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EFFECTS OF TEMPERATURE ON CONCRETE

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ABSTRACT

The objective of this limited study is to provide an overview of the effects of temperature on the behavior of concrete materials and structures. In meeting this objective the effects of temperatures as it elevates and depresses from ambient temperature, are worked out.

This paper also deals with the procedure and precautions to be observed while concreting in extreme weather conditions- hot and cold weather so as to minimize the detrimental effects of weather on concreting in general types of construction, such as -buildings, bridges, highways, pavements and other similar structures.

I. INTRODUCTION

Laboratory testing of concrete is usually performed at a controlled temperature, normally constant. As the early testing was done in temperate climates, the standardized temperature chosen was generally in the region of 180 to 210C so that much of the basic information about the properties of both fresh and hardened concrete is based on the behavior of concrete at these temperatures. In practice however the concrete is mixed and remains in service at a variety of temperature. Indeed, the actual range of temperature has widened up considerably with much modern construction taking place in countries which have a hot climate. Also, new developments, mainly offshore, take place in very cold regions.

Conventionally, researchers have used strength properties of concrete as criteria for evaluating its performance. A concrete having high strength does not necessarily imply that it will have long service-life. Thus, it is now well recognized that concrete performance should be determined in terms of both strength and durability under anticipated environmental conditions.

II. EFFECTS OF HIGH TEMPERATURE

Under normal conditions, most concrete structures are subjected to a range of temperature no more severe than that imposed by ambient environmental conditions. However, there are important cases where these structures may be exposed to much higher temperatures (e.g., jet aircraft engine blasts, building fires, chemical and metallurgical industrial applications in which the concrete is in close proximity to furnaces, and some nuclear power-related postulated accident conditions). Concrete's thermal properties are more complex than for most materials because not only is the concrete a composite material whose constituents have different properties, but its properties also depends on moisture and porosity. Exposure of concrete to elevated temperature affects its mechanical and physical properties.

III. EFFECTS ON STRENGTH OF CONCRETE

It has been found that high early temperature has negative impacts on later strength of concrete.

Some researchers investigated the adverse effect on long term strength of concrete due to high initial temperature. High initial rate of hydration due to increased temperature retards the subsequent hydration and produces a non-uniform distribution of the products of hydration. Its reason is that at high initial rate of hydration, there is insufficient time available for the diffusion of the products of hydration away from the cement particle and for a uniform precipitation in the interstitial space. All this results in concentration of the products in the vicinity of the hydrating particles which causes subsequent retardation in hydration and effects strength.

The effect of temperature on compressive strength of concrete with increasing temperature can be better understood by the following experimental work done by researcher H. A. M. Bishr of Sana'a University, Yemen. [REF. ICCBT 2008 - A - (019) – pp217-220]

IV. EXPERIMENTAL WORK

To show the effects of elevated temperature on compressive strength of concrete, basalt aggregate concrete was mixed according to ASTM C192. The specifications of the specimens, concrete proportions and testing conditions are as follows:

