DOI: 10.23977/jceup.2023.050405
ISSN 2616-3969 Vol. 5 Num. 4

Experimental Study on Fracture Energy of Graphene Oxide Recycled Concrete

Kai Guo*, Mingzhe Zhang

School of Civil Engineering, Shenyang Jianzhu University, Shenyang, Liaoning, China
**Corresponding author*

Keywords: Graphene oxide, recycled concrete, fracture property, three-point bending method

Abstract: To explore the effects of the replacement rate of recycled aggregate, the content of graphene oxide (GO) and GO oxygen content on the fracture performance of recycled concrete (RC). In this paper, three point bending method was used to study the fracture property of GO-RC. The results show that the use of recycled aggregate will reduce the fracture property of RC, and the fracture property of RC will gradually improve with the increase of GO content. With the same amount of GO, the strengthening effect of 20% GO with oxygen is better than 40% GO with oxygen. The fracture energy and fracture toughness increase with the addition of GO, so GO plays an important role in improving the fracture performance of RC.

1. Introduction

Along with the rapid development of economy and urbanisation, China produces a large amount of waste concrete every year from old buildings. The crushing of waste concrete as recycled aggregates can deal with both the problem of natural aggregate resource scarcity and the air pollution of urban waste, so it can be seen that the reuse of waste concrete has very obvious socio-economic benefits. The reuse of waste concrete is the best solution for the disposal of construction waste, saving resources and protecting the environment, which is of great significance for the reuse of construction waste in China [1]. Compared to natural aggregates the basic mechanical properties of recycled aggregates have a large difference. It is characterised by its low density, high water absorption and poor solidity [2]. At this stage, many scholars in China have carried out in-depth research on the basic mechanical properties of RC, from which it was found that the tensile strength, modulus of elasticity and splitting tensile strength of RC are reduced compared with natural aggregate concrete [3].

The introduction of the new nanomaterial GO into RC is a fusion of traditional technology with new materials. Many researchers have conducted numerous studies on GO incorporation into cementitious materials and found that the compressive strength and frost resistance of RC can be effectively improved along with the increase of GO incorporation [4-5].Fakhim Babak [6] in their experiments on the mechanical properties of GO cementitious composites clearly suggested that GO can promote the generation of C-S-H gels in the hydration products of cement. Snigdha Sharma [7] observed the role of two GOs in cement hydration crystals and found that the GO with larger sheet size had a more significant modulating effect in the hydration crystals.

It is evident from the current study that there are more studies on the compressive strength and frost resistance of GO-RC, but there is still a lack of research on the fracture properties of GO-RC. Therefore, this paper focuses on the effects of recycled aggregate substitution rate, GO dosing and GO oxygen content on the fracture properties to provide an experimental basis for the application of GO-RC beams in specific engineering projects.

2. Test

2.1. Raw Material

Cement: Grade 42.5 ordinary Portland cement made by Conch Cement Co., LTD.

Coarse aggregate: Natural coarse aggregate is made of natural crushed stone, and the particle size is controlled between 5mm and 25mm. The reclaimed coarse aggregate is made of discarded C40 concrete members, which are artificially broken and screened to obtain the reclaimed coarse aggregate with a particle size of 5mm~25mm. Specific physical and mechanical property parameters are shown in Table 1.

Table 1: Physical and mechanical property parameters of coarse aggregate

Variety	Performance density(kg/m3)	Water absorption /%	crush index /%
NA	2674.3	0.7	6.42
RA	2539.2	2.3	16.3

Fine aggregate: natural river sand, controlled particle size range between 0.15mm~4.75mm.

GO: Shanghai Angxing Brand GO powder with 40% oxygen content, basic parameters are shown in Table 2.

Table 2: Basic parameters of 20% GO and 40% GO in oxygen content

Thicknes (nm)	Single sheet diameter (μm)	Stripping ratio (%)	oxygen content (Wt.%)	carbon content (Wt.%)
1	0.2~10.0	>95	40	56

Test of water: drinking water in general.

Test admixture: polycarboxylic acid water reducing agent powder, water reduction rate of 20%~40%.

