Flexural characteristics of a polypropylene fibre concrete topping on a precast concrete slab

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Abstract. Concrete ductility and other technical qualities, such as toughness and load-bearing capacity after cracking, are known to benefit from the presence of different kinds of fibres. Recent years have seen a rise in the application of polypropylene fiber-reinforced concrete (PFRC) to a variety of structural elements. The incorporation of polypropylene fibres into concrete to increase the load-bearing capacity of existing structural elements has garnered significant attention. A technique known as "cement-base bonded overlay" has been used recently to increase the flexural capacity of concrete slabs by covering an existing slab with a light covering of PFRC. The aim of this study is to examine the flexural behaviour of a precast concrete slab that has a concrete topping made of Polypropylene fibre (PF). Experiments revealed that the addition of polypropylene fibres to the topping influenced the flexural performance. Despite this, the results indicated that the PFRC covers slab's ductility factor and deflection were better than those of a regular concrete topping slab.

1 Introduction

By overlaying a layer of reinforced concrete on top of the existing slab, concrete slab performance has been strengthened. The goal is to increase the slab's thickness in order to increase its load-carrying capability. For both suspended and ground floors in any kind of building construction, precast concrete flooring provides a flexible option. Precast slabs are supplemented with cast in-situ concrete toppings to provide a finished floor finish or, more frequently, to improve the floor's structural performance by creating a composite structure. Typically, in-situ concrete is poured over a prefabricated slab without any reinforcing in between the two types of concrete. The shear strength and connection between the contact surfaces must be relied upon.

In order to minimise shrinkage, in-situ concrete tops typically have a thickness of 40 to 100 mm and a minor quantity of steel reinforcing. The compressive strength of the concrete topping typically ranges from 25 to 40 N/mm^2. Overlay reinforcement is typically achieved with steel reinforcing in the form of welded matting and linked bars. Nevertheless, the use of steel bars or welded fabric under thin coverings is limited to rather thick overlays and results in extensive fissures. It is anticipated that fibre substitution in concrete would solve these issues and postpone overlay debonding. Such limitations have no effect on fibres, and they offer a lower danger of corrosion. Because fibres are put straight to the concrete, they also shorten the time it takes to complete the project and need fewer steel bars. Despite the fact that both forms of reinforcement function similarly, research indicates that fibre reinforcement is more successful. It is well known that adding discontinuous fibre reinforcement to concrete significantly enhances its behaviour. According to compressive studies, the addition of fibres to concrete does not significantly enhance its strength.

The overlay's reinforcement lessens the severity of the mechanical discontinuity at the fracture region and permits force to pass through the crack. Overlay debonding is delayed as a result of the built-in peak pressures at the interface decreasing. Overlay reinforcement is typically achieved with steel reinforcing in the form of welded matting and linked

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bars. But only in moderately thick overlays may steel bars or welded fabric be employed under thin coverings without creating broad fissures [1]. It is anticipated that fibre substitution in concrete would solve these issues and postpone overlay debonding. In addition to being unaffected by these limitations, fibres also provide a lower risk of corrosion [1]. Because fibres are added straight to the batch of concrete, they also shorten the time it takes to complete the building and need fewer steel bars [2]. Despite the fact that both forms of reinforcement function similarly, research indicates that fibre reinforcement is more successful. The type of fibre and the properties of its binding will determine how many fibres are needed to get the desired outcome[10].

2 Literature review

Hong Ni *et al.* (2021) examined a prefabricated hollow-core concrete wall system's seismic, shear, and compressive performance. Every wall specimen's maximum capacity exceeded the design load needed for an apartment block. Increasing wall length or decreasing compressive load will improve walls' compressive capability and assure safety. There were several places where the wall cracked; by reinforcing these weak areas, the load-bearing capacity may be increased. Shear strength of concrete hollow core wall specimens was underestimated by the design standard for typical masonry components; thus, new design techniques are required to appropriately anticipate the strength of the wall system [3].

