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Numerical Investigation of Fracture Behavior for Glass Fiber Composite Concretes

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Abstract. Waste aggregate-based composite cementitious materials preserve natural resources and reduce environmental concerns throughout green concepts. In this view, recycled waste aggregate-based concrete and its innovative design require advanced computational modeling techniques. Accordingly, this comprehensive and computational research is conducted to investigate the fracture behavior of notched glass fiber reinforced concrete beam modeled with finite element method. The impacts of substitution ratios of the waste on strains and crack opening displacements of validated beam models are investigated and argued.

Key words: Fracture behavior, Crack, Glass fiber, Composite concretes, CMOD, Numerical modelling.

1. Introduction

Concrete is the most widely used construction material in the world. The material performance of concrete meets engineering structure needs. The safety requirements, aesthetics, and durability are some factors for the selection of concrete as a building material in engineering. The application of innovative concrete types with improved durability properties ensures flexibility in product design and improves structural performance. Recycled waste-based composites are aimed to preserve natural resources, reducing health risks related to human and biotic components, recovering waste, resolving the problems of aggregate lack, and reducing environmental issues. Besides, recycling waste into building materials reduces the cost of building materials.

In this point, aggregates are valuable components of concrete with their superior properties such as high strength, dimensional stability, and high durability. However, the aggregate need persists due to rapid aboveground structures and infrastructure activities worldwide. The exploitation of aggregates creates today an ecological imbalance in several ways: biodiversity damage to the surrounding areas, coastal erosion, and rivers, water pollution by increasing turbidity and suspended solids, destruction of livelihoods populations dependent on pollution by dust, damaging the landscape, and generating waste in mines and processing sites (De Brito et al, 2013).

Waste creates significant environmental and economic problems in the world, particularly, glass and plastic bottles, tire waste, construction, and demolition waste are some of those wastes. The solution to the mentioned waste problem is to create a new generation of building materials using these types of waste. Several discussions and initiatives have already been taken to reduce the amount of produced waste and its recycling or reuse around the world. However, a widespread assessment is necessary before the use of waste as an aggregate in concrete.

The literature contains many examples of the use of waste materials replacing natural aggregates with fibers in concrete mixtures. Glass waste was used as a replacement for fine aggregates (Batayneh et al 2007; Arslan, 2016). In addition, glass waste is used in concrete mixes and aesthetically in masonry, which can give a shiny clean finishing effect on the surface of the concrete product (Batayneh et al 2007). Also, a study on the effect of low glass sand was conducted (Marcin et al 2020) and aimed to determine the material and mechanical properties. (Prasad et al, 2019; Parmar et al, 2021) studies concluded that the addition of fibers in plain concrete will control the cracking due to shrinkage and also reduce the bleeding of water. fibers help to improve the post-peak ductility performance, pre-crack tensile strength, fatigue strength, impact strength, and eliminate temperature (Prasad et al, 2019). Previous test results significantly contribute to the possibility of using post-consumer glass in mortar and concrete, thereby reducing landfills.

Fiber-reinforced concrete is used to avoid corrosion in civil structures, it is better suited to minimize cavitation/erosion damage in structures such as sluiceways, navigational locks, and bridge piers where high-velocity flows are encountered (Prasad et al, 2019).

Composite Fiber Concrete is like high-performance concrete, which provides high strength, high durability, and high structural integrity compared to conventional concrete because of glass fiber (Parmar et al, 2021).

The present study aims to investigate numerical simulations of notched beams made of recycled waste glass fiber reinforced concrete with waste aggregate. A validated model is used, and results are argued.

2. Modelling approach

2.1. Beam model and geometry

In this section, numerical analysis was conducted and validated with the research of Arslan (Arslan, 2016). Arslan carried out three-point bending tests on notched beams with 480x100x50 mm (Figure 1), and the beams included glass fibers (GF) at 0.5, 1, 2, and 3 kg/m3. The study provided valuable data on fracture energy and mechanical properties, and the results of the fibers and concrete are presented in Table 1 and Table 2 below.