GO dispersion: In this test, CJJ78-1 magnetic heating agitator was used to heat and stir the polycarboxylic acid superplasticizer, GO powder and water evenly at a rotational speed of 1500r/min for 10min. After that, JT-410HT ultrasonic cleaning machine was used for ultrasonic dispersion of the solution obtained after magnetic stirring. The heating temperature was controlled at 20°C, and the time of each dispersion was 20min. Finally, a good dispersing GO dispersing liquid was obtained.

2.2. Mix Ratio Design of Specimen

Table 3: Test the mix ratio

Specimen	concrete	pellets	gravel	recycled aggregate	water	GO
NC-0	432	698.6	1242	0	180	0
RN-0	432	698.6	621	621	180	0
RC-6	432	698.6	0	1242	180	0.2592
RC-4	432	698.6	0	1242	180	0.1728
RC-2	432	698.6	0	1242	180	0.0864
RC-0	432	698.6	0	1242	180	0

In this test, a total of 18 specimens were produced in 6 groups with 3 specimens in each group. The size of each group was 100×100×400mm, the mid-span prefabricated crack length was 30mm, and the seam width was 3mm. According to the GO content was 0, 0.02%, 0.04% and 0.06% of cement mass, the samples were numbered as RC-0, RC-2, RC-4 and RC-6. According to the substitution amount of RA was 0, 50% and 100%, the specimens were numbered as RC-0, RN-0 and NC-0; The default for unmarked oxygen content is 40%. The test mix is shown in Table 3:

2.2.1. Testing Program

The GO-RC beam meeting the test requirements was tested on the electro-hydraulic servo universal test machine with measuring range of 60kN. Before the start of the test to the specimen in preloading process, to ensure that the test load are not significantly affected by mutation test at the beginning of the final conclusion. In the test process, concentrated load is applied to the mid-span part of the beam specimen, and the loading form is displacement loading. The specimen slowly rises at the rate of 0.1mm /s until it reaches the maximum deflection value. The net displacement of the loading point is taken as the deflection value of the specimen. The load and deflection values are collected in real time by the computer data acquisition system. Three point bending test loading diagram is shown in figure 1:

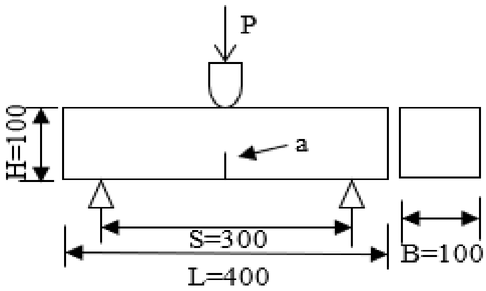


Figure 1: Schematic diagram of three-point bending test

2.2.2. Calculation of Fracture Energy and Fracture Toughness

Fracture energy is the main parameter to measure the performance of concrete materials [8]. In 1985, the International Association for Structural and Material Research and Experiments (RILEM) recommended the three-point bending beam method to calculate the fracture energy of concrete by measuring the load-deflection curve (P-δ) of precast slotted concrete beams [9-10]. RILEM proposes to test three-point curved beams with notch gaps under stable conditions, and to represent the concrete fracture energy by the energy consumed when the fracture surface is generated per unit projected area. In order to ensure that GO-RC beams can be used in practical engineering, it is necessary to test GO-RC beams with prefabricated cracks and determine their fracture energy. Fracture energy calculation method as shown in (1):

$$G_f = \frac{W_0}{A} + \frac{mg\delta_0}{A} \tag{1}$$

Wo: area under P-δ full curve; *δo*: the maximum displacement at the loading point of the specimen; *A*: ligament area; m: $m=m_1+m_2$, m_1 is the mass of the test piece between the two supports, m_2 is the mass of the additional piece placed on the test piece.

Fracture toughness measures the effect of material on the propagation of macroscopic crack instability, and the fracture toughness of three-point bending beam can better reflect its fracture resistance. In this paper, the GO-RC beam is calculated according to the calculation formula proposed by American Society for Materials and Testing (ASTM). The formulas are shown as (2) and (3):

