Finite element analysis of flexural performance of self-compacting recycled concrete beams with FRP slag

Liu Yi, PEI Changchun*
Civil Engineering, School of Engineering, Yanbian University, Yanji 133002, China
*peicc@ybu.edu.cn

Abstract. In order to use glass powder steel slag recycled concrete in building structures, improve the recycling rate of industrial waste, and reduce environmental pollution, this paper replaces part of cement with glass powder and steel slag instead of some fine aggregates. The effect of glass powder steel slag is studied by ANSYS finite element simulation. Influence of self-compacting recycled concrete beams on flexural performance. The research result suggested: at the initial stage of cracking, the mid-span moment and mid-span deflection of C1, C2 and C3 groups of beams constructed with recycled concrete incorporating milled glass and steel slag were significantly improved compared with those of baseline group of beams and with increasing steel slag, their mid-span moment was not much changed but mid-span deflection was increased; at the yield stage, the mid-span moment and mid-span deflection of C1, C2 and C3 groups of beams constructed with recycled concrete incorporating milled glass and steel slag were significantly improved compared with those of baseline group of beams and were further increased with increasing steel slag.In this paper, the bending performance of the beam is best when 20% glass powder is used instead of cement and 80% steel slag is used instead of fine aggregate.

1. Introduction
In recent years, self-compacting concrete has been widely used in engineering due to its own weight, which can freely fill the formwork, and does not require vibrating during pouring. However, in order to obtain better fluidity and filling performance, self-compacting concrete needs more cement and fine aggregate than traditional concrete, which leads to serious environmental pollution and some resource shortage and exhaustion problems. In order to solve the above problems, many scholars have started a lot of research from the cement component and aggregate component of self-leveling concrete. For example, in 2019, Liu Leiming[1] studied the influence of waste glass powder admixture on the mechanical properties of concrete, and concluded that adding glass powder can improve the working performance of concrete and has good water retention. In 2020, Yang Zhenying [2] found that the tension-compression ratio of recycled concrete increased with the increase of glass powder content. The multi-angular characteristics of GP enhanced the bite force and bonding effect between the aggregate and the matrix, and improved Brittleness of recycled concrete. In 2019, Zhang Ping [3] studied the effect of replacing fine aggregate with steel slag on the performance of concrete, and concluded that when the replacement amount of steel slag is 50%, it can effectively improve the impermeability of concrete without causing concrete stability problems. However, most of the above studies are related to the basic properties of concrete materials that are single or mixed with glass powder or steel slag, and there are
few studies on the performance of concrete structural members. The general concrete structure is easily affected by its own composition, and its stress condition also changes complicatedly with the change of the composition. Therefore, the application of FRP slag recycled concrete structural components needs further research.

In order to use glass powder and steel slag recycled concrete in building structures, improve the recycling rate of industrial waste, and reduce environmental pollution, this paper replaces part of cement with glass powder and steel slag instead of some fine aggregates. The influence of glass powder and steel slag on the flexural performance of self-compacting recycled concrete beams was studied by ANSYS finite element simulation.

2. Test plan design
In this paper, the concrete without glass powder and steel slag is used as the reference concrete, and 20% (relative to the mass percentage of cement) glass powder is added to the reference concrete, and the steel slag mixing rate is changed to 40%, 60%, 80% (relatively fine Aggregate mass percentage) 4 groups of beams are designed, and ANSYS finite element simulation is performed on the 4 groups of beams to analyze the initial cracking load and mid-span deflection of the beams, the load under the yield state, and the mid-span deflection. In this paper, the 4 groups of beams are all 1500mm long, the net span is 1200mm, and the cross-sectional size is 120mm×180mm. Selection of longitudinal tensile steel bars in beams 2C22, the reinforcement level is HRB400, Reinforcement rate is 3.51%; compression steel bars are selected 2C16, Rebar grade is HRB400, stirrups are selected 2B8 HRB335 steel bar, the elastic modulus of steel bar is 200GPa.

