Subcommittee on Evaluation of the Effect of High Temperature on Concrete Performance (352)

In producing mass concrete, prestressed concrete with a rich mix, steam-cured precast concrete, and normal concrete in hot weather, the temperature of the cast material can rise to 60-80°C depending on internal and external factors. The aim of this subcommittee is to understand the current situation, issues, and any further research that is necessary related to concrete exposed to these high temperatures, both in terms of macroscopic performance, as it relates to design and construction, and related physical and chemical microscopic characterization.

1． Background

In recent years, extremely hot days where the maximum temperature exceeds 35ºC have been observed more commonly over large areas of Japan during the summer season. In such hot weather, even if the casting temperature of concrete is within the upper limit value, hydration heat can cause the internal temperature of the cast material to rise excessively. Hydration heat can also cause quite high temperatures at an early age in prestressed concrete structures, where mass concrete with a rich mix is commonly used. This is also the case for precast concrete members. Further, Japanese companies are expected to play an important future role in the development of infrastructure in developing countries in tropical regions, such as Southeast Asia, where it will be necessary to design for the casting of concrete in a hot environment. This makes it ever more important to understand the influence of high temperatures on concrete. (Figure-1)

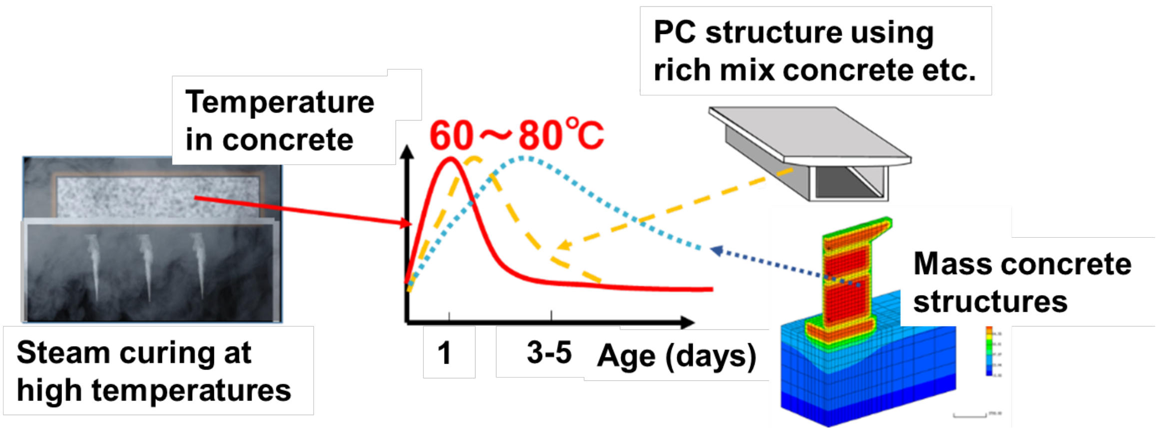

Figure-1 Types of concrete experiencing high temperatures

In a technical sense, ‘high temperature’ often refers to the effect of fire on concrete. The Japan Concrete Institute has established a research committee to focus on the problem of concrete exploding when exposed to fire and the fire resistance of concrete structures, and is conducting vigorous research in this area. On the other hand, the influence of 60-80ºC curing temperatures on concrete performance has not been studied separately with a focus on specific physical and chemical phenomena and behavior under certain temperature conditions. This means that a systematic understanding of the effect of such high curing temperatures on the performance of concrete itself and the structural performance and durability of completed structures has not been sufficiently clarified.

It is well known that long-term strength development is inhibited and shrinkage and creep are reduced after cast concrete is exposed to temperatures of 60-80ºC before returning to normal ambient temperature. In addition, it is understood that the microstructure of the hardened cement, in terms of the hydration reaction, C-S-H structure, and pore structure, is affected by high temperatures. In recent years, it has also been pointed out that temperatures above 70°C may cause delayed ettringite formation (DEF). In addition, large temperature variations may cause internal damage around aggregate particles and rebars due to differential coefficients of expansion. There is a need to appropriately evaluate the risk of such curing temperatures and consider design and construction risks in order to ensure a good quality infrastructure stock for future generations.

An important part of the activities carried out by this subcommittee was a review of past findings on the macroscopic and microscopic effects of high temperature action in the range of 60-80ºC, and a summarization of the issues in each case. In addition, trial analysis has been used to study the influence of both materials and structure on the mechanical reaction of a completed structure. This report, as an introduction to one of the committee’s activities, is concerned with the thermal cracking analysis of mass concrete focusing on variations in material properties caused by high temperature at an early age.

2. Numerical study of mechanical response of structures where material properties vary with curing temperature

The effect of variations in the coefficient of thermal expansion and Young's modulus of concrete over time on the thermal cracking of mass concrete was investigated.

