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Punching Shear Strength Improvement of Flat Slabs using Polypropylene Fibers

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Abstract. The punching shear failure at the region around the column is considered the most dangerous type of failure in the flat slab system, causing an instantaneous collapse of the buildings. It is a brittle failure mode that happens suddenly without any warning. Recently many techniques were introduced by researchers to avoid shear punching failure and enhance shear punching resistance of flat slab. Improving the mechanical properties of concrete is a powerful approach line using polypropylene fibers (PF) in concrete in which details are presented in this paper. Twelve slabs were made with dimensions of (1000×1000) mm, and 100mm in thickness. The flexural reinforcement was the same for all models; for the upper layer was (6 ϕ 6), while the lower layer was (10 ϕ 12) without shear reinforcement. The factors studied in this investigation involve the polypropylene fibers quantity, compressive strength value. The results showed a noticeable improvement in punching shear strength when adding (PF%=1%) by cement weight. However, the impact of polypropylene fibers was negligible when adding a ratio greater than 2%, and it was also observed that the failure changed from a brittle failure of non-polypropylene fibers models to a ductile failure in slabs containing polypropylene fibers. The failure cracks in a slab with polypropylene fibers are tiny and less in number than the NC slab. This is because fibers increase the internal bonding of the concrete material component. Also, increasing the ratio of polypropylene fibers reduced the perimeter and area of the punching shear region while the failure angle slightly increased.

Keywords. Punching , Flat slabs, Polypropylene ,Fiber.

1. Introduction

The reinforced concrete slab is an essential part of the structural building and provides floors and ceiling. Flat slabs are reinforced concrete slabs that usually do not have girders or beams; the loads are transferred directly to the concrete columns [1]. Flat slabs have four different types: slabs with column head, slabs with drop panel, slabs without column head and drop panel, and slabs with drop panel and column head [2]. It is also called a beamless slab system. It is widely used in construction because of the flexibility of construction space, providing greater clear-ceiling heights. It is easy to install sprinkler and piping, and other utilities as beams were absent [3]. In addition, a flat slab gives an attractive appearance, and its formwork is simple and hence not costly, and the arrangement of flexural reinforcement is simple. This system reduces the slab's self-weight on the columns and foundations, and it is more economical than that of the conventional slab with beams [4].

However, the punching shear failure at the region around the column is considered the most dangerous type of failure in a flat slab system, causing a gradual collapse of the buildings. In addition to some other shortcomings in this system, such as more significant vertical displacements, the horizontal



forces cause less stability and possible and more massive moments at the column connection [5]. Punching shear is the shear failure of structural members (slabs, foundation) due to highly localized forces or high concentrated load. It is a brittle failure mode that happens suddenly without any warning. No sign can be identified before failure is occurred [6, 7]. In the past decades, punching shear failure has happened many times. This distressing may result in a progressive collapse if the structures do not have enough load redistribution [8].

This failure may happen in the thin slab under concentrated load leading to high shear stress in small areas around the column. It begins from the genesis of diagonal cracks in the tension face around the loaded region, which leads to a conical failure [9]. The average angle of the failure surface relative to horizontal is usually between 20° and 45°. It depends upon the amount and nature of reinforcement in the slabs [10], several ways were used to increase the capacity of slab against punching shear stress surrounding area of columns. Some of these techniques are directly enhanced the punching resistance, such as increasing the thickness of the slabs, shear head reinforcement, shear stirrups, shear studs, column heads, and drop panels [11], but these techniques are somewhat expensive and complicated [12]. However, other ways indirectly increase the punching shear strength by improving the mechanical properties of concrete like ultrahigh-performance cement, high concrete strength, and fiber additives [4, 7]. Many concrete properties can be improved by adding fibers depending on fibers' types and properties and the percentage of fiber addition. Fibers work to increase interconnects among concrete materials. In this paper, polypropylene fibers were utilized to improve the strength of the flat slab for punching.

