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Management Of Concrete Production In The Tropics

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***Abstract:** The aim of this paper was to examine the management methods of concrete production in the tropics. The paper considered crucial factors responsible for overall concrete quality and management in the tropics. It concluded that poor development of high performance concrete in terms of high strength concrete, high consistence concrete and high durability concrete were responsible for problems in concrete production management. The paper also recommended an understanding of basic mechanisms involved in deterioration processes in the tropics as well as eventual application of codified performance-based approach in quantitative and qualitative terms in the near future.*

***Keywords:** management, concrete, production, temperature, humidity, durability*

I. INTRODUCTION

Whenever large volume of fresh concrete is poured during the construction of large homogeneous structures such as dams, bridges, water retaining structures and foundations, consideration is always given to the amount of heat that will be generated (Gajda, 2007; Klemczak, 2014). The concrete hydration is an exothermic reaction that can produce high amounts of heat during curing, especially in the first few days or weeks after casting (ACI Committee 318, 2005; Lawrence, 2009). This heat production can produce high temperatures at the centre of the mass concrete due to the insulating effect of the concrete. Since the concrete surface temperatures are lower due to the heat dissipated into the ambient environment, temperature gradients are formed (Khan, Cook, & Mitchell, 1998; Lachemi & Aitcin, 1997; Lawrence, 2009; Pofale, Tayade, & Deshpande, 2013). These changes in temperature create volumetric changes, i.e. expansion from heating and contraction from cooling in the concrete (Lin & Chen, 2015; Tia, Lawrence, Ferraro, Do, & Chen, 2013). When these volumetric changes are restrained by the supports and the more mature interior concrete, tensile stresses are formed on the concrete's surface (Riding, Poole, Folliard, Juenger, & Schinder, 2012). If the surface tensile stresses become higher than overall tensile strength of the concrete, cracking normally occurs (de Borst & van den Boogaard, 1994; Kim, 2010; Lawrence, 2009). The cracking is even magnified in early age concrete that is still developing its full strength (Cervera, Faria, Oliver, & Prato, 2002; Lee & Kim, 2009).

Past research works on the creation of numerical models for the prediction of temperature distribution in mass concrete mainly focused on using basic heat generation functions for the calculation of adiabatic temperature rise (Ballim, 2004; Chini & Parham, 2005; De Schutter, 2002; De Schutter, Yuan, Liu, & Jiang, 2014; Ilc, Turk, Kavčič, & Trtnik, 2009; Tanabe, Kawasumi, & Yamashita, 1986; van Breugel,1991). The used of real measured heat of hydration results from calorimetry testing of the cement paste is mostly uncommon in Africa, especially Ghana due to the initial cost in acquiring the instruments (Kim, 2010; Milestone & Rogers, 1981). However, available literature reveals that numerous labs in North America and Europe have calorimeter(s) for measuring the real heat of hydration (Cao, Zavaterri, Youngblood, Moon, & Weiss, 2014). Instead, attempts at modelling hydrating mass concrete have treated the heat generated by the reacting cement as being uniform throughout the concrete mass. Whereas, in reality, the heat generation is a function of the temperature and time history of the Concrete at individual locations in the concrete mass (Lawrence, 2009; Radovanovic, 1998).

Although the effects of thermal gradients on mass concrete is well known in developed countries, there is no agreed maximum allowable temperature differential value between the centre of a mass concrete element and its surface. Bobko, Edwards, Seracino, & Zia (2015), have modelled the thermal behaviour of hydrating mass concrete with some degree of success and have fixed the temperature differential at 20°C (35°F). However, in the country where this temperature differential value was developed, a several agencies have established their own guidelines to regulate and control the adverse effect of thermal cracking in mass concrete depending on the time and location where such massive concrete projects are taking place (Edwards, 2013; Lawrence, Tia, Ferraro, & Bergin, 2012; Lawrence, 2009). This confirms the fact that heat generation in mass concrete structures varies for the tropics and the temperate zones for the same type of cement (Do, Lawrence, Tia, & Bergin, 2015). But in the tropics, specifically Ghana, these values do not even exist.

II. EFFECT OF TEMPERATURE ON FRESH CONCRETE

Major considerations for effects of temperature on properties of fresh concrete are:

- ✓ Consistence and Stiffening Times
- ✓ Thermal Stresses, Plastic Shrinkage and Potential Plastic Cracking
- ✓ Potential Delayed Ettringite Formation in Fresh Concrete
- ✓ Hardened Concrete

Each of the above is discussed in the following sections.

