# HEAT CURING PRACTICE IN CONCRETE PRECASTING TECHNOLOGY – PROBLEMS AND FUTURE DIRECTIONS

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## *Biography*

Dr. Stephen Ekolu is a Lecturer of construction materials engineering at University of the Witwatersrand. He completed his first degree in civil engineering from Makerere University. For six years, he worked as a construction engineer and later as a civil engineer specializing in construction materials and project management. In 1997, he obtained M.Sc with Distinction from University of Leeds, United Kingdom and was awarded a Ph.D from University of Toronto, Canada in 2004. Dr. Ekolu has conducted teaching and research at Universities in Uganda, Canada, and South Africa. His areas of interest are materials aspects of concrete, cement extenders, concrete durability, concrete repair, petrography, evaluation methods and techniques.

**ABSTRACT**

While heat curing is mostly used in the precast concrete industry, freshly cast insitu concretes can also potentially attain high temperatures even without artificial heat application. The demands of the modern construction industry coupled with advances in cement manufacture promote the use of high early strength cements and high cement contents. These factors in addition to hot weather conditions in tropical countries, and large concrete pours may raise concrete temperatures to levels similar to those of heat cured concretes.

This article attempts to give an overview of the modern application of heat curing practice, discusses problems associated with exposing concretes to undesireably high temperatures at an early age. Current needs and recent developments associated with delayed ettringite formation are highlighted while potential future advancements are speculated.

**1.0 INTRODUCTION**

The terms *heat curing*, *heat treatment*, *accelerated curing*, and *elevated temperature curing* are often used interchangeably to mean a deliberate and defined application of some form of heat on fresh concrete with the intent of promoting rapid cement hydration. The process is a low pressure curing operation conducted in enclosed chambers, tunnels or beds where the precast elements are subjected to some form of heat exposure. Steam and radiant heat sources are often used. Steam curing refers to the application of heat by use of live steam. Radiant heat may be applied by direct electric heating elements or electric blankets, by circulating warm air around formwork, or by using pipes to circulate hot water, steam or hot oil (CSA, A23.4; Dafstb, 1989; Neville, 1996).

Concrete precasting plants often need to attain relatively high concrete strengths in a matter of hours in order to meet construction time demands (ACI, 1992). The attainment of high early strength is the main engineering benefit of heat curing and is achieved by subjecting the newly cast concrete elements to elevated temperatures. Creep and shrinkage are major contributors to prestress losses in prestressed concrete. Heat curing reduces creep and shrinkage of concrete by up to 50% and 30% respectively, while prestress loss may reduce by up to 40% (Hanson, 1964). The use of heat curing gives precasting technology an important edge of ensuring speedy supply of elements required for construction. Common practice is that concrete elements may be heat cured overnight and demoulded the next day, ready for use. There is also the economic benefit of quick turnaround of formwork and minimization of storage space when heat treatment is used in production. These aspects have been of key contribution to the success of concrete precasting technology.

But heat curing is riddled with obscure problems and future improvements in the precasting technology might be of critical importance. From its inception, heat curing practice has been based on the basic response of portland cement to heat application. Since the second half of the last century, significant advances in cement chemistry and manufacture have occurred, and concrete mixtures have evolved. Undesireable durability-related problems attributed to heat curing have been exposed while high performance concretes are increasingly being used. These are some of the driving pressures for improvement of heat curing practice.

