A Review on Behaviour of Concrete Subjected to Extreme Temperature

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Abstract - *Concrete is one of the most common and versatile construction materials and has been used under a wide range of environmental conditions. Temperature is one of them, which significantly affects the performance of concrete, and therefore, a careful evaluation of the effect of temperature on concrete cannot be overemphasized. Temperature changes could cause cracks or sapling, distress, and aggregate expansion which leads to concrete strength deterioration. Temperature is an important parameter which affects the design and performance of slab. Knowledge of temperature effects is essential for the design and maintenance requirement. The temperature differential depends mainly on the thickness of slab and the grade of concrete. The reinforced concrete slab has experienced significant level of stressing and cracking as a result of restrained thermal deformation.*

***Key Words*: Concrete, slab, Critical Climatic temperature, Deformation, Stress-Strain, Finite Element Model (FEM).**

1. INTRODUCTION

The changes we are experiencing in our climate are affecting all of our lives. Every industry is being affected by what is happening, but is having an especially big impact on the construction sector. All around the world Governments are waking up to the fact that extremes of weather are rapidly becoming the usual. In many countries, they are gradually changing construction legislation to take account of this fact. Across the world, new laws are being occurred that require both residential and commercial builders to work on higher standards. Buildings that can withstand higher summer temperatures, colder winters, as well as floods and high winds, are now essential. In some areas of the world, they also need to be built to withstand earthquakes.[14]. In the last few years, many research works have been introduced on the structure behaviour and resistance of temperature rising in accidental situations such as nuclear or fire under service loads. The analysis of reinforced concrete structures constitutes an important part in the design. In the analysis, considering high temperature produced from fire, various formulas are usually employed for the fire resistance of structures offered by building codes, without really estimating the thermo – mechanical behaviour of structure during fire. The objective of this limited study is to provide an overview of the effects of elevated climatic temperature on the behaviour of concrete materials and structures. In meeting this objective, the effects of elevated temperatures on the properties of ordinary Portland cement concrete constituent materials and concretes are summarized. The effects of elevated temperature on concrete are noted and their performance compared to different type of concretes. A review of concrete materials for elevated 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 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 depend on moisture and porosity. Exposure of concrete to elevated temperature affects its mechanical and physical properties.

2. BASIC TERMINOLOGY

Solar radiation: The effect of solar radiation on fresh and hardened cement paste is through its contribution in raising the temperature of the fresh cement paste, thereby increasing the early-age hydration and rate of evaporation, and the influence of these parameters effect the properties of concrete.

Cold: Cold weather is defined [13] 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.

3. Literature Review

Experimental study was conducted to determine the sensibility of the concrete to its climatic environment, during the period of service in the Saharan region. by **Benoudjafer Imane** [1]. It has been shown, by using three different compositions of concrete based on local materials, that the performance of concrete fall considerably with the increase of the temperature until 60 ° C. A thermal enclosure was conceived; the evolutions of the strength are presented and compared with those obtained for the reference results at 20°C temperature. This paper presents the results of compressive-test specimens that were subjected during 24 hours to cold temperature (-15 and -10°C) and to high temperatures such as 40, 50 and 60 °C. For the preparation of various concretes, drinking water was used. Globally its own specific characteristics are conforming to the used specifications of water according to the standard NF P18-303. The cement CPJ-CEM II / A 42.5 (NA 442-200) was used. Standard concrete specimen molds were prepared according to ASTM standard C470. A total of 200 specimens were cast, cured and tested. After 28 days, the specimens were stored in the thermal enclosure during 24 hours at different temperature (-15, -10, 10, 20, 30, 40, 50 and 60 °C) in order to evaluate the short- term thermal effect on the strength of concrete. Three specimens were consumed during each compression end tensile test. The overall results indicate that the strength decreases as temperature increased. The concrete specimens are stronger at lower temperatures and weaker at higher temperatures.

