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Study on the properties of high strength polypropylene fiber concrete

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Abstract

The properties of high strength polypropylene (PP) fiber reinforced concretes with 0, 0.5, 1 and 1.5% fiber content, 0.2 water-binder ratio are designed and evaluated. The results show that the addition of PP fiber to high strength concretes will reduce 3~5% compressive strength as well as decreasing 5% of the dynamic modulus of elasticity. The flexural strength of PP fiber reinforced concrete at 7 days was decreasing 10% as compared with the specimen without addition PP fiber. At 28 days, the addition of PP fiber tends to improve the toughness index and the impact loading as well.

1. Introduction

The concrete is one of the most useful construction materials, but the defects of concretes are brittle and low tensile strength. As a result, the concrete is liable to tensile crack and threat to the durable performance. Goldfein (1965) pointed out that adding fiber to concrete improves the concretes toughness, compressive, flextural strength and reduce drying shrinkage crack. Therefore, Gal, and Kryvoruk, and Cagatay and Dincer (2011) pointed out the fiber, including Polypropylene (PP) fiber, steel fiber and carbon fiber was situated to reinforcing the performance of concrete. Romualdi and Batson (1964) further proposed the fiber spacing theory base on the fracture mechanics. As a result, addition fiber to brittle concrete material will compensate the tensile strength and improve the durability. Krenchel (1985) pointed out that the vertical and parallel direction of the fiber arrangement affects the performance of fiber concrete, and consider the influential of fiber spacing and the volume ratio. If the fiber volume ratio is too low, the fiber spacing is not overlapped, then the strengthened effect will be low.

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Bentur, Diamond and Mindess (1985) figure out the porous transition zone will significantly influence the strength of concrete materials. As the fiber surrounded by CH crystal it will reduce bond stress and influence the structure intensity. Lin and Yang (2002) pointed out the fiber content promotes the impact resistance and the mechanical properties of concrete. Also, the fiber type and the content have the different influence to the concretes performance.

Therefore, Hwang, et.al (2008) try to apply the Fuller's curve to design the densified concrete mixture to compensate the defect as compare to the traditional design.

2. Material preparation and testing method

2.1Raw material

Type I cement, crushed aggregate with specific gravity (SSD) 2.68, the maximum particle size 12.5(mm) and fineness moduli of fineness and coarse aggregate are 3.1 and 6.7, respectively, slag furnace powder with the specific surface area 6000(cm^2/g), type F fly ash and also Elkem silica fume are used in this study. The PP fiber in corrugated shape with the length 46mm and L/D=40~45 is used as shown in Fig. 1. The PP fiber content is varied from 0%, 0.5%, 1% to 1.5%. The carboxylic based superplasticizer is used to reduce mixing water significantly. The W/B of concrete is fixed as 0.20 and the coating thickness on the surface of aggregate and PP fiber is 15μm. The mixture proportion is designed by DMDA (Hwang 2008) as shown in Table 1 with designed slump and slump flow of fresh concrete are 250 mm and 500 mm, respectively, and the specimen size is 10cm-ϕ×H20cm tested at 28, 56 and 90 days.

Fig. 1 The feather of pp fiber

Table 1 The mix proportion of PP fiber concrete (kg/m^3)

Designation	Cement	PP Fiber (%)	Slag	Fly ash	Silica fume	Fine aggregate	Coase aggregate	Fiber
PP201500	409	0.0	136	100	28.2	955	718	0
PP201505	410	0.5	137	99	28.0	947	712	4.5
PP201510	411	1.0	137	98	27.7	939	706	9
PP201515	412	1.5	137	97	27.5	931	701	13.5

2-2 Properties of fresh PP fiber concrete

The entrapped air content and other physical properties of fresh PP concrete such as slump, slump flow and unit weight are shown in Table 2.