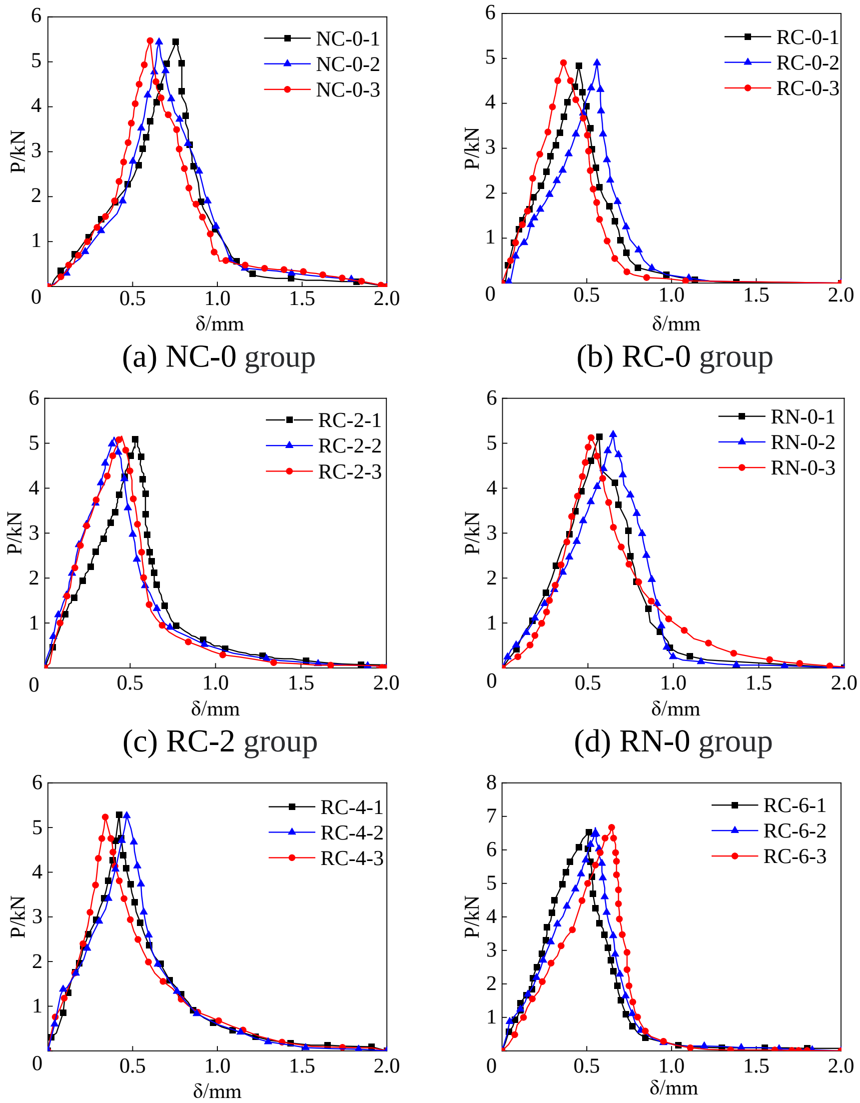
$$k_{IC} = \frac{P_{max} S}{bh^{\frac{3}{2}}} f\left(\frac{a_0}{h}\right) \tag{2}$$

$$f\left(\frac{a_0}{h}\right) = 2.9\left(\frac{a_0}{h}\right)^{\frac{1}{2}} - 4.6\left(\frac{a_0}{h}\right)^{\frac{3}{2}} + 21.8\left(\frac{a_0}{h}\right)^{\frac{5}{2}} - 37.6\left(\frac{a_0}{h}\right)^{\frac{7}{2}} + 38.2\left(\frac{a_0}{h}\right)^{\frac{9}{2}} \tag{3}$$

S: Span of three-point bending beam specimen; h: is the height of the specimen; b: thickness of specimen; *a*o: initial fracture length; Pmax: the maximum load obtained in the test;

2.2.3. Testing Result

The P-δ curves of 7 groups of RC-GO beams obtained by the test are drawn by origin software, as shown in Figure 2:



(a) NC-0 group (b) RC-0 group (c) RC-2 group (d) RN-0 group (e) RC-4 group (f) RC-6 group

Figure 2: P-δ curves of each group

2.2.4. Calculation Result

The mean values of fracture energy and fracture toughness of 7 groups of GO-RC beams were calculated by formulas (1), (2) and (3) in Section 1.4, as shown in Table 4:

Table 4: Fracture energy and average value of each group

Specimen number	Mean fracture energy	Mean fracture energy
NC-0	362.93	0.7814
RN-0	343.73	0.7434
RC-0	258.37	0.7030
RC-2	314.90	0.7405
RC-4	328.71	0.7583
RC-6-40%	380.20	0.9545
RC-6-20%	386.89	0.9920

2.2.5. Effect of Regenerated Aggregate Substitution Rate, GO Content, GO Oxygen Content on Fracture Performance

2.2.5.1. Effect of Replacement Rate of Regenerated Aggregate on Fracture Property

Figure 3 shows the effects of different replacement rates of regenerated aggregate on fracture energy and fracture toughness under the same GO content and GO oxygen content conditions.