A. CONSISTENCE AND STIFFENING TIMES

Both the initial level of consistence at the end of mixing as well as the subsequent rate of loss in consistence over time are significantly influenced by higher ambient temperatures. Not only are constituent materials at higher storage temperatures, the rate of initial hydration during mixing is also higher. The advance of chemical admixtures from the early 1930 to currently available engineered admixtures has provided economic solutions to most of these issues. Very high consistence up to flowing concrete, like SCC, is available to meet special site situations in construction and is used extensively in some sectors of the concrete industry, e.g. precast post-tension elements. Retention of high consistence and desired delay in setting are both enabled by the addition of appropriately formulated admixtures. Hence large volume pours of over 10,000 m3 can be placed in a single continuous operation.

Typically this is evaluated through the carrying test based on reaching a prescribed level of penetration resistance of wet-sieved mortar from the concrete, e.g. ASTM C 403-08 [2]. Even though the test is not directly related to potential cold joint formation, it is indicative of the time since the mixing of the concrete to the time when vibration is no longer able to homogenize newly placed fresh concrete with previously-placed concrete. This leads to the formation of a cold joint affecting the integrity of the structural element, particularly in its performance in shear. A more desirable approach that can indicate directly the potential for formation of cold joint has yet to be developed.

B. THERMAL STRESSES, PLASTIC SHRINKAGE AND POTENTIAL PLASTIC CRACKING

The thermal stresses that occur during the hardening of mass concrete are extremely complex and difficult to measure. This is due to several factors, chief among which is the complex distribution of temperature changes throughout the volume of the mass concrete. The central region of the mass concrete at early age experiences high but uniform temperatures while the temperature in the outer region decreases as we move closer to the surface (Folliard et al., 2008). Since the maturity of concrete and strength are functions of temperature, the central region of the mass concrete structure will be matured and stronger than the outer region. As the concrete hydrates faster in the middle, large thermal gradients are produced, and strength and maturity are decreased moving outwards towards the surface.

Restraint against this contraction will cause tensile stresses and strains to develop, creating the possibility for cracks to occur at or close to the surface of the concrete (Atrushi, 2003; Yuan & Wan, 2002). These cracks are initiated when the tensile stresses exceed the low tensile strength at the surface. The magnitude of the tensile stresses are dependent on the difference in the mass concrete, creep or relaxation of the concrete, the coefficient of thermal expansion, the degree of restraint in the concrete and elastic modulus. The development of cracks will affect the ability of the concrete structure to withstand its design load, and further allow the infiltration of lethal materials which will undermine the integrity and durability of the mass concrete structure (De Schutter et al., 2014; Lawrence, 2009; Lawrence et al., 2012).

Plastic shrinkage may be affected by the rate of evaporation. The rate of evaporation may be affected by concrete (water surface) temperature (oC); air temperature (oC); relative humidity of air (%) and wind velocity (km/h). The critical rate for plastic shrinkage has been proposed as 1kg/m2h (0.20lb/ft2h) for Portland cement concrete. It is reduced to 0.7 kg/m2h for Portland cement concrete with more than 15% pozzolan and 0.5 kg/m2h for Portland cement concrete with more than 5% silica fume. In late afternoons in tropical climates, the air temperature lies around 32O to 35OC, relative humidity drops to about 60% (0.60), together with a wind velocity of 10 km/h and the concrete temperature reaching 5OC higher than the air due to mixing and transportation with agitation, the critical rate of 1 kg/m2h is easily reached. Hence, early curing and mitigating methods to reduce wind velocity (wind breakers) is required, e.g. casting floor slabs at higher levels of tall buildings.

The causes of early age thermal cracking may include either internal or external restraint (ACI Committee 207, 2005a; Kim, 2010). Internal restraint is brought about by strain gradients within the material while exterior restraint is brought about by externally applied loads. This degree of restraint varies between 0 and 100% depending on the physical boundary conditions and on the geometry of the structure (Muhammad, 2009). To accurately predict these thermal cracks, thermal properties that need to be modelled include the specific heat, the coefficient of thermal expansion, thermal diffusivity and heat production. Mechanical properties that need to be quantified, in order to simulate a finite element model of the experimental block include the tensile strength, tensile strain and elastic modulus (Atrushi, 2003; Gawin, Pesavento, & Schrefler, 2006a, 2006b; Ulm & Coussy, 1995). According to de Borst and van den Boogaard (1994), Ishikawa (1991), Jaafar (2007), Lawrence et al. (2012), Noorzaei, Bayagoob, Thanoon, & Jaafar (2006), and Tang, Millard, and Beattie (2015), Finite Element Method (FEM) which is a numerical modelling method is seen as the best predictor of thermal cracks in concrete. It offers a step-by-step approach in solving the problem though it has its own limitations of been costly and impossibly used at site to quickly determine the maximum heat of hydration of concrete (De Freitas, Cuong, Faria, & Azenha, 2013; Tatro & Schrader, 1992; Zhai, Wang, & Wang, 2015).

