Enhancing the flexural load capacity of the reinforced concrete beams using Dramix 3D 80/60 BG steel fibres

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Abstract. The purpose of this study was to investigate the effect of adding Dramix 3D 80/60 BG steel fibres to the reinforced concrete beams experimentally. The main specimens were 6 reinforced concrete beams (dimension of 150 x 180 x 1700 mm) with a variety of the flexural reinforcement (i.e. 2D6, 2D10 and 3D10) and the fibre volume fraction (i.e. 0%, 0.5%, 1% and 1.5%). The concrete compressive strength was 25 MPa, no superplasticizer was added in the concrete mix. The test set-up of the beam specimen is, the beam was simply supports at the distance of 1500mm, 2 concentrated loads gradually were applied until it collapses. During applying the loads, measurements were taken including the deflection in the mid-span of the beam, the crack propagation and crack width. The results showed that the increase of fibre content will increase the load capacity and stiffness without reducing the ductility of the reinforced concrete beams. The steel fibre volume fraction of 1% is the maximum content that can be used without using superplasticizer to maintain the workability of the fresh concrete. The addition of 0.5% steel fibre provides a similar flexural performance to the addition of one D10 (flexural reinforcement) in a reinforced concrete beam.

1. Introduction

Reinforced concrete structures consist of vertical structural elements (or called columns) and horizontal structural elements (also called beams). Beams experience bending due to loads acting on them. In the reinforced concrete beam collapse theory, there are 2 types of collapse, namely ductile collapse and brittle collapse. Reinforced concrete beams must be designed to experience ductile collapse by limiting the flexural reinforcement ratio ($\rho$) between $\rho_{\text{min}}$ and $\rho_{\text{max}}$, or it is called under-reinforced. Ductile collapse in a beam is a typical safe collapse because the beam will show physical signs such as substantial deflection and cracks before collapse. Conversely, if the flexural reinforcement ratio is over-reinforced ($\rho_{\text{used}} > \rho_{\text{max}}$) then the beam will experience a brittle collapse which is dangerous because it is a sudden collapse without showing any physical signs.

Research on the use of fibre reinforced concrete (FRC) in reinforced concrete beam structures has been widely carried out. Some researchers [1,2,3,4] have studied the effect of using steel FRC (SFRC) on the flexural behaviour of reinforced concrete beams. Several researchers have also made an approach model to analyze the strength of reinforced concrete beams using the finite element method [5, 6]. The results of these studies indicate that SFRC can improve the flexural performance of...
reinforced concrete beams using the flexural reinforcement ratio ($\rho$) is between $\rho_{\text{min}}$ and $\rho_{\text{max}}$, or called under-reinforced.

From the results of previous studies, it is not known how the effect of SFRC on the behavior of reinforced concrete beams with flexural reinforcement less than $\rho_{\text{min}}$ or greater than $\rho_{\text{max}}$. This information is important to know, for example in the reinforced concrete beams repair with the method of enlarging the dimensions of the beam section which will also increases the amount of used flexural reinforcement. The addition of this reinforcement also increases the flexural reinforcement ratio. If not careful, then the flexural reinforcement ratio after repair is greater than $\rho_{\text{max}}$ which will resulting a brittle collapse.

Therefore, it is necessary to anticipate so that even though there is excessive flexural reinforcement, it still performs a ductile flexural behaviour. One of them is by combining it with steel fibre reinforced concrete (SFRC). Steel fibre reinforced concrete is a mixture of ordinary concrete which steel fibres was added in the mixing process of the concrete, so that when the concrete hardens, the steel fibres are scattered randomly and evenly in the concrete, which can withstand the tensile stress in the concrete in any directions. SFRC has advantages over ordinary concrete, including having higher tensile strength, ductility, resistance to impact loads, and a modulus of elasticity in comparison with ordinary concrete, and has a lower shrinkage rate than ordinary concrete [7].

The main objective of this study is to investigate the flexural behaviour of SFRC beams using various volume fraction of Dramix 3D 80/60 BG steel fibres and the flexural reinforcement of the beam, in terms of the load-deflection relationship, ductility and beam failure pattern experimentally.

2. Experimental Program

The main specimens are reinforced concrete beams with the dimensions of 150 x 190 x 1700 mm. Detailed dimensions and reinforcement of the test specimens are presented in Figure 1 and the details of the test specimens variation are shown in Table 1.

