International Journal of Impact Engineering 86 (2015) 40–56

Contents lists available at ScienceDirect

International Journal of Impact Engineering

journal homepage: www.elsevier.com/locate/ijimpeng

Combined effects of high temperature and high strain rate on normal weight concrete

Li Chen [a], Qin Fang [a,*], Xiquan Jiang [b], Zheng Ruan [a], Jian Hong [a]

[a] PLA University of Science and Technology, State Key Laboratory of Disaster Prevention & Mitigation of Explosion & Impact, Nanjing, 210007, China
[b] Army Officer Academy of PLA, The No.4 Department, Hefei, 230031, China

A R T I C L E I N F O

Article history:
Received 30 January 2015
Received in revised form
24 June 2015
Accepted 2 July 2015
Available online 10 July 2015

Keywords:
Concrete
High temperature
High strain rate
Microwave oven
SHPB

A B S T R A C T

Concrete in structures is possibly exposed to fire and blast due to occasional accidents or terrorist attack during the service life. Yet, there are few experimental studies on the responses of normal concrete structures subjected to high temperature and high strain rate loading simultaneously, although some high strain rate experiments were performed before or after fire exposure. This paper reports an experimental study of the combined effects of high temperature and high strain rate on normal concrete material, which is a preliminary basis for calculating and assessing the performances of RC structures in blast and fire. The dynamic properties of normal concrete at elevated temperature from 20 °C up to 950 °C were systematically studied using a specially manufactured *microwave–heating automatic time-controlled Split Hopkinson Pressure Bar* (MATSHPB) apparatus. The concrete specimens were first efficiently heated in a specially designed industrial microwave oven, and then rapidly loaded after quickly rolling to the SHPB system. Quasi–static and low strain rate tests at elevated temperatures were also carried out for comparative analysis. In contrast with previous experimental research, the test results showed that the dynamic strength and stress–strain curve of normal concrete at high temperature still experienced remarkable strain rate effects. Moreover, the failure appearances of normal concrete subjected to both high temperature and high strain rate loading were significantly different from those of concrete at ambient temperature. In contrast with quasi-static test data, a new empirical model on *dynamic increase factor of strength* and *secant elastic modulus of concrete at elevated temperature* (DIF_{TS}, DIF_{TE}) were established that can be used in a very wide range of application.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Concrete material is commonly used in engineering structures e.g. high-rise building, subway project, and some other civil infrastructures, with the rapid development of urbanization. In addition to the normal design loadings, some engineering structures may suffer impact or explosion in occasional accidents, gas explosions, even man-made explosions in the terrorist attack, during the service time. It leads to the fact that concrete material in the structures are in danger of fire exposure and impact or blast simultaneously. Hence a thorough knowledge of concrete mechanical properties and failure criteria is required, over a wide range of strain rate (Fig. 1 [1]) and temperature (Fig. 2 [2]), to properly design a structure subjected to blast and fire likely to be encountered during the design lifetime.

Safety concern about combined effects of fire and blast or impact which significantly aggravates the damage of structures, was greatly raised by scientists and engineers ever since the 9.11 terrorist attacks in New York (2001). Impact or blast loadings on structures usually induce the high strain rate effect on concrete material, while fire basically causes the high temperature effect. Actually, concrete is a composite material composed of coarse aggregate, cement, water and some other additives. Strain rate effect and temperature effect are two important factors affecting the mechanical behaviors of concrete as a brittle material [3]. During the past several years, those two effects have been extensively studied. High strain rate dependence causes the behaviors of concrete to be significantly different from what is observed under quasi-static conditions [1,4,5], while high temperature induces severe micro-structural changes that alter mechanical properties of concrete at ambient temperature [6–9]. It has been concluded that

* Corresponding author. Tel.: +86 25 84871530; fax: +86 25 84604496.
E-mail address: fangqinjs@139.com (Q. Fang).

http://dx.doi.org/10.1016/j.ijimpeng.2015.07.002
0734-743X/© 2015 Elsevier Ltd. All rights reserved.

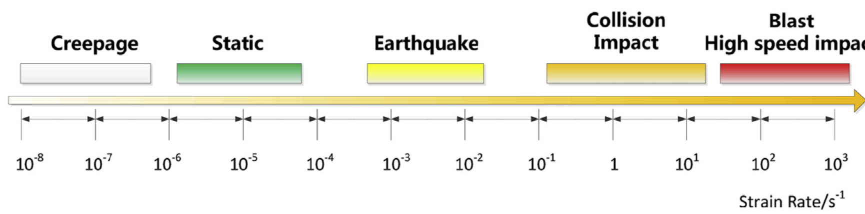

Fig. 1. Magnitude of strain rates expected for different loading cases.

