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Analysis on impact resistance of waste fiber recycled concrete slab

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ABSTRACT

The impact performance of waste fiber recycled concrete slab is studied by ABAQUS finite element simulation. The studies show that the crack form of waste fiber recycled concrete slabs are spread from the middle to the periphery, and the addition of waste fibers makes the stress distribution of the slabs uniform. With the increase of waste fibers incorporation, the impact time of waste fiber recycled concrete slabs increased, which indicates that the addition of waste fibers can improve the impact resistance of recycled concrete effectively. By comparing the damage patterns of waste fiber recycled concrete slabs with different waste fibers contents, the incorporation of waste fibers can delay the formation and development of cracks caused by the impact force.

1. INTRODUCTION

Over the last twenty years recycled concrete is one of the most concerned construction materials on account of beneficial to the improvement and protection of the natural environment. According to (Xiao 2012), the mechanical properties of recycled concrete were inferior to those of ordinary concrete. The improvement of the performance of recycled concrete is a research hotspot, and (Kakooei 2012) proposed that the addition of fibers was one of the improved methods.

However, due to the limited knowledge on its impact resistance performance, the use of recycled concrete is still limited. The damage caused by the impact force to the safety of the construction structure is irreversible. When subjected to impact force, fiber reinforced concrete withstands higher impact fore compared to ordinary concrete and prevents the emergence and display of plastic cracks inside and outside the concrete.

(Badr 2006) evaluated the impact resistance of polypropylene fiber reinforced concrete with a length of 12mm by drop hammer impact test. He investigated that there is a great deal of discrepancy between the number of initial and final cracks. In order to

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achieve a test error of less than 10%, the number of specimens for each test should be not less than 40. (Nia 2008) also simulated the impact process of steel fiber reinforced concrete and polypropylene fiber concrete by the drop hammer impact test, and concluded that the improvement of the impact resistance of high strength concrete is less than that of ordinary concrete with the addition of fibers.

In summary, waste fiber recycled concrete, as a kind of green concrete, is put forward in this paper. Waste fibers come from waste carpets, which are composed of polypropylene. (Zhou 2017) illustrated that the addition of waste fibers can effectively improve the performance of recycled concrete. Based on this foundation, the impact resistance of waste fiber recycled concrete slabs with different waste fiber volume incorporation was studied.

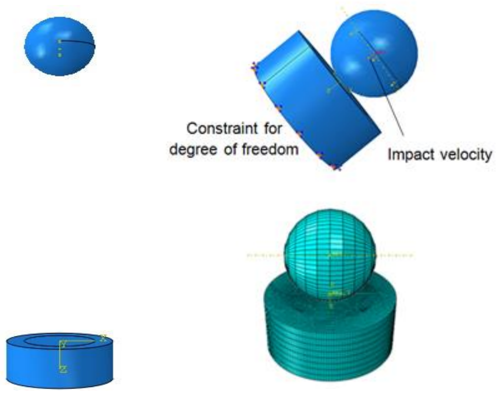
2. ESTABLISHMENT OF FINITE ELEMENT MODEL

2.1 Test situation and finite element model

The finite element model is established based on the drop hammer impact test, in accordance with ACI544. The drop hammer with a weight of 4.5kg falls freely from the height of 457mm, and then strikes the steel ball with a diameter of 63.5mm which is placed on the top surface of the specimen. Further, the cylindrical specimen with a diameter of 152mm and a thickness of 63.5mm undergoes the impact. The impact velocity of the steel ball reaches the center of the concrete slab through free fall is 3m/s. The equipment of the drop hammer impact test is shown in Fig. 1(a).

The steel ball is set as non-deformable rigid body in the finite element model. The calculated density is 7800kg/m^3, the elastic modulus is 206.8Gpa, and the Poisson's ratio is 0.3. In this paper, a complete integration unit and the 3-D solid element (C3D8R) of 8-node hexahedron are used to establish the model. This model can improve the efficiency of the software and ensure the accuracy of the simulation. The finite element model and grid partition are illustrated in Fig. 1(b).

(a) Test equipment



(b) Finite element model

Fig. 1 Test and simulation of drop hammer impact test

There are three specimens Z0, Z8 and Z12, and the design variable is the volume fraction of waste fibers. The replacement ratio of recycled aggregates is 50%, and the compressive strength is 40 MPa. Where "0" represents does not add waste fibers, "8" indicates that the volume of waste fiber is 0.08% and "12" means that the volume of waste fiber is 0.12%.

2.2 Constitutive relation

The constitutive model adopts the damage factor calculation model of fiber reinforced concrete. Symbolic meaning in Eq.1,2 can be found in (Liang 2014).

