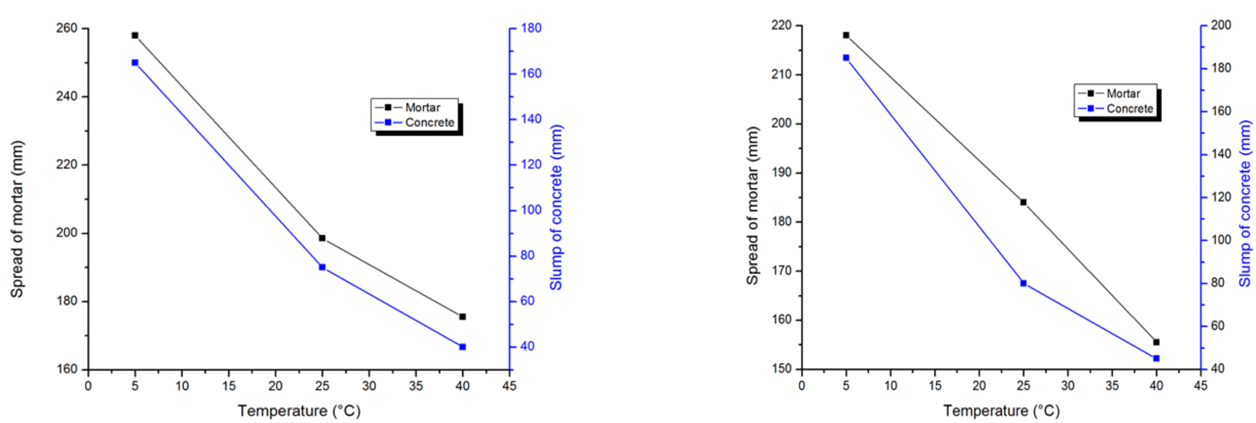


Figure 10 Correlation between fluidity of mortar and concrete with temperature for the (a) PCE and (b) SNF mixes

3.10 Comparison between the strength of cement mortar and concrete

It was seen in the previous sections that the later-age (i.e., 7 and 28 day) strengths of cement mortar and concrete decrease with an increase in initial temperature. Since it would be interesting to compare the development of strength of cement mortar and concrete at different ages with varying temperature, the change in strength of the mortar and concrete were calculated as a percentage increase/decrease from the strength at 5°C and given in Table 6.

The compressive strengths of cement mortar and concrete generally gave a similar trend. The short-term (3 day) compressive strength of cement mortar and concrete was observed to increase with initial ambient temperature (Note that the negative sign in the table indicates a loss in strength). The concrete shows a higher increase in compressive strength compared to cement mortar at 3 days. The PCE-based cement mortar shows a lower strength after 7 days of curing at 25 and 40°C compared to 5°C; however, the concrete shows an increase in strength at 25°C and has almost the same at 40°C and 5°C at 7 day. For the SNF-based superplasticizer, the cement mortar shows a marginal gain in strength at 25°C and a marginal loss in strength at 40°C compared to 5°C after 7 days of curing, whereas the concrete with SNF based superplasticizer shows a gain in strength at both 25 and 40°C. The 28-day compressive strength shows good correlation between cement mortar and concrete.The PCE-based superplasticizer gave a marginal decrease in compressive strength for mortar at 25°C, while the concrete shows almost same strength at 5 and 25°C. At 40°C both mortar and concrete gave a significantly lower strength. It can be observed from the results that the gain in strength at early ages due to increase in temperature reduces at a faster rate in the case of cement mortar compared to concrete.

The flexural strength of mortar and splitting tensile strength of mortar were also compared to get a qualitative idea about the development of tensile strength of concrete with age for specimens exposed to different temperatures. The change in strength compared to 5°C for each age was calculated for 25 and 40°C and given in Table 7.

The cement mortar and concrete gave lower 28-day strength for the specimens exposed to higher temperature initially. There exists a good correlation between the strength of cement mortar and concrete. The 28-day flexural strength of mortar and splitting tensile strength of concrete also show trends similar to that of the compressive strength.