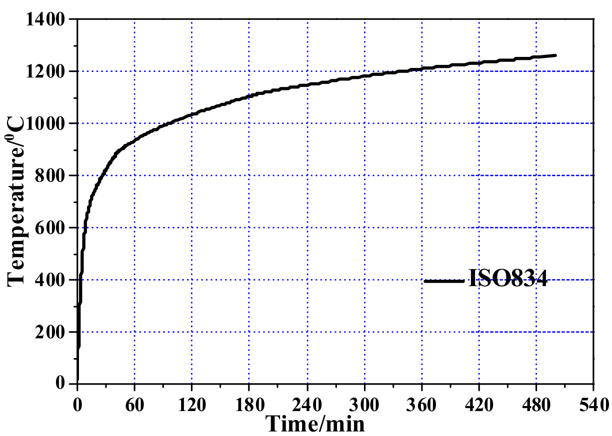

Fig. 2. Stand temperature–time curve of indoor fire suggested by ISO834.

the elevated temperature exposure over 400 °C leads to a great static ultimate strength loss of normal concrete [10]. Actually, the fire exposure would not only deteriorate the quasi-static concrete strength but also lead to a remarkable influence on the strain rate effects that change the dynamic strength and cracking criterion of concrete which is different from those at ambient temperature [11]. Thus, it is very important and even imperative to systematically study the combined effects of high temperature and high strain rate on normal weight concrete material, in order to predict responses of concrete structures in fire and blast more precisely.

Split Hopkinson Pressure Bar (SHPB) is widely used to experimentally study the mechanical properties of materials undergoing rapid compression deformation. The referred strain rate basically covers a range of 10–10^4 s^{-1} that actually depends on material features [12,13]. Most of the SHPB experiments considering temperature focused on the alloys, which basically used small diameter bars [13]. Although there were some experiments conducted on the dynamic behaviors of concrete using large diameter SHPB, i.e., the diameter of specimen and pressure bar is at least larger than 75 mm, owing to the size of aggregates in concrete [1]. Most of them were limited to ambient temperatures or post-fire cases. Liu et al. [15] carried out an experimental study on the dynamic performances of normal concrete after exposure to high temperature of 400 °C, 600 °C and 800 °C with a 100 mm diameter SHPB referring to strain rate from 30s^{-1} to 220 s^{-1}. The results showed that the heated concrete suffered compressive strength degradation due to high temperature exposure and remarkable enhanced strain-rate effect. The effect of high temperature on the dynamic performances of fire-damaged concrete was more remarkable than that of strain rate. Huo et al. [16] proceeded with similar experiments on normal concrete after exposure to elevated temperatures up to 700 °C using a 74 mm diameter SHPB. No evident effects of high temperature and strain rate on the shape of the ascending branches of the normalized stress–strain curves of concrete were observed after exposure to high temperatures. However, these researches only focused on the post-fire properties of concrete that was cooled down from high temperature to the ambient temperature. The dynamic mechanical response simultaneously at elevated temperature, which is of great importance for engineering safety and structural design, were not covered.

Liu and Xu [17] carried out a series of experiments on the marble material at high temperatures using a 100 mm diameter SHPB device. The bars and specimens in the test were maintained and heated together up to temperature of 1000 °C. An aluminum silicate fiber blanket was sandwiched between heated specimen and the bars to insulate heat conduction in the pressure bar, which is similar as Rosenberg et al. [18]. However, the heating efficiency was very low to heat the thermal preservation layer together, and cost much time. He and Huo [19] conducted SHPB experiments to study dynamic properties of concrete at elevated temperatures. The tested results demonstrated that concrete at elevated temperatures under impact loading tended to be more sensitive to strain-rate with the increase of high temperature. The dynamic performances of concrete at ambient temperature was obviously different from that elevated temperatures higher than 200 °C. Su et al. [20] used a self-designed high temperature SHPB apparatus to conduct similar experiments at elevated temperature up to 800 °C. The results showed that the elastic modulus of concrete decreases greatly when it is subjected to elevated temperature. The dynamic compressive strength at temperature of 400 °C increased by nearly 14% compared to the ambient temperature. Contrarily, it decreases at temperatures of 200 °C, 400 °C and 800 °C. In the two studies mentioned above, the concrete specimen was heated by a cylinder-shaped electrical furnace, which induced much uncertainty about thermal homogeneity and perturbation of specimen during heat transfer process. Also, the available data heated by electrical furnace were very limited due to too much cost of heating time and man power. It approximately took more than 6 h to heat a concrete specimen in an electrical furnace.

In a word, the existing researches on combined effects of high temperature and high strain rate on normal concrete were very limited, discrete and inconsistent, or even contradictory because the experimental devices and methods were different, as well as some disruptive, even uncertain factors always existed in the experimental process. There are basically four kinds of difficulties in large diameter SHPB apparatus designed for high temperature: (i) commercial available heating devices and method do not match the large diameter of concrete specimen and pressure bar; (ii) temperature increase in the pressure bars due to heating transferring disturbs the wave propagation [21]; (iii) temperature distribution in the testing specimen is inhomogeneous when impulse arrives; (iv) the electric and magnetic fields generated by the heating device disturbs strain gauge measurements. These difficulties may explain why there are very limited reliable experimental data reported in the open literature about combined effects of high temperature and high strain rate on normal plain concrete. On the other hand, Ouedraogo et al. [22] has reported that the concrete exhibits some viscous behavior from 800 to 1200 °C based on the various quasi-

Download English Version:

https://daneshyari.com/en/article/776385

Download Persian Version:

https://daneshyari.com/article/776385

Daneshyari.com