In checking temperature-induced crack initiation and crack width, temperature and stress analysis were based on the three-dimensional finite element method. In general, the coefficients of thermal expansion and Young's modulus are based on the JCI guidelines. However, it is currently difficult to determine whether or not material behavior at a young age is considered in the analysis on which the JCI guidelines are based. Therefore, in order to investigate the influence of the initial concrete temperature, a trial calculation was carried out based on the latest understanding and assuming a changing coefficient of thermal expansion over time and Young's modulus of concrete at the young age. The difference between the results and the thermal crack verification used in the current JSCE specification was examined. It was found that the effect of the changing coefficient at a young age was smaller for higher concrete temperatures with higher strength development, and the effect tends to be greater when the cement has a moderate strength expression, the concrete temperature is low.

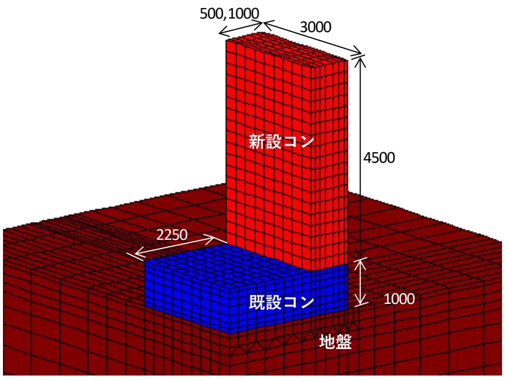

Figure-2 Mesh geometry of target structure

Table-3 Example of analysis results for a wall 1.0m thick (ambient temperature = 30℃)

Parameters			Mix used OPC				Mix used BSC				Mix used LHC			
No.	Thermal expansion coefficient	Young’s modules	Max temp. [℃]	Min Crack index	Max tensile strength [N/mm^2]	Max compre ssive strength [N/mm^2]	Max temp. [℃]	Min Crack index	Max tensile strength [N/mm^2]	Max compre ssive strength [N/mm^2]	Max temp. [℃]	Min Crack index	Max tensile strength [N/mm^2]	Max compre ssive strength [N/mm^2]
1.	JCI guideline	JCI guideline	68.2	0.98	2.93	-0.76	64.4	0.91	3.05	-0.65	50.4	1.99	1.38	-0.19
2.	Considering changes while young	JCI guideline	68.2	1.02	2.82	-0.91	64.4	0.94	2.95	-0.78	50.4	2.04	1.35	-0.24
3.	JCI guideline	Considering changes while young	68.2	0.94	3.03	-0.66	64.4	0.87	3.21	-0.50	50.4	1.73	1.56	-0.06
4.	Considering changes while young	Considering changes while young	68.2	0.97	2.96	-0.76	64.4	0.88	3.16	-0.57	50.4	1.72	1.58	-0.07

3. Problems caused by high temperatures and future vision

According to the review of the literature, there have been many studies of the effects of high temperature action, including hydration heat, steam curing, and summer casting, on strength and mechanical properties (such as volume change, creep, and mass transfer resistance to water and chloride ions). The effects of early high temperature action on microscopic phenomena such as hydration reactions, hydrate formation, and pore structure have also been studied energetically, mainly in other countries. On the contrary, there is no consensus either domestically or internationally on the mechanisms by which microscopic properties altered by high temperature action effect changes in macroscopic material properties. The subcommittee discussed at an early stage the necessity to study the meso region linking the microscopic and macroscopic regimes. In the first phase, the effects of high temperature on each target structure at each scale, as well as the issues, have been summarized in a report. While various studies and results aiming to solve the issues have been reported, the mechanism of each behavior has not yet been clarified. This is because each property can vary greatly depending on the materials used, the temperature of the action, its timing, and its duration. There are many unresolved problems in this temperature range, and vigorous research is needed in the future. What is important here is how to link microscopic changes in material properties with macroscopic changes in material properties.

In the design of concrete structures, one of the main problems in dealing with high temperature action in the range of about 60-80°C is how to appropriately express the changing characteristics of the concrete that constitutes the structure. The temperature within structural members varies greatly and there may be a temperature gradient even within members. The type of thermal action and the time for which it acts lead to variations in the material properties of concrete within a structure, and these in turn change its mass transfer characteristics. This fact further increases the variations in the material properties of concrete within a structure increases the variability of the concrete material properties. There seems to be no engineering method to determine how to adopt appropriate material property values and material design values while considering the variation of material design values within the structural members. In order to deal with these values appropriately, it is essentially required to design the materials in conjunction with the structural design work, including the cross-sectional specifications. In other words, ideally, it is desirable for the designer to understand both structural design and materials design and take into consideration the effect of high temperature action on the whole system, instead of carrying out structural design and materials design separately. However, this kind of coupled material-structure design process requires a high level of engineering skill and is not feasible in practice. For this reason, future engineering progress will rely on further research and discussion leading to improved understanding of the effects of high temperatures on material design values and their effects on structural performance. We hope that the activities of this research sub-committee will help to advance this area of concrete structure design.