Finite Element Analysis of Waste Fiber Recycled Concrete Slab

Jinghai Zhou[a], Dongye Lin[b], Li Zhao[c], Junwen Lu[d]

School of Civil Engineering, Shenyang Jianzhu University, Shenyang 110168, China.

[a]476088880@qq.com, [b]892864880@qq.com, [c]2993052817@qq.com, [d]656360596@qq.com

Keywords: waste fiber; recycled concrete slab; finite element; loading capacity

Abstract: To study the mechanical properties of waste fiber recycled concrete slabs, four pieces of the specimens were designed and simulated by the finite element analysis software. The design variables were the replacement ratio of recycled aggregates and the volume of waste fibers. The static load tests were simulated under uniform load. We loaded the waste fiber recycled concrete slabs. Then the mid-span deflection of the specimens and steels strain were compared and analyzed. The test results show that the addition of recycled aggregate reduces the loading capacities of the specimens, but the addition of waste fibers can not only effectively improve the mechanical properties of recycled concrete slabs, but also make the concretes and steels produce better-coordinated deformation. And it can also improve the bonding between them. When the volume of waste fibers is 0.12%, the loading capacity of concrete slabs is the best.

1. Introduction

As urbanization construction accelerate and improve constantly in China, the production and demolition of building materials increase rapidly. For example, concretes are the one of the largest quantities of building materials. The increase in the use and demolition of concretes have a huge negative impact on urban development. It not only causes excessive consumption of territorial resources, but also causes environmental pollution. At present, China is vigorously advocating the conservation and reasonable utilization of resources. The problems of natural resources shortage and construction waste can be treated scientifically by the recycled concrete technology [1-2]. Several studies show that the performance of recycled concrete is worse than that of ordinary concrete, but the addition of waste fibers can compensate for the strength of recycled concrete and the performance of specimens. The concrete slabs are the one of the important components of structural specimens. If recycled concrete technologies are applied to concrete slab specimens, then resources will be utilized effectively. It is great significance for the future development of urbanization. It is found that [6-7] the mechanical properties of recycled concrete slabs decrease when the replacement ratio of recycled aggregates increases. Therefore, we can start from the structural properties of waste fiber reinforced concretes. The static load tests of four concrete slabs are simulated by finite element analysis software under uniform loads. The effects of the replacement ratio of recycled aggregates and the volume of waste fibers are mainly analyzed on the mechanical properties of recycled reinforced concrete slabs. It is hoped that waste fiber reinforced concretes can be applied to the future projects.

2. Design of Concrete Slab Model

Concrete mix proportion and cubic compressive strength are shown in Table 1. NC means natural concrete; RC-50 means that recycled concrete with the replacement rate of recycled aggregates is 50%; FRC-50-08 means that recycled concrete with the replacement rate of recycled aggregates is 50% and the volume of waste fibers is 0.08%; FRC-50-12 means that recycled concrete with the replacement rate of recycled aggregates is 50% and the volume of waste fibers is 0.12%.

Table 1. Concrete mix proportion and compressive strength in this test

Number	Water Cement Proportion	Mix proportion (kg/m^3)					Compressive Strength (MPa)
		Cement	Sand	Natural Aggregate	Recycled Aggregate	Water	
NC	0.5	390	709	1156	0	195	40.6
RC-50	0.5	390	709	578	578	205	37.7
FRC-50-08	0.5	390	709	578	578	205	37.9
FRC-50-12	0.5	390	709	578	578	205	38.7

Four unidirectional slab specimens were made by the simulation. The specimens were designed according to the Code for Design of Concrete Structures (GB50010-2010). The reinforced steels are made of HRB400 hot-rolled ribbed reinforced steels as shown in Fig.1.The thickness of the specimens is 60 mm. The thickness of the protective layers is 15 mm. The size of the specimens is 2400 mm *1600 mm. The span of the axis is 2000 mm and the boundary conditions are fixed on both sides [8].

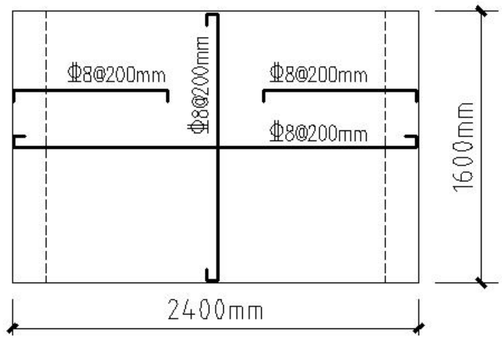


Figure 1. Specimen size and reinforcement

3. Constitutive Model of Materials

(1) Constitutive model of ordinary concrete

The constitutive relation of ordinary concretes under compression is proposed by Sargin's curve [9]:

$$\sigma = k_3 f_c \cdot \frac{A \cdot \frac{\varepsilon}{\varepsilon_O} + (D-1)(\frac{\varepsilon}{\varepsilon_o})^2}{1+(A-2)\frac{\varepsilon}{\varepsilon_O} + D(\frac{\varepsilon}{\varepsilon_O})^2} \tag{1}$$

