Numerical simulation and experiment on steel fiber concrete beams

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Abstract. The present study aims to investigate the effect of steel fiber addition on the behavior of the concrete beam in terms of crack formation, displacement, and deformation. The normal concrete (B20) was designed for making the beam with the target strength of 20 MPa. Different percentages of steel fiber (4% and 8% by volume) were added to the B20 mixture in order to evaluate the effectiveness of steel fiber addition to the concrete beams. The steel fiber concrete beams were subjected to the tests of crack formation, displacement, and deformation under loading. The numerical simulation by ANSYS computer software was also performed for comparison. As a result, the addition of steel fiber to the concrete beams was found to have positive effects as reducing both crack formation and the displacement as well as the deformation of the beams. Besides, the ANSYS modeling showed similar results as observed by the experiment.

1. Introduction
Concrete has become an indispensable part of the construction industry due to its superior properties-compressive strength, and the application of concrete was mainly used to sustain the compressive load in the construction components like column and foundation. On the other hand, the use of concrete was also known in combination with steel bars to create a building unit, which has an extraordinary capacity to withstand the flexural strength – reinforcement concrete beam (RCB). While the utilization of concrete in the compressive zone upholds its function, almost concrete is introduced into the facing site – the tensile zone does not influence the load-bearing ability of RCB, and it always found the advent of cracks. The presence of cracks could also be awful in the long run because of the infiltration of substances from the external environment such as moisture, corrosive airs, etc. Especially, when the RCB components work in sensitive and hazardous places like water and mist, it can be downright disastrous according to the damages that stem from the exposure of steel reinforcement bars to destructive agents. Whereby, this issue should be taken into account by the consolidation of the steel fiber (SF) embedded into the flexural area of RCB. It is not only an opportune intervention to prevent the ruin caused by the cracks and to strengthen the RCB, which is proved through the restriction in the progress of micro-crack and strengthen the quality of recycled coarse aggregate concrete (RCA) [1–3], but the introduction of SF could wield enormous advantages in the attributes of RCB. In relations to
the enhancement in the strength of RCA made with SF, the finding from Carneiro et al. [4] indicated that the addition of a minimal amount of SF (0.75%) led to the increase in both compressive strength and the resistance to the ductile failure; hence the toughness was improved. Besides that, the application of SF into concrete mixture has a significant gain in the modulus of rupture and tensile strength of the plain concrete samples [5]. Nevertheless, it was also demonstrated that the reduction in the structural ductility of RCB when incorporating SF into the concrete mixture was observed the lower efficiency at a low reinforcement ratio and a small amount of SF content (ranging under 2% by volume) [6-8]. For that matter, the research on RCB in this study is going to delve deeper into the use of a higher amount of SF up to 8% (by volume) to ascertain the possibility of using SF at high content. Additionally, when taking a closer look at the cracked sections of the concrete components reinforced by SF, some scientists indicated that the stress transfer in these areas was often influenced by the bond properties between SF and matrix, and the mechanism of the failure in the matrix is variably depended on the distribution of stress, which is transferred by the SF [9–11]. Therefore, the use of SF in the production of RCB in this investigation was administered to examine the possibility of deformation, displacement, and cracking of RCB in terms of the analysis of RCB by analyzing the model in ANSYS numerical simulation based on finite element principle. And some studies about numerical simulation and experiment on steel fiber concrete beams [12-14] and some another studies [15-16].

2. Materials and methods

2.1. Materials

The raw materials used in this study includes grade-40 Vicem Bim Son Cement (PCB40) conformed to TCVN 6260-2009 [17] and TCVN 6067-2004 [18] Vietnamese standards, grade 10×20mm natural stone with maximum size of 20mm, river sand with particle sizes of 1.5-5mm, Dramix steel fibers (as shown in Figure 1) with diameter of 0.5mm, length of 30mm, tensile strength of >1100 MPa conformed to ASTM A820-01 [19], and diameter-to-length ratio of 50-100 according to ACI 544.1R-1996 [20].

In this study, the concrete (namely B20) was designed with the target strength of 20 MPa (see Table 1). Then, different steel fiber contents (4% and 8% by volume) was added to the B20 mixture to prepare the steel fiber concrete (as shown in Figure 1b).

![Steel fibers](image1.png)  
![Steel fiber concrete](image2.png)  

**Figure 1.** The appearance of steel fibers and steel fiber concrete

| Table 1. Mix proportion of B20 concrete mixture |
|-----------------------------------------------|
| **Materials**                          | **Mass (kg)** | **Volume (liter)** |
| Cement PCB40                          | 295           | 95                |
| River sand                            | 764           | 288               |
| Stone 10×20mm                         | 1195          | 443               |
| Dramix Steel fibers (0.5×30mm)       | 0             | 0                 |
| Water                                 | 174           | 174               |
| Total                                 | 2428          | 1000              |
2.2. The preparation of steel fiber concrete beams

The steel fiber concrete beams with dimensions as presented in Figure 2a were casted (see Figures 3 and 4), and the displacement- and deformation-measuring devices were set up to the beams as shown in Figure 2b.

![Figure 2](image-url)

**Figure 2.** Dimensions of the beam and location of the measuring devices

Where PDT-1 and PDT-3 were used to measure the deformation in the compression area of the beam; PDT-2 and PDT-4 were used to measure the deformation in the tensile area of the beam; V-1, V-2, and V-3 were used to measure the vertical displacement at the position between the span of the beams and the position of the forces.

