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Dynamic Mechanical Behavior of Reactive Powder Concrete under High Temperature

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In this paper, the mixture proportion of reactive powder concrete was determined by formula method. The dynamic mechanical behavior of reactive powder concrete and ordinary concrete at three kind of over-temperature 20℃, 300℃ and 800℃ were analyzed and compared. Besides, the energy mechanism of reactive powder concrete was analyzed. The results showed that the dynamic compressive strength of the reactive powder concrete increased with the increment of the strain rate under different temperatures, and the change of the peak strain was not obvious when the temperature and strain rate changed. With the increment of temperature, the dynamic compressive strength of reactive powder concrete gradually decreased. The stress-strain curves of the active powder concrete did not show a significant elastic interval. The stress and strain of ordinary concrete were almost the same with those of reactive powder concrete under different temperature, but the dynamic compressive strength was obviously smaller than that of reactive powder concrete, which reflected the high performance and excellent durability of reactive powder concrete. The energy mechanism of the reactive powder concrete showed that the bigger the strain rate is, the more energy is absorbed by the specimen. Under the similar strain rate, the higher the over-temperature is, the less energy is absorbed by the specimen.

1. Introduction

Nowadays, concrete has become the main material of the building structure, and is widely used in bridges, houses, tunnels and other fields. In recent years, the urban fires have increased and the mechanical properties of concrete under high temperature conditions have attracted the attention of researchers (Chan, Luo and Sun, 2000). Since the studies are mostly focused on static mechanical properties of concrete under high temperature, therefore, it is important to study the dynamic mechanical behavior of concrete under high temperature (Sancak, Sari and Simsek, 2008; Youssef and Moftah, 2007; Huo et al., 2009).

Reactive Powder Concrete (RPC) is a new type concrete with high toughness, high strength and high durability, there have many engineering applications which use it to replace the ordinary concrete as building material. The mixture proportion of reactive powder concrete is an important condition affecting its performance. The reasonable mixture proportion is able to reducing the internal defects of the reactive powder concrete and making the microstructure densification, and the researchers have carried out many researches (Yazıcı et al., 2009; Chan and Chu, 2004; Lee et al., 2007), and have analyzed the influencing parameters (water-cement ratio, sand ratio, steel fiber, curing conditions, etc.) when design the mixture proportion of RPC.(Olivito and Zuccarello, 2010; Ahmad, Zubair and Maslehuddin, 2015; Zhu et al., 2014). At the same time, the related researches of mechanical properties changes for the reactive powder concrete under high temperature have done. (Poon et al., 2004; Lau and Anson, 2006; Yang et al., 2010; Aslani and Samali, 2014; Bayramov, Taşdemir and Taşdemir, 2004)

This paper adopted formula method to determine the mixture proportion of reactive powder concrete. The dynamic mechanical behavior of reactive powder concrete and ordinary concrete at three kind of over-temperature 20℃, 300℃ and 800℃ were analyzed and compared. Besides, the energy mechanism of reactive powder concrete was analyzed too.

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2. Test scheme

2.1 Raw materials and mixture proportion

The reactive powder concrete mixture proportion is calculated based on Formula 1

$$F_{cu} = \alpha\lambda\delta A_1 f_{ce}\left(\frac{C}{W} - B\right) \quad (1)$$

F_{cu} is the strength of the reactive powder concrete; f_{ce} is the cement strength; C/W is the cement/water ratio of RPC; A_1, B_1 is the regression equation coefficient based on the data of the cement/water ratio; α, λ, δ is the bone glue ratio, Cohesive material particles and steel fiber influence coefficient.

The many times testes according to formula 1 show that the cement/water ratio of RPC is 0.23, mixture proportion m(silica flour): m(cement): m(silica sand 109-210μm): m(silica fume): m(ilica sand 210-380μm)= 0.37: 100: 0.61: 0.24: 0.60. Among which the cement strength is 42.5Mpa; silica flour particle diameter 5—25μm; Water reducing agent dosage is 2.4%.

The material compost ratio of ordinary concrete is cement: sand: stone: water=1:0.947:2.335:0.42. Cement strength is also 42.5MPa; sandstone diameter is 4-8mm, concrete design strength is 30MPa.