The beam specimens were cast with the concrete strength of 25 MPa. The yield strength of steel reinforcement was 380 MPa. Dramix 3D 80/60 BG steel fibre was used in this study with the variations of 0%, 0.5%, 1%, 1.5%. The variation of the flexural reinforcement of the beam specimens were 2-D6, 2-D10 and 3-D10. The reinforcement of 2-D10 is identified under the minimum reinforcement requirement. The beams with 2-D10 and 3-D10 were lied within the required reinforcement range. These beams are designed to experience flexural failure. The material composition for plain concrete and concrete with various steel fibre volume fraction is shown in Table 2.

The beam specimen tests were carried out at 28 days of concrete. The beam specimen was placed on 2 supports at a distance of 1500mm on a loading frame, then 2 concentrated loads vertically were applied at the distance as shown in Figure 2, until the beam collapses. In the middle of the beam span, a dial gauge was installed to measure the deflection of the beam. During the loading process, the measurements including the deflection, crack development and crack width according to the load increase were recorded.

To measure the mechanical properties of concrete, cube samples (150 x 150 x 150) and prism (100 x 100 x 600 mm) were also made to determine the compressive strength and flexural strength of concrete (modulus of rupture). The tests were conducted according to ASTM C39 and ASTM C496. They were tested at the same day with the testing of the beam specimens.
Figure 1. The beam specimen detail

Figure 2. The test set-up of the beam specimen
Table 1. Detail reinforcement of the reinforced concrete beam.

| Beam specimen | Flexural reinforcement | \( \rho \) | \( \rho_{\text{min}} \) | Tied | Steel fibre volume fraction, \( V_f \) (%) |
|---------------|------------------------|------------|----------------|------|----------------------------------------|
| BL1           | 2-D10                  | 0.0066     | 0.0037         | \#6-50 | 0                                      |
| BL2           | 2-D10                  | 0.0066     | 0.0037         | \#6-50 | 0.5                                    |
| BL3           | 2-D10                  | 0.0066     | 0.0037         | \#6-50 | 1                                      |
| BL4           | 2-D10                  | 0.0066     | 0.0037         | \#6-50 | 1.5                                    |
| BL5           | 3-D10                  | 0.0099     | 0.0037         | \#6-50 | 1                                      |
| BL6           | 2-D6                   | 0.0023     | 0.0037         | \#6-50 | 1                                      |

Table 2. Material for plain/steel fibre reinforced concrete (per m³)

| Steel fibre volume fraction, \( V_f \) (%) | Cement (kg) | Sand (kg) | Coarse aggregate (kg) | Water (kg) | Steel fibre (kg) |
|-------------------------------------------|-------------|-----------|-----------------------|------------|------------------|
| 0                                         | 375         | 768       | 902                   | 225        | -                |
| 0.5                                       | 363,771     | 745,003   | 874,990               | 218,262    | 39,25            |
| 1                                         | 362,005     | 741,386   | 870,743               | 217,203    | 78,50            |
| 1.5                                       | 360,256     | 737,805   | 866,536               | 216,153    | 117,75           |

3. Test results

3.1. Mechanical properties

Table 3 and Figure 3 and 4 provide data on the effect of adding steel fibres to the concrete workability (slump test), compressive strength and flexural tensile strength (modulus of rupture) of the concrete.

Figure 3. The slump - fibre volume fraction relationship

Figure 4. The flexural strength – fibre volume fraction relationship
Table 3. Slump, average of compressive strength and flexural tensile strength

| Steel fibre volume fraction, Vf (%) | Slump (cm) | Ave. compressive strength | Ave. flexural tensile strength |
|------------------------------------|------------|--------------------------|-------------------------------|
|                                    |            | Cube strength (N/mm²)     | Covert to cylinder strength (N/mm²) | Increase (%) | Flexural tensile strength (N/mm²) | Increase (%) |
| 0                                  | 16.75      | 30.54                    | 25.35                         | 0            | 3.72                          | 0            |
| 0.5                                | 13.50      | 28.58                    | 23.72                         | -6.43        | 8.14                          | 118.82       |
| 1                                  | 9.25       | 33.06                    | 27.44                         | 5.39         | 11.30                         | 203.76       |
| 1.5                                | 4.00       | 31.93                    | 26.50                         | 4.53         | 14.20                         | 281.72       |

Workability of the concrete mix determines the ease of mixing, transporting, molding, compaction, and finishing. Generally concrete slump value (obtained from Slump Test) is used to find the workability. The higher the slump value, the easier the workability. The workability is determined by several factors, such as the water-cement ratio, the amount of water used, the aggregate condition (wet, dry or saturated surface dry). In this study, the design slump values for normal concrete ranged from 60-180 mm. The slump value of concrete/fibre reinforced concrete for each concrete mix is presented in Table 3 and Figure 3.