Table 2 The fresh property of PP fiber concrete

Designation	Fiber content (%, vol.)	Fresh PP fiber concrete			Air content (%, vol.)
		slump (mm)	slump flow (mm)	flow time (sec)	
PP201500	0	280	740	165	1.95
PP201505	0.5	280	700	180	1.97
PP201510	1	270	650	150	2.64
PP201515	1.5	270	620	270	2.95

2-3 Properties of harden PP fiber concrete

The specimens of PP fiber concretes are prepared and tested according to relevant standards. The properties measured are compressive strength, flexural strength and toughness. Impact load with 9 kg hammer falling test repeats 200 times. The resonance frequency and the dynamic modulus calculated according to ASTM C215 as Eq. (1):

$$E_d = 4n^2L^2 \rho 10^{-15} \quad (1)$$

Where

E_d: the dynamic modulus (GPa),

n: the resonance frequency of specimen in longitude direction (Hz),

L: the length of specimen (mm), and

ρ : density (kg/m^3).

3. Results and discussion

3.1 Fresh PP concrete

The maximum packing volume was 0.740 (m^3/m^3) in this study and the power of exponent h is 0.5 by Fuller's curve. The unit weight of PP fiber concrete is between 2,340 to 2,445 (kg/m^3), the entrapped air content is about 2% to 3% and the concretes flow like honey in slump, slump flow test, the results are 210~280(mm), 500~700(mm), respectively and flow time is 33~300 (sec). It is shown that the more the fiber volume (%), the more the air content and the less the unit weight. Nevertheless, It is shown that the fly ash physically acts like ball to reduce the viscusity between aggregate and chemically act as binder to achieve the design properties.

3-2 Properties of harden PP fiber concretes

3-2-1 Compressive strength

The compressive strength of all mixture before 28 days the addition of PP fiber tends to slightly improve the strength, after 28 days it is higher than 13,000 psi (55 MPa)

since the w/b for all mixture is 0.2 and the addition of PP fiber tend to slightly reduce (~5%) the compressive strength as shown in Fig. 2. As a result, the PP fiber concrete would be worth to develope as a durability concrete.

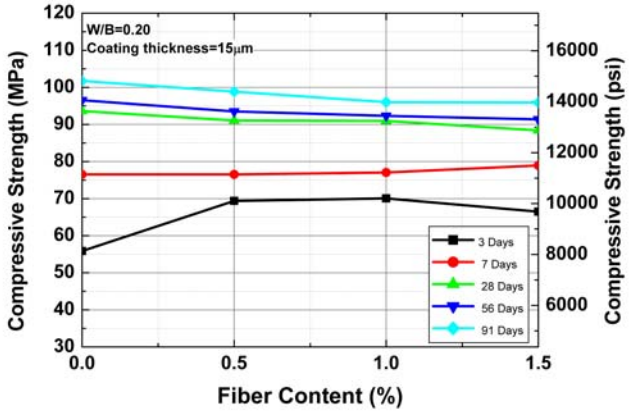


Fig.2 The compressive strength of PP fiber concrete versus fiber content

3-2-2 The flexural strength

The specimen dimension for bending test is 150mm x150mmx 500mm and test ages are 7 days and 28 days. As the fiber content more than 1% it shows the flexural strength over 11.45 kgf/cm^2 (1,600psi) as shown in Fig. 3. At 7 days, the more the fiber content the less the flexural strength is, however at 28 days the more the flexural strength is. As shown in Fig. 4 the deflection of PP fiber concrete specimen is higher than that without PP fiber under the same loading. Therefore, the increasing of the PP fiber may slightly increase for the flexural strength at long term of age.

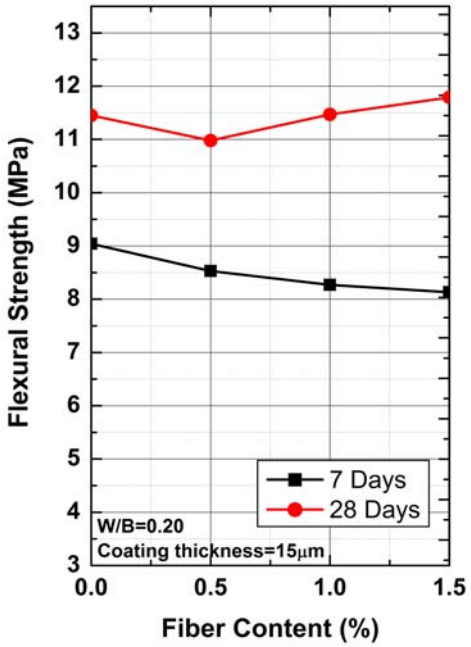


Fig. 3 The effect of the addition of PP fiber on the flexural strength of concrete