The damage factor of uniaxial compression is calculated according to Eq.1.

$$d=\begin{cases}0 & (\varepsilon\le\varepsilon_{c,r},\sigma_c\le 0.5f_{c,r})\\ 1-\sqrt{\dfrac{\rho_c n}{n-1+x^n}} & (\varepsilon\le\varepsilon_{c,r},0.5f_{c,r}\le\sigma_c\le f_{c,r})\\ 1-\sqrt{\dfrac{\rho_c}{\alpha_c(x-1)^2+x^n}} & (\varepsilon>\varepsilon_{c,r})\end{cases} \tag{1}$$

The damage factor of uniaxial tensile is calculated according to Eq.2.

$$d=\begin{cases}0 & \varepsilon\le\varepsilon_{t,r}\\ 1-\sqrt{\dfrac{\rho_t}{\alpha_t(x-1)^{1.7}+x}} & \varepsilon>\varepsilon_{t,r}\end{cases} \tag{2}$$

Where α_c and α_t are the parameter values of stress-strain curves, $\varepsilon_{c,r}$ is the peak strain of concrete corresponding to uniaxial compressive strength $f_{c,r}$, $\varepsilon_{t,r}$ is the peak strain of concrete corresponding to uniaxial tensile strength $f_{t,r}$, and E_0 is the initial elastic modulus.

In the damage constitutive model, the concrete is in the elastic state at the initial stage. When the strain reaches 0.5 times of the peak stress, the concrete begins to damage and the damage will increase gradually with the increase of strain.

3. ANALYSIS OF FINITE ELEMENT RESULTS

3.1 Comparison between experimental and finite element results

The failure mode of the finite element simulation model compares with that of the test specimen, as showed in Fig.2. It can be seen that both of them have the same shape of the final crack. The specimens showed obvious cracks, and they exhibited through-breaking and flat fracture surfaces. At the center of the concrete slabs, the impact traces of the steel ball can be seen obviously.

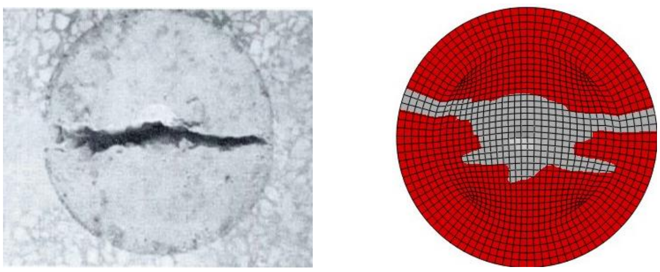


Fig. 2 Comparison between impact test and simulated failure patterns

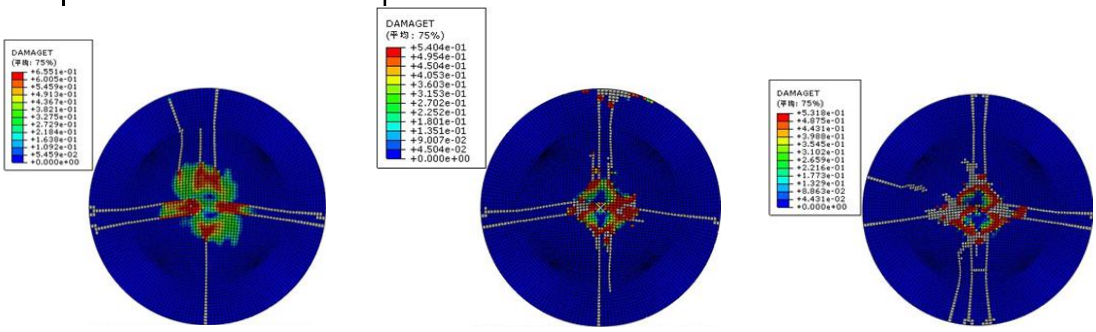
Table1 gives the results of the experiment and finite element simulation, and compares the data of initial crack impact time, final crack impact time and penetration depth. Among them, P_d is an important basis for validating the correctness and applicability of the finite element simulation. The P_d of the test data is 1.9mm, the P_d of the simulated data is 1.6mm, and the error is 15%. It shows that the simulation results of the finite element are in good agreement with the experimental data. Therefore, the correctness and applicability of the model and simulation method of the finite element simulation in this paper can be verified.

Table1 Comparison of impact test and simulation results

Series	Initial crack impact time	Final crack impact time	Initial crack impact energy (N·M)	Final crack impact energy (N·M)	Penetration depth P_d(mm)
Test results	14	17	278.11	337.71	1.9
Simulation results	14	17	282.15	342.61	1.6

3.2 Failure mode of waste fiber recycled concrete

The failure mode of waste fiber recycled concrete slabs is illustrated in Fig.3. From the failure patterns of the final crack, the addition of waste fibers can reduce the crack width of the waste fiber recycled concrete slab at the time of final failure, and also makes the stress distribution uniform. The damage of Z0 is the most serious, which indicates that the addition of waste fibers improve the crack resistance of recycled concrete matrix. Although the waste fiber recycled concrete slab has withdrawn from work when it bears more impact time, the phenomenon of cracking is not completely destroyed due to the addition of the fibers. When the waste fibers are broken, the concrete presents a destructive phenomenon.



