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A Review on the Influence of High Temperature on Mechanical Behavior of Cementitious Composites

Xiaohe Lu[1]*, Cheng Xiao[1], Yue Ma[2]

[1]University of Technology Sydney, Ultimo NSW 2007, Australia

[2]University of Newcastle, Callaghan NSW 2308, Australia

*Correspondence author: xhelu.frank@gmail.com

ABSTRACT

The influence of temperature on cementitious composites is essential in infrastructures because of the potential hazards associated with fire. Fire response is dependent on the mechanical properties of cementitious composites or concretes. These properties vary significantly with temperature and also depend on heating rate and other environmental conditions. This paper discusses some important mechanical behavior related to high temperature. The various properties that influence fire resistance performance, together with the role of these properties on fire resistance, are discussed. The variation of mechanical properties with temperature for different types of cementitious composites are presented.

Keywords : Cementitious Composites, High Temperature, Mechanical Behavior

I. INTRODUCTION

Cementitious composite is the most widely used material on earth. Concrete structural members when used in buildings have to satisfy appropriate fire safety requirements specified in building codes.This is because fire represents one of the most severe environmental conditions to which structures may be subjected; therefore, provision of appropriate fire safety measures for structural members is an important aspect of building design. Fire safety measures to structural members are measured in terms of fire resistance which is the duration during which a structural member exhibits resistance with respect to structural integrity, stability, and temperature transmission. Concrete generally provides the best fire resistance properties of any building material [1, 2]. This excellent fire resistance is due to concrete's constituent materials (i.e., cement and aggregates) which, when chemically combined, form a material that is essentially inert and has low thermal conductivity, high heat capacity, and slower strength degradation with temperature. It is this slow rate of heat transfer and strength loss that enables concrete to act as an effective fire shield not only between adjacent spaces but also to protect itself from fire damage [3-5]. The behaviour of a concrete structural member exposed to fire is dependent, in part, on thermal, mechanical, and deformation properties of concrete of which the member is composed. Similar to other materials the thermophysical, mechanical, and deformation properties of concrete change substantially within the temperature range associated with building fires [6-8]. These properties vary as a function of temperature and depend on the composition and characteristics of concrete [9]. The strength of concrete has significant influence on its properties at both room and high temperatures. The properties of high strength concrete (HSC) vary differently with temperature than those of normal strength concrete (NSC). This variation is more pronounced for mechanical properties, which are affected by strength, moisture content, density, heating rate, amount of silica fume, and porosity. In practice, fire resistance of structural members used to be evaluated mainly through standard fire tests [10-12].

II. INFLUENCE OF HIGH TEMPERATURE

The mechanical properties that determine the fire performance of RC members are compressive and tensile strength, modulus of elasticity, and stress-strain response of constituent materials at elevated temperatures [13]. Compressive strength of concrete at an elevated temperature is of primary interest in fire resistance design. Compressive strength of concrete at ambient temperature depends upon water-cement ratio, aggregate-paste interface transition zone, curing conditions, aggregated type and size, admixture types, and type of stress [14, 15]. At high temperature, compressive strength is highly influenced by room temperature strength, rate of heating, and binders in batch mix (such as silica fume, fly ash, and slag). Unlike thermal properties at high temperature, the mechanical properties of concrete are well researched. The strength degradation in HSC is not consistent and there are significant variations in strength loss, as reported by various authors. The tensile strength of concrete is much lower than compressive strength, due to ease with which cracks can propagate under tensile loads. Concrete is weak in tension, and for NSC, tensile strength is only 10% of its compressive strength and for HSC tensile strength ratio is further reduced [16, 17]. Thus, tensile strength of concrete is often neglected in strength calculations at room and elevated temperatures. However, it is an important property, because cracking in concrete is generally due to tensile stresses and the structural damage of the member in tension is often generated by progression in microcracking. Under fire conditions tensile strength of concrete can be even more crucial in cases where fire induced spalling occurs in a concrete structural member. Tensile strength of concrete is dependent on almost same factors as compressive strength of concrete. Another property that influences fire resistance is the modulus of elasticity of concrete which decreases with temperature. At high temperature, disintegration of hydrated cement products and breakage of bonds in the microstructure of cement paste reduce elastic modulus and the extent of reduction depends on moisture loss, high temperature creep, and type of aggregate [18].