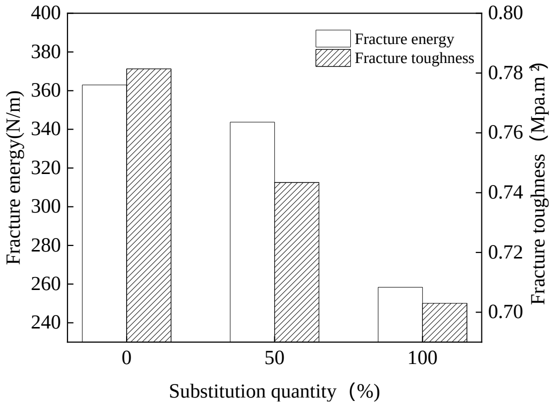


Figure 3: Relation between RC substitution and fracture energy

By comparing the fracture energy and fracture toughness of three groups of beam specimens with different replacement rates, it is found that the fracture energy and fracture toughness decrease when the replacement rate of regenerated aggregate is increased. Compared with the natural aggregate concrete, the fracture energy and fracture toughness of the reclaimed aggregate with the replacement rate of 50% decreased by 5.57% and 5.11%, respectively, and the decrease range of fracture energy and fracture toughness was basically the same. However, the fracture energy and fracture toughness decreased by 32.85% and 5.74%, respectively, when the fracture energy and fracture toughness were compared with 50% and 100%, and the decrease of fracture energy at this stage was much higher than that of fracture toughness. Therefore, it can be seen that the fracture energy and fracture toughness of regenerated aggregate decrease to some extent when the replacement rate is 100%, and the fracture toughness presents a linear decline trend, but the fracture energy decreases the most when the replacement rate is between 50% and 100%.

It is found from previous studies that [11] when the replacement rate of regenerated aggregate is 100%, the fracture energy of RC decreases by 27%. Compared with the concrete with natural aggregate as coarse aggregate, the reduction range of compressive strength and tensile strength of RC is smaller, and the reduction range of fracture energy and fracture toughness is larger. RC fracture energy is related to the reduction of fracture toughness and low compressive strength of recycled aggregate [12]. Compared with natural aggregate concrete, recycled concrete has lower compressive strength [2]. Therefore, the fracture energy and fracture toughness in this paper are inversely proportional to the aggregate substitution rate and related to the low compressive strength of recycled concrete.

2.2.5.2. Effect of GO Content on Fracture Performance

Figure 4 shows the effects of different GO dosage on RC fracture energy and fracture toughness when the replacement rate of regenerated aggregate and GO oxygen content are the same.

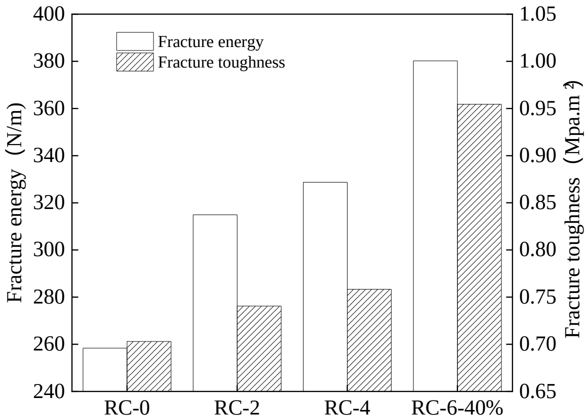


Figure 4: Relationship between GO content and fracture energy

By comparing the four groups of data with different GO content, it can be seen that the fracture energy and fracture toughness of RC gradually increase with the increase of GO content. When GO content increased from 0 to 0.02 %, the mean fracture energy and fracture toughness of RC increased by 21.8% and 5.33%, and the increase of fracture energy was more obvious. When GO content is 0.04%, the mean fracture energy is 328.71N/m, which is higher than that when GO content is 0.02% is 314.90N/m, and the mean fracture energy of the control group without GO is increased by 27.22%. However, when GO content is 0.04%, the fracture toughness of the control group is 7.86% higher than that of the control group without GO, and the fracture toughness is lower than the increase of fracture energy. When GO content is 0.06%, the fracture energy is increased by 49.83% and the fracture toughness is increased by 36.19% compared with the control group without GO. In this case, the improvement effects of fracture energy and fracture toughness are similar.