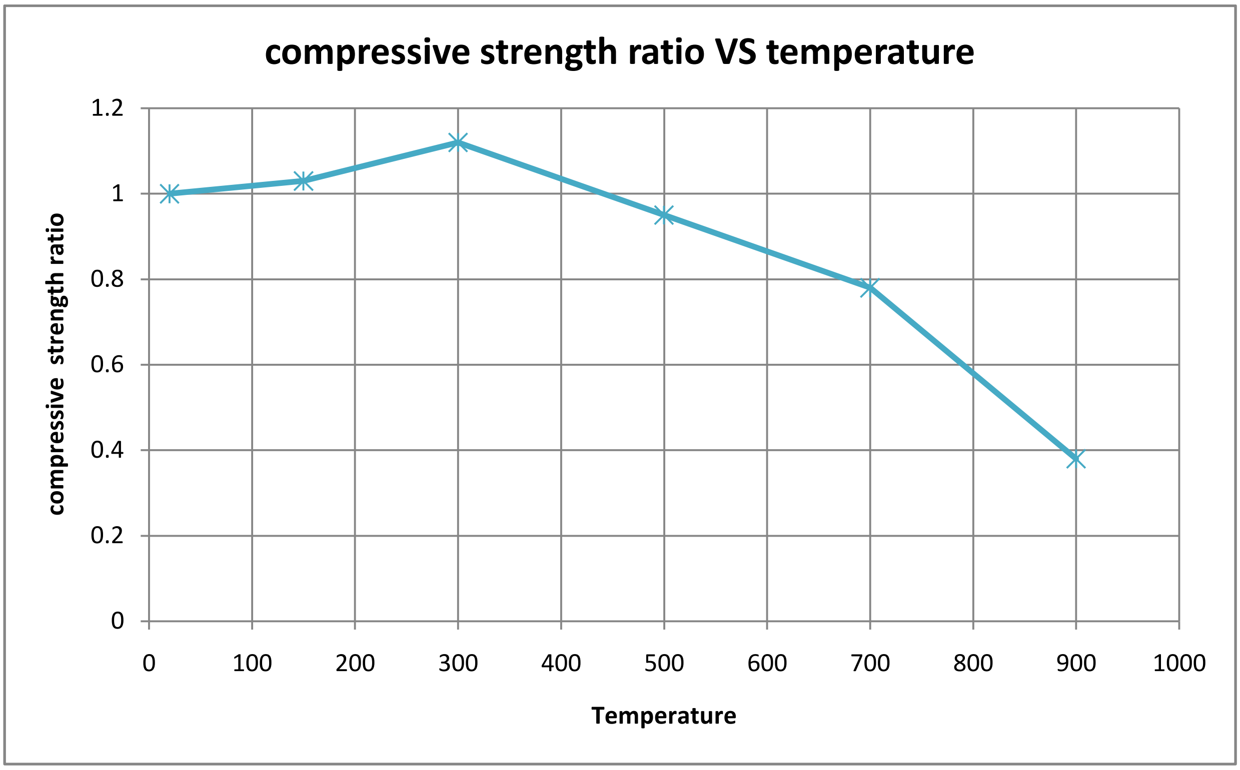
- Cube specimens with dimensions 100*100*100 mm3.
- Cement : Ordinary Portland Cement 350 kg/ m3
- Coarse aggregate: Basalt aggregate (crushed stones)
- Fine aggregate : Local sand
- Water : 175 Liters (W/C = 0.50)
- Temperatures: 20, 150, 300, 500, 700, 900^0 C.
- Curing age : 28 days

Specimens were left in the oven for 4 hours to achieve a uniform temperature distribution across them. After that, specimens were allowed to cool in the oven for 20 hours, a total of 24 hours of heating and cooling past the curing age. A loading rate of 3 kN/s was used to get the residual compressive strength of concrete.

Observations:

Temperature	20	150	300	500	700	900
Ratio of compressive strength to compressive strength at ambient(20^{0}C) temperature	1	1.03	1.12	0.95	0.78	0.38

Graph:



GRAPH-1

4.1 Effects on Poisson's ratio

Poisson's ratio is needed for conducting structural analyses of flat slabs, arch dams, tunnels, tanks, and other statically indeterminate members. At normal ambient conditions, Poisson's ratio for concrete can vary from 0.11 to 0.32, but is generally in the range from 0.15 to 0.20. Available data do not indicate a consistent trend for variation of Poisson's ratio with age, strength, or other concrete properties. However, some test results indicate that the ratio increases with age of concrete up to about 2 years and is lower for higher strength concretes. Data on the effect of elevated temperature on Poisson's ratio are somewhat limited and tend to be inconsistent. Some data indicate that the Poisson's ratio decreases with increasing temperature, whereas elsewhere it has been reported that it ranged from 0.11 to 0.25 at 20°C to 400°C, while above 400°C it increased. Additional data for higher strength concrete indicated that when the stress did not exceed 50% of peak value, poisons ratio decreased with an increase in temperature. Fig 01 shows Poisson's ratio results for a hard sandstone aggregate concrete after various heating periods (i.e., 1, 7, 28, and 91 d) at 175°C for specimens that were either sealed or unsealed during heating. Poisson's ratio ranged from 0.14 to 0.22 with the trend for it to increase with increasing moisture content of the concrete.