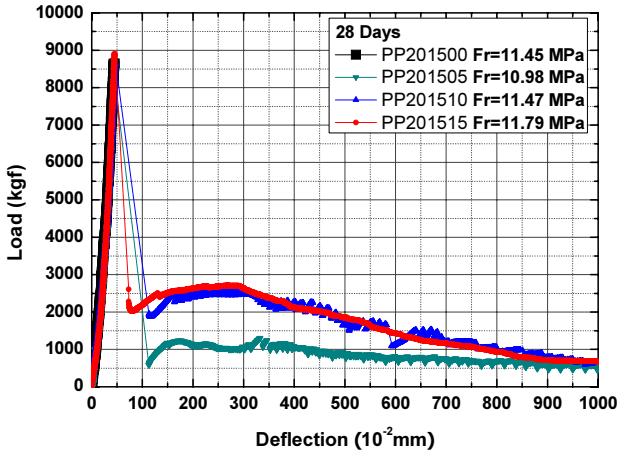


Fig.4 The relationship of deflection and loading of PP fiber content change

3-2-3 Toughness index

The addition of PP fiber is obviously positive to the toughness index as shown in Fig. 5. It is obviously that the addition of PP fiber help toughness of concrete and the toughness index. Moreover, the toughness index increases 17% with the addition the PP fiber increases at 28 days.

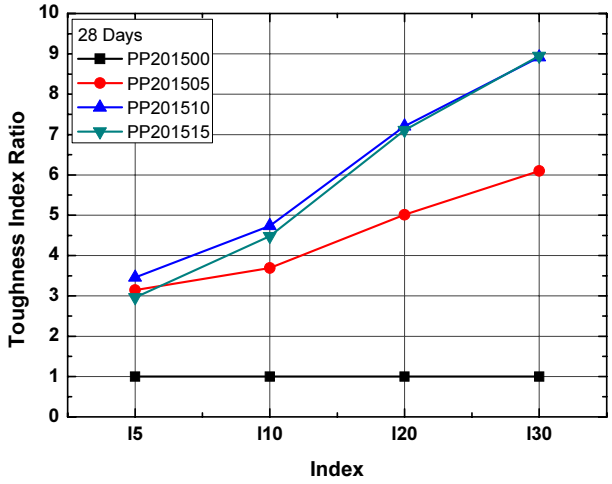


Fig. 5 The relationship of toughness of PP fiber concrete with fiber content

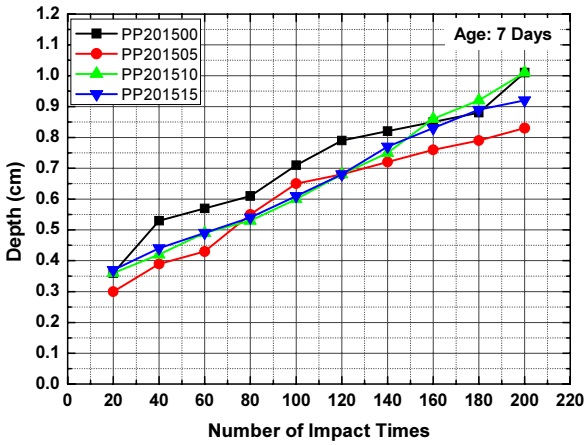
3-3 Impact loading effect

The impact result of the specimen at 7 days, 28 days and 91days after hammer drop 200 times until the destruction of specimen is shown in Table 3. The impact number of drop times as well as the impact depth is smaller. It is shown that the fiber does decreasing the crack, and clearly shows the addition PP fiber in concrete improves impact loading resistence. Nevertheless, the addition of PP fiber effectively improves