It is found from related studies that the decrease of RC fracture property [11] is due to the increase of porosity when the content of recycled aggregate increases. In addition, it has been found in numerous GO studies that GO can repair micro-cracks in the internal structure of cement-based raw materials by virtue of its high toughness, which can significantly reduce the pore size of cement matrix and thus improve the mechanical properties of cement-based materials [12-13]. Therefore, the incorporation of GO reduces the micro-cracks in the internal structure of cement-based raw materials, reduces the porosity of RC, and improves the fracture performance accordingly.

3. Conclusion

(1) The increase of the replacement rate of recycled aggregate will reduce the fracture performance of concrete. When the recycled aggregate is completely used, the fracture energy is 40.46% lower than natural aggregate concrete, and the fracture toughness is 11.15% lower than natural aggregate concrete.

(2) The fracture energy and fracture toughness of recycled concrete are directly proportional to GO content. When GO content is 0.06%, the fracture energy and fracture toughness increase by 49.83%

and 36.19%, respectively.

Acknowledgements

This paper was supported by a project from the foundation "(LJKZ0565), Natural Science Foundation of Liaoning Provincial Education Department."

References

[1] Tang Xiaochun. Review of research status of recycled concrete in our country. Today Science and Technology, 2008 (16): 158-159.
[2] Li Jiabin, Xiao Jianzhuang, Sun Zhenping. Characteristics of recycled coarse aggregate and its influence on Properties of recycled concrete. Journal of Building Materials, 2004, (04): 390-395.
[3] Zhou Jinghai, He Haijin, Meng Xianhong, Yang Youzhi. Experimental study on basic Mechanical Properties of recycled Concrete. Journal of Shenyang Jianzhu University (Natural Science Edition), 2010, 26 (03): 464-468.
[4] Lei Bin, Zou Jun, Rao Chunhua, Fu Mingfu, Xiong Jingang, Wang Xingang. Experimental study on graphene oxide modification of recycled concrete. Journal of Building Structures, 2016, 37 (S2): 103-108.
[5] Guo Kai. Study on properties and Modification mechanism of Graphene oxide recycled concrete. Dalian University of Technology, 2021.
[6] Fakhim Babak, Hassani Abolfazl, Rashidi Alimorad, Ghodousi Parviz. Preparation and Mechanical Properties of Graphene Oxide: Cement Nanocomposites. The Scientific World Journal, 2014.
[7] Sharma, Snigdha, Kothiyal, N. C..Influence of graphene oxide as dispersed phase in cement mortar matrix in defining the crystal patterns of cement hydrates and its effect on mechanical, microstructural and crystallization properties. RSC Advances, 2015, 5 (65).
[8] X. -Z. Hu, F. H. Wittmann. Fracture energy and fracture process zone. Materials and Structures, 1992, 25(6).
[9] Tada H, Paris P C, Irwin G R. Determination of the fracture energy of mortarand concrete by means of three-point bend tests on notched beams. Materials and Structures, 1985, 18 (4).
[10] A. Hillerborg. The theoretical basis of a method to determine the fracture energy GF of concrete. Materials and Structures, 1985, 18 (4).
[11] Elhem Ghorbel, George Wardeh. Influence of recycled coarse aggregates incorporation on the fracture properties of concrete. Construction and Building Materials, 2017, 154.
[12] M. Casuccio, M.C. Torrijos, G. Giaccio, R. Zerbino. Failure mechanism of recycled aggregate concrete. Construction and Building Materials, 2007, 22 (7).
[13] Samuel Chuah, Zhu Pan, Jay G. Sanjayan, Chien Ming Wang, Wen Hui Duan. Nano reinforced cement and concrete composites and new perspective from graphene oxide. Construction and Building Materials, 2014, 73.