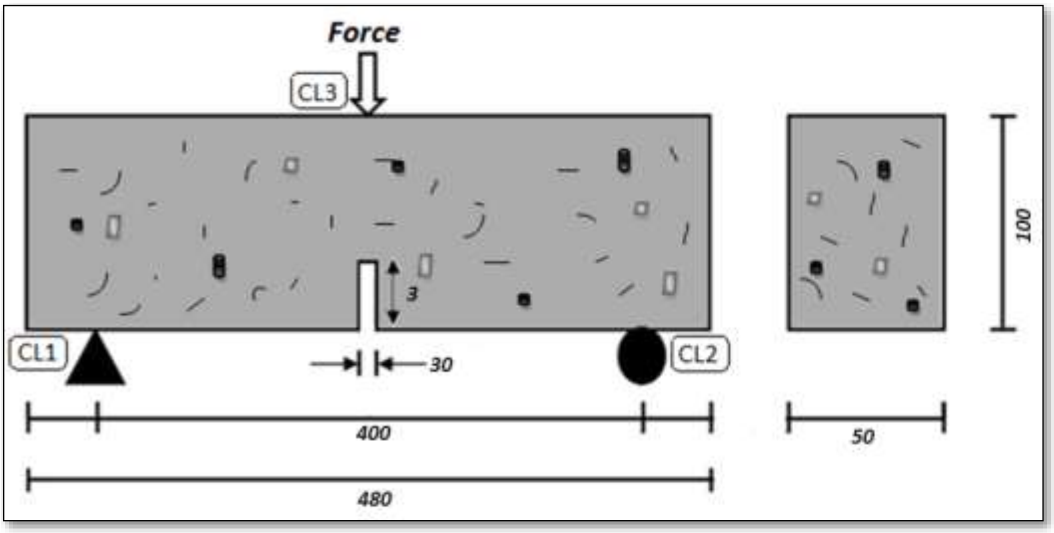

Fig 1. Geometry of the beam specimen.

TABLE 1. Mechanical Properties and Fracture Energy Values of the Specimens (Arslan, 2016).

Mechanical characteristics Waste aggregate %	E (GPa)	Gf (N/m)	Fc (MPa)	Ft (MPa)
GF 0.5	33.70	73.55	45.59	3.79
GF 1.0	33.90	96.06	45.83	3.99
GF 2.0	33.10	85.19	44.89	3.85
GF 3.0	31.50	72.07	43.41	3.62
E: Elasticity modulus, Gf: Fracture energy, Fc: Compressive strength, Ft: Tensile strength				

TABLE 2. Properties of glass fiber (Arslan, 2016).

Glass fiber properties	l (mm)	d (μm)	D (g/cm3)	E (GPa)	Ft (MPa)
GF	24	10-17	73.55	76	3000-3600
L: Fiber length, d, Diameter, D: Density, E: Elasticity modulus, Ft: Tensile strength					

2.2. Modeling beam with finite element

A notched prismatic specimen with dimensions of 480x100x50 mm^3, a notch dimensions of 3x30 mm^2 throughout the depth of the beam, and a free span beam of 400 mm, was subjected to a three-point bending test. The imposed displacement loading was applied to the midpoint of the beam. Quadrilateral elements (4-node elements with linear interpolation, QUA4) were employed to model the beam in the finite element method, the choice of weak (linear) kinematics is justified by the primary objective of studying the influence of meso representation on the enrichment of both kinematic and static variables.

As depicted in Fig. 2, three different mesh sizes were considered for Zone 1, 2, and 3. The reason for the use of different mesh sizes was to assess the opening displacement of notch properly. Zone 1 comprises the widest mesh, while Zone 2 is more finely meshed, with elements three times smaller than those in Zone 1. In the central part of the beam, which corresponds to the area where damage may occur (Zone 3), elements near the notch are three times smaller than the surrounding elements in Zone 2. This refinement extends to a thickness corresponding to the width of the strip, as shown in Fig. 2.

