Fire resistance of high strength fiber reinforced concrete filled box columns

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ABSTRACT

This paper presents an investigation on the fire resistance of high strength fiber reinforced concrete filled box columns (CFBCs) under combined temperature and loading. Two groups of full-size specimens were fabricated. The control group was a steel box filled with high-strength concrete (HSC), while the experimental group consisted of a steel box filled with high strength fiber concrete (HFC) and two steel boxes filled with fiber reinforced concrete. Prior to fire test, a constant compressive load (i.e., load level for fire design) was applied to the column specimens. Thermal load was then applied on the column specimens in form of ISO 834 standard fire curve in a large-scale laboratory furnace until the set experiment termination condition was reached. The test results show that filling fiber concrete can improve the fire resistance of CFBC. Moreover, the configuration of longitudinal reinforcements and transverse stirrups can significantly improve the fire resistance of CFBCs.

1. INTRODUCTION

Building fires can affect the loadbearing capacity of structural bearing elements, thereby causing structural damage or collapse. Thus, most building codes stipulate that the structural members of any structure or building have to satisfy appropriate fire safety requirements (ACI-318 2014, Eurocode 2 2004, Kodur 2014). Usually, fire safety measures to structural members are measured in terms of fire resistance, which is the ability of a particular structural member to fulfil its designed function for a period of time in the event of a fire (Purkiss 2007).

The structural design of steel reinforced concrete (hereafter designated as SRC) structures can effectively combine the individual features of steel structures and reinforced concrete structures (Liu et al. 2014). In addition, SRC structures have several practical benefits. For instance, compared with bare steel or reinforced concrete columns, the use of concrete filled box columns (CFBCs) may have as a

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relatively small sectional dimension, omission of formwork and thus reducing the construction cost and time (Han et al. 2005). Consequently, CFBCs have been widely used in high-rise buildings and plant construction throughout the world over the past few decades (Lie and Kodur 1996, Kodur et al. 2004, Eurocode 4 2005, Kim et al. 2005, Kodur 2007, Ding and Wang 2008, Espinos et al. 2009, Hong and Varma 2009, Song et al 2010, Aslani et al 2015, Qu et al 2015, Khan et al 2016, Ekmekyapar 2016, Mago and Hicks 2016, Tao et al. 2016, Wan and Zha 2016).

In recent years, the use of high-strength concrete (hereafter designated as HSC) with compressive strength higher than 40 MPa has become increasingly popular. A number of fire test results show that there are significant differences between HSC and normal-strength concrete (NSC) after being subjected to high temperature. In general, HSC exhibits slightly lower specific heat throughout the 20–800 °C temperature range, as compared to NSC (Kodur and Sultan 2003). Moreover, HSC elements are susceptible to explosive spalling when subjected to rapidly rising temperatures such as in the case of a fire (Castillo and Durrani 1990, Sanjayan and Stocks 1993, Phan and Carino 1998, Phan and Carino 2002). Consequently, the integrity and loadbearing capacity of the structure may be reduced. However, the strength degradation in HSC at elevated temperatures is not consistent and there are significant variations in strength loss, as reported by various authors (Kodur 2014).

Fiber reinforced concrete (FRC) consists of concrete and discontinuous, discrete, uniformly dispersed fibers (Somayaji 2001). Overall, FRC is much tougher and more resistant to impact, compared to plain concrete. According to the nature of the material, fiber may be classified into metal fiber, inorganic fiber and organic fiber. Metal fibers can be further divided into steel fibers and stainless steel fibers; inorganic fibers are mainly natural and artificial mineral fibers; organic fibers are mainly synthetic fibers and plant fibers. Fibers of various shapes and sizes produced from steel, plastic, glass, and natural materials are generally being used (Metha et al. 2006). The tensile strength, Young’s modulus, ultimate elongation, and specific gravity of various kinds of fibers are shown in Table 1 (ACI Committee 544 1982). On the other hand, aspect ratio, defined as the ratio between the fiber length and diameter, is an important characterizing parameter that affects the performance of a fiber (Somayaji 2001). Addition of fibers to concrete influences its fresh and mechanical properties which significantly depend on the type and percentage of fiber (ACI Committee 544 1982, Naaman 1985). In general, the appropriate aspect ratio of the steel fibers is about 50 to 100, and the fiber content is generally 1 to 2% (volume percentage). In practice, the workability of FRC decreases with increasing aspect ratio. In particular, if the aspect ratio is greater than about 100, it is very difficult to achieve a uniform mix (Swamy and Mangat 1974).

Since the 1970s, a great number of fire, static, and dynamic tests have been carried out to explore the effects of type, shape, aspect ratio and content of the fiber on the mechanical properties of FRC and the toughness of FRC components (Krenchel 1974, Swamy and Mangat 1974, ACI Committee 544 1982, Bilodeau et al. 2004, Sideris et al. 2009, Ding et al. 2012, Ozawa and Morimoto 2014, Yan et al. 2015, Kim et al. 2016, Lee and Yi 2016, Xu et al. 2016). It was observed that the extent of explosive spalling can considerably be reduced by use of adequate amount of polypropylene (PP) fibers (Hannant 1998, Tatnall 2002, Atkinson 2004, Larbi and Polder 2007). The reason is the burning of PP fibers produces microchannels for

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