2.2 Specimen preparation and SHPB test device

Preparation of reactive powder concrete: put raw materials into the mixer in accordance with the mixture proportion, add water and then stir evenly, pour the mixture into the mould, vibrate 10min molding, move the molding specimen into the conservation room for 24 hours, after the demolition of the specimen put it into the 50℃ incubator curing 5d, incubator device in the laboratory is shown in Figure 1(a) below. After the specimen was cured, it was placed in a heating furnace, and the specimen was divided into four groups. The over-temperature of each specimen was 25℃, 200℃, 400℃ and 800℃ respectively. After heating, the specimen was standing for 24 hours. Ordinary concrete preparation procedure and over-temperature process are the same with reactive powder concrete, not repeat here.

The split Hopkinson pressure bar(SHPB) test device is show in Figure 1(b), the impact bar and the bullet are alloy steel material, the length of incident rod and the transmission rod are 2400mm, the bullet diameter is 30mm with the length of 250mm. The impact compression strain rate is divided into three grades, R_1=(70-85s^{-1});R_2=(90-105s^{-1});R_3=(120-135s^{-1}).

(a) Incubator

(b) SHPB experimental system

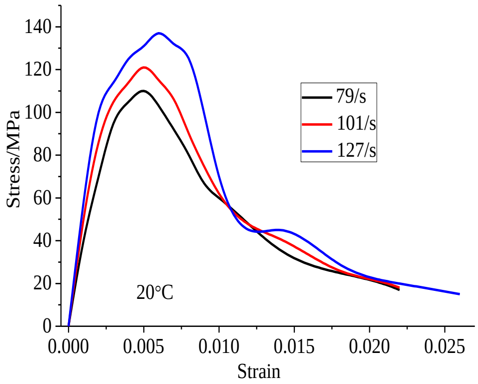
Figure 1: Concretes mechanical properties test system under high temperature

3. Experimental Results and analysis

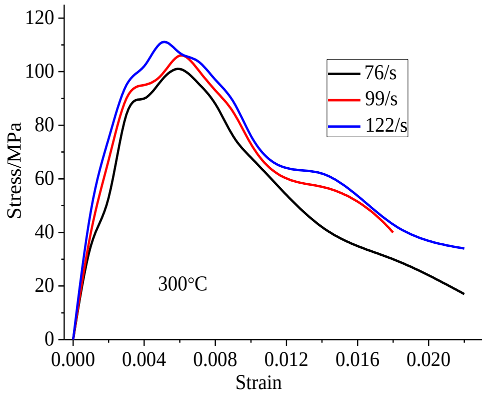
3.1 Stress-strain analysis of concrete under different temperatures

Figure 2 shows the stress-strain curves of the reactive powder concrete at three strain rate levels under different over-temperature conditions. It can be seen from the figure that the dynamic compressive strength of

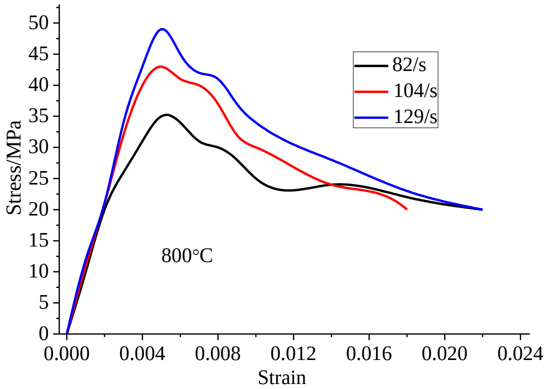
the reactive powder concrete increases with the increment of strain rate at the over-temperature of 20℃, 300℃ and 800℃. Let the stress maximum value corresponding to the strain value as the peak strain ε_{max}, from the figure it can be seen, when the temperature and strain rate changes, ε_{max} changes little, that is ε_{max} does not show a typical phenomenon of changing with the increase of strain rate or temperature.
With the increase of temperature, the dynamic compressive strength of the reactive powder concrete decreases gradually. When the temperature rises to 300℃, the descending trend is not obvious, while the temperature rises to 800℃, the maximum compressive strength of concrete decline about 1.8 times compared to 20℃.
It also can be seen from the figure that the stress-strain curve of the reactive powder concrete does not show a significant elastic interval, the curve is mainly composed of non-linear non-significant segments and typical nonlinear sections, that is, when the strain increases, the stress-strain curve of concrete showing typical non-linear characteristics. This is due to the fact that RPC material has more micro-cracks during the curing process and exhibits significant strain hardening and damage softening properties under the impact of the Hopkinson rod. From the figure, in the early stage of the impact, the damage of concrete is small, the material mainly shows the strain hardening effect, the curve is almost straight; and when the impact load is further increased, the damage of material intensified, there are many micro-cracks, and thus increased Toughness of concrete.