The constitutive relation of ordinary concretes under tension is proposed by Rein-hardt's exponential descent formula [10]:

$$\frac{\sigma}{f_t} = \left[1 + c_1(\frac{\varepsilon}{\varepsilon_t})^4\right] e^{-c_2 \cdot \frac{\varepsilon}{\varepsilon_f}} \tag{2}$$

(2) Constitutive model of recycled concrete

The constitutive relation of recycled concretes under compression is proposed by Professor Xiao Jianzhuang[10] :

$$y=\begin{cases} 1.830x+0.834x^2-0.917x^3 & 0 \le x<1 \\ \frac{x}{7.032(x-1)^2+x} & 1 \le x \end{cases} \tag{3}$$

The rising curve of the constitutive relation of recycled concretes under tension is proposed by Professor Xiao Jianzhuang [10]:

$$y = 1.26x - 0.26x^3 \quad (4)$$

(3) Constitutive model of waste fiber recycled concrete

The constitutive relation of waste fiber recycled concretes is proposed by Professor Zhou Jinghai[11] :

$$y = \begin{cases} \dfrac{Kx - x^2}{1 + (K-2)x} & 0 \le x \le 1 \\ \dfrac{x}{a(x-1)^2 + x} & x \ge 1 \end{cases} \quad (5)$$

At present, there is only a little research about the constitutive model of waste fiber reinforced concretes under tension, so the author has not found the constitutive models suitable for this simulation. Therefore, constitutive model of ordinary concretes is adopted under tension.

(4) Constitutive Model of Reinforced Steel

In the process of simulation, because reinforced steels are not the main factor, they adopt a simple double-fold constitutive model. The stress and strain relationship of reinforced steels is an oblique line in the elastic stage. It is a smooth oblique line after reinforced steels are yielded. It can speed up the simulation. The constitutive model of reinforced steels likes these:

$$\sigma_s = E_s \varepsilon_s \qquad \varepsilon_s \le \varepsilon_y$$
$$\sigma_s = f_y + E_s'(\varepsilon_s - \varepsilon_y) \qquad \varepsilon_y \le \varepsilon_s \le \varepsilon_u \quad (6)$$

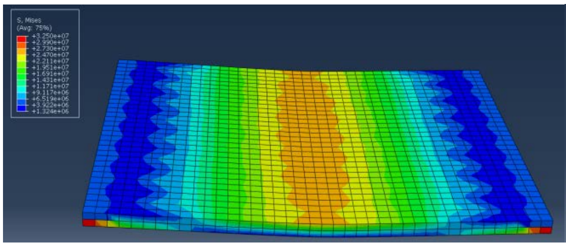
4. Finite Element Analysis of Concrete Slab

4.1 Establishment of Model

Stress analysis of concretes is complex. Now, ABAQUS is used to analyze by the most simulation tests of concrete specimens. According to the constitutive model of concretes and reinforced steels, the material properties are defined. In the process, the model is established by the finite element software. The concretes adopt the hexahedral element and obey the small deformation theory. And they do not consider the influence of shrinkage and creep. Therefore, the concretes are not considered as anisotropic material when the constitutive model of concretes is set up. Because the simulation mainly considers the stress of waste fiber recycled concretes, the meshing of concretes is more compact. The reinforced steels adopt the truss element. In addition, the reinforced steel elements are consistent with the concrete elements on the deformation. “Embedded” is used to simulate the slip contact between concretes and reinforced steels in ABAQUS.

According to the actual test device, displacement constraints of six directions are applied at both ends of the specimens. Both ends of the unidirectional slabs are simulated as the fixed constraints. The uniform loads are applied to the top of the concrete slabs. It can simulate the positive monotonic loading mode in the real test. The stress of the concrete slabs in the simulation is like the slabs in the actual test.

To see the deformation of the specimens more intuitively, the deformation is expanded by three times. It can be found that the damage mainly concentrates on the upper surface of the slabs and the mid-span of the bottom of the slabs. The concrete slabs of the upper surface of the slabs are tensed. The concrete slabs of the mid-span of the bottom of the slabs are also tensed. It is consistent with the phenomena in the test. Before the specimens withdraw, the stress nephograms of the concrete slabs and reinforced steels frame are shown in Fig. 2 and Fig. 3.