Hager [2] presented the impact of high temperature on cement concrete.[15-16] generally agreed that when heated to between 300 ◦ C and 600 ◦ C concrete containing siliceous aggregates will turn red; between 600 ◦ C and 900 ◦ C, whitish-grey; and between 900 ◦ C and 1000 ◦ C, a buff color is present. This paper presents the results of the investigation of the cement concrete behaviour at a high temperature. It has been shown that the color change of heated concrete might be the first indication of the potential deterioration of concrete due to heating. The most common way to evaluate this deterioration is to expose the material to a high temperature and test the material in compression and/or tension. Changes in the mechanical properties of concrete caused by heating have been presented in this paper. Tested "hot" mechanical properties, including stress-strain relationship, compressive strength, and modulus of elasticity, decline with the increase of temperature. The possible explanations of the observed gradual decrease of mechanical properties have been discussed in detail. Moreover, the important role of water was put forward, both in the context of the changes of concrete properties as well as in the occurrence of the spalling phenomenon. It has also been revealed that water also plays an important role in a transient thermal strain development.

He Zhu [7] studied the restrained cracking behavior and criterion, a self-developed temperature stress testing machine (TSTM) was utilized and found to have good performance when examining concentric deformation and reproducibility. Restrained cracking experiments were performed considering different mixtures, temperature histories, shrinkages, and loading ages. The results indicated that concrete would crack when the restrained tensile stress exceeded 76% of the direct tensile strength, while the failure strain was 103%–137% of the tensile strain capacity. A combined stress–strain failure criterion was proposed under the assumption of linearity, and the prediction errors range from 7.61% to 12.89%. The proposed criterion will aid evaluations of the safety of restrained concrete. The effect factors of concrete mixture, temperature histories, shrinkage histories, and loading age were studied in the restrained cracking test. Two types of cement with different hydration heat, namely low heat cement and moderate-heat cement, were employed. The restrained cracking behavior of concrete was studied with a self-developed TSTM. Factors of different temperature and shrinkage histories, concrete mixtures, and loading ages were considered. Under the assumption of equal failure energy, a combined stress– strain failure criterion for concrete suffering sustained loading (thermal and shrinkage stresses) was developed.

Diyyala Naga Moulika,[12] in this article, the reinforced concrete beam has been modelled and analyzed when subjected to two-point loads at one third span from each support, using Finite Element Analysis tool, popularly called ANSYS software. The modelled and analyzed beam having size 600 mm × 160 mm × 160 mm with 3 numbers of 12 mm diameter bars as main reinforcement, 2 numbers of 8 mm diameter as hanger bars and 8 mm diameter at 100 mm c/c as shear reinforcement. The behaviour of the analyzed beam has been observed in terms of the flexural behaviour, crack pattern and displacement for various loading conditions such as 50 kN, 150kN, 250kN, 350kN, 450kN and failure load (690kN). Based on the analysis carried out on the RC beams using ANSYS, it is found that results are more sensitive to mesh size, materials properties, load increments, etc.

G. Benedict Darwin [8] studied the behavior of reinforced concrete slab exposed to fire. Two stages of analysis are carried out using Finite Element package ABAQUS to find thermal response of structural members namely thermal analysis and structural analysis. In the first step, the distribution of the temperature over the depth during fire is determined. In the next step, the mechanical analysis is made in which these distributions are used as the temperature loads. The responses of structure depend on the type of concrete and the interactions of structural members. The RCC slab were modeled to show the role of slab thickness, percentage of reinforcement, width of slab and different boundary condition when expose to fire loading. Effects for both materials in RCC slab at elevated temperatures are also evaluated. Experimental results were taken from the test conducted by BRE (Building Research Establishment) slab test on RCC in Cardington, Bedford. The tests were made in the fire resistance floor furnace at the Warrington Fire Research Centre heated under ISO-834 curve. The slab is design to resist up to 90 minutes. The ends of each slab were simply supported. RCC models are taken to study the thermal response of building subjected to fire. Non - linear analysis is carried out with full temperature on different boundary condition. Similarly, non - linear analysis is carried out on different bars and different thickness Thermal analysis is done based on steady state condition in three dimensional Role of width of slab, role of rebar and role of slab thickness were also observed in this paper and it was found that for simply supported slab , displacement increases when width of slab increases, displacement decreases when percentage of steel in RCC slab increases, displacement decreases when thickness increases, role of boundary condition were also observed and it was found that fixed-fixed have the highest safe temperature and followed by pinned-pinned, fixed-roller, pinned-roller.