Table 1. Parameters of specimen

| Specimen number | Glass powder mixing rate (%) | Steel slag mixing rate (%) | Tensile steel | Cube compressive strength Test value (MPa) | Elastic Modulus (MPa) |
|-----------------|-----------------------------|---------------------------|---------------|-----------------------------------------|----------------------|
| C0              | 0                           | 0                         | 2C22          | 21.3                                    | 23000                |
| C1              | 20                          | 40                        | 2C22          | 22.5                                    | 24480                |
| C2              | 20                          | 60                        | 2C22          | 23.4                                    | 26100                |
| C3              | 20                          | 80                        | 2C22          | 23.9                                    | 26751                |

3. Finite element simulation
In this paper, because the compressive capacity of recycled high-strength concrete is far greater than the tensile capacity, the SOLID65 element is selected, and the longitudinal and stirrups are all LINK8 rod elements. Since there are few domestic experimental studies on the constitutive relationship of basic magnesium sulfate cement concrete, this paper uses the stress-strain curve equation proposed by Professor Guo Zhenhai, and the concrete Poisson's ratio is 0.25. The reinforcement in the beam in the finite element simulation analysis adopts the bilinear BGIN follow-up strengthening model, and the corresponding parameters are determined according to GB50010-2010 "Specification for Design of Concrete Structures", and the Poisson ratio of the reinforcement in the beam is 0.3. The relationship between stress and strain is linear before concrete cracking and crushing during compression, while the William-Warnke failure criterion is used after cracking and crushing. And the complete Newton-Raphson equilibrium iteration is used for nonlinear solution.
4. Finite element simulation results and analysis

4.1 Analysis of mid-span bending moment and deflection of beam during initial cracking

4.1.1 Stress cloud diagram and mid-span bending moment of beam during initial cracking

Figure 1 is a stress cloud diagram of a recycled concrete beam with FRP slag during initial cracking. It can be seen from the figure that the maximum compressive stress in all beams in the initial cracking stage occurs on the upper surface of the mid-span area of the beam. Among them, the maximum compressive stress of the recycled concrete beam C0 of the benchmark group is 0.854MPa. With the incorporation of glass powder steel slag, the maximum compressive stress of the concrete of each test group is between 0.854 and 0.885, and the concrete stress of the C3 group reaches the maximum. The maximum compressive stress of the concrete is 3.63% higher than that of the C0 beam. This is because with the incorporation of glass powder and steel slag, the strength of recycled concrete increases, and the maximum compressive stress also increases.

![Stress cloud diagram of recycled concrete beams](image1)

Figure 1. Stress nephogram of glass powder steel slag recycled concrete beam at initial cracking.

![Mid-span bending moment diagram](image2)

Figure 2. Mid span bending moment diagram of recycled glass fiber reinforced concrete beams with initial cracking.
Figure 2 is the mid-span bending moment diagram of the FRP slag recycled concrete beam during initial cracking. It can be seen from the figure that the mid-span bending moment of the recycled concrete beam C0 of the benchmark group is 1.572KN·m. When glass powder and steel slag are mixed, the initial cracking moment of C1 beams is 2.494KN·m, which is greatly improved compared with the initial cracking moment of C0 beams. With the increase of steel slag mixing rate, the initial cracking moments of beams C2 and C3 group beams were 2.567 KN·m and 2.585 KN·m, respectively, which did not change much.

4.1.2 Analysis of beam deflection during initial cracking

Figure 3 is a diagram showing the mid-span deflection of a recycled concrete beam with FRP slag during initial cracking. First, the mid-span deflection of the reference group C0 beam is 0.133mm. With the incorporation of glass powder and steel slag, the mid-span deflection of C1, C2, and C3 beams are 0.206mm, 0.198mm, and 0.196mm, respectively, which is greatly improved compared to the deflection of the reference beam. This is because glass powder exerts the pozzolanic effect and filling effect in the gelling system [4], forming more stable hydrated calcium silicate and other hydrated products, thereby improving the microstructure of the slurry and increasing the strength of the concrete. At the same time, the tiny particles in the steel slag can fill the pores in the cement paste. As time goes by, some of the active ingredients in the steel slag are hydrated, which improves the microstructure of the concrete, thereby increasing the later strength.