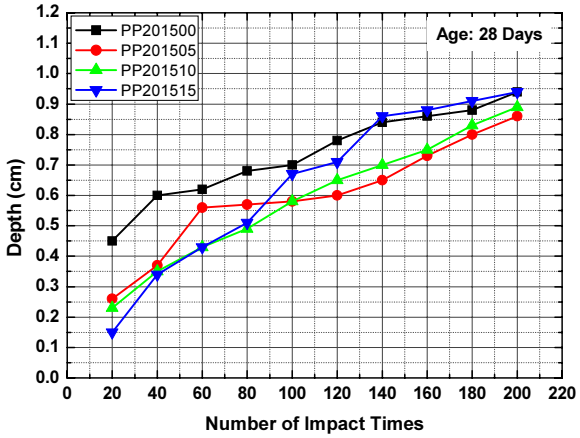
26% impact loading, reduces 10% of impact indent depth and 1.5% of fiber was the lowest depth at 91 days as shown Fig. 6.

Table 3 The failure mode of the impact loading

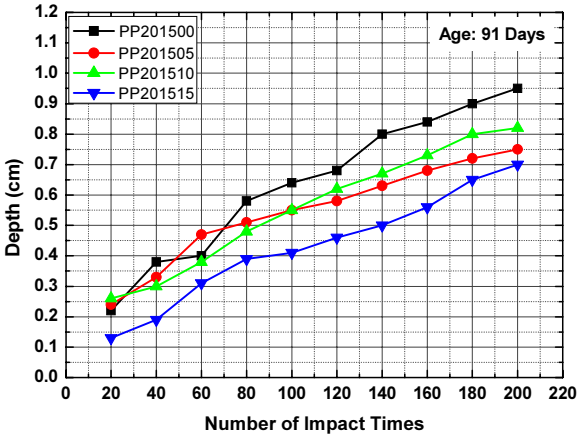
PP251510	**PP301510**	**PP351510**
		
Age：**7 days** Initial crack number：**42** Smash number：**153**	Age：**7 days** Initial crack number：**30** Smash number：**36**	Age：**7 days** Initial crack number：**37** Smash number：**53**
ACI 2010	**PP301510**	**PP351510**
		
Age：**7 days** Initial crack number：**46** Smash number：**65**	Age：**28 days** Initial crack number：**83** Smash number：**189**	Age：**28 days** Initial crack number：**132** Smash number：**146**
PP301510	**PP351510**	**ACI 2010**
		
Age：**91 days** Initial crack number：**190** Smash number：**195**	Age：**91 days** Initial crack number：**129** Smash number：**136**	Age：**91 days** Initial crack number：**56** Smash number：**63**



(a)



b)



(c)

Fig. 6 The relationship of impact times and indent depth and fiber content (a) 7 days (b) 28 days (c) 91 days

3-4 Dynamic moudulus

The resonance frequency and dynamic modulus is calculated according to Eq. (1) as shown in Table 4, and the dynamic moudulus range from 43 to 47 GPa decreases 3% with fiber content increasing with 28 days of PP fiber concrete.

Table 4 The dynamic moudulus of harden PP fiber concrete

Designation		PP201500	PP201505	PP201510	PP201515
Dynamic moudulus (GPa)	3 days	43.98	42.77	42.51	41.37
	7 days	46.10	44.74	44.73	43.75
	28 days	47.90	46.44	46.43	45.53
	56 days	47.90	47.22	47.20	46.32
	91 days	48.65	47.97	47.94	46.98

4. Conclusion

(1). The mixture proportion designed by Hwang's Fuller densified mix design algorithm for PP fiber concrete can meet the design requirements.
(2). The PP fiber concrete may enhance compressive and flexural strength at early age, but at 28 days the addition of fiber decreases 5% compressive strength as well as decreases 3% dynamic moudulus.
(3). The addition of the PP fiber decreases flexural strength at 7 days, but slightly increases at 28 days, and increases 17% toughness index.
(4). The addition of PP fiber effectively improves 26% impact loading and reduces 10% impact indent depth.

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