(a) 20 °C



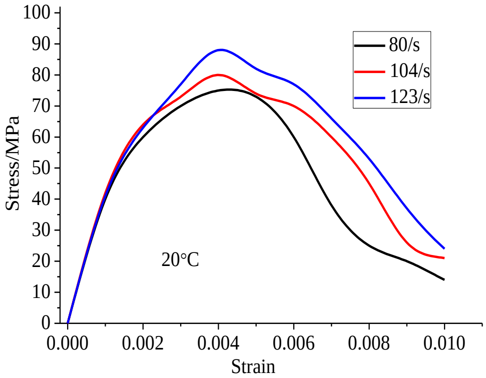
(b) 300 °C



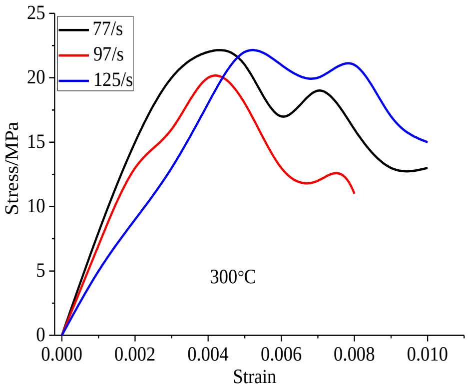
(c) 800 °C

Figure 2 Dynamic stress strain curves for RPC specimens under different temperature

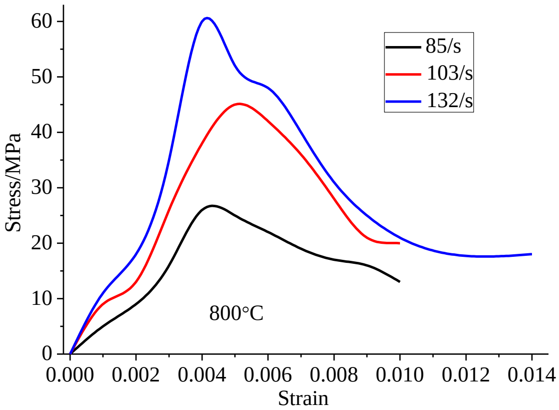
Figure 3 shows the stress-strain curves of ordinary concrete tested at three strain rate levels under different over-temperature. It can be seen from the figure that the stress-strain curve of the concrete is almost the same as that of the reactive powder concrete at the temperature of 20℃ and 800℃., that is, the curve is approximately linearly rising at the initial stage, When the stress reaches the peak, the curve shows a significant nonlinear change. The results also show that the dynamic compressive strength of the concrete increases with the increment of the strain rate. However, the peak stress of ordinary concrete is obviously smaller than that of reactive powder concrete at three over-temperature. The peak stress at 20 ℃, 300 ℃ and 800 ℃ is 64.3%, 20.9% and 117% of reactive powder concrete respectively. At 300℃ the concrete appears the phenomenon of reducing the dynamic strength, which needs to be further studied.



(a) 20 °C



(b) 300 °C



(c) 800 °C

Figure 3: Dynamic stress strain curves for ordinary concrete specimens under different temperature

3.2 Energy mechanism analysis of reactivate powder concrete

According to the impact signals collected by the SHPB device, to calculating the energy mechanism of the concrete specimen from loading to unloading. The formula is as follow:

$$W_{ab} = W_I - \left(W_R + W_t\right) = A_a E C_w \int \left(\varepsilon_I^2 - \varepsilon_R^2 - \varepsilon_T^2\right) \tag{2}$$

W_{ab}, W_I, W_R and W_T are the absorbed energy, the incident energy, the reflected energy and the transmitted energy, respectively; ε_I^2, ε_R^2 and ε_T^2 are incident signals, the reflected signals and the transmitted signals respectively; E is the elastic modulus, A_a is the cross-sectional area of the press bar. The energy time-history curve is calculated according to the ε_I^2, ε_R^2 and ε_T^2 obtained in the experiment.