## 2.0 PROBLEMS IN HEAT TREATMENT

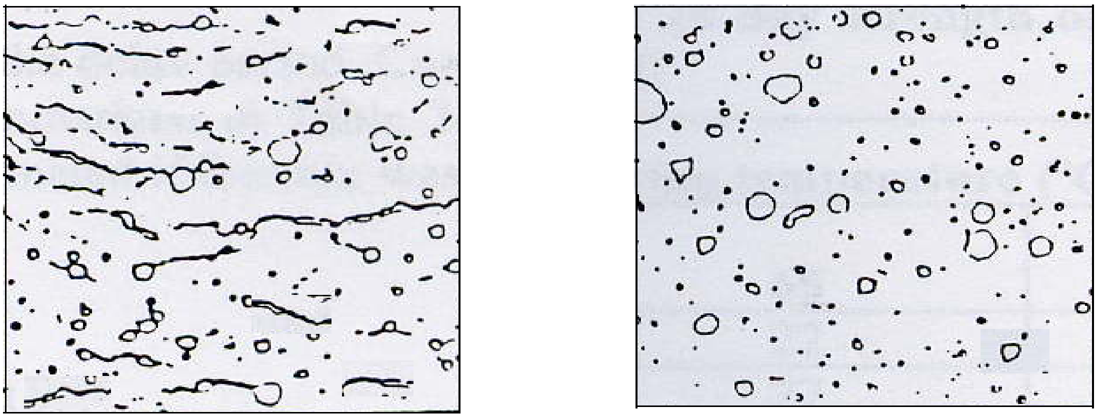
### 2.1 The heat treatment cycle

Heat is applied on fresh concrete using a carefully controlled heat cycle. European countries, USA, Canada, and South Africa have standard specifications outlining recommended practices for heat treatment of precast concretes. Most regulations (CSA A23.4; Neville, 1996; SABS 0100-2, 1992; Fulton’s, 2001) recommend how long concrete must be left to hydrate before heat is applied, the rate of heating and cooling, and the maximum concrete temperature not to be exceeded.

Internal microcracking of concrete during heat treatment is a problem that might occur due to inadequate precure period, also discussed later in Section 3.1. After casting of concrete, it is usually left to hydrate for about 3 to 5 hours under normal conditions until an initial set has been attained. This precure period allows concrete to develop sufficient tensile strength required to resist pressures generated in the air pores. Figs. 1 and 2 are micrographs showing typical microcracking damage induced within the cement paste matrix during heat treatment and consequently affecting the structural integrity of the paste matrix.

### 2.2 Significance of the temperature threshold limit of 60 to 70ºC

The maximum curing temperature limit of 60 to 70ºC has been maintained from the early use of heat curing in the precast concrete industry. These limits were fixed based on the influence of heat curing on physical properties. Whereas the main purpose of heat curing is to achieve early strength development, it is also recognized that there is reduction in long-term strength when compared to normal moist curing as shown in Fig. 3. Due to the retrogression in late strength, it has been considered that the optimum curing temperature should balance the attainment of high early strength and high late strength, thus the use of 60 to 70ºC threshold temperatures. The prevailing view is that curing of concrete beyond this temperature range offers little or no benefit to engineering properties of concrete (Hanson, 1963; Pfeifer and Marusin, 1991; Kosmatka et al., 1991). This understanding was based primarily on the influence of heat curing on physical properties of concrete.



(a) Short precure period - microcracks formed in paste

(b) Adequate precure period or normal moist curing - undamaged paste matrix

**(ILLUSTRATIVE ONLY)**

Fig 1. Influence of precure period on microstructure of heat treated cementitious systems (adapted from Alexanderson, 1972)

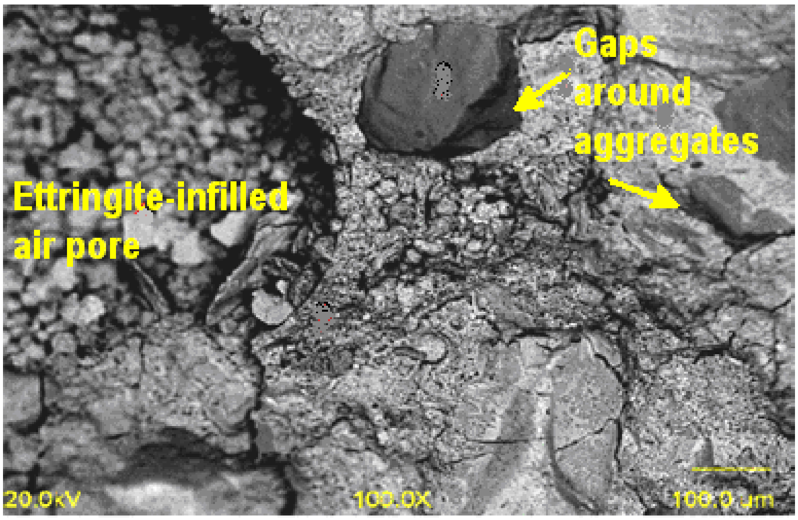



Fig. 2 Inadequate precure period results in development of microcracks and gaps around aggregates upon heat treatment (Ekolu, 2004)