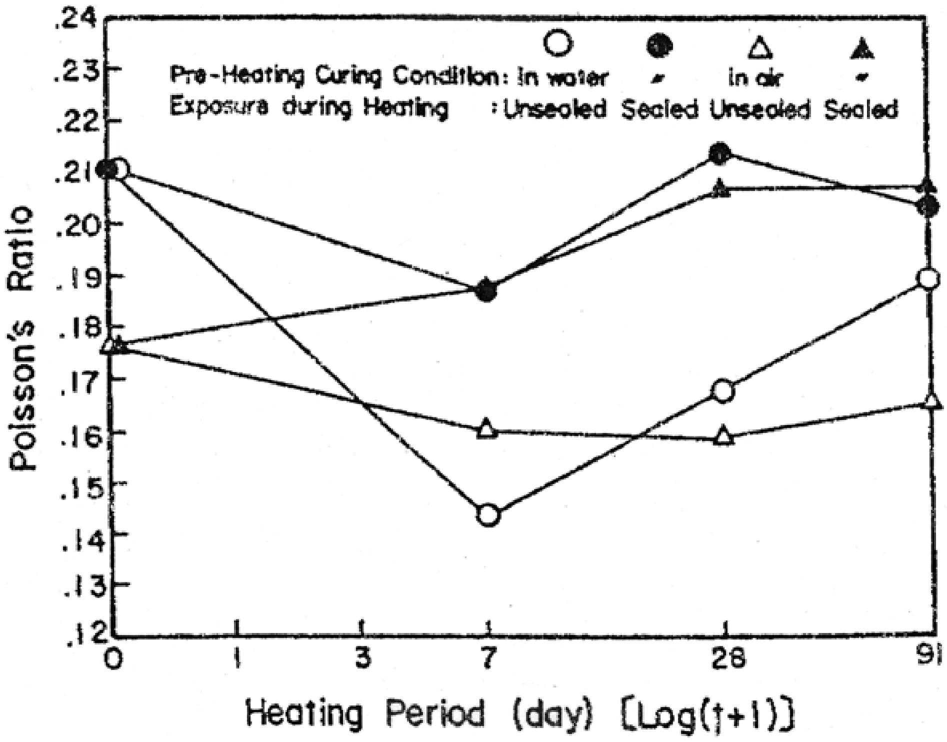


Figure 01 Poisson's ratio results. Source: K. Hirano et al., "Physical Properties of Concrete Subjected to High Temperature for MONJU," Paper P2-25, Power Reactor and Nuclear Fuel Development Corporation, Tokyo, Japan.

4.2 Effects on modulus of elasticity

Concrete's modulus of elasticity—a measure of its stiffness or resistance to deformation—is used extensively in the analysis of reinforced concrete structures to determine the stresses developed in simple elements and the stresses, moments, and deflections in more complicated structures. Because concrete's stress-strain curve is nonlinear, the modulus of elasticity is determined either by the initial tangent modulus, secant modulus, or tangent modulus method. Principal variables affecting the modulus include (1) richness of the mix (richer the mix, the greater the modulus increase with age); (2) water/cement ratio (higher values reduce modulus); (3) age (modulus increases rapidly during first few months and shows continual increase up to ~3 years); (4) kind and gradation of aggregate (stiffer aggregates produce higher modulus concretes, and the modulus increases with aggregate fineness modulus as long as the mix is workable); and (5) moisture content at time of test (wet specimens produce higher modulus values than dry specimens). Temperature can significantly affect the modulus values. Figure 02 summarizes results from several researchers on the temperature dependence of the concrete modulus of elasticity.