Figure 4 shows the absorption energy curves of the reactive powder concrete samples at three strain rates (79s^{-1}, 101s^{-1} and 127s^{-1}) at 20 °C. As can be seen from the figure, the bigger the strain rate, the more energy the specimen absorbs. Since the energy is mostly used for the cracking of the specimen and the expansion of the crack, thus when the strain rate is low, the number of cracks in the specimen is small and the blockiness of the specimen is large, so the energy absorbed is relatively small. Accordingly, when the train rate is large, therefore the specimen has more cracks, the absorption of energy is larger.

Figure 5 shows the energy absorption of the specimen under different strain rates (120-135s^{-1}) at different over-temperature. As can be seen from the figure, the higher the over-temperature, the less energy the specimen absorbs. This is because when the temperature is high, the structural damage in the concrete increases, the bonding strength between the different aggregates becomes smaller, the crack only needs less energy to achieve the extended effect.

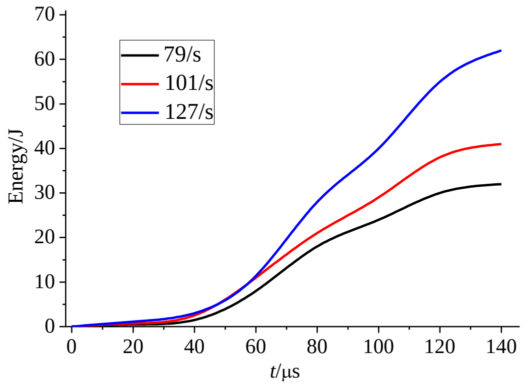


Figure 4: Energy time-history curves with different strain rates under 20 °C

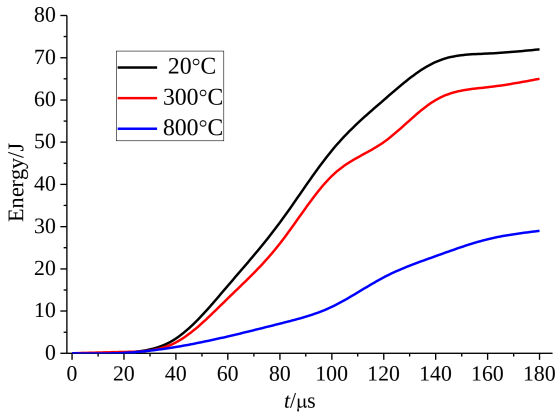


Figure 5: Energy time-history curves with different temperature under strain rates 120-135s^{-1}

4. Conclusion

By using of the SHPB device, the dynamic mechanical behavior of the reactive powder concrete and ordinary concrete at three over-temperatures of 20℃, 300℃and 800℃ were analyzed, and the mixture proportion of reactive powder concrete was determined by adopting the formula method. The analysis of energy mechanism of reactive powder concrete is done, the conclusions are as follows:

1. The dynamic compressive strength of the reactive powder concrete increases with the increase of the strain rate at different temperatures. When the temperature and strain rate both change, the change of the peak strain is not obvious. With the increase of temperature, the dynamic compressive strength of reactive powder concrete gradually decrease. The stress-strain curve of the reactive powder concrete does not show a significant elastic interval, and the curve mainly consists of non-linear, non-significant segments and typical nonlinear segments.

2. The stress and strain change of ordinary concrete at different temperatures is almost the same with that of reactive powder concrete, but the dynamic compressive strength is obviously smaller than that of reactive powder concrete, which reflects the high performance and excellent durability of reactive powder concrete.

3. The energy mechanism analysis of the reactive powder concrete shows that the higher the strain rate is, the more energy will be absorbed by the specimen. Under the similar strain rate, the higher the over-temperature is, the less energy is absorbed by the specimen.

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