1.1. Literature review

Haider et al. (2019) studied the effects of polypropylene fibers and HP-cement on concrete mechanical properties. They indicated significant improvement of compressive strength of cubes with different addition percentages of PF were ranged between 0.5% to 3% by weight of the cement and HP-cement with only two percentage 10% and 20% by cement replacement. They conducted that by adding polypropylene fibers advanced flexural strength from 72 to 277%, tensile strength from 37 to 175%, and 4 to 24% for compressive strength [13]. Freccy R. et al. (2017) investigated lightweight foamed concrete to split tensile strength with the effects of polypropylene fibers additive. They were found that, for the foamed concrete, the polypropylene fibers enhanced the tensile strength but not with reasonable increment [14]. Archana et al. (2017) examined the properties of concrete with polypropylene fibers (shear, flexural, split tensile and compressive strength). The experimental work included adding different polypropylene fibers (PF) ratios to the concrete mixture. An enhancement in concrete properties was perceived when the polypropylene fibers were added, but these properties decreased at 1% and above of PF percentage [15]. Divya and Aswathy (2016) studied the effect of adding polypropylene fibers (mingled type) (24mm, 40mm, 55mm) with different ratios range between (0.5%-2%) on concrete features like workability, flexural, compressive, and splitting tensile strengths. The results showed a significant increase in split tensile strength, compressive strength, modulus of elasticity, and flexural strength rise to 22%, 17%, 11%, and 24%, respectively, at a 1.5% of polypropylene fibers volume comparison with traditional concrete. They also found that the addition of polypropylene fibers more than 1.5% caused adverse effects on the concrete properties [16]. Fethi and Anil (2016) studied polypropylene and steel fibers' behavior on flat slabs' punching capacity. The volumetric fraction in the mixture of 0.5% was used for polypropylene and steel fibers. The results indicated that the displacement and punching shear strength increased by 20.14% and 15.28%, respectively, for a slab with polypropylene fibers and 12.42% and 21.43%, respectively, with steel fibers. It was also observed that the displacement of the polypropylene fibers slab was higher than that displacement of steel fibers concrete [17].

The flexural behavior of 24 slabs made from self-compacting concrete (SCC) Ferro cement fiber-reinforced slabs were studied by Deepa and Thenmozhi (2012). The variables content of fibers, Ferro cement slabs, thickness, and weld mesh layers number, were investigated. It was realized that there is improving in the ultimate load, increasing deflection, and enhancing energy absorption when using

SCC Ferro cement hybrid polypropylene fibers [18]. Also, it was indicated that the number of cracks was increased, the width of crack was decreased, and there was a delay in the growth of cracks.

2. Materials and experimental work

Twelve slabs were made with dimensions of (1000×1000) mm, and 100mm in thickness. The flexural reinforcement was the same for all models; the upper layer was (6 ϕ 6), while the lower layer was (10 ϕ 12) without shear reinforcement in slabs.

To study the effect of concrete compressive strength, three types of concrete mixtures were made to obtain different compressive strength values (24, 38, 46) MPa and expand the study area of their effect with various percentages of polypropylene fibers. These mixtures had the same amount of sand and gravel, but they differed in the amount of cement and additive. Different proportions of the polypropylene fibers were added (0%, 1%, 2%, and 3%) by cement weight as they are described in Tables 1 and 2. The slabs were tested by subjecting a concentrated load at the center of the model with a clear span of 950 mm for both directions. The loading steel plate was located under load points and above points of support to avoid nearby failure. Testing hydraulic machine (universal machine) shown in Figure 1 was used to test all slabs with a maximum range capacity of 2000kN in the structural laboratory of Faculty of Engineering, Kufa University.

Table 1. Quantities of different types of concrete mix.

Group	A	B	C
Symbol			
F_{cu} (28 days) Mpa	24.0	38.0	46.0
Cement (Kg/m ³)	310.0	420.0	550.0
Sand (Kg/m ³)	720.0	720.0	720.0
Gravel (Kg/m ³)	1190.0	1190.0	1190.0
Water (L/m ³)	154.5	154.5	154.5
Admixture (L/m ³)	-	3.0	6.0

Table 2. Material properties.