Kaiqi Lin *et al.* (2019) suggested the MHRPC frame, a unique prefabricated frame technology, to increase the robustness of multi-story RC frame structures against many hazards. Three different frames' seismic and progressive collapse performances are assessed and contrasted. According to the study, RC frames' resistance to progressive collapse may be increased by using the progressive collapse design, although doing so may cause the frame beam to become too strong. In comparison to RC specimens, the MHRPC specimen S-PC6 has less component damage and residual deformations, and following uncomplicated repair, it can recover and sustain stable seismic performance. Additionally, the MHRPC substructure met the criteria for chord rotational capacity and showed higher load redistribution capability [4].

Linfeng Lu *et al.* (2022) examined the maximum load capacity of a bolt shear connection with high strength G8.8 as well as the flexural capacity of composite slabs made of RAC and NWC. The findings demonstrate that the profiled steel sheeting connection, which is three inches high, satisfies all shear connection requirements and has a satisfactory bonding effect. The majority of Chinese civil buildings' bearing capacity needs may be satisfied by the suggested precast concrete composite slab. For RAC, however, a suitable replacement ratio is required. Although floor slippage may beyond the tolerance limit, the bolt shear connections' ultimate bearing capacity satisfies design criteria [5].

Ju H *et al.* (2018) introduced a novel Precast slab with an optimised section and structural beauty (OPS) system with cross-sections that are optimised to withstand outside pressures. The system is curved, and there was no damage seen where the PC unit and topping concrete interact. However, in PC unit shear specimens, critical fractures develop in the vicinity of the variable cross-section. At continuous ends, the flexural capabilities and negative moment resistance capacity are accurately evaluated by the present design rules. The OPS is anticipated to be employed in long-span constructions with great load carrying capacity, structural aesthetics, and economic viability, such as subterranean parking lots and logistics warehouses. But it's important to figure out where the tensile reinforcement's cutting point and variable cross-section should be placed [6].

Hui Zheng *et al.* (2023) investigated how UHPC keyed joints performed in direct shear under various lateral compressive loads. The main failure mode identified in the results was brittle failure, with good overall performance. The performance of direct shear and the lateral compressive stress showed a positive correlation, with double-keyed joints exhibiting a greater peak stress. Because the shear strength was overestimated in the existing requirements, a formula based on Mohr's stress circle theory was developed and is highly accurate when applied to engineering design [7].

Cheng Hong *et al.* (2023) demonstrated a lightweight, steel-foamed concrete wall panel for prefabricated homes that exhibited remarkable load-bearing capability and seismic performance. The failure modes and deformations were precisely anticipated by the panel's finite element approach. A prototype home project was used to test the system, and the findings showed that the axial compression ratio, internal forces, mode forms, and structural deflection were all adequate [8].

Peng *et al*., (2008) carried out a study to determine how precast-prestressed floor units affected the seismic performance of moment-resisting reinforced concrete frames. The results showed that the units' presence partially restricted the elongation of plastic hinges, resulting in beam strength that exceeded the requirements of major structural design codes. In significant earthquakes, this underestimate may result in brittle column failure modes. The study also discovered that beams with precast-prestressed floors had flexural strengths that are underestimated by both the ACI and NZ concrete regulations [9].

3 Test specimens

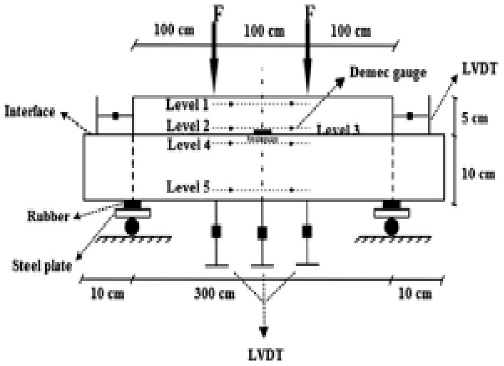
Two frameworks measuring the dimensions are 500 mm wide, 3200 mm long, and 100 mm thick. were created, together with a control specimen. A thin layer of deformed steel bars serves as mild reinforcement for the precast slab with simple concrete toppings. The 200 mm distant steel bars have an 8 mm diameter and are arranged in both directions [11,12]. We gave it a 20 mm covering. The precast slab in the fibre topping condition instance had the same dimensions as the control specimens, which were cast and stored for a week to cure. The 50 mm-thick tops were strengthened with polypropylene fibres and steel bars. Polypropylene fibres were used as reinforcement in the PFRC-topped slab (Fig. 4), with a dose of about 1.5% by concrete volume. After casting, all specimens underwent a 28-day curing period [13-15].