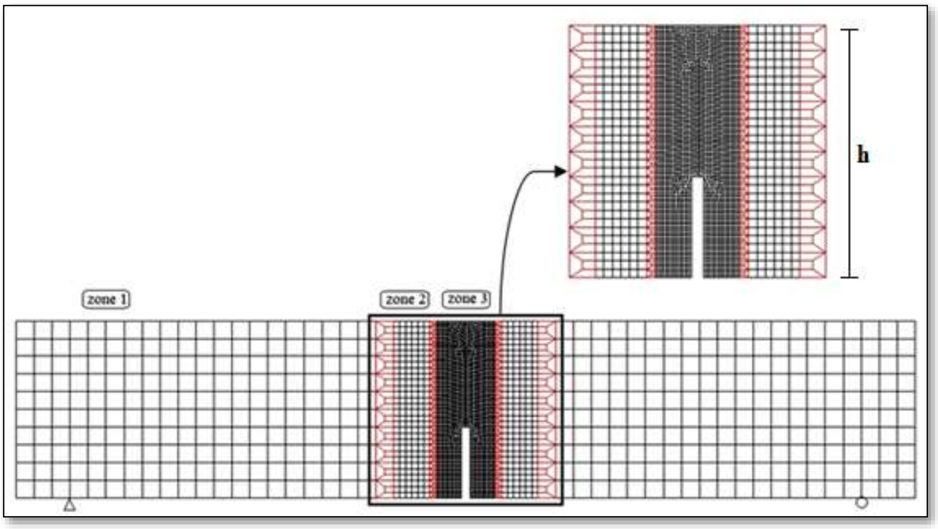

Fig 2. Finite Element Meshing Near the Crack Tip

A connection is established between the different zones of the beam using a progressive meshing technique, facilitating a smooth transition. This approach was employed to reduce computation time for the finite element analysis. The boundary conditions are imposed on the beam, which is simply supported at its ends. There are three key boundary conditions denoted as CL1, CL2, and CL3 (Fig. 1):

CL1: This condition applies to the left support of the specimen.

CL2: Similarly, CL2 corresponds to the right support of the specimen.

CL3: This is located at the load application node in the mid-span of the beam.

Here, the horizontal displacement is constrained, preventing any movement in that direction.

3. Results and discussion

The Load-CMOD curves for notched beams with 0.5, 1.0, 2.0, and 3.0 kg/m3 glass fiber inclusions are presented in Fig. 3, both in numerical simulations and experimental tests. Fig. 3 presents how content impacts load-bearing capacity and CMOD.

It can be seen from Fig. 3 that, for all fiber contents, the peak load obtained from numerical simulations closely aligns with the results of experimental tests. The numerical results suggest that there is no significant influence of fiber contents on the maximum load capacity. Notably, GF1 exhibits the highest load-carrying capacity. GF1 demonstrates the closest agreement between numerical and experimental results. The difference between the numerical and experimental peak load is only 6%. For the remaining mixtures, the difference between the maximum load of experimental testing and numerical simulation varies from 10% to 20%. The findings indicate that, in some cases, there is an increase in plasticity.

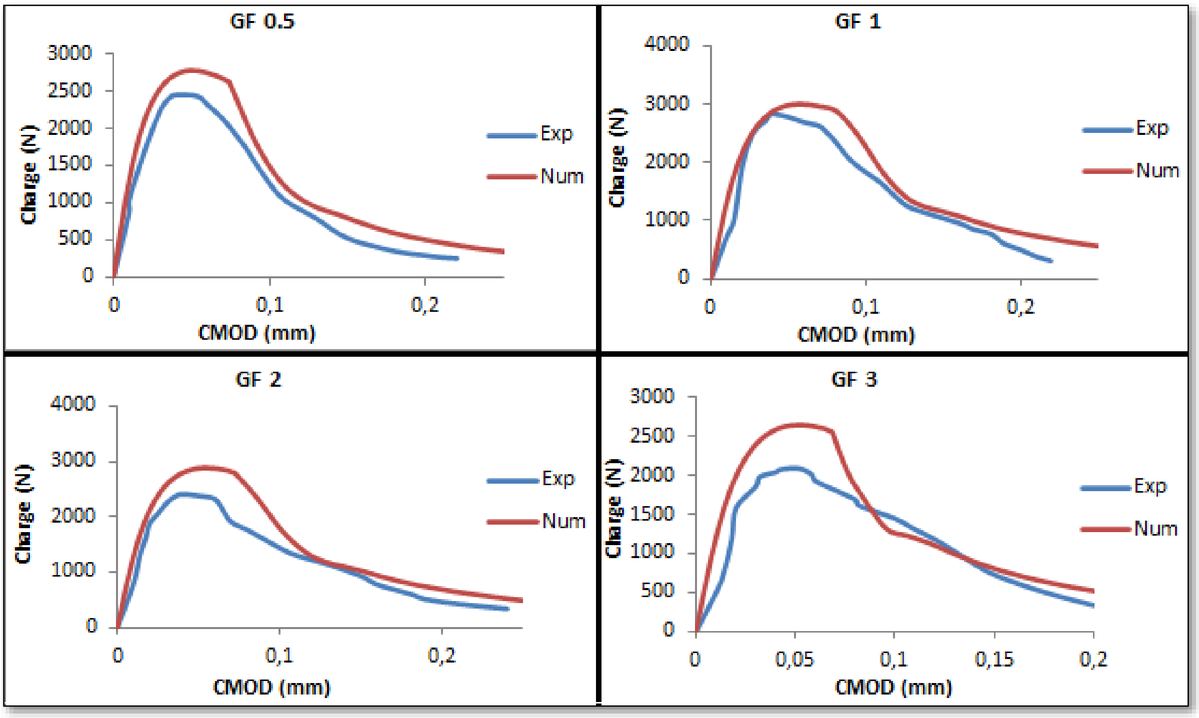

Fig 3. Results of numerical simulations Versus experimental Load-CMOD curves (Arslan, 2016) for Glass Fibers.