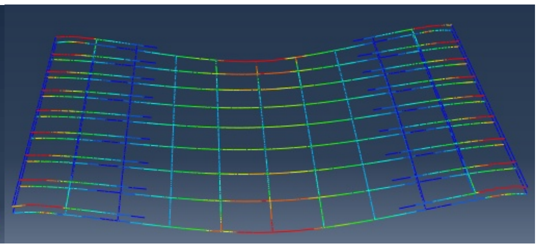
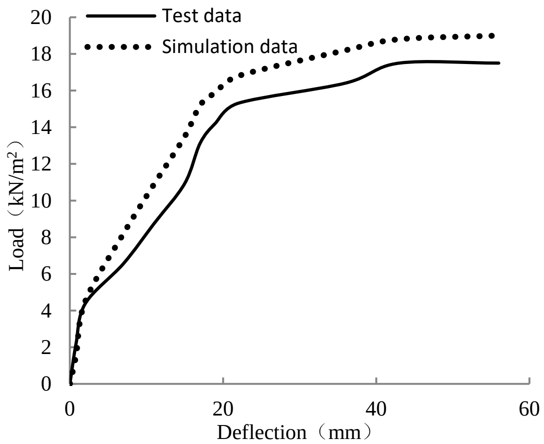


Figure 2. Upper surface stress nephogram on slab   Figure 3. Reinforced steel stress nephogram

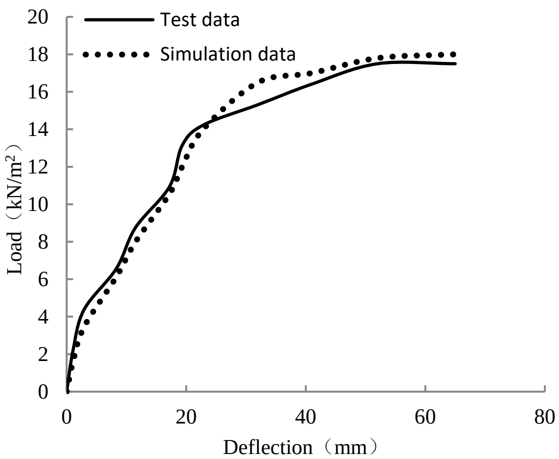
4.2 Analysis of Finite Element Results

4.2.1 Analysis of Load and Deflection Curve of Concrete Slab

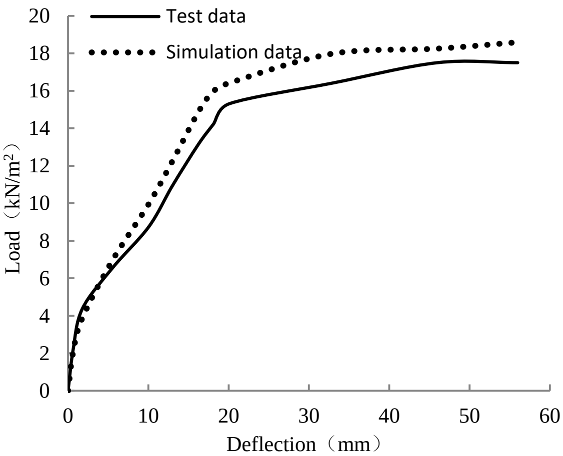
The mid-span load and deflection curve of concrete slabs are simulated by test and software under static load, as shown in Fig.4.The mid-span deflection of concrete slabs increases with the load, and the trend is generally similar. The main changes are linear, curve and gentle stages, but the final changes are different. In the gentle stage, the limit mid-span deflection of RC-50 is the largest under the same load. The deflection is about 60-65 mm. The limit mid-span deflection of NC-50 is minimum. The deflection is about 45 mm. The limit mid-span deflection of FRC is about 50-55 mm. At the same time, the cracking loads of four concrete slabs are about 4.375kN/m2. In terms of loads, the limit load of NC-50 is the largest, reaching 11.56kN/m2. The limit load of RC-50 is about 10.31kN/m2.However, the limit load of waste fiber recycled concrete slabs is better than recycled concrete slabs which is about 10.78kN/m2. And the limit load of FRC-50-12 is slightly larger than FRC-50-08. It shows that recycled aggregates will have a negative impact on the mechanical properties of the specimens. The conclusion is the same as the references [3-5], but the volume of waste fibers will enhance the mechanical properties of specimens. When the volume of waste fibers is 0.12%, the load of concrete slabs is the best.