2.1. Spalling

In addition to thermal, mechanical, and deformation properties, another property that has a significant influence on the fire performance of a concrete structural member is spalling. This property is unique to concrete and can be a governing factor in determining the fire resistance of an RC structural member. Spalling is defined as the breaking up of layers (pieces) of concrete from the surface of a concrete member when it is exposed to high and rapidly rising temperatures such as those encountered in fires. The spalling can occur soon after exposure to rapid heating and can be accompanied by violent explosions or it may happen during later stages of fire when concrete has become so weak after heating such that, when cracks develop, pieces of concrete fall off fromthe surface of concrete member. The consequences are limited as long as the extent of damage is small, but extensive spalling may lead to early loss of stability and integrity [19, 20]. Influence of Temperature on Mechanical performance The mechanical properties that are of primary interest in fire resistance design are compressive strength, tensile strength, elastic modulus, and stress-strain response in compression. Mechanical properties of concrete at elevated temperatures have been studied extensively in the literature in comparison to thermal properties. High temperature mechanical property tests are generally carried out on concrete specimens that are typically cylinders or cubes of different sizes [21, 22].

Unlike room temperature property measurements, where there are specified specimen sizes as per standards, the high temperature mechanical properties are usually carried out on a wide range of specimen sizes due to a lack of standardized test specifications for undertaking high temperature mechanical property tests.

2.2. Compressive Strength

Traditionally, the compressive strength of concrete used to be around 20 to 50MPa, which is classified as normalstrength concrete (NSC). In recent years, concrete with a compressive strength in the range of 50 to 120 MPa has become widely available and is referred to as high-strength concrete (HSC). When compressive strength exceeds 120MPa, it is often referred to as ultrahigh performance concrete (UHP). The strength of concrete degrades with temperature and the rate of strength degradation is highly influenced by the compressive strength of concrete. Figures 1 illustrates the variation of compressive strength ratio for NSC and HSC at elevated temperatures, respectively, with upper and lower bounds (of shaded area) showing range variation in reported test data. A wider variation is observed for NSC in this temperature range (above 500 ˚C) when compared to HSC as seen from Figure 1.This is mainly because of the higher number of test data points reported for NSC in the literature and also due to the lower tendency of NSC to spall under fire. Overall the variation in compressive strength mechanical properties of concrete at high-temperatures is quite high. These variations fromdifferent tests can be attributed to using different heating or loading rates, specimen size and curing, condition at testing (moisture content and age of specimen), and the use of admixtures. In the case of NSC, the compressive strength of concrete is marginally affected by a temperature of up to 400 ˚C. NSC is usually highly permeable and allows easy diffusion of pore pressure as a result of water vapor. On the other hand, the use of different binders in HSC produces a superior and dense microstructure with less amount of calcium hydroxide which ensures a beneficial effect on compressive strength at room temperature.

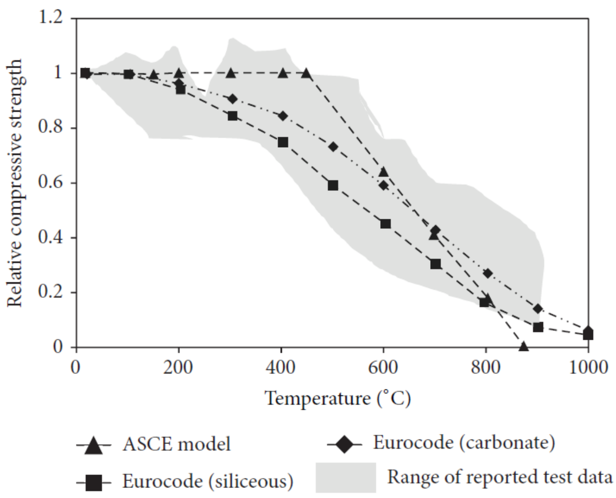

Figure 1: Variation of relative compressive strength of normal strength concrete as a function of temperature