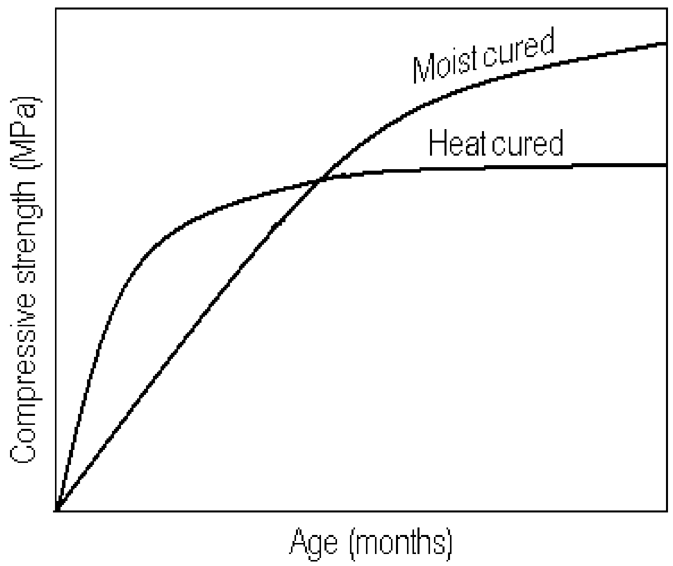



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Fig.3 Compressive strength development for heat treated and normally moist cured cementitious systems (adapted from Dafstb, 1989).

But from the 1950's and 1960's, failures in field concretes exposed to high temperatures at early age have been experienced. Recent research has shown that the temperature range of 60 to 70ºC is actually a threshold for chemically-induced changes in a cementitious system exposed to elevated temperatures at an early age. The chemical changes occur once the temperature range is exceeded. These chemical changes may later, under moist conditions result in a disruptive onset of expansion in hardened cementitious systems due to delayed ettringite formation (DEF). It now appears that at the threshold temperature range, there could be a link between the chemical disruption and the physical properties of concrete as used in earlier studies to underpin the threshold temperatures for heat curing practice but this relationship has not been clearly understood.

Another underlying problem is that even non-heat treated concretes may easily attain temperatures far in excess of the 60 to 70ºC threshold. This is potentially an important issue in tropical countries when large concrete sections are cast under hot weather conditions. Research has shown that concrete temperatures can rise to levels in excess of 80ºC even without external application of artificial heat (Hobbs, 1997; Johansen and Thaulow, 1997). In this regard, it is clear that both heat-treated and non-heat treated concretes can be vulnerable to elevated temperatures.

**2.3 Durability of heat-treated concrete**

The rate of hydration of cementitious systems increases with an increase in curing temperature. As a result, there is insufficient time for the rapidly-formed hydration products to diffuse away from the surface of the hydrating cement grains. The hydration products are then deposited within the vicinity of the hydrating cement particles. Further hydration leads to accumulation of the hydration products at the grain surface, which in turn block water penetration towards the partially hydrated cement grain. The effects are that hydration of the cement grain slows down and may soon stop, while a smaller volume of hydrates form than would otherwise develop under normal moist curing conditions (Roy and Parker, 1983; Detwiler et al., 1991; Kjellsen et al., 1991). The resulting pore structure is made of open and loosely packed hydrates, which are also non-uniformly distributed throughout the cement matrix. Such is a generally coarse pore structure. Fig. 4 shows greater hydration of cement grains in the concrete that was moist cured under normal conditions as compared to the grains in the heat cured concrete given in Fig. 5. The implications of a coarse pore structure are largely detrimental including reduced late strength, ultimately reduced durability characteristics due to increase in permeability and other transport properties (Goto and Roy, 1981; Detwiler et al., 1991), allowing enhanced ingress of deleterious ions into concrete and reducing its service life.