Material	Description
Cement	sulfate resistance - type V
Sand	normal sand from Najaf zone
Gravel	max. size 10 mm
Superplasticizer	admix HP 580
Polypropylene Fiber	micro propylene fiber length 8mm
Water	clean tap water



Figure 1. Hydraulic testing machine.

3. Results and discussion

This paper's main objective is to establish the effectiveness of adding polypropylene fibers to the concrete slab with various polypropylene ratios at different compressive strength levels on reinforced concrete flat slabs' structural behavior.

3.1. Mechanical properties results

Table 3 shows the compressive strength (F_{cu}) results of the tests obtained for concrete mixtures with different polypropylene fibers ratios. The optimum ratio of polypropylene fibers can be indicated as PF=1%, where the compressive strength increased by 34 %, 19%, and 23% for the groups' A, B and C, respectively. Also, splitting tensile strength was increased by 34% for group A with PF= 2%, while it was increased by 23% and 31% for groups B and C, respectively, at PF=3%. On the other hand, the modulus of rupture increased by 10% and 22% for groups B and C, respectively (PF =1%). For group A the optimum value of PF%=2% at which the modulus of rupture was increased by 21%.

Table3. The mechanical properties results.

Symbols	PF(%)	F_{cu} (MPa)	Splitting Tensile (MPa)	Modulus of rupture (MPa)
SAFP0	0	24.90	1.32	5.2
SAFP1	1	33.38	1.65	6.0
SAFP2	2	27.65	1.77	6.3
SAFP3	3	16.51	1.73	4.8
SBFP0	0	38.01	2.23	5.7
SBFP1	1	45.37	2.60	6.3
SBFP2	2	38.83	2.65	5.9
SBFP3	3	32.00	2.75	5.2
SCFP0	0	46.03	2.99	7.4
SCFP1	1	56.73	3.39	9.0
SCFP2	2	52.33	3.56	7.1
SCFP3	3	42.19	3.52	6.7

It can be concluded that when increasing PF% by more than 1%, the surface area of the fibers increases, which leads to reduce mixing water of concrete mixture, thus reducing workability and cement paste was conglomerated due to saturation with polypropylene fibers which causes a kind of segregation.

3.2. Testing results

The models will be classified into three groups; each group represents a value of compressive strength (i.e., groups A, B, and C as listed before). In each group, four models with different polypropylene fiber ratios are (0%, 1%, 2%, and 3%) by weight of cement. Through this classification, the influence of polypropylene addition on the structural behavior of slabs will be investigated.

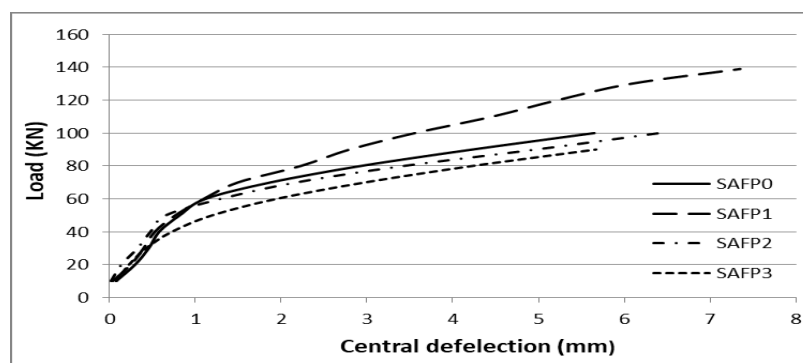
1) Group (A): Polypropylene fibers had a considerable effect on the failure load, but there is no effect on the first crack load. The first cracks formed at about 60%, 50%, 50%, and 55% of the ultimate load for slab SAFP0, SAFP1, SAFP2, and SAFP3, respectively.

Table 4 lists the results of group A; it can be recognized that the ultimate load capacity was increased by (39%) for SAFP1 compared to the control slab (SAFP0). However, the ultimate load of slab SAFP2 does not change compared to the results of slab SAFP0. In contrast, in the model SAFP3, the ultimate load was decreased by 10% compared with SAFP0, by increasing the polypropylene fibers ratio, more than 1% leads to a decrease in workability and interior weakness bond among concrete components.