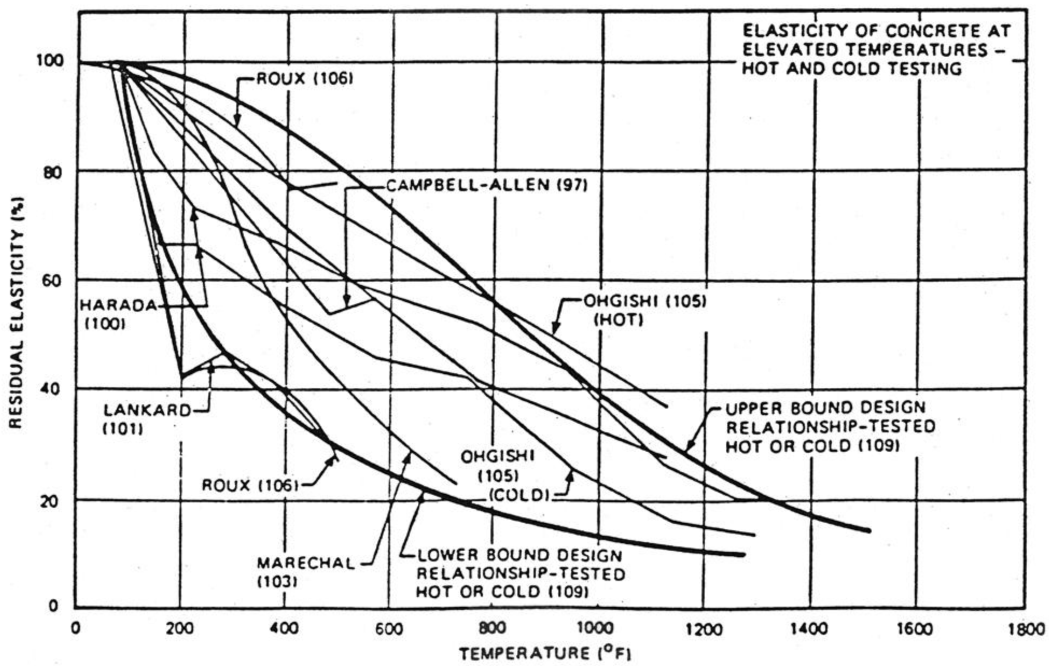


Figure 02 Effect of temperature on the modulus of elasticity of concrete: hot and cold test results. Source: G. N. Freskakis, "Behavior of Reinforced Concrete at Elevated Temperature," Paper 3-4, Source: ASCE Conf. on Civ. Eng. and Nuclear Power 1, Paper 3-5, pp. 3-5-1 to 3-5-21, Knoxville, Tennessee, Sept. 15–17, 1980.

The strong influence of aggregate type on modulus is presented in Fig. 03

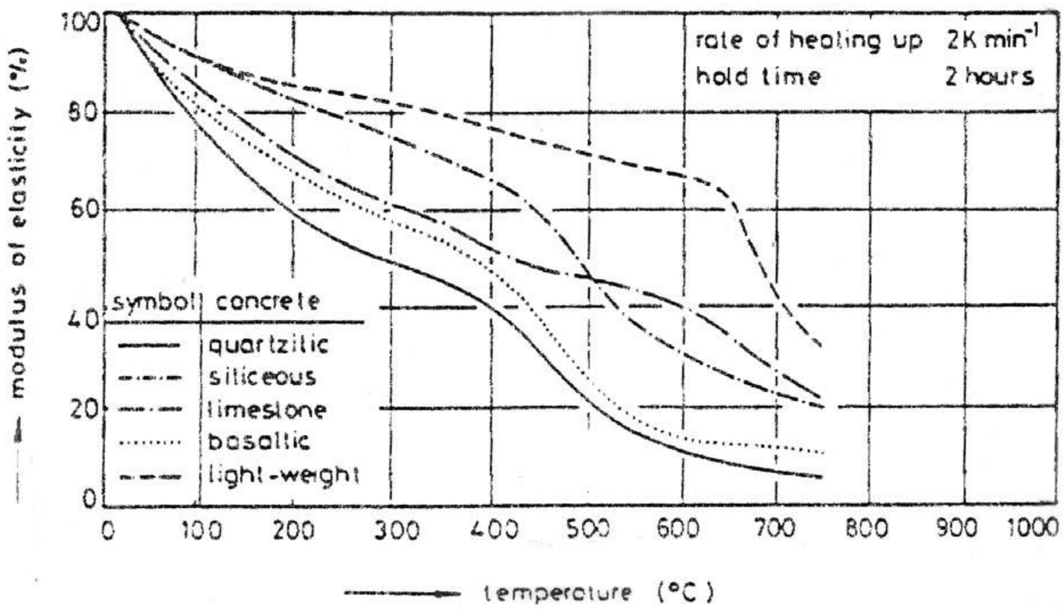


Figure 03 Modulus of elasticity of different concretes at elevated temperature. Source: U. Schneider,C. Dierenichs, and C. Ehm, "Effect of Temperature on Steel and Concrete for PCRV's," Nuclear Engineering and Design 67, 245–258 (1981).

V. HOT WEATHER CONCRETE

Concrete placed during the hot months of the year is subject to conditions that can adversely affect the properties and serviceability of the hardened concrete. Some of these conditions are:

5.1 Problems

- Increased water demand
- Increased rate of slump loss
- Increased rate of setting
- Increased tendency for plastic shrinkage cracking and drying shrinkage cracking
- Lower ultimate strengths
- Decreased durability
- Undesirable surface appearance

Hot weather as defined by ACI committee 305 1.2.1, is any combination of the following conditions that tend to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration, or otherwise resulting in detrimental results:

5.2 Detrimental Conditions

- High ambient temperature
- High concrete temperature
- Low relative humidity
- Wind velocity

The term “hot weather” can be misleading, as some of the undesirable effects on concrete can and do occur in the spring and fall seasons and in arid climates any time of the year. The ideal conditions for placing concrete occur when the temperature is 68°F to 72°F, the relative humidity is at 50% or higher, and wind speeds low. As the temperature rises the humidity begins to drop, the wind velocity increases, or any combination of these conditions occur, control procedures are needed to minimize the harmful effects.