Metin Husem [6] studied the changing of the compressive strength of ordinary and high-performance concrete after having cured at low temperature experimentally. To accomplish this purpose, concrete specimens of 150 mm diameter and 300 mm high were prepared. After their production the specimens were cured at different conditions for 7 days. Some of them were at 23(+ -)2 degree C (standard curing); the others were at 10, 5, 0 and -5degree C, respectively. In the 7th day, some of the specimens cured at different temperature (10, 5, 0 and 5 C) were broken under uniaxial compression. On the other hand, some of the specimens were applied to standard curing during 28 days. In the end of 28 days, compressive strength of all specimens was obtained. According to the results, compressive strength of the specimens at 10 C and less than 10 C during 7 days was lower than that of the specimens at standard curing. In the end of 28th day loss of compressive strength of concrete specimens cured at different temperatures were more than that of specimens cured at standard cure. Shortly performed experimental studies show that to reach expected compressive strength of both high performance and ordinary concrete, fresh concrete should be set in its mould and should be compacted, more important than this it should be cured with suitable method and period. It is said in technique literature that concrete should not be set under +5 C moreover, compressive strength of concrete even 10 C has negligible loses compared with standard cure. That's why if concrete at lower temperature required precautions to reach expected strength.

M. Mehdi Mirza Zadeh [9] investigated the static behaviour of reinforced concrete beams at low temperatures compared to similar beams tested at room temperature. Four large-scale beams were fabricated and tested. The testing program for the beams consisted of four stages: incrementally loading the beams to a service load of 90 kN, sustaining the load at 90 kN for 48 h, cycling the load between 50 kN and 90 kN for 10 cycles, and loading the beam to failure. All of the beams had temperature differentials over their depth to simulate solar radiation and in-service temperature of the bridges. The beams tested at low temperature (25 C) demonstrated an increase in strength and ductility up to 13% and 34% respectively compared to the beams tested at +15 C. The results also show that the cracking load increased while the number and the depth of the cracks decreased at low temperature. In addition, the widths of the shear cracks were reduced at low temperature compared to their counterparts at room temperature. The load at which the stirrups contributed structurally also increased drastically at low temperature. In this research, DIC/ PIV technique was used to measure the widths of the shear cracks, and the effect of low temperature on the camera system was investigated through calibration tests to ensure the accuracy of the measured crack widths. Low temperature delays the initiation and retards the propagation of both flexural and shear cracks at service loads, and the number and depth of the cracks was reduced at low temperature. This indicates that the cracking behaviour of the reinforced concrete improves at lower temperatures. Low temperature reduced the widths of the cracks particularly during the initial load stages. The difference became less pronounced at higher loads and after several load cycles. The beams tested at low temperature had lower crack widths and higher crack spacings than their counterparts that were tested at room temperature. Based on the MCFT, the shear and compressive forces transferred across the crack through aggregate interlock were increased at low temperature, which resulted in an increase in the shear capacity of the reinforced concrete. The ultimate load capacity of the beams with and without stirrups increased from 157 kN to 169 kN and from 123 kN to 139 kN, 8% and 13% increased, respectively.

J. Ortiz [5] presented study on the influence of mixing hour on the properties of concrete, such as workability and compressive strength, under hot and cold weather conditions, with a view to industrial application. The focused was on the concrete mixing hour, and five different mixing hours were used for each type of weather condition. Three batches of concrete were prepared for each mixing hour, and the compressive strength of 15 cylindrical concrete specimens was measured after 7 and 28 days. In addition, the hydration kinetics of each batch of concrete was studied on the basis of the climatic conditions and the mixing hour. The results for compressive strength show that the concrete's best mechanical performance occurred when there was the least difference between ambient temperature and concrete temperature, that is, during the later hours of the day in hot weather conditions.

S. O. Osuji [4] presented the results of investigation of the effects of elevated temperatures on the compressive strength of Grade 40 concrete. A total of thirty cube specimens were cast, cured in water at ambient temperature in the laboratory and subjected to various temperature regimes before testing. A concrete mix of 1:1:3 (cement: fine aggregates: coarse aggregates) with water content ratio of 0.44, fine aggregates lying in zone 2 of sieve tests as well as granite of maximum size 12.5mmwas designed for these investigations. Specimens cured for 7 and 28 days were subjected to uniaxial compressive loading tests at room and elevated temperature of 24, 100, 150, 200, 250 and 300 degree Celsius at one hour duration. The result indicated 14.49%, 25%, 51%, 35.51% and 43.88% decrease in compressive strength at the earlier quoted temperatures respectively. At an elevated temperature of 300 degrees Celsius a peak decrease of 53.47% in compressive strength was observed.