2.3. Elasticity

The modulus of elasticity (E) of various concretes at room temperature varies over a wide range, 5.0 × 103 to 35.0 × 103 MPa, and is dependent mainly on the water-cement ratio in the mixture, the age of concrete, the method of conditioning, and the amount and nature of the aggregates. The modulus of elasticity decreases rapidly with the rise of temperature, and the fractional decline does not depend significantly on the type of aggregate. Fromother surveys, it appears, however, that the modulus of elasticity of normal-weight concretes decreases at a higher pace with the rise of temperature than that of lightweight concretes. Figure 2 and 3 illustrates variation of ratio of elastic modulus at target temperature to that at room temperature for NSC and HSC. It can be seen fromthe figure that the trend of loss of elastic modulus of both concretes with temperature is similar, but there is a significant variation in the reported test data. The degradation modulus in both NSC and HSC can be attributed to excessive thermal stresses and physical and chemical changes in concrete microstructure.

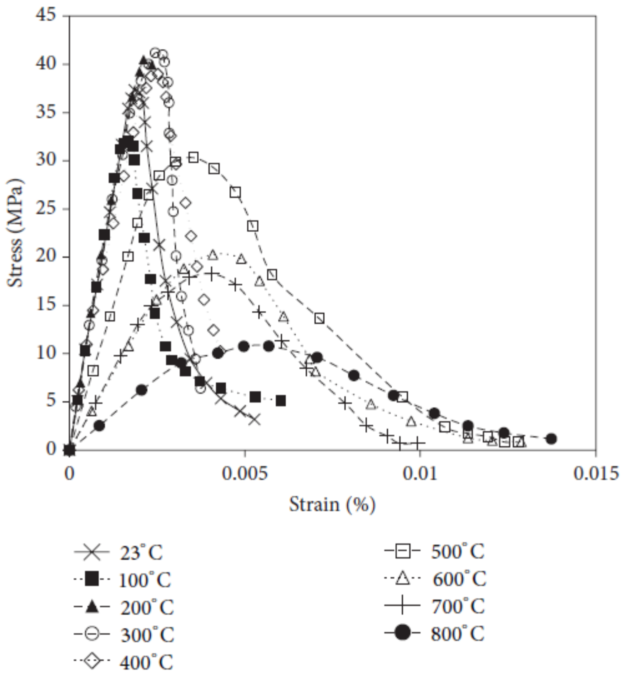

Figure 2 : Stress-strain response of normal strength concrete at elevated temperatures

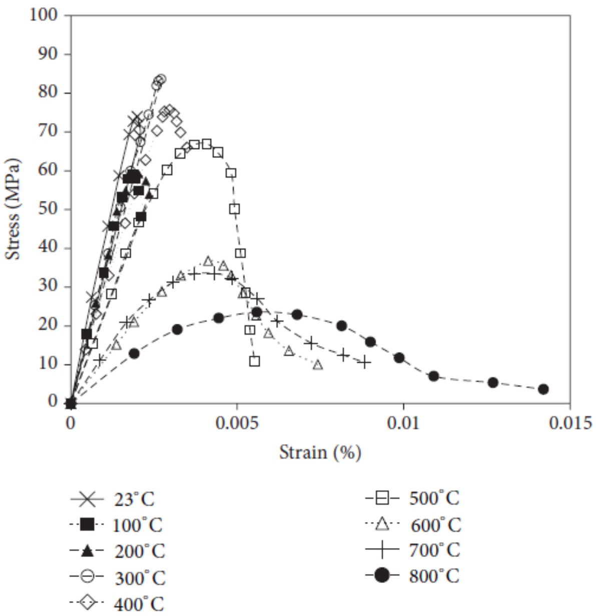

Figure 3 : Stress-strain response of high strength concrete at elevated temperatures