5.3 Controls for Hot Weather

- Using a concrete mixture that is properly proportioned for conditions expected in the field can help to minimize the rate of slump loss, and water demand.
- Consider the use of a set-retarding admixture to control set times. The use of fly ash can also reduce the effects of fast-setting concrete.
- Have adequate manpower and equipment available to handle the concrete at the desired rate of placement and to unload the concrete trucks promptly.
- Drying shrinkage cracking is greatly influenced by the amount of water in the mix. As the temperature rises so does the amount of water needed to maintain the specified slump. Add water only once—adjust the slump when the truck first arrives and follow through with prompt placement.

- Plastic shrinkage cracking is one of the most common types of cracks found in flat work. These cracks usually occur in the surface of fresh concrete within the first few hours after placement. These are usually short, random, discontinuous cracks. These type of cracks can be virtually eliminated by proper construction practices. When the rate of evaporation at the surface exceeds the rate at which bleed water rises to the surface, then these cracks are likely to occur. Low humidity and high winds greatly affect the surface evaporation rate. To minimize plastic shrinkage cracking, keep the surface wet (not saturated) by applying moisture with a fog sprayer until the final curing method is ready to be applied.

VI. EFFECTS OF LOW TEMPERATURE

At temperature ranging from the freezing point of water down to about -200^{0}C, the strength of concrete is markedly higher than at room temperature. the compressive strength may be 2 to 3 times the strength at room temperature when the concrete is moist while being chilled, but the compressive strength of air-dry concrete increases very much less.

6.1 What Happens When Concrete Freezes?

- Pore water in concrete starts to freeze around -1°C (30°F)
- As some water freezes the ion concentration in the unfrozen water goes up, further depressing the freezing point.
- At around -3 to -4°C (25 to 27°F), enough of the pore water will freeze so that hydration will completely stop, and depending on the extent of hydration, and thus the strength of the concrete, the forces generated by the expansion of ice (ice occupies ~9% more volume than water) may be detrimental to the long term integrity of the concrete.

VII. COLD WEATHER CONCRETE

7.1 Objectives of cold weather concrete

- The objectives of cold weather concreting are to:
- Prevent damage to concrete due to freezing at early ages
- Assure that concrete develops the required strength for the safe removal of forms
- Maintain curing conditions that foster normal strength development without using excessive heat
- Limit rapid temperature changes in the concrete to prevent thermal cracking
- Provide protection consistent with the intended serviceability of the structure for every 10°C (18°F) reduction in concrete temperature, the times of setting of the concrete double, thus increasing the amount of time that the concrete is vulnerable to damage due to freezing. It should be noted that warm concrete placed on cold sub-grade will lose heat and its temperature will drop. It is important to understand that having the concrete reach the specified 28-day strength is irrelevant if the structure is damaged by inadequate curing and protection. Concrete that is protected from freezing until it has attained a compressive strength of at least 3.45 Mpa (500 psi) will not be damaged by exposure to a single freezing cycle. Concrete that is protected and properly cured will mature to its potential strength despite subsequent exposure to cold

weather. Except in heated, protective enclosures, little or no external supply of moisture is required for curing during cold weather.

7.2 Definition

Cold weather is defined by ACI committee 306 as "a period when for more than 3 successive days, the following conditions exist: 1.) the average daily air temperature is less than 40°F, and 2.) the air temperature is not greater than 50°F for not more than one half of any 24 hour period. The average daily air temperature is the average of the highest and lowest temperatures occurring between the period from midnight to midnight. Normal concrete practices can resume once the ambient temperature is above 50°F for more than half the day." Concrete can be placed safely throughout the winter months if certain precautions are met. During cold weather, preparations should be made to protect the concrete; enclosures, windbreaks, portable heaters, insulated forms and blankets should be ready to maintain the concrete temperature.

7.3 Effects of cold weather on concrete

Effects of cold weather on concrete, in the absence of special precautions, may be as follows:

a) **Delayed Setting -** When the temperature is falling to about 5°C or below, the development of concrete strength is retarded compared with the strength development at normal temperatures.