Table 1. Concrete properties of precast member

Slab name	Percent of PF in topping (%)	Toppings thickness (mm)	Compressive strength (MPa)	Splitting tensile strength (MPa)	Flexural strength (MPa)
S1	0	5	27.1	2.80	11.6
S2	1.5	5	30.3	2.91	12.4

3.1 Testing set up

The loading frame was used to test the specimens once they were lifted and positioned. To improve visibility of the crack growth, a small coating of white cement was applied to the specimens to make them whiter [16,17,19]. The specimens were only held in place and then exposed to a point load in the middle. The specimens' bottom centres were equipped with linear variable differential transducers (LVDT). The test specimen's displacement was measured by LVDT [18,20]. Up to failure, the load is applied at each stage. The load responsible for the specimen's flexural failure is known as the failure load.



4 Observation and results

A loading frame was used to evaluate the slab with topping and the control specimen. The following part contains the test results.

4.1 Load Vs Deflection

When loads were applied to the specimens, the maximum load that each specimen could support was discovered, along with the centre deflections of each specimen. Tables 2 display the load vs deflection mm for the control slab and the slab with polypropylene fibre topping. The fact that the deflections measured at one metre from both supports were constant throughout the test indicated that the test rig location and the loads were centrally aligned. Up to a specific load (i.e., the yield load), the mid-span deflection first increases linearly with the load. It then fluctuates in a non-linear manner until it attains its highest value. Once the load exceeds the maximum, there is a noticeable increase in deflection. The load versus deflection of the control slab specimen with plain concrete toppings (S1) in Table 1 shows that, as the load increased, there was a 0.25 mm deflection. The deflection also increased linearly up to a load of 47.2 kN, after which the mid-span deflection varied non-linearly and reached a maximum value at 52.1 kN. At a 52.1kN load, the greatest deflection of 5.01mm was observed.

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Table 2. Control specimen

Control specimen		**Slab with PFRC topping**	
Load(kN)	**Deflection (mm)**	**Load(kN)**	**Deflection (mm)**
0	0	0	0
2.4	0.25	3.5	0.29
4.9	0.92	5.0	0.86
9.8	1.36	10.6	1.42
12.2	1.92	14.3	1.76
15.7	2.1	17.9	1.89
19.1	2.3	21.1	2.25
23.6	2.42	26.2	2.36
25.0	2.65	29.3	2.48
29.5	3.3	34.8	3.20
34.8	3.68	39.0	3.73
38.0	4.10	47.2	4.26
45.1	4.95	56.1	4.62
47.2	4.96	59.2	4.62
49.3	4.96	60.1	4.70
50.0	4.98	62.0	4.91
52.1	5.01	65.2	5.03