Table 4. Experimental results of group A.

Symbols	PF (%)	First crack load (kN)	Ultimate load (kN)
SAFP0	0	60.5	100.4
SAFP1	1	70.2	139.3
SAFP2	2	50.1	100.4
SAFP3	3	50.2	90.5

The conducted ultimate load capacity of slab specimens is occurred in a similar mechanism of compressive concrete strength of cubes as the polypropylene fibers addition increased. On the other hand, it was detected that the polypropylene fibers had an apparent effect on the deflection where the deflection was increased by 30%, 13.45%, and 0.35% for Slab SAFP1, SAFP2, and SAFP3, respectively in comparison with slab SAFP0 (i.e., control slab). Figure 2 shows a comparison between loads versus central slab deflections of models of group A. Also, the brittle shear failure type in the control slab was changed into ductile punching failure due to the addition of polypropylene fibers.

**Figure 2.** Comparison of Load-deflection curves of specimens of group A.

- 2) **Group (B):** Table 5 shows the experimental results of specimens group B. It is clear to observe that the polypropylene fibers had an inconsiderable effect on the ultimate load but had an influence on the first cracking load. The first crack was consistent at about 33%, 45%, 53%, and 42% of the failure load for slabs SBFP0, SBFP1, SBFP2, and SBFP3. The ultimate load was increased by 8.1% for slab SBFP1, but it was decreased by about 13.5% and 16.1% for slabs SBFP2 and SBFP3, respectively, compared with SBFP0.

Table 5. Experimental results of group B.

Symbols	PF (%)	First crack load (kN)	Ultimate load (kN)
SBFP0	0	60.7	185.1
SBFP1	1	90.3	200.2
SBFP2	2	85.5	160.2
SBFP3	3	65.2	155.3

Figure 3 presents the central displacement of slab versus a load of group B. A slight improvement can be indicated for SBFP1 with PF=1% compared with slab SBFP0 and other specimens. Also, the improvement in failure mode for specimens containing PF was gradual and occurred in a ductile manner, unlike the control slabs that failed suddenly.

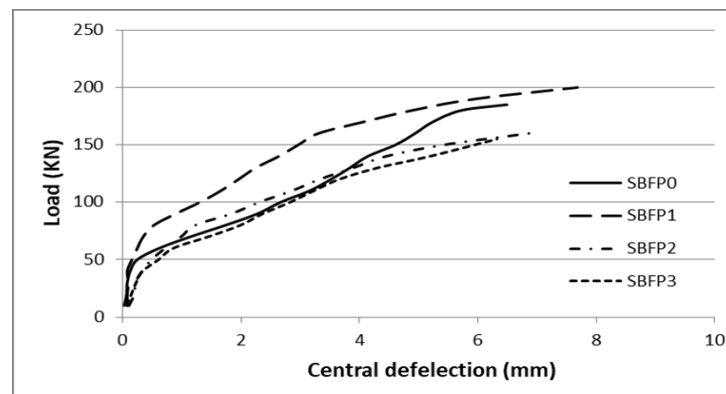


Figure 3. Comparison of load-deflection curves of specimens of group B.

- 3) Group (C):** Experimental results of group C are illustrated in Table 6. The first crack was formed at about 38%, 40%, 41%, and 47% of the ultimate load for specimens SCFP0, SCFP1, SCFP2, and SCFP3. Also, a noticeable improvement in the ultimate load has been utilized; it was increased by 12.5% and 5% for slabs SCFP1 and SCFP2, respectively, with respect to slab SCFP0, while the ultimate load in model SCFP3 was decreased by about 15%.

Table 6. Experimental results of group C.

Symbols	PF(%)	First crack load (kN)	Ultimate load (kN)
SCFP0	0	75.1	200.1
SCFP1	1	90.3	225.1
SCFP2	2	85.2	210.2
SCFP3	3	80.1	170.4

Figure 4 shows curves of load-deflection for flat slabs of group C. The deflection was increased by 12.3% and 8.25% for slabs SCFP1 and SCFP2, respectively, compared with slab SCFP0. In contrast, it was decreased in slab SCFP3 by about 3.0% with respect to control specimen SCFP0.