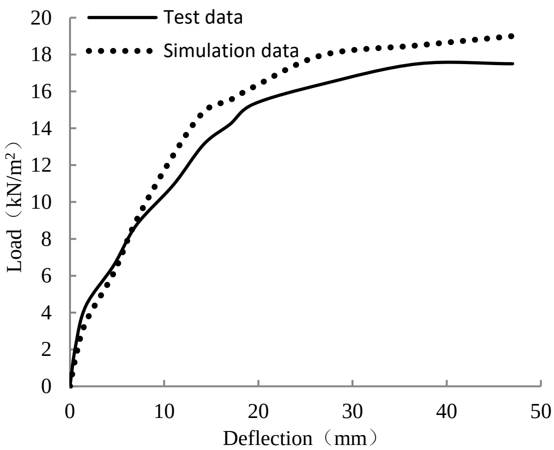
NC-0



RC-50



FRC-50-08



FRC-50-12

Figure 4. Load and deflection curve of the mid-span

4.2.2 Analysis of Load and Strain Curve of Reinforcement Steel

The load and strain curve of reinforced steel is simulated by test and software under static load, as shown in Fig.5. The strain of reinforced steel concrete slabs increases with the load, and the trend is generally similar. The main changes are linear, curve and gentle stages, but the strain changes are different. When the tensile reinforced steels of NC and RC reach the limit state, the strain is about 4000$\mu\varepsilon$. But the strain is about 3000$\mu\varepsilon$, when the tensile reinforced steels of FRC reach the limit state. It can be found that the effect of waste fibers is obvious, because it plays the role of additional reinforced steels.

The yield load of reinforced steels is approximately 6.25kN/m2. And the strain of reinforced steels is almost the same, which is about 500$\mu\varepsilon$.It shows that the concretes and steels produce have better-coordinated deformation. And they can resist internal force together. The effect of waste fibers is not obvious before the reinforced steels yield. When the reinforced steels reach the limit state from the yield state, the load of RC-50 is minimum and the load of FRC-50-12 is maximum under the same strain. It shows that the addition of recycled aggregates reduces the loading capacities of the specimens, but the addition of waste fibers can not only effectively improve the mechanical properties of recycled concrete slabs, but also make the concretes and reinforced steels have better-coordinated deformation and improve the bonding between them. When the volume of waste fibers is 0.12%, the loading capacity of concrete slabs is the best.

