Flexural behaviour of RC beams with steel and polypropylene fibres

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Abstract. The flexural behaviours of reinforced concrete (RC) beams incorporating steel and polypropylene fibres under four-point bending test is examined in this paper. A total of nine beam specimens were designed, cast and tested under flexural loadings. Three types of concrete mixture – plain, concrete with steel fibres and concrete with polypropylene fibres – were employed in this study. Fibre content is fixed at 3% by the weight of sand as sand replacement for both mixtures containing either steel or plastic fibres. Compression tests were also conducted at 7, 14 and 28 days for twenty-seven concrete cubes prepared using the three mixtures. Comparisons of results were done in term of compressive strength, ultimate flexural load and deflection capacity. The crack pattern and failure mechanism of RC beams subjected to four-point bending are discussed. Finally, the effect of steel and polypropylene fibres on the flexural behaviour of RC beams are justified.

1. Introduction
Concrete is the crucial element in construction industries, and it has become the most favourable construction material due to the cost and maintenance factors. In addition, this material could also be improved to fit current standard and demand. Many researchers have performed studies to improve concrete characteristics by using cost effective substances. One of these substances is fibres. There are many types of fibres available in the current industry, such as glass fibres, steel fibres, plastic fibres and also carbon fibres. Steel and plastic fibres are the two popular compounds that have been used extensively in research as a replacement in concrete mixture due to their potential to enhance concrete features and cost savings.

A study [1] showed that only a small percentage of volume fraction of steel or plastic fibres is needed to improve the load resisting capacity of RC beams, while another study [2] reported that low dosage of steel fibres can increased the flexural rigidity and lowers the number of cracks in beams. Steel fibres can also improve the impact and residual strengths, flexural toughness, fracture properties and ductility of concrete [3-5]. In most practical system, steel fibres had achieved many useful properties in composite members [6-9]. On the other hand, the usage of polypropylene fibres has increased in general construction in the United State of America (USA) about 10% of the ready mixed concrete [9-11].

A number of researchers reported that a small volume fraction of fibre content provides the optimum dosage to increase the performance of concrete in flexure, shear, compression, cylinder
splitting tensile strength and modulus of rupture [1-2, 12-15]. Most of the researchers used fibres as additive to the concrete, studies on the use of fibres as cementitious replacement is rare. Hence, the objective of this paper is to explore the effect of using fibres as replacement of sand content in RC beams. Two types of fibre i.e. steel and polypropylene are incorporated in concrete mixture by replacing 3% of the weight of sand. Apart from that, the effect of different types of fibre on compression, flexure, deflection, crack pattern and failure of concrete were also studied.

2. Experimental programme

2.1 Materials

Three mixtures consisting of control (plain concrete), steel fibre reinforced concrete (SFRC) and polypropylene fibre reinforced concrete (PFRC) were prepared in this study. Table 1 shows the design mix proportion of the three mixtures for casting cube and beam specimens. Generally, all mixtures were designed to have the same density as shown in table 1. For SFRC and PPFRC, fibers were incorporated in the cementitious matrix as sand replacement at 3% by the weight of sand. It is worthy to mention that the equivalent percentage of fibers in volume fraction are 0.2% and 1.7% for SFRC and PPFRC, respectively.

Table 1: Mix proportion (kg/m³)

| Mixture | Cement | Sand | Aggregates 10 mm | Aggregates 20 mm | Water | Steel Fibre | PP Fibre | Density |
|---------|--------|------|------------------|------------------|-------|-------------|---------|---------|
| Control | 287    | 520  | 467              | 928              | 165   | -           | -       | 2367    |
| SFRC    | 287    | 505  | 467              | 928              | 165   | 15          | -       | 2367    |
| PPFRC   | 287    | 505  | 467              | 928              | 165   | -           | 15      | 2367    |

2.2 Preparation of specimens and testing

For each mixture, nine number of cube specimens of size 100 mm × 100 mm × 100 mm and three number of beam specimens of size 150 mm × 210 mm × 4000 mm were prepared for compression and flexural tests. Compression test was performed on cube specimens at 7, 14 and 28 days and slump test were also carried out to study the workability of fresh concrete. Each beam was reinforced with four high-yield strength bars of nominal diameter 12 mm and twenty-four number of low-yield strength stirrups of size 6 mm. Figure 1 shows the dimensions and test set up of the beam specimen. All tests were carried out in the heavy lab, Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam.

(a)

(b)
Figure 1: (a) Strain gauge positions at 50 mm from bottom at middle of beam, (b) LVDT positions on beam and (c) four-point bending test set up

3. Results and discussions

3.1 Compressive strength and slump test

Figure 2 shows the comparison of compressive strengths for control, SFRC and PFRC at 7, 14 and 28 days. Plain concrete has the highest compressive strength of 29.13 N/mm$^2$, 33.97 N/mm$^2$ and 40.12 N/mm$^2$ at 7, 14, and 28 days, respectively. These are followed by SFRC with compressive strength of 24.33 N/mm$^2$, 28.22 N/mm$^2$ and 37.71 N/mm$^2$ and PFRC with compressive strength of 8.85 N/mm$^2$, 13.17 N/mm$^2$ and 20.42 N/mm$^2$ each at 7, 14, and 28 days, respectively.