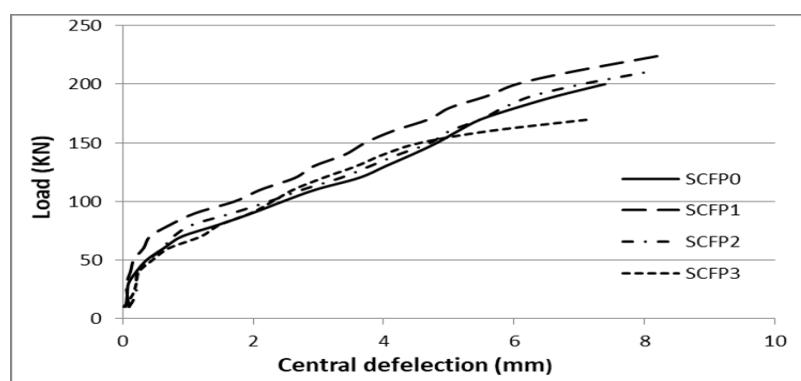


Figure 4. Comparison of Load-deflection curves of specimens of group C.

However, experimental results showed that the use of polypropylene fibers connector (PFC) instead of normal concrete (NC) had a considerable enhancement on the first crack load due to the high modulus of rupture for PFC. Also, a significant effect on the ultimate load capacity can be distinguished, especially for effective PF=1%. Besides, the effectiveness of PF=1% was visible at the specimen with $F_{cu}=24\text{Mpa}$ (i.e., group A) and decreased as the compressive strength increased $F_{cu}=38\text{Mpa}$ and $F_{cu}=46\text{Mpa}$ in group B and C, respectively. On the other hand, the critical area of punching shear

failure and numbers of cracks of PFC slabs became less compared with control slab SCFP0, as shown in Figure 5 to Figure 8.

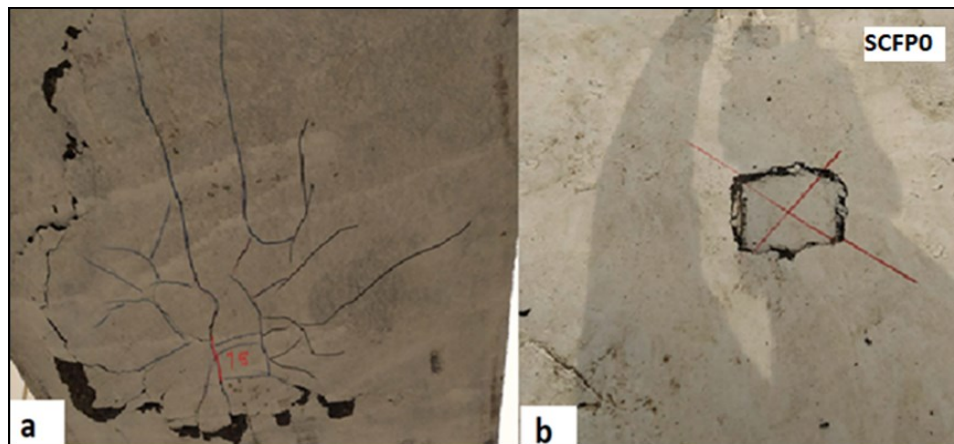


Figure 5. a-Tensile (bottom) face, b-Compressive (upper) face for specimen SCFP0.