(a)Z0 (b)Z8 (c)Z12

Fig. 3 The simulation damage cloud chart of specimens

3.3 Finite element simulation analysis of impact resistance

Fig.4 represents the relationship between the impact force and time. The ability of three specimens to withstand impact is decreasing. When the impact time is less than 8 times, the curves almost coincide. When the impact time is greater than 8 times, the ability to withstand impact is Z12>Z8>Z0. Since the elastic modulus of the waste fibers is lower than that of the recycled concrete, the impact force of the steel ball on the recycled concrete slab is mainly borne by recycled concrete before the initial crack, and the impact force is mainly consumed by the waste fibers after the specimen is cracked.

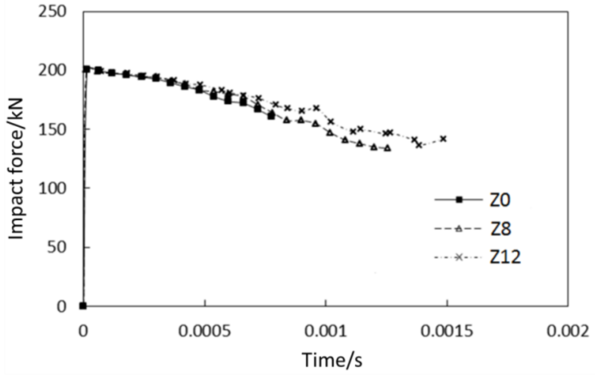


Fig.4 The impact-time curve

The points on the curves in Fig.5 represent the relationship between the maximum logarithmic strain at the bottom center of the specimen and the number of impact time during each impact process. The logarithmic strain of the three specimens fluctuates at the beginning of the initial crack, and then increased linearly until the final crack of the specimens. The logarithmic strain value of Z0 is always greater than Z8 after being impacted 9 times by the steel ball. After the 14 times impact of the steel ball, the logarithmic strain value of Z8 has been greater than Z12. This shows that waste fibers can play a role in cracking and delaying the deformation of recycled concrete matrix.

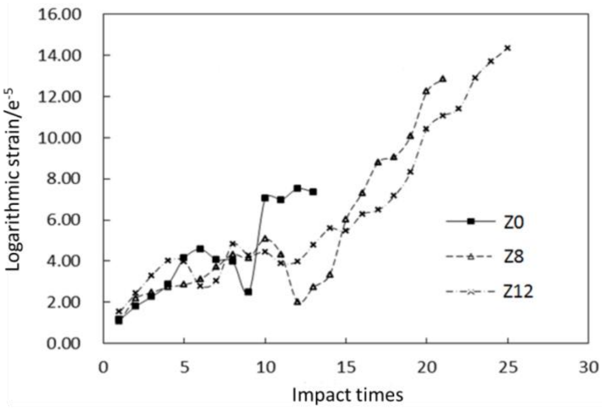


Fig. 5 The logarithmic strain-impact time curve

Fig.6 describes the number of hits needed for three specimens to reach the initial and final crack. The initial crack frequency of Z0 is 10 times and the final crack impact time is 13. The initial crack frequency of Z8 is 17 times and the final crack impact time is 21. The initial crack frequency of Z12 is 21 times and the final crack impact time is 25 times. The results show that the impact resistance of recycled concrete is greatly improved by the addition of fibers, which are consistent with the previous conclusion.

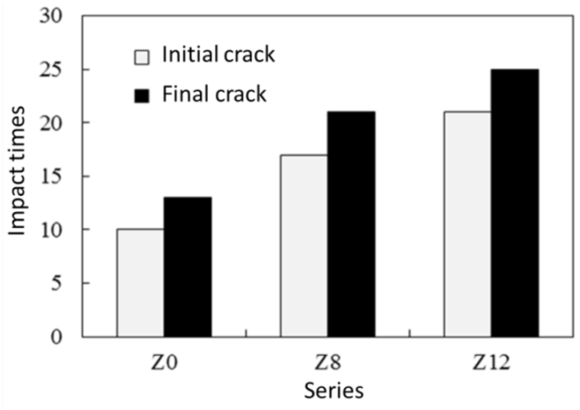


Fig.6 Impact time of initial and final crack

4. CONCLUSIONS

(1) The incorporation of waste fibers can delay the formation and propagation of cracks. With the increase of fibers volume incorporation, the number of cracks increases continuously, while the average crack width decreases when the specimen is damaged. The addition of waste fibers makes the stress distribution of recycled concrete gradually uniform.

(2) When the waste fiber recycled concrete slabs are impacted, the impact force in the early stage is mainly undertaken by recycled concrete, and the maximum impact force of the specimen is almost the same under the different volume fraction of waste fibers.

(3) The greater volume fraction of waste fibers is, the greater the deformation will be when the specimen destroyed. The addition of waste fibers improves the impact resistance of recycled concrete slabs effectively.

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