Figure 2: Comparison of compressive strength at 7, 14 and 28 days

It was observed during test that concrete containing steel and polypropylene fibres were able to hold its shape under load and did not crush completely after the end of test, as shown in Figure 3. This is due to the bridging effect provided by fibres, as reported in [1]. Concrete containing fibres have lesser compressive strength but demonstrate more ductile failure mode under compression if compared to plain concrete.

Slump test results indicate that SFRC yields similar workability as control, both achieved moderate slump value of 89 mm. On the other hand, PFRC demonstrated slightly low workability i.e. 79 mm.
3.2 Flexural behaviour

Figure 4 shows the comparison of load-deflection curves for plain RC, SFRC and PPFRC beams under flexural test. It can be observed that plain RC and SFRC beams display similar steady linear line and continue to reach the brittle failure load. PPFRC beam exhibits a similar curve pattern but at a significantly lower load as compared to plain RC and SFRC beams. The maximum load recorded for plain RC beam is 34 kN. For SFRC and PPFRC beams, the maximum loads are 33 kN and 11 kN, respectively. The corresponding deflection value recorded at maximum load for plain RC beam is 49 mm while for SFRC beam is 62 mm. For PPFRC beam, the corresponding deflection value is 53 mm.

As reported in [1], RC beams containing low dosage of fibres, i.e. 0.5% and 1% volume fraction, have higher flexural load resistance capacity and improved condition of beams at failure in comparison to plain RC beam. In this study, however, both SFRC and PPFRC beams containing 0.2% and 1.7% volume fraction of steel and polypropylene fibres do not contribute to any improvement as compared to plain RC beam.

3.3 Crack propagation and failure mechanism

Figure 5 shows the crack patterns on plain RC, SFRC and PPFRC beams. The first crack appeared on plain RC beam at the mid-third segment of the beam after a few minutes of load being applied. The corresponding load at the first crack is 24 kN, 20 kN and 22 kN for all three beam specimens. As load
increases, more flexural cracks appeared on the lower part of the beam along with those propagating from the initial cracks. A large number of minor cracks and longer cracks with wider width were found to emerge on both sides of the beam during testing. Plain RC beam is considered to fail in flexure when major cracks formed at the centre of the specimen.

![Image](a)

![Image](b)

![Image](c)

**Figure 5**: Comparison of crack patterns on beams – (a) plain RC, (b) SFRC and (c) PPFRC

Almost identical initial crack patterns and crack propagation process were observed for SFRC and PPFRC beams but with less cracks formed on SFRC beams under increasing load. PPFRC beams have the least number of cracks, which focused only at the middle section of the beam, as compared with the other type of beam specimens as seen in Figure 5. The reduction in number of cracks for RC beams containing fibres is due to the activation of fibres after cracking has occurred; fibres help to increase the beam resistance in re-distributing high stresses over cracking region until the pull out of fibres, as stated in [16]. In the case of PPFRC beams, fibres pull out occurred swiftly after the initial cracks and simultaneously with total failure, hence, presenting the least number of cracks appearing on the specimens.

For SFRC beams, the first crack occurred at 17 kN, 20 kN and 19 kN for all three specimens while for PPFRC beams, the first crack emerged at 8 kN, 5 kN and 4 kN for all three specimens. SFRC and PPFRC beams also failed in flexure due to major formation of flexural cracks at the centre of each specimen.

### 4. Summary and conclusions

A series of experimental investigation has been carried out to determine the flexural behaviour of RC beams containing steel fibres and polypropylene fibres cast separately. A total of twenty-seven concrete cubes and nine beams (control, SFRC and PPFRC) have been prepared for compression and flexural tests and the following conclusions are drawn.

- The compressive strengths of plain concrete cubes at 7, 14 and 28 days are 29.13 N/mm², 33.97 N/mm² and 40.12 N/mm², respectively. For concrete cubes containing steel fibres, the compressive strengths are 24.33 N/mm², 28.22 N/mm² and 37.71 N/mm² while for concrete cubes...
containing plastic fibres the compressive strengths are 8.85 N/mm², 13.17 N/mm² and 20.42 N/mm² each at 7, 14, and 28 days, respectively. The use of fibres as sand replacement into the concrete mixture does not increase the compressive strength in comparison with the control mix. However, concretes containing fibres demonstrated more ductile failure mode under compression. This is due to the bridging effect provided by fibres which made the specimen able to hold its shape under load and did not crush completely till the end of test.

- Plain RC and SFRC beams display similar behaviour under flexural load. PPFRC beam exhibits a similar curve pattern but at a significantly lower load as compared to plain RC and SFRC beams. The maximum load recorded for plain RC beam is 34 kN with corresponding deflection of 49 mm/m. For SFRC and PPFRC beams, the maximum loads are 33 kN and 11 kN, respectively, with corresponding deflections of 62 mm/m and 53 mm/m for SFRC and PPFRC beams, respectively. Both SFRC and PPFRC beams containing 3% of steel and polypropylene fibres (by the weight of sand) do not contribute to any improvement in load resisting capacity or beam condition during test as compared to plain RC beam.

- Almost identical initial crack patterns and crack propagation process were observed for SFRC and PPFRC beams but with less cracks formed on SFRC beams and least cracks formed on PPFRC beams as compared to plain RC beams. The reduction in number of cracks for RC beams containing fibres is due to the activation of fibres after cracking has occurred, which in turn help to increase the beam resistance in re-distributing high stresses over cracking region until pull out of fibres. For PPFRC beams, fibres pull out occurred swiftly after the initial cracks and simultaneously with total failure and this led to the least number of cracks appearing on the specimens.

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