Table 6 Comparison between the compressive strengths of cement mortar and concrete

SP	Age (days)	Cement mortar					Concrete				
		Compressive strength			% change in strength (with respect to the 5°C value)		Compressive strength			% change in strength	
		5°C	25°C	40°C	25°C	40°C	5°C	25°C	40°C	25°C	40°C
PCE	3	36.4	40.0	40.7	9.8	11.7	33.3	38.7	40.4	16.3	21.2
	7	52.6	47.3	47.5	-10.1	-9.7	49.3	57.5	49.2	16.7	-0.2
	28	60.8	58.2	54.0	-4.2	-11.1	68.9	69.3	60.1	0.6	-12.7
SNF	3	35.6	39.9	41.6	12.2	17.0	33.7	41.2	44.1	22.4	30.9
	7	47.3	48.5	46.5	2.5	-1.7	48.3	56.6	52.0	17.3	7.6
	28	64.2	61.1	58.2	-4.9	-9.4	68.6	64.7	63.1	-5.7	-8.0

Table 7 Comparison between the flexural strength of cement mortar and splitting tensile strength of concrete

SP	Age (days)	Cement mortar					Concrete				
		Flexural strength			% change in strength (with respect to the 5°C value)		Splitting tensile strength			% change in strength	
		5°C	25°C	40°C	25°C	40°C	5°C	25°C	40°C	25°C	40°C
PCE	3	7.8	7.8	7.5	-0.4	-4.6	3.3	3.4	3.3	3.4	1.8
	7	9.4	8.4	8.3	-10.8	-11.9	3.4	3.8	3.5	11.8	2.7
	28	10.4	10.6	9.5	2.8	-7.9	4.4	4.5	4.1	2.5	-6.2
SNF	3	6.8	7.5	7.3	9.7	7.7	2.9	3.0	2.6	6.3	-8.1
	7	7.8	8.9	8.9	14.9	13.9	3.5	3.7	3.5	7.3	2.3
	28	10.4	10.9	9.6	4.4	-7.9	4.1	4.1	4.0	0.5	-3.2

4. Conclusions

The influence of temperature and superplasticizer and their interaction on the different standard properties of cement mortar and concrete have been studied. The results of the initial fluidity of cement mortar and concrete were correlated to establish relations between them. The study has led to the following conclusions:

- The mixing temperature has a significant influence on the initial fluidity and loss in fluidity with time of cement mortar. The fluidity decreases with an increase in temperature, both with and without superplasticizer. The loss in fluidity is more predominant in the first half hour compared to the second half hour, especially at higher temperature. Therefore, the ambient temperature should be taken into consideration while finalising the proportion of the mix to get the required fluidity for the mortar.
- The slump of concrete also decreases rapidly with an increase in temperature. The higher hydration of cement, increased water absorption of the aggregates and the higher evaporation of water from the mix, at higher temperature, could be the reasons for the decreased slump at higher temperature.
- The compressive strength of cement mortar increases initially with an increase in initial temperature, however, the long-term strength decreases with an increase in the exposure temperature. The higher rate of hydration at the greater temperature at early ages can be the reason for the higher early strength, however, at later ages this effect is nullified and detrimental effects of higher temperature exposure become more predominant. The changes in the microstructure due to rapid hydration at higher temperature and the effect of variation in the compaction due to low fluidity at higher temperature can be the reason for the lower strength in the specimens exposed to initial higher temperature. Therefore, a proper study has to be done to make sure that the required strength will be obtained at the actual exposure conditions. The flexural strength of mortar also decreases with an increase in temperature.
- The compressive strength of concrete increases initially with an increase in ambient temperature to which the concrete is exposed. However, the long term strength reduces with increase in initial

temperature. Therefore, the ambient temperature to which the concrete is subjected should be considered in the determination of the proportioning of the ingredients of concrete. The splitting tensile strength of concrete was also found to decrease with an increase in ambient temperature to which the concrete is exposed initially.

- The influence of temperature on the 28-day compressive strength of cement mortar and concrete can be generally comparable even though the development of strength is varying marginally. The advantage of initial increased rate of hydration due to higher temperature disappears early in the case of cement mortar, whereas the increased strength is observed for longer time for concrete.

Generally, it can be concluded that mix proportioning of concrete should be done by considering the ambient temperature to which the concrete is exposed to. Unexpected increase in temperature can affect the fresh and hardened state properties of concrete drastically. The fluidity of cement mortar and concrete decrease significantly with an increase in temperature. Hence, the superplasticizer dosage should be selected by considering the temperature to get the required slump, and proper care has to be made to ensure the required strength at later ages. Again, the strength of mortar and concrete were seen to decrease with an increase in ambient temperature.

Acknowledgements

Funding for the environmental chamber was made possible by the grant for the "Investigation of compatibility issues between Indian cements and water-reducing admixtures" by the Department of Science and Technology, Government of India (CIE/06-07/128/DSTX/MANU), 2007-10. The testing was done in the Construction Materials Laboratory of IIT Madras.

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