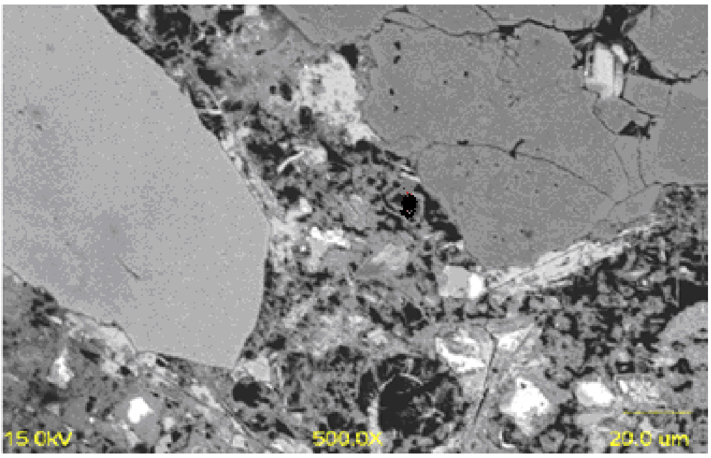


Fig. 4 The bright alite (cement) grains are seen to be partially consumed during hydration (Ekolu, 2004)

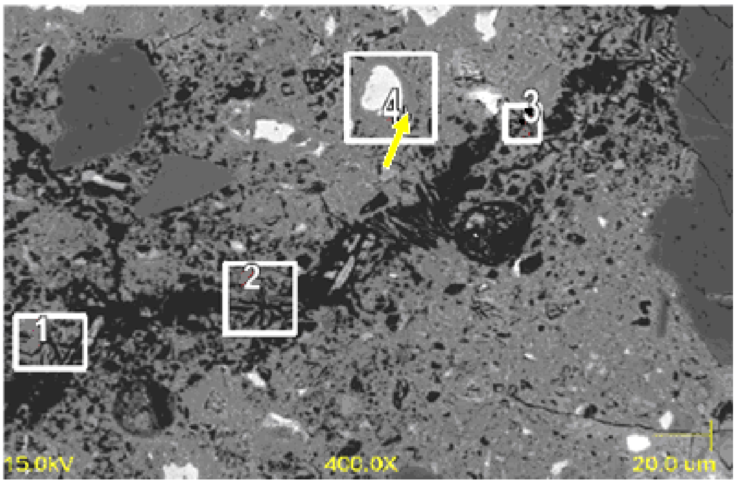


Fig. 5. *4* – Dense, packed C-S-H layers formed at the surface of the cement particle prevents further hydration of the grain due to lack access to water. Note that the grain has not been significantly consumed since hydration likely stopped; *1, 2, 3* – ettringite formed inside a crack (Ekolu, 2004)

## 2.4 Delayed ettringite formation

DEF is a deterioration phenomenon in concrete that only came to the limelight recently. It has been reported in several countries including South Africa. It is rare and not yet fully understood. DEF is a form of internal sulphate attack, so far considered to occur only in concretes exposed to high curing temperatures in excess of 70ºC (Famy, 1999; Ekolu, 2004; See Fig. 6). But DEF has also been reported in field concretes that were not heat treated (Lawrence et al., 1997; Thomas, 1998). When fresh concrete is subjected to high temperatures, the ettringite that normally forms during hydration is destroyed releasing sulphate and aluminate ions, which then get adsorbed on calcium silicate hydrate (C-S-H). In the presence of moisture, the sulphate ions are released from the C-S-H, they react with monosulphate found within the cement paste re-forming ettringite and causing disruption in the hardened concrete (Famy, 1999).

DEF is considered to occur only with certain portland cements while the influence of aggregates varies depending on aggregate type. Rapid hardening portland cements are particularly susceptible to DEF. Often, the cements used in heat cured concretes to achieve high early strength also contain high levels of sulphates and they generate substantial heat evolution that can raise concrete temperatures to higher levels. Ironically, these factors in combination with other chemical influences set up conditions suitable for DEF.

Studies have shown that DEF co-exists and interacts with other deterioration mechanisms that occur in concrete especially alkali-silica reaction (Pettifer and Nixon, 1980; Diamond and Ong, 1994; Brown and Bothe, 1993; Shayan and Ivanusec, 1996; Oberholster et al., 1992), chloride attack (Ekolu et al., 2006), and frost action (Ekolu, 2004). The influences between these processes and DEF are not fully understood, and are sometimes controversial.

# 3.0 INADEQUACY OF CURRENT COUNTER MEASURES

## 3.1 Standardization of heat treatment

Standardization of the heat treatment cycle can be seen as a recognition of the potential adverse effects associated with elevated temperature curing. Typically the heat curing cycle consists of 3 to 5 hours precure period followed by heating at a rate of 20 K/hour to a maximum temperature of 60 to 70ºC. The maximum temperature is maintained for a specific time period before cooling at about 20 K/hour. In reality, the setting time of concrete depends on the mix design and the ingredients used. Use of plasticizing chemical admixtures can extend setting time. Unless the setting time is monitored and properly allowed for during heat curing, there is a potential risk of microcracking during heat treatment as a result of extended setting times. Also, high performance concretes might be capable of withstanding high temperatures above 70ºC without exhibiting unusual adverse effects. It cannot therefore be considered that applying the standard heat curing cycle is optimal for executing heat treatment of concretes.