The hardening period, necessary before the removal of forms is thus increased and the experience from concreting at normal temperature cannot be used directly.

b) **Freezing of Concrete at Early Ages -** When concrete is exposed to freezing temperature, there is the risk of concrete suffering irreparable loss of strength and other qualities, that is, permeability may increase and the durability may be impaired.

c) **Repeated Freezing and Thawing of Concrete - If** concrete is exposed to repeated freezing and -thawing after final set and during the hardening period, the final qualities of the concrete may also be impaired.

d) **Stresses Due to Temperature Differential -** It is a general experience that large temperature differentials within the concrete member may promote cracking and have a harmful effect on the durability. Such differentials are likely to occur in cold weather at the time of removal of form insulations.

7.4 Recommended Practices and Basic Principles

Planning

Prior to the pour, clearly define the cold weather concreting methods that will be used. A pre-placement meeting with the contractor, specifier, producer, laboratory and other interested parties is highly recommended.

Curing and Protection

Where a specified concrete strength must be attained in a few days or weeks, protection at temperatures above 10°C (50°F) is required.

Temperature Records

Temperature of the concrete determines the effectiveness of protection, regardless of air temperature. Maintaining temperature records of concrete in place is essential.

Heated Enclosures

Must be strong enough to be windproof and weatherproof. Combustion heaters must be vented to the outside to prevent carbonation.

Exposure to Freezing and Thawing

Concrete should be properly air entrained if it will be saturated and exposed to freezing and thawing cycles during construction.

Slump

All else being equal, lower slump and/or lower water/cement ratio mixes are particularly desirable in cold weather for flatwork. This reduces bleeding and decreases setting time.

Truck Travel Time

The distance from the plant to the point of placement can have a severe effect on the temperature of concrete.

Hot Water

While hot water improves setting time of cold weather concrete, after the first few batches of concrete hot water heaters may not be able to maintain hot water temperature. Later in the pour, concrete may be cooler than at the beginning of the pour.

Acceleration of Concrete Hydration in Cold Weather

The reduction of setting time and the acceleration of strength gain often result in substantial savings due to shorter protection periods, faster form reuse, earlier removal of shores, and less labor in finishing flatwork.

- Setting time is more important in flatwork finishing
- Early strength gain is more important for early form removal

Acceleration may be encouraged by using:

- Type III Portland cement
- 20% additional Type I or II cement to provide Type III response

Calcium chloride is the most cost effective accelerator available, but it causes corrosion of embedded metals in the presence of oxygen and moisture. This is why limits exist on the use of chlorides in concrete It is important to verify that non-chloride accelerating admixtures are also noncorrosive.

Some accelerating admixtures which are labeled as non-chloride may still contain materials which cause the products to be corrosive to embedded metals. Non-chloride, noncorrosive accelerators are more expensive up-front, but when life-cycle costs and regulations limiting chlorides are considered, they are the most cost effective products. Accelerators have been introduced successfully into concrete both before and after the addition of cement to the mix, but it may be best policy to add the accelerator to the mix after the cement has been wetted. On rare occasions, when accelerators are added to the mix prior to the batching of “under-sulfated” cements, there may be adverse reactions with the tricalcium aluminate (C3A) in the cement which may result in retardation. Therefore, we recommend that if the accelerator is to be added up-front, before the cement, it should be tested with the intended cement at the intended use temperature, prior to placement. Different mixes and materials will exhibit different setting times. It should not be assumed that two different Portland cements will set at similar rates. If pozzolans are to be used in the concrete, they should also be included in trial mixes prior to placement.

VIII. CONCRETE TESTING

Concreting in winter time requires that the quality control of concrete is carried out with great care. The test results shall be used for fixing the time of removal of insulations, forms, etc, or be the basis for further precautions at the building site.

In addition to the regular quality control, special emphasis shall be placed on:

a) Determination of the suitability of concrete making materials for winter concreting and control of the properties of fresh concrete,

b) Records of air temperature and measurements of concrete temperature at placing and during concreting, and

c) Control of strength development in the structure by testing similarly cured specimens.

IX. CONCLUSIONS

Concrete is widely used commodity. It is used in a variety of environments. Concreting, though a relatively easy concept is less under stood sometimes and even small factors like temperature can play a big role in the proper and satisfactory performance of concrete. The guidelines for concreting in extreme weather conditions should be properly followed to have a durable, serviceable and relatively better concrete. Moreover keeping in mind the loss of concrete strength under severe temperature conditions the factor of safety should be accordingly modified in special structures like nuclear reactors.

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