It can be seen in Table 3, the greater fibre volume fraction, the lower the concrete slump value. This is because the steel fibres in the concrete mix lock the coarse aggregate, thereby reducing the movement of the coarse aggregate. In addition, the water in the concrete mix, besides lubricating the surface of the aggregate, must also lubricate the surface of the steel fibres so that the free water content in the concrete mix is reduced.

Based on the above results, it can be seen that the addition of the steel fibres up to Vf = 1% results in a slump value that still meets the design slump of 60-180 mm. However, at Vf = 1.5%, the slump value no longer meets the requirements, which means that the workability of the concrete mix is very low. This is not good because it will reduce the solidity of the concrete; the concrete has many porous.

To overcome this, the use of superplasticizer is unavoidable when using fibre volume fraction Vf ≥ 1.5%, this is to improve the concrete workability so that the design slump can be achieved.

Based on the Table 3, it can be seen that the addition of steel fibres to the concrete mix does not have a significant effect on the increase in the concrete compressive strength, which is only around 0 - 10%.

The presence of steel fibres in the concrete has a significant effect on the failure mode during the compression test. The plain concrete has collapsed by releasing some parts of the sample cube. Meanwhile, the fibre reinforced concrete cube sample only suffered cracks without any loose concrete parts. This is because the steel fibres that are randomly scattered in the concrete hold/bind the coarse aggregates to each other so that they do not release when experiencing tensile stress. This shows that the addition of steel fibres to the concrete can change the concrete become more ductile material.

Figure 4 shows the concrete flexural strength increases with increasing the fibre volume fraction. The highest flexural strength of concrete is found in the volume fraction of 1.5%, which is 14.20 MPa (an increase of 281.42% from the plain concrete). This shows that the addition of steel fibre to the concrete mixture can increase the tensile strength of concrete.

The curve in Figure 4 continues to increase. It is not known whether after Vf = 1.5%, the curve will continue to increase. This is possible, but the problem is when adding Vf = 1.5%, of steel fibre, the concrete mix become stiffer and nor workable, so that the superplasticizer is needed to solve the workability problem.

In the plain concrete, the tensile stress that occurs is only held by the concrete itself, while in the fibre reinforced concrete the tensile stress that occurs is held together by the concrete and steel fibres. This is why the flexural strength of the steel fibre reinforced concrete is higher than those of the plain concrete.
3.2. Reinforced concrete beam performance

Table 4 and Figure 5-7 show the data from the reinforced concrete beam testing, which shows the effect of the steel fibres content on the maximum load capacity, the load-deflection curve of the beam, the crack-pattern and the crack width.

As a result of the applied loading, all beam specimen experienced flexural collapse. The first crack occurred between the 2 point loads and then propagated vertically. Then cracks formed again along the centre-span of the beam. The crack pattern of each beam specimen was recorded and the results are shown in Figure 5.

Table 4 shows the effect of steel fibre volume fraction (Vf) on the first crack load, the yield load, the ultimate load and the crack width. It can be seen that those loads increased with the increasing of steel fibre content mixed into the concrete. This means that steel fibres in the concrete improved the load capacity of the beam.

The presence of steel fibres that are randomly scattered in the concrete reduces the crack widths of the cracks that occur, as shown in the load - crack width relationship in Figure 6. The more amount of fibre incorporating the concrete, the smaller crack-width occurs. This is because the steel fibres bridge the cracks that occur thus slowing the rate of propagation of the cracks, which in turn increases the load capacity of the beam.