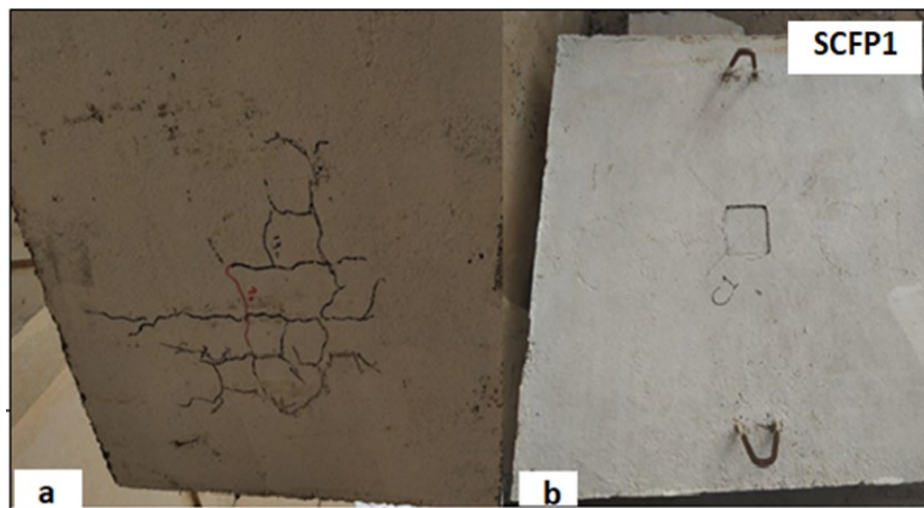


Figure 6. a-Tensile (bottom) face, b-Compressive (upper) face for specimen SCFP1.

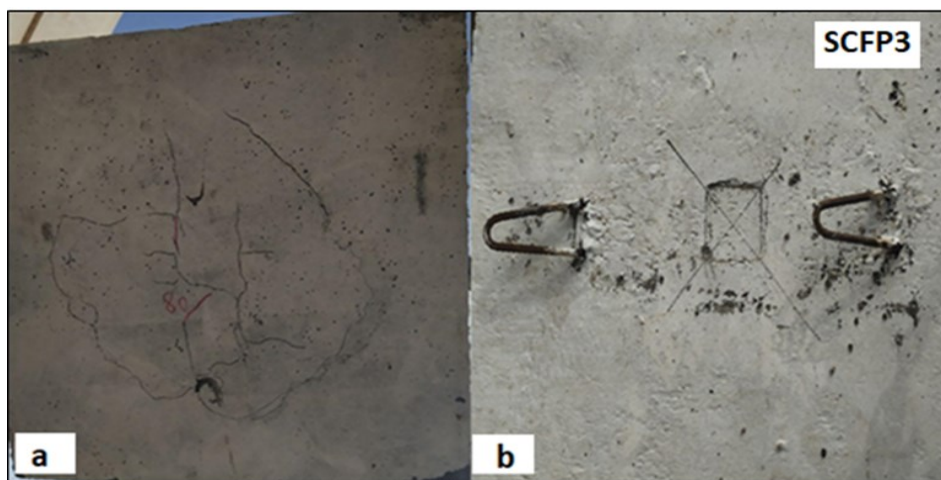


Figure 7. a-Tensile (bottom) face, b-Compressive (upper) face for specimen SCFP2.

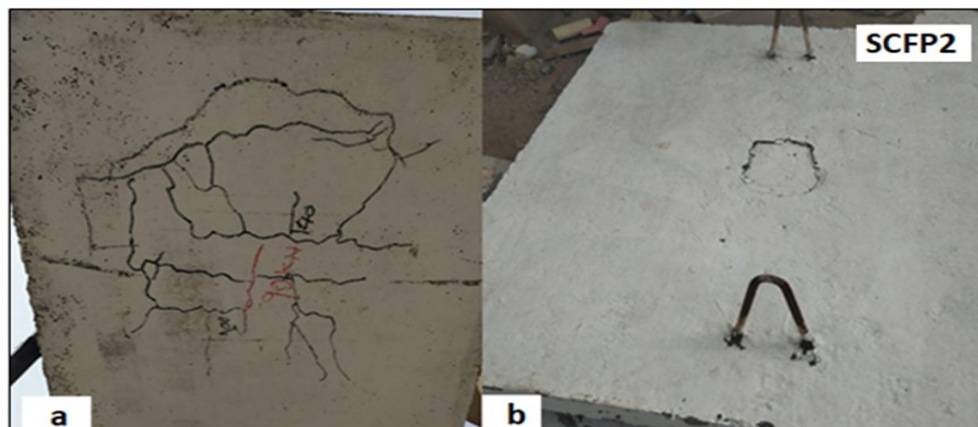


Figure 8. a-Tensile face, b-Compressive face for specimen SCFP3.