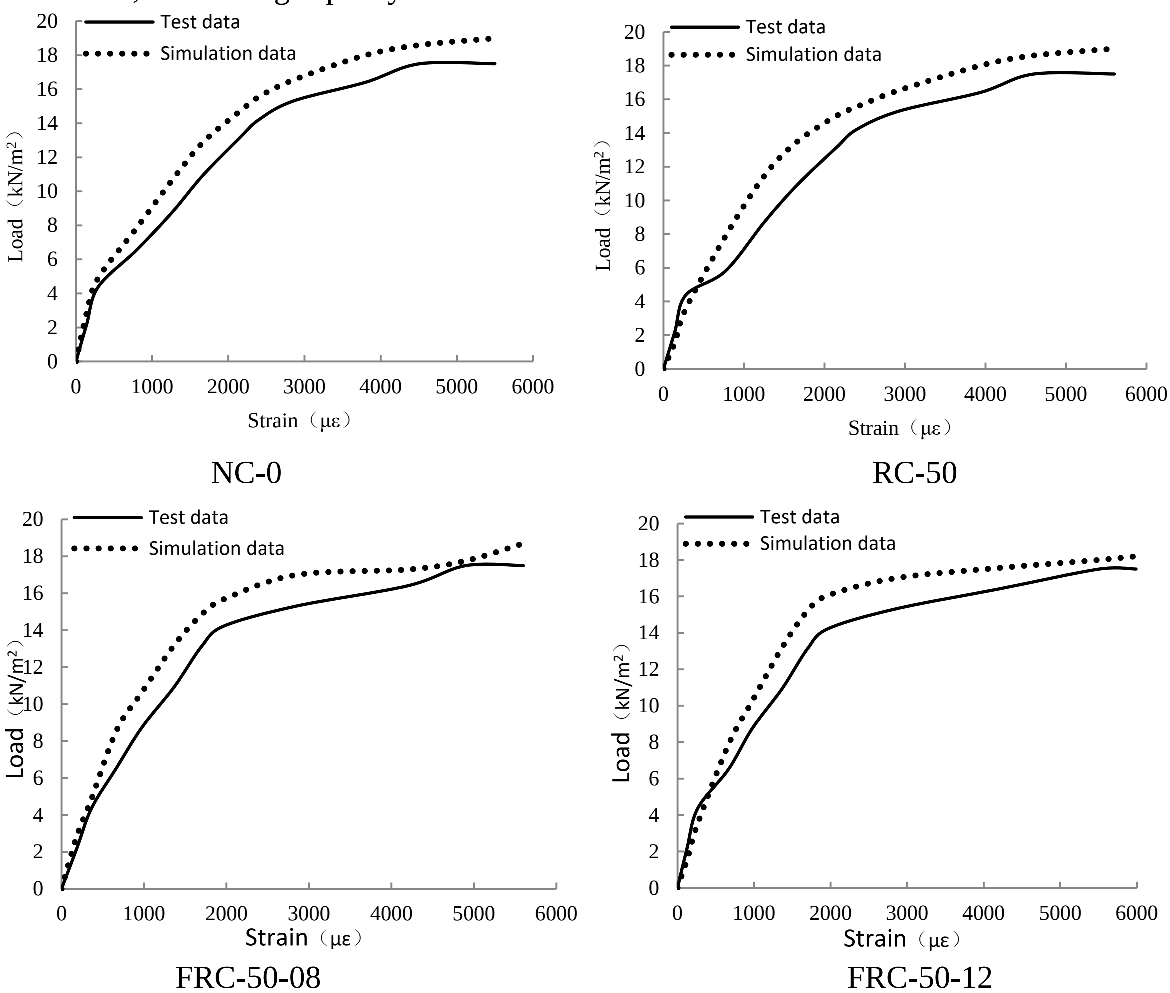


Figure 5. Load-strain curve of steel reinforcement in the span

5. Conclusion

(1) The mid-span load and deflection curves of concrete slabs are generally similar. The load of

FRC is slightly lower than the load of NC. Compared with the load of RC, the load increases by 4.5%. When the volume of waste fibers is 0.12%, the load of concrete slabs is the best.

(2) The load and strain curves of reinforced steels are generally similar. The addition of recycled aggregates reduces the loading capacities of the specimens, but the addition of waste fibers can effectively improve the mechanical properties of recycled concrete slabs. When the volume of waste fibers is 0.12%, the loading capacities of concrete slabs are the best.

(3) The simulation results are in good agreement with the experimental results. Therefore, the simulation method can be used to calculate the loads of waste fiber recycled concrete slabs. At the same time, as an environmental building material, waste fiber recycled concretes are worth applying in future projects.

Acknowledgements

This work is supported by the fund of Nation Natural Science Foundation of China (Grand No. 51678374). The financial support is gratefully acknowledged.

References

[1] Xiao Jianzhuang. Recycled concrete [M]. Beijing: China Architecture & Building Press, 2008:7–15.

[2] Du Ting, Li Huiqiang, Wu Xianguo. Current research on recycled concrete and problems needed to resolve

[3] Architecture Technology, 2003, 34(2): 133–135.

[4] Omary S,Ghorbel E,Wardeh G. Relationships between recycled concrete aggregates characteristics and recycled aggregates concretes properties [J].Construction and Building Materials,2016,108:163–172.

[5] Zhang Wenjiao, Bao Chengcheng, Kong Xiangqing, et al. Experimental study on mechanical properties of hybrid fiber basic of recycled concrete [J]. Technology and Engineering, 2016, 16(13): 106–114.

[6] Carneiro J A, Lima P R L, Leite M B, et al. Compressive stress-strain behavior of steel fiber reinforced- recycled aggregate concrete [J]. Cement and Concrete Composites,2014,46(4): 65–72.

[7] Liu Maojun, Wang Genwei. Experiment on flexural bearing capacity of recycled aggregate concrete hollow slbs [J]. Science Technology and Engineering, 2015, 15(5): 293–310.

[8] Yazdi M A, Motaghi S, Yang J. The effect of concrete containing recycled concrete aggregate and crushed clay bricks on slab under dynamic loading [J]. Key Engineering Materials,2015(629-630): 330–336.

[9] Zhou Jinghai, Kang Tianbei, Wang Fengchi, et al. Bearing capacity of waste fiber recycled concrete slabs under uniformly distributed load [J]. Science Technology and Engineering,2019,19(1): 221–226.

[10] Jiang Jianjing, Lu Xinzheng, Ye Lieping. Finite element analysis of concrete structure [M]. Beijing: Tsinghua University Press, 2005.

[11] Xiao Jianzhuang. Experimental investigation on complete stress-strain curve of recycled concrete under uniaxial loading [J]. Journal of Tongji University, 2007, 34(13):1410–1443.

[12] Zhou Jinghai, Liu Dan, Dong Jianfei. Constitutive relationship of waste fiber recycled concrete [J]. Concrete, 2013(2): 54–58