The crack patterns of the beam specimens with no-fibre and with fibre look identical, which is starting with the formation of flexural cracks and them flexural-shear cracks leading to the supports. However, the beam specimen with no-fibre experienced more cracks.

| Specimen | Load (kg) | Increase (%) | Deflection (mm) | Crack width (div) |
|----------|----------|--------------|-----------------|-------------------|
| BL 1     | First crack | 1108.78     | 0.42            | -                 |
|          | Yield     | 3191.95     | 4.54            | -                 |
|          | Ultimate  | 3796.74     | 14.57           | -                 |
|          | First crack | 1175.98    | 6.06            | 2                 |
| BL 2     | Yield     | 3326.34     | 4.21            | 4.83              | 38                |
|          | Ultimate  | 4065.53     | 17.31           | 131               |
|          | First crack | 1579.17    | 42.42           | 0.60              | 4                 |
| BL 3     | Yield     | 4065.53     | 27.37           | 5.02              | 23                |
|          | Ultimate  | 4603.12     | 16.84           | 112               |
|          | First crack | 2452.76    | 121.21          | 1.05              | 5                 |
| BL 4     | Yield     | 5543.91     | 73.68           | 7.67              | 62                |
|          | Ultimate  | 5947.10     | 17.13           | 108               |
|          | First crack | 1982.37    | 78.79           | 0.79              | 2                 |
| BL 5     | Yield     | 5947.10     | 86.32           | 16.03             | 98                |
|          | Ultimate  | 6081.50     | 17.82           | 104               |
|          | First crack | 1175.98    | 6.06            | 1.32              | 4                 |
| BL 6     | Yield     | 2049.57     | -35.79          | 4.22              | 58                |
|          | Ultimate  | 2318.36     | -38.94          | 16.99             | 118               |
The data of the maximum load of the reinforced concrete beam specimens as well as the percentage increase can be seen in Table 4. While, the load-deflection curve of each beam are presented in Figure 7.

From Figure 7 it can be seen that the addition of steel fibres to reinforced concrete beams can increase the beam stiffness and the maximum load capacity of the beam with the similar maximum deflection, as shown by the BL1 - BL4 curves.

The addition of $V_f = 0.5\%$ of steel fibres in the reinforced concrete beam specimen only has a very small effect on the stiffness and maximum load capacity of the beam, which is about 7\% (see BL1 and BL2 curves in Figure 7). While, a significant increase in the maximum load occurred in BL4 specimens ($V_f = 1.5\%$), which was 56\% compared to BL1. However, as has been described above, at this fibre volume fraction, the workability of the fresh concrete is no longer acceptable.

Figure 5. The crack-pattern of the beam specimens

Figure 6. The load-crack width relationship of the beam specimens
As has been described above, BL4 contained 2-D10 of flexural reinforcement and \( V_f = 1.5\% \) and BL5 contained 3-D10 of flexural reinforcement and \( V_f = 1\% \). It can be seen that both have almost the same maximum load. So it can be said that the addition of \( V_f \) from 1\% to 1.5\% can provide the same performance by adding one D10 of the flexural reinforcement (from 2D10 to 3D10). Or in other words in this case, the addition of \( V_f = 0.5\% \) of steel fibre is equal to the addition of 1D10 of flexural reinforcement \((\rho = 0.0033)\) to the beam.

BL6 curve (with 2-D6 of flexural reinforcement and \( V_f = 1\% \)) has lower stiffness and maximum load (-38.94\%) than the reference specimen (BL1). The BL6 specimen has a flexural reinforcement ratio \((\rho)\) that is smaller than the minimum reinforcement ratio \((\rho_{\text{min}})\). So it can be concluded that the existence of steel fibres could not improve the flexural performance of the beam that has \( \rho < \rho_{\text{min}} \).

In general, the addition of steel fibre can increase the flexural load capacity and stiffness without reducing beam ductility.

4. Conclusions
The conclusion that can be drawn from this study are:
1. The addition of steel fibre with the volume fraction of 1\% is a moderate value because it provides sufficient workability without the use of a superplasticizer and provides a fairly good strength.
2. The addition of steel fibres to the concrete mixture does not increase the compressive strength but increases the flexural tensile strength and change the concrete into a more ductile material.
3. The width of the cracks that occur is smaller, the first-crack load, the yield load and the ultimate load are getting higher along with the higher the steel fibre volume fraction contained in the beam.
4. The stiffness of the beam specimen increases with the increasing of steel fibre volume fraction without reducing its ductility.
5. Steel fibre contained in the beam with the flexural reinforcement ratio \((\rho)\) less than \(\rho_{\text{min}}\) is not sufficient to improve the flexural performance of the beam.
6. In the case of BL4 and BL5 specimens, it was found that an increase in \( V_f = 0.5\% \) from the previous results in a similar flexural performance with the addition of 1 bar flexural reinforced concrete beam.
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5. References

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