2.4. Tensile strength

Figure 4 illustrates the variation of splitting tensile strength ratio of NSC and HSC as a function of temperature as reported in previous studies and Eurocode provisions. The ratio of tensile strength at a given temperature, to that at room temperature, is plotted in Figure 6. The shaded portion in this plot shows a range of variation in splitting tensile strength as obtained by various researchers for NSC with conventional aggregates.The decrease in tensile strength of NSC with temperature can be attributed to weak microstructure of NSC allowing initiation of microcracks. At 300 ˚C, concrete loses about 20% of its initial tensile strength. Above 300 ˚C, the tensile strength of NSC decreases at a rapid rate due to a more pronounced thermal damage in the form of microcracks and reaches to about 20% of its initial strength at 600 ˚C.

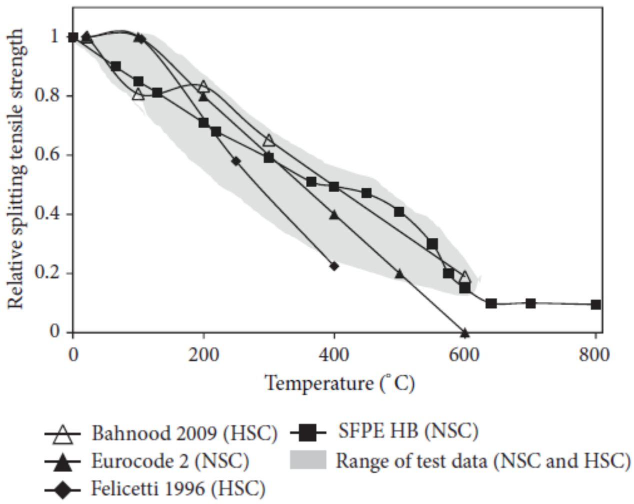

Figure 4 : Variation in relative splitting tensile strength of concrete as a function of temperature.

III. Conclusion

Concrete, at elevated temperatures, undergoes significant physicochemical changes. These changes cause properties to deteriorate at elevated temperatures and introduce additional complexities, such as spalling in HSC. Thus, thermal, mechanical, and deformation properties of concrete change substantially within the temperature range associated with building fires. Furthermore, many of these properties are temperature dependent and sensitive to testing (method) parameters such as heating rate, strain rate, temperature gradient, and so on. Based on information presented in this chapter, it is evident that high temperature properties of concrete are crucial for modeling fire response of reinforced concrete structures. A good amount of data exists on high temperature thermal, mechanical, and deformation properties of NSCand HSC. However, there is very limited property data on high temperature properties of new types of concrete such as self-consolidated concrete and fly ash concrete at elevated temperatures. The review on material properties provided in this chapter is a broad outline of currently available information.Additional details related to specific conditions on which these properties are developed can be found in cited references. Also, when using the material properties presented in this chapter, due consideration should be given to batch mix properties and other characteristics, such as heating rate and loading level, because the properties at elevated temperatures depend on a number of factors.

IV. REFERENCES

[1]. S Zhang, W. Shen, D. Li, X. Zhang, B. Chen, Nondestructive ultrasonic testing in rod structure with a novel numerical Laplace based wavelet finite element method, Latin American Journal of Solids and Structures, (2018) 16.

[2]. L-p. Wang, B.-y. Chen, C. Chen, Z.-s. Chen, G.-l. Liu, Application of linear mean-square estimation in ocean engineering, China Ocean Engineering, 30 (2016) 12.

[3]. W Shen, D. Li, S. Zhang, J. Ou, Analysis of wave motion in one-dimensional structures through fast-Fourier-transform-based wavelet finite element method, Journal of Sound and Vibration, 400 (2017) 18.

[4]. L-p. Wang, B.-y. Chen, J.-f. Zhang, Z. Chen, A new model for calculating the design wave height in typhoon-affected sea areas, Nat Hazar, 67 (2013) 15.

[5]. R Wen, A.C. Umeano, S. Dhar, Accessing Mitochondrial Targets Using NanoCargos, Intracellular Delivery III, (2016) 26.