Jyoti Makate [3] presented comparative study, the temperature behaviour of R.C.C flat slab and conventional slab is evaluated by finite element method with different temperature loading with the help of STAAD Prov8 software. The main parameters evaluated in this study are storey displacement and bending moment. The temperature loading is being considered due to frequent occurrences of fire accidents and also due to the need for knowledge in people about fire hazards. Fire will not only cause casualties but also effect the structure predominantly leading to its destruction. From results it can be concluded that conventional slab of 225 mm thickness is more effective for G+4 For normal and high temperature 275mm thickness is good for G+4. About 5.10% of displacement is more in flat slab than RCC Conventional slab in case of without temperature is observed considering G+4 with thickness of 225mm and 275mm in RCC Conventional and Flat slab respectively. Bending moment in X plane in flat slab is greater by 66.95% than RCC slab. Bending moment in Y plane in flat slab is greater by 60.55% than RCC slab.

Ayman [10] presented the study on supposition that casting and curing at near freezing temperatures leads to the loss of stiffness of the hardened concrete and causes microstructure disruption and abnormalities was investigated. The research programme reported here involved 25 concrete slabs, 750 *750 * 300 mm, which were subjected to various curing regimes in the range of 20 degree C to -5 °C. The extent of loss of stiffness and the degree of microcracking were quantified using the Stiffness Damage Test (SDT). This test is effective in quantifying the extent of disruption to the microstructure of concrete caused by various damage mechanisms. In addition to the SDT, the cold cured concrete was evaluated by the full stress–strain test as well as ultrasonic, dynamic, and petrographic methods. Concreting at temperatures near freezing resulted in approximately 20% reduction of the 28-day stiffness and a Damage Index of 5 as determined by the SDT. Cold weather curing resulted in the development of microcracks in the paste and adversely affected the interfacial zone. Storage of the constituents of concrete at near freezing conditions prior to mixing adversely affects the long-term stiffness and strength of concrete. The water absorption of hardened concrete increased as a result of cold-curing. The loss of stiffness because of low temperature curing is not remedied by using stiff aggregate such as granite nor by PFA cement replacement.

N. Raveendra Babu [11] studied, temperature distribution over the surface of concrete slab is obtained using finite element computer program (ABAQUS). Two different cases are considered to estimate the heat propagation through slab. In the first case, slab is subjected to fire at its centre region. In the second case, slab is subjected to fire at outer region means along the walls. Modelling is carried out to predict the temperature distribution and thermal strains of concrete slab. The other parameters considered for this study are varying thickness of slab (100 and 200 mm) and exposed temperature (100, 200, 300 and 400 °C). The duration of exposure considered for the study is 4 h. Observed that on the bottom surface (exposed) heat propagation was high as compared to other layers. On the other two layers (middle and top) has same pattern of distribution. But the temperature was found to be less when compared to the bottom surface. On the exposed surface, initially a sudden decrease of temperature was observed. Whereas on the other two conditions gradual decrease of temperature was observed. By the comparison of propagations for two different exposure conditions, we can say that the propagation of fire was limited up to 300 mm distance from exposed surface. The propagation of fire on any intermediate layer was same, but its magnitude differs from the exposed surface for both 100- and 200-mm thick slabs. The 100 mm thick slab for exposure of 300 and 400 °C found to exceed the integrity limit of most of the codes of unexposed surface. The thermal strains induced were maximum near to the exposure and gradually decreases to minimum within the region of small distance. When the thickness of slab was high, the thermal strains induced in intermediate layers were very low as compared to in the exposed surface.

4. CONCLUSIONS

Concrete strength is fairly sensitive to temperature effects. Extreme temperature conditions significantly affect the concrete compressive strength and its development. Concrete as one of the substantial materials used in residential buildings and infrastructures is subjected to a massive strength change under critical weather conditions but Concrete is still in service at different temperatures. This range of temperature varies indifferent countries, with warm climate, at the same time with very cold regions. We can have situations in which it is exposed to very high temperatures, sometimes exceeding 50°C, for the Saharan climate. It seems now essential to know the effect of temperature on the variation in material properties. Therefore, temperatures play as large role in affecting the properties of concrete. Higher temperatures yield lower concrete strength in compression. Both heat and cold poses dangers to cured concrete. Heat reduces the strength of concrete due to several reasons including spalling. The cold indirectly causes cracks formation in the concrete, which reduces its strength. At the molecular level, assuming no moisture presence in the concrete, heat will always reduce the concrete strength, while the cold will increase the concrete strength. This is due to the fact that the molecules are packed more closely together when the concrete is cold.