4. Critical area of punching shear

It is known that the critical pattern of punching failure of flat slab occurred at $d/2$ from the column face as recommended in ACI318M-14 (d is the effective depth) [19]. In addition, area, perimeter and angle of punching shear failure for all tested specimens slabs are presented in Table 7. It is evident that as the additive percentage of polypropylene fibers is increased, the shear punching area is decreased.

Table 7. Characteristics of punching shear failure of PFC slabs.

Symbol	Punching Shear		
	Area (m ²)	Perimeter (m)	Ø (°)
SAFP0	0.3983	2.5330	18
SAFP1	0.2015	1.7560	26
SAFP2	0.2046	1.7402	25
SAFP3	0.2737	1.9392	22
SBFP0	0.4077	2.6877	18
SBFP1	0.1990	1.8616	26
SBFP2	0.2095	1.8317	26
SBFP3	0.2144	1.8141	25
SCFP0	0.4383	2.6350	17
SCFP1	0.1610	1.5183	30
SCFP2	0.1986	1.6939	26
SCFP3	0.2238	2.0316	25

The punching shear area becomes smaller due to increasing the number of polypropylene fibers, where the failure section of punching becomes closer to the column edge. On the contrary, the shear force, especially for PF=1%, becomes more extensive because of polypropylene fibers, which need more punching shear force to pull or cut a higher amount of fibers. According to ACI 318M-14, the punching area is 0.028224 m², which is much less than the actual area, so it can be concluded that the ACI 318M-14 Code is conservative at this recommendation.

5. Conclusions

5.1. Material properties

- Experimental results show that a considerable improvement of concrete properties was indicated at the optimum addition percentage of polypropylene fibers for a concrete mix, PF=1% by cement weight. Also, this optimum percentage value was established through

different levels of concrete compressive strength for specimens of group A ($F_{cu}=24\text{MPa}$), B ($F_{cu}=38\text{MPa}$), and C ($F_{cu}=46\text{MPa}$).

- Using PF=1% in concrete mix will increase the compressive strength of cube for PFC by (34 %, 19%, and 23%) for groups A, B, and C), respectively, compared to normal concrete. However, there is no noticeable enhancement in compressive strength for further addition of PF due to conglomerate and mix saturation by polypropylene fibers, which causes a kind of segregation during the mixing process.
- Polypropylene fibers' effects on splitting tensile strength were more than the compressive strength. The tensile strength of cylinders displayed at PF=1% was increased by 34%, 19%, and 23% for groups A, B, and C, respectively.
- The modulus of the rupture of PFC prisms was increased by 15%, 10%, and 22% for groups A, B, and C, respectively, by using PF=1%.

5.2. Testing results of PFC slabs

- Testing results show a significant enhancement of punching shear resistance, first crack loading, and load-deflection curve of flat slabs with a percentage of polypropylene fibers at PF=1% by weight of cement in comparison with NC. However, more addition of PF will not give significant improvement.
- Using an optimum percentage of PF=1% in concrete mixture causes an improvement of punching load capacity of flat slabs by 39.0%, 8.1%, and 12.5% with concrete compression strength $F_{cu}=24\text{MPa}$, $F_{cu}=38\text{MPa}$, and $F_{cu}=46\text{MPa}$, respectively. In contrast, by using PF=2%, the experimental result shows a slight improvement while using PF=3% led to reduced punching shear resistance of slabs.
- The failure mode of concrete flat slabs with polypropylene fibers under punching load occurred in a gradual and ductile manner while the non-fiber models failed suddenly and in a brittle way.
- Failure cracks in normal concrete slabs are obvious and broad, while such cracks are very tiny and less number in a slab with polypropylene fibers. This is because the fibers increase the internal bonding of concrete components.
- The addition of polypropylene fibers to the concrete mix reduces the punching area and perimeter of the critical section, while the failure angle was slightly increased with increasing PF%.

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