Due to higher tropical ambient temperatures the addition of set-retarding admixture is necessary for large volume casting, e.g. thick raft foundations. During the plastic stage of fresh concrete until its initial setting time, concrete tends to settle downwards. If this downward movement is hindered, e.g. by top reinforcement bars in a raft foundation or a deep transfer girder, a crack may develop directly over the location of bars, indicated by a crack pattern similar to that of the bars. Although it is possible to close the cracks if noticed before the concrete sets, it is better to mitigate the potential by avoiding longer-than-necessary retardation times and by having a more cohesive concrete to minimise settlement. Such cracks can occur within the first hour or the next couple of hours after placing. When fresh concrete is exposed after finishing and bleeding tends to end, continued loss of moisture from the surface due to evaporation may lead to potential plastic shrinkage cracking.

C. EFFECT OF HIGH TEMPERATURE ON POTENTIAL DELAYED ETTRINGITE FORMATION IN FRESH CONCRETE

The current interest in high strength concrete for structural elements of large dimensions is on the increase e.g. columns in tall buildings and transfer girders. The need for thick raft foundations or deep pile caps for such development is also facing the issue of exceeding the peak temperature limit of 70oC for which potential delayed ettringite formation (DEF) may occur. Unlike temperate countries where even in summer, the average ambient temperature is only around 20oC, in tropical climates the average ambient temperature throughout the year is about 30oC. Even when low heat of hydration cement is used at typical characteristic heat of hydration at 7 days is not more than 270 kJ/kg. The concrete temperature at the end of mixing is a few degrees higher than the ambient temperature as most constituents are at least at ambient temperature and cement in a silo lies at a much higher temperature. By the time the concrete is delivered to the site, additional gains in temperature are caused by hydration of cement and agitation energy during the transportation from plant to site. Typically concrete at time of discharge is around 5OC or higher above the ambient temperature. In tropical climates, the temperature of cement stored in silo is usually between 40o to 60ºC and the other constituent materials at around ambient temperatures of 25ºC to 30ºC when stored under the shade and sheltered from the sun. Without the use of chilled water or ice as partial replacement of batch water, initial temperature at the time of discharge is typically between 32oC to 35ºC. This level of initial temperature poses difficulties to meet limiting peak temperatures of 70OC and above where there is risk of delayed ettringite formation, a potential cause of thermal induced cracking (considered in the next section).

D. EFFECT OF TEMPERATURE ON HARDENED CONCRETE

The effect of temperature on the rate of cement hydration and hence the rate of strength development over the duration of moist curing is well-known. The higher ambient temperature in tropical regions promotes faster strength gain with time. However, it is important to note that higher temperatures at the time of setting have the opposite effect on later age strength development, i.e. faster hydration during setting leads to a lower strength gain at later ages. Hence, a slower rate of hydration during settling leads to a longer period of significant strength development. Concrete set and cured at a lower temperature will eventually overtake one set and cured at a higher temperature in strength. The cross-over point is usually after 90 days between temperatures of temperate climate (20oC) and tropical climate (30oC). This implies that for equal 28-day strength adopted in design, the long term quality of tropical concrete is expected to be lower than concrete in temperature climate. Thus together with a faster rate of deterioration in severe exposure conditions due to higher tropical temperatures, the durability of concrete with the same nominal 28-day strength will show distress at an earlier time if designed for the same nominal exposure conditions based on recommendations adopted for temperate climate, e.g. European practice, BS EN 206-1.

Tropical concreting practice should factor in the experience of earlier than expected distress in the Middle East even though the conditions in tropical climate are less severe. The carbonation coefficient is higher by a factor of 1.2 to 1.3 for temperatures of 30oC compared to 20oC. The estimated incubation period, propagation period, acceleration period and life due to chloride-induced corrosion in reinforced concrete is about 70% in tropical climates, e.g. South East Asian countries, compared to temperate regions such as Japan.

III. CONCLUSION AND RECOMMENDATIONS

Management and quality control of concrete production in the tropics could be prone to some basic technical problems. These problems, are however, taken care of by the introduction of concrete admixtures. The introduction of chemical admixtures firstly as air-entraining agent, followed by water-reducing and set-retarding through to the latest engineered super-plasticizers has enabled enhancement in concrete performance. These include the development of high performance concrete in terms of high strength concrete, high consistence concrete and high durability concrete. Understanding of basic mechanisms involved in deterioration processes have also increased over the years in the tropics.

However, international standardization is also necessary for an effective concrete production management. One can look forward to the eventual codified performance-based approach in quantitative and qualitative terms in the near future. In order to adopt the basic principles provided in quantitative and qualitative models for durability design, calibration based on monitored performance in local tropical climates for materials used calls for provisions in national annexes and supporting guidance standards. Hence, there exists the urgent need to establish centres to carry out these tasks, as at 10 to 20 years of performance data well correlated with *insitu* concrete quality and documented exposure history will be required for such purposes.

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