Fig. 4 presents the relationship of CMODs and glass fiber ratios for experimental and numerical results. Notably, the numerical results consistently exceed those of experimental tests. Fig. 4 illustrates a nearly uniform convergence rate between the numerical and experimental results for all specimens. The most substantial convergence is observed for GF3. There is a 4% alignment between the simulation and test results for GF4. Besides, GF0.5, GF1, and GF2 display convergence ratios of 19%, 30%, and 26%, respectively.

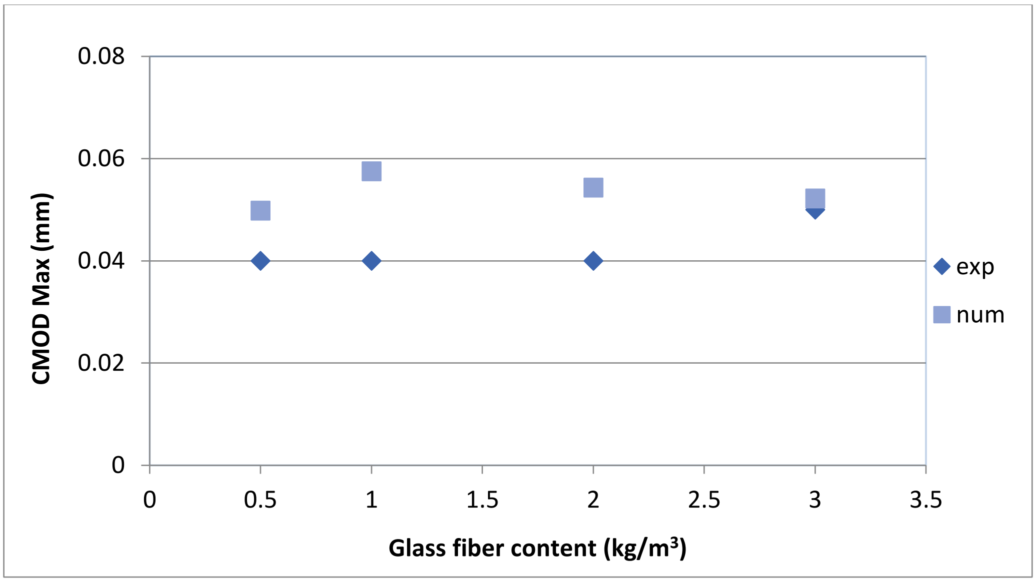

Fig 4. Experimental (Arslan, 2016) and numerical CMOD values versus glass fiber contents (GF).

4. Conclusions

This paper presents a numerical investigation to examine the fracture behavior of concrete beams under a three-point bending test. The numerical results obtained are influenced by the substitution rates of recycled glass fiber used in the concrete mix as reinforcing fibers. The mechanical properties of the recycled waste significantly impact the flexural behavior of the analyzed reinforced concrete beams in terms of strength, brittleness, and ductility. The introduction of fiber glass into the concrete mix results in numerical Load-CMOD curves that closely match the experimental results. Furthermore, the numerical results indicate that the quantity of fibers hasn't a specific effect on the maximum load capacity. GF1 shows the smallest difference between numerical and experimental results. The findings underline the importance of considering both numerical simulations and experimental tests to understand the behavior of the reinforced concrete structures. Future research could focus on refining numerical models to capture the observed difference more and further investigate the mechanisms behind the variations in plasticity.

5. References

Arslan, M. E. (2016). Effects of basalt and glass chopped fibers addition on fracture energy and mechanical properties of ordinary concrete: CMOD measurement. Construction and Building Materials. 114, 383–391.

Batayneh, M., Marie, I., Asi, I. (2007). Use of selected waste materials in concrete mixes. Waste Management. 27, 1870–1876.

De Brito, J., Saikia, N. (2013). Recycled aggregate in concrete: use of industrial, construction and demolition waste. London: Green Energy and Technology, Springer-Verlag.

Marcin, M., Waldemar, Ł., Mateusz, J., Marta, K. (2020). Effect of waste glass addition as a replacement for fine aggregate on properties of mortar. Materials. 13, 1-19.

Parmar, C., Salla, S. R., Pitroda, Dr. J. R. (2021). Investigation on composite fiber concrete: a review. International Research Journal of Modernization in Engineering Technology and Science.

Prasad, B., Ameersohel, Basavannevva, N., Suhas, M., Veergangadhar, A. (2019). Glass fiber reinforced concrete. SSRG International Journal of Civil Engineering.