![Figure 3. Mid span deflection diagram of recycled glass fiber reinforced concrete beams with initial cracking.](image)

4.2 Analysis of mid-span bending moment and deflection of beam under yielding state

4.2.1 Stress cloud diagram and mid-span bending moment of beam in yield state

Figures 4 and 5 are respectively the stress cloud diagram and the mid-span bending moment diagram of the FRP slag recycled concrete beam in the yielding state. It can be seen from the figure that the maximum compressive stress in all beams in the yield stage occurs on the upper surface of the mid-span area of the beam. Among them, the mid-span bending moment of the recycled concrete beam C0 of the benchmark group is 10.134KN·m. When glass powder and steel slag are mixed, the bending moment of the C1 group beams under the yield state is 11.088KN·m, which is slightly higher than that of the C0 group beams under the yield state. With the increase of the steel slag mixing rate, the mid-span bending moments of beams C2 and C3 in the yield state are 11.883KN·m and 12.329KN·m respectively, which have a slight increase.
4.2.2 Analysis of beam deflection under yielding state

Figure 6 is a diagram showing the mid-span deflection of a recycled concrete beam with FRP slag in a yielding state. First, the mid-span deflection of the beams in the reference group C0 is 1.555mm. With the incorporation of glass powder and steel slag, the mid-span deflection of C1, C2, and C3 beams are 1.676mm, 1.754mm, and 1.831mm, respectively, which is slightly improved compared to the deflection of the reference beam. This is because with the increase of the glass powder content, the pozzolan effect and filling effect are exerted in the cementing system, resulting in the increase of concrete strength. At the same time, the steel slag block is loose and non-bonded, the texture is relatively dense, the internal structure is complete \cite{5}, and it has a honeycomb shape and high porosity \cite{6}, which can effectively improve the microstructure of the paste and increase the strength of the concrete.
5. Conclusion and Outlook
In this paper, ANSYS finite element simulation analysis is used to study the effects of initial cracks, mid-span bending moment and deflection of self-compacting recycled concrete beams using glass powder and steel slag. Research indicates:

(1) First, at the initial cracking stage, the mid-span moment of C1, C2 and C3 groups of beams constructed with recycled concrete incorporating milled glass and steel slag were significantly improved compared with that of baseline group of beams but was not much changed with increasing steel slag; the mid-span deflection of C1, C2 and C3 groups of beams constructed with recycled concrete incorporating milled glass and steel slag was significantly improved compared with those of baseline group of beams but was slightly reduced with increasing steel slag.

(2) In the yielding stage, with the incorporation of glass powder and steel slag, the mid-span bending moment and mid-span deflection of the C1, C2, and C3 recycled concrete beams when yielding are both greater than the reference beams, and with The increase of steel slag content all tends to increase. This paper mainly uses finite element analysis software to study the flexural performance of self-compacting recycled concrete beams, which provides a theoretical reference for the future experimental research on the flexural performance of self-compacting recycled concrete beams.

Acknowledgment
Fund Project: First-class undergraduate professional construction project of Yanbian University (Yanbian University Jiaofa [2020] No. 16)

Author
Liu Yi (2000—), female, from Changchun, Jilin Province, undergraduate student. The main research field is concrete theory and application;

Corresponding author: Pei Changchun (1976-), male, Yanji City, Ph.D., lecturer, master tutor, the theory and application of concrete main research areas; peicc@ybu.edu.cn.

References
[1] Liu,L Experimental study on the influence of waste glass powder admixture on the mechanical properties of concrete [D]. Zhongyuan Institute of Technology, 2019.
[2] Yang,Z.Y, Zhou,C.S. The influence of glass powder on the mechanical properties of recycled concrete[J]. Bulletin of the Chinese Ceramic Society, 2020, 39(12): 3874-3880.
[3] Zhang,P, Ning,J,M, Chen,X and Gu,L.L. The effect of steel slag replacing fine aggregate on concrete properties[J]. Commercial Concrete, 2019(04): 68-71.
[4] Liu,S.H, Wu,M,Q and Gao,Z.Y. Research on the application of waste glass powder in reactive powder concrete[J]. Concrete, 2019(07): 125-127.
[5] Zhang,Z.H, Jiao,Z.Y, Ju,J,T and Lu,H.H. Analysis of physical chemistry and mineral properties of converter steel slag[J]. Iron and Steel, 2011, 46(12): 76-80.
[6] TAKAHASHI T, YABUTA K. *New applications for iron and steelmaking slag* [J]. Nkk Technical Review, 2002(87): 38-44.