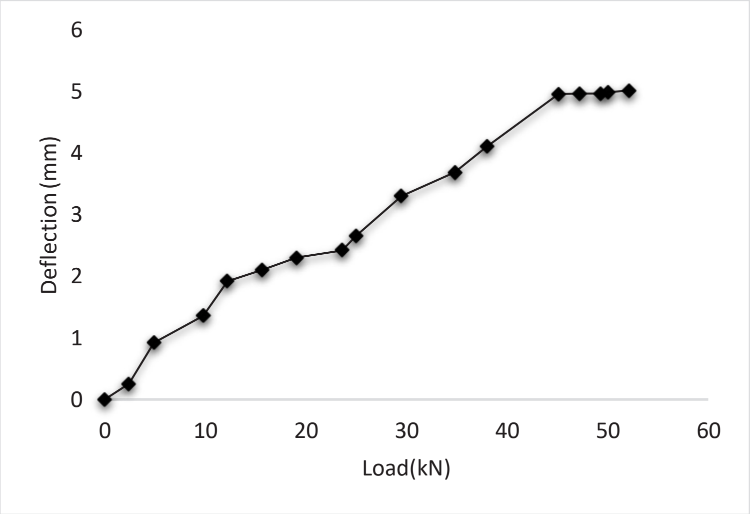

Fig. 1. Load vs deflection of S1 slab

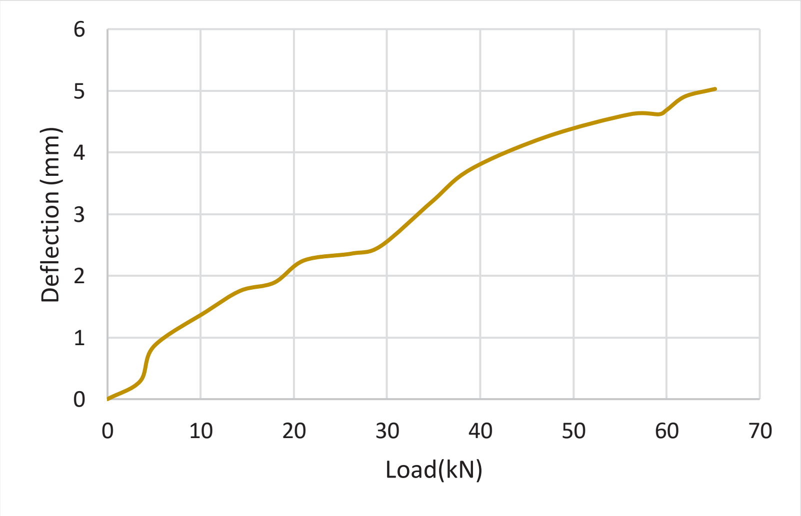

Figure 2. Load vs deflection of S2 slab

Table 2 shows the load versus deflection of the specimen with polypropylene fibre topping (S2). Up to a particular load of 56.1 kN, the deflection increased linearly with the load. Subsequently, the mid-span deflection exhibited non-linear fluctuations, culminating in a peak value of 65.2kN. With a 65.2kN load, the maximum deflection of 5.03mm was observed. The load vs deflection curves of slabs S1 and S2 are shown in Figs. 1&2.
The ultimate load bearing capability of slab S2, which has PF in its topping, is clearly higher than the slab with simple toppers (S1), as can be seen from the load vs deflection curves. The ultimate load reported for the S1 slab is 52.1 kN, whereas the ultimate load for the S2 slab is 65.2 kN.

4.2 Ductility factor

Ductility is the property that allows a material to change without significantly losing strength. The displacement ductility index, or ductility factor, is a metric for ductility that is derived from the ratio of the ultimate deflection to the deflection at the tensile reinforcement yielding [10]. Table 3 displays the displacement ductility factors computed in accordance with the specification.

Table 3. Ductility Factor of S1 and S2 slab specimen

Slab name	Ultimate Load(kN)	Yield Deflection (mm)	Ultimate Deflection(mm)	Ductility factor
S1	52.1	2.53	5.01	1.98
S2	65.2	2.35	5.03	2.14

With a ductility factor of 2.0, it is demonstrated that S2 has the maximum ductility. Control specimen S1 has the lowest ductility factor of 1.98. S2 outperforms S1 in terms of ductility, with an improvement of 8%. The findings demonstrate the benefits of PF in the topping. Addition of 1.5% PF to concrete topping has favourable results, as seen by Slab S2.

5 Conclusion

The Loading Frame was used to test the two specimens, which were cast with a slab thickness of 100 mm and topping thickness of 50 mm. The specimens with plain concrete tops (S1) and precast slab with PFRC toppings (S2) were tested. The following conclusion may be drawn from the specimen testing utilising the loading frame:

- It was discovered that specimens with PF toppings had a higher load bearing ability.
- A slab with PFRC topping has a maximum load bearing capability of 65.2 kN and a 5.03mm deflection.
- Compared to a slab with plain concrete topping, a precast slab with PFRC topping has a capacity of 65.2 kN with a load augmentation of 25%.
- The Precast slab with PFRC topping (S2) has a ductility factor of 2.14, which is 8% more than the slab with plain concrete topping.

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