ACKNOWLEDGEMENT

I take the opportunity to acknowledge Integral University, Lucknow, India to facilitate this research study. I would also like to thank reviewer for their valuable suggestion in order to enhance the manuscript of interests regarding the publication of this paper.

REFERENCES

[1] BENOUDJAFER Imanea, MERBOUH M Hammeda, LABBACI Boudjemaaa, Hamouine Abdelmadjida. (2013). Contribution to the experimental study of the concrete behavior in its climatic environment. Science Direct Energy Procedia, doi: 10.1016/j.egypro.2013.07.150.

[2] HAGER. (2013). Behaviour of cement concrete at high temperature. Journals Pan, BULLETIN OF THE POLISH ACADEMY OF SCIENCES TECHNICAL SCIENCES, Vol. 61, No. 1, 2013.

[3] Jyoti Makate, Priyanka Lohar, Rashmi Shetti, Prof. Priyanka Patil. (2019). EFFECTS OF THERMAL LOADS ON RCC CONVENTIONAL SLAB AND FLAT SLAB. International Research Journal of Engineering and Technology. Volume: 06 Issue: 07.

[4] S. O. Osuji, U. Ukeme. (2015). Effects of Elevated Temperature on Compressive Strength of Concrete: a case study of grade 40 concrete. Nigerian Journal of Technology (NIJOTECH) Vol. 34 No. 3, pp. 472 – 477.

[5] J. Ortiz, Aguado, L. Agullo, T. Garcia. (2005). Influence of environmental temperatures on the concrete compressive strength: Simulation of hot and cold weather conditions. Elsevier Cement and Concrete Research, doi: 10.1016/j.cemconres.2005.01.004.

[6] Metin Husem, Serhat Gozutok. (2004). The effects of low temperature curing on the compressive strength of ordinary and high-performance concrete. Construction and Building Materials. doi: 10.1016/j.conbuildmat.2004.04.033.

[7] He Zhu, Yu Hu, Qingbin Li, Rui Ma (2020). Restrained cracking failure behaviour of concrete due to temperature and shrinkage. Construction and Building Materials doi.org/10.1016/j.conbuildmat.2020.118318.

[8] G. Benedict Darwin, B. Jose Ravindraraj (2018). BEHAVIOUR OF REINFORCED CONCRETE SLAB SUBJECTED TO FIRE. International Journal of Civil Engineering and Technology (IJCIET). ISSN Print: 0976-6308 and ISSN Online: 0976-6316

[9] M. Mehdi Mirzazadeh, Martin Noel, Mark F. Green (2016) Effects of low temperature on the static behaviour of reinforced concrete beams with temperature differentials. Construction and Building Materials..doi.org/10.1016/j.conbuildmat.2016.02.216

[10] Ayman Y. Nassif, Michael F. Petrou. (2013). Influence of cold weather during casting and curing on the stiffness and strength of concrete. Construction and Building Materials. .doi.org/10.1016/j.conbuildmat.2013.03.016.

[11] N. Raveendra Babu, M.K. Haridharan and C. Natarajan. (2015). Behaviour of Two Way Reinforced Concrete Slab at Elevated Temperature. Springer India. DOI 10.1007/978-81-322-2187-6_173.

[12] Diyyala Naga Moulika. Reshma Vasireddy. P. Polu Raju. (2017). Modelling and Analysis of Reinforced Concrete Beam Under Flexure Using ANSYS. ISSN Print: 0976-6308 and ISSN Online: 0976-6316.

[13] Asif Husain, Jabbar Ahmad, Abdul Mujeeb, Rehan Ahmed. (2016). Effects of Temperature on Concrete. Vol. No.5, Issue No.03. IJARSE.

[14] S.N.K. Pravin, Dr.K. Murali, Mr.R. Shanmugapriyan. (2017). Review on Climate Change and its Effects on Construction Industry. Volume: 04 Issue: 11. IRJET.

[15] N.R. Short, J.A. Purkiss and S.E. Guise, (2001) “Assessment of fire Damaged Concrete using Colour Image Analysis”, Construction and Building Materials. 15,9-15.

[16] M. Colombo and R. Felicetti, (2007) “New NDT techniques for the assessment of Fire-damage Concrete Structure”, Fire Safety J. 42(6-7), 461-472.