[6]. D Li, S. Zhang, W. Yang, W. Zhang, Corrosion Monitoring and Evaluation of Reinforced Concrete Structures Utilizing the Ultrasonic Guided Wave Technique, International Journal of Distributed Sensor Networks, 10 (2014) 9.

[7]. L Wang, X. Xu, G. Liu, B. Chen, Z. Chen, A New Method to Estimate Wave Height of Specified Return Period, Chinese Journal of Oceanology and Limnology, 35 (2017) 8.

[8]. B Chen, S. Escalera, I. Guyon, V. Ponce-Lopez, N. Shah, M. Simon, Overcoming calibration problems in pattern labeling with pairwise ratings: application to personality traits, Computer Vision–ECCV 2016 Workshops, (2016) 14.

[9]. Y Cao, N. Tian, D. Bahr, P.D. Zavattieri, J. Youngblood, R.J. Moon, J. Weiss, The influence of cellulose nanocrystals on the microstructure of cement paste, Cement and Concrete Composites, 76 (2016) 10.

[10]. V. Ponce-Lopez, B. Chen, M. Oliu, C. Corneanu, A. Clapés, I. Guyon, X. Baro, H.J. Escalante, S. Escalera, ChaLearn LAP 2016: First Round Challenge on First Impressions-Dataset and Results, Computer Vision–ECCV 2016 Workshops, (2016) 19.

[11]. H.J. Escalante, V. Ponce-Lopez, J. Wan, M.A. Riegler, B. Chen, A. Clapes, S. Escalera, I. Guyon, X. Baro, P. Halvorsen, Chalearn joint contest on multimedia challenges beyond visual analysis: An overview, 23rd International Conference on Pattern Recognition (ICPR), (2016) 7.

[12]. R. Wen, A.C. Umeano, L. Francis, N. Sharma, S. Tundup, S. Dhar, Mitochondrion: a promising target for nanoparticle-based vaccine, Vaccines, 4 (2016) 25.

[13]. Y. Cao, K.P. Verian, A VEDA simulation on cement paste: using dynamic atomic force microscopy to characterize cellulose nanocrystal distribution, MRS Communications, 7 (2017) 5.

[14]. R. Wen, S. Dhar, Turn up the cellular power generator with vitamin E analogue formulation, Chemical Science, 7 (2016) 9.

[15]. Y. Cao, P. Zavaterri, J. Youngblood, R. Moon, J. Weiss, The influence of cellulose nanocrystal additions on the performance of cement paste, Cement and Concrete Composites, 56 (2015) 11.

[16]. Z. Zhang, J. Ou, D. Li, S. Zhang, Optimization Design of Coupling Beam Metal Damper in Shear Wall Structures, Applied Sciences, 7 (2017) 12.

[17]. R. Wen, B. Banik, R.K. Pathak, A. Kumar, N. Kolishetti, S. Dhar, Nanotechnology inspired tools for mitochondrial dysfunction related diseases, Advanced Drug Delivery Reviews, 99 (2016) 18.

[18]. Y. Cao, P. Zavattieri, J. Youngblood, R. Moon, J. Weiss, The relationship between cellulose nanocrystal dispersion and strength, Construction and Building Materials, 119 (2016) 9.

[19]. Z. Zhang, J. Ou, D. Li, S. Zhang, J. Fan, A thermography-based method for fatigue behavior evaluation of coupling beam damper, Fracture and Structural Integrity, 40 (2017) 13.

[20]. Y. Cao, J. Weiss, J. Youngblood, R. Moon, P. Zavattieri, Performance-enhanced cementitious materials by cellulose nanocrystal additions, Production and Applications of Cellulose Nanomaterials, (2013) 2.

[21]. Z. Zhang, C. Drapaca, Z. Zhang, S. Zhang, S. Sun, H. Liu, Leakage Evaluation by Virtual Entropy Generation (VEG) Method, Entropy, 20 (2018) 10.

[22]. R. Wen, A.C. Umeano, Dual role of nanoparticle for cancer immunotherapy and imaging, Trends in Immunotherapy, 1 (2017).