## 3.2 Use of cement extenders in heat-cured cementitious systems

The use of extenders is of double benefit for concretes subjected to heat treatment. Firstly, cementitious systems incorporating extenders give proportionally higher early strength gain upon heat treatment compared to systems with portland cement alone. Secondly, the use of extenders are an important counter measure to durability-related detrimental effects of heat treatment.

The extenders fly ash, silica fume, slag, and natural pozzolans, when incorporated in concretes, have the distinct ability to promote a more refined and tortuous pore structure. Through this influence, extenders reduce the pore coarsening effect of heat treatment and as such minimize the related adverse effects of heat treatment on concrete durability (Detwiler, 1991; Roy and Parker, 1983; Fapohunda, 1992; Campbell and Detwiler, 1993; Titherington, 1998). However, the use of extenders neither stops retrogression in late strength due to heat treatment nor prevents coarsening of the pore structure.

## 4.0 WHAT IS REQUIRED

Future trends could involve attempts to develop heat cured concrete mixtures that are free of adverse effects due to heat treatment and that could possess properties superior to moist cured concretes. To this end, the need for smart materials and different approaches in material science might be essential. The complex but key requirement involves control of heat evolution while promoting cement hydration to obtain ideally robust cement paste matrix. Attempting to replace heat treatment with use of high performance concretes of low water-cement ratios does not resolve temperature related problems since even non-heat cured concretes can experience heat exposure levels similar to those of heat cured concretes.

## 5.0 SUMMARY

The foregone discussion identifies issues associated with the use of heat treatment and advances that the use of the standard heat treatment cycle as currently practiced is only a secondary means of minimizing significant adverse effects from occurring. Presently, there are no known methods of avoiding adverse effects due to heat curing. The use of extenders only improves performance but cannot prevent the detrimental causes involving late strength retrogression and coarsening of the pore structure. Despite some extensive research, there are still many unknown issues regarding the recent and controversial DEF phenomenon including the need for appropriate test methods, cement susceptibility, prevention and control measures, and DEF interaction with other deterioration processes in concrete.

Future advancements in promoting heat curing practice could involve rigorous efforts towards development of heat-cured concretes that will be free of the adverse effects of heat curing and could exhibit superior behaviour to their non-heat cured counterparts. That way, heat curing practice can be a contribution to the improvement of concrete technology rather than simply an essential practice.

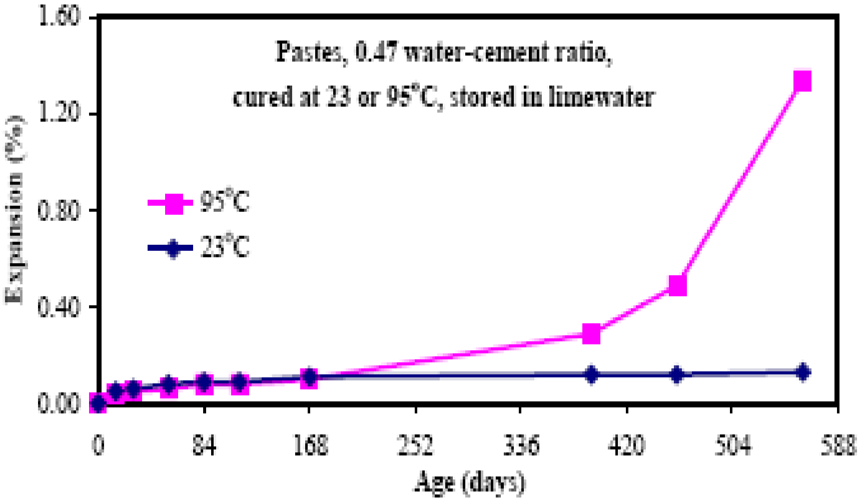


Fig. 6 Expansion of heat-cured cement pastes due to delayed ettringite formation (Ekolu, 2004)

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