To investigate the effect of steel fiber contents (0%, 4%, and 8% by volume) on behavior of steel fiber concrete, the number of beams with dimensions of 150×200×2200mm were prepared, including: two beams (D1 and D2) using normal concrete with 0% steel fiber content, two beams (D3 and D4) with 4% of steel fiber content, and two beams (D5 and D6) with 8% of steel fibers content. The main steps of the fabrication process of the beams are shown in Figure 3.

![Figure 3](image-url)

**Figure 3.** The preparation of steel fiber concrete beams
2.3. Experimental methods for steel fiber concrete beams
The beams were subjected to the measurements of displacement and deformation under loading (Figure 4). The procedures can be described as follows:
  Step 1: beams were painted to observe cracks easily;
  Step 2: measuring devices were set up to the designed positions on the beams;
  Step 3: experimental data were observed and recorded;
  Step 4: analyzing the data.

Figure 4. Measurements of displacement and deformation of the beams under loading
3. Results and discussion

3.1. Analysis of crack measurement

The results of crack measurement on beams are shown in Figure 5.

![Crack measurement results](image)

**Figure 5.** The behavior of crack formation in the beams

Figure 5 shows that there were more cracks obtained in concrete beams (D1 and D2) without steel fiber content as compared to other steel fiber concrete beams. Especially, cracks were introduced early at 25 kN of loading. Further increase of load to 60 kN caused the rapid cracks development to the compressive part of the beams and the beams were destroyed at this loading level.

For the concrete beams (D3 and D4) with 4% steel fibers content, cracks appeared on the beams at a loading rate of 25 kN, but the number of cracks was smaller than that of the beams D1 and D2. However, the D3 and D4 beams were also failed at the loading level of 60 kN. It is found that adding 8% of steel fiber content significantly reduced the number of cracks on the concrete beams, and the load-bearing capacity of the beam also enhanced remarkably. The fact that the concrete beams (D5 and D6) with 8% steel fibers content exhibited cracks at the loading rate of 35 kN and the cracks developed slowly with increasing the loading rate. At the loading rate of 60 kN, the cracks were still located only in the tensile area of the beams.

3.2. Relationship between load and deformation

Figure 6 displays the load and deformation relation of the tested beams.

Figure 6a shows that the deformation in the compression area at the mid-span of all concrete beams at the loading rates of 0-30 kN was similar regardless of the steel fiber content. At the low loading rates of below 30 kN, the cracks did not observe, and the addition of steel fibers was also not efficient.
However, when the loading rate kept increasing further, the cracks appeared, leading to the difference of compression deformation of the concrete beams. At this stage, the inclusion of steel fiber in the concrete beams improved their compressive deformation significantly.

![Figure 6. Relationship between load and deformation of the beams](image)

Similarly, it can be observed from Figure 6b that the tensile deformation at the tensile zone in the mid-span of all concrete beams at the loading rates of 0-25 kN was almost the same no matter the steel fiber contents. When the load exceeded 25 kN, the tensile deformation patterns of the concrete beams with different steel fiber contents were different but not significant. At this stage, it is found that the higher the steel fiber content, the lower the tensile deformation of the concrete beams.

3.3. Relationship between load and displacement

Figure 7 presents the relation between load and displacement in the mid-span and at the focused force of the beams.

![Figure 7. The load and displacement relationship](image)

Figure 7 shows that concrete beams with 0% and 4% of steel fibers had vertical displacement values of similar patterns. In this case, the addition of 4% of steel fiber affected the vertical displacement behavior of the beams insignificantly. However, the vertical displacement of the concrete beams reduced significantly with increasing the content of steel fiber to 8%.

3.4. Comparison of experimental and numerical model results

Nowadays, there are many well-known computer software based on the finite element principles using for structural analysis such as Ansys, Adina, Abaqus, Midas civil, etc. In this study, ANSYS software was applied to simulate the concrete beam incorporating 8% steel fiber (Figure 8a). The load vs.
displacement curve at mid-span of the concrete beam obtained from both experiment and numerical analysis is shown in Figure 8b.

Figure 8. Model of the concrete beam (a); the load-displacement relationship at mid-span of the concrete beam from experimental results and numerical models (b).

As can be seen from Figure 8b that the experimental results and numerical simulation of ANSYS were quite consistent as the error between the two methods was acceptable.

On the other hand, the formation of cracks in concrete beams obtained by ANSYS analysis is displayed in Figure 9. The numerical simulation results showed a similar pattern of cracks formation, as observed from the experimental results (Figure 5c). The cracks between the position of applied forces were concentrated on the beam, and the cracks were vertical. It is noted that this section has zero shear force and the moment equals a constant.

Figure 9. Cracks in beams modeling by ANSYS

Furthermore, the relationship between load and deformation was also drawn from the experimental results and ANSYS analysis (Figure 10).

Figure 10. Load and deformation relationship between experimental results and numerical models.

As a result, it is found that the difference/ error between the experimental results and ANSYS modeling was insignificant, meaning that the model by ANSYS software was reliable.
4. Conclusion

1. The addition of steel fiber to concrete beam resulted in a positive effect on reducing crack formation under loading, significantly at 8% of steel fiber content. The crack development within the steel fiber concrete beams was also slower than in the steel fiber-free concrete beams.

2. Concrete beams with 0% and 4% of steel fiber contents showed a similar displacement degree. However, the displacement in the concrete beam containing 8% of steel fiber was reduced significantly. In addition, the cracks on the concrete beams with 0% and 4% steel fiber contents were firstly introduced at the loading level of 25 kN, whereas cracks appeared firstly at 35 kN for the concrete beams with 8% steel fiber addition.

3. The numerical analysis by ANSYS computer software provided similar results as compared to the experiment, indicating that the results obtained from ANSYS modeling were reliable.

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