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Effect of Polypropylene Fibre on Self- Compacting High-performance Concrete

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Abstract: This study conducted tests on the design mixture of Polypropylene Fibre Reinforced Self-Compacting High-performance Concrete (PFRSCHPC) and Self-Compacting high-performance concrete (SCHPC) to determine the mechanical properties of the concrete, and the beams behaviour under bending loads. The composition of the mixtures of PFRSCHPC and SCHPC refer to Oesman, et al. (2022), which conducted research on UHPC (ultra-high-performance concrete) using natural sand and crushed stone through a 4.75mm sieve. PFRSCHPC and SCHPC compositions using Portland Slag Cement (PSC); 1% superplasticizer and 30% silica fume of the total binder; 1% Polypropylene fibre (PP); the ratio of sand to crushed stone 45%: 55%; and the w/b was 0.23. However, SCHPC as the control concrete mixture does not contain PP. The testing results of the PFRSCHPC showed compressive strength, tensile strength, flexural strength, and modulus of elasticity were 42.73 MPa; 4.33 MPa; 8.98 MPa; 45.51 GPa, respectively. When compared to SCHPC, PP has an influence in increasing tensile strength by 2.38 MPa (122.05%), flexural strength by 2.67 MPa (42.77%), and concrete elasticity modulus by 6.67 GPa (17.32%). However, 1% PP decreased compressive strength of PFRSCHPC, lower by 4.93 MPa (10.34%) compared to SCHPC. PFRSCHPC beam reached a peak load of 27.5 kN; initial stiffness of 5.32 kN/mm; ductility of 5.6; and toughness of 1606.08 kNm. PFRSCHPC beam with PP fibre content of 1% are able to increase 17.02% of peak load; 14.75% of ductility, and 113.91% of toughness.

Keywords: *SCHPC; PFRSCHPC; Polypropylene fibres; mechanical properties*

1. Introduction

Today, Self-Compacting Concrete (SCC) technology for structures continues to develop, one of which is Polypropylene Fibre Reinforced Self-Compacting High-performance Concrete (PFRSCHPC), which is the concrete that has high performance because it can compact itself without going through the compaction process by using a vibrating tool and using fibre as reinforcement. The application of PFRSCHPC to structural elements can increase the ability of concrete to tensile forces, especially in zones that are weak to cracking or areas in concrete where there are no reinforcement elements can increase the ability of concrete to tensile forces.

When concrete in the process reaches its characteristics, it will suffer shrinkage which causes cracks to spread and extend at the end of the crack. The fibres located within the crack area serve as connecting bridges by inhibiting the separation of cracked concrete, thereby increasing the concrete's ability to resist tensile forces. Therefore, the use of fibre as reinforcement will increase the ability of concrete to resist tensile in volume and dimension because the fibre will be evenly distributed in areas where there is no reinforcement. The combination of SCC with polypropylene fibre content can be an alternative in improving the mechanical properties of high-performance concrete, the combination is known as Polypropylene Fibre Reinforced Self-Compacting High-performance Concrete (PFRSCHPC).

In general, concrete mixture uses Ordinary Portland Cement (OPC) type cement, aggregate gradation size uses 5 – 20 mm. Meanwhile, this study used Portland Slag Cement (PSC), polypropylene fibre, local aggregate (natural sand and crushed stone) passed by 4.75 mm sieve, silica fume, and superplasticizer. One of the objectives of this study was to determine the mechanical properties of PFRSCHPC. The proportion of the mixture refers to Oesman, et al. (2022) research on UHPC (ultra-high-performance concrete), which is using 4.75 mm sieve pass aggregate and the addition of steel fibre so that it can achieve ultra-high concrete quality, while in this study polypropylene fibre be used.

Self-Compacting Concrete (SCC) refers to the behaviour of fresh concrete mixtures that are able to compact themselves flowing under their own weight, filling the space in the formwork, producing a solid and fairly homogeneous material without the need for compaction (Schutter, et al, 2008). Based on ACI 237R-3, SCC is a non-segregated concrete that can easily flow, scatter, fill formwork, and wrap reinforcement without mechanical consolidation. SCC is also defined as self-compacting concrete, self-placing concrete, and self-levelling concrete. Basically, SCC is made using conventional concrete material and, in some cases, coupled with viscosity-modifying admixture (VMA).

According to ACI CT-21 (2021), Fibre Reinforced Concrete (FRC) is concrete made from hydraulic cement, aggregate, and reinforcing fibres with normal proportions or mixtures specifically formulated for specific applications. Fibre is used as reinforcement unlike reinforcement. The fibres are evenly distributed in concrete with the average distance between the fibres smaller than the typical distance for reinforcement. Thus, the tensile stress that causes the beginning of the crack will be suffered by the fibre, so that the crack does not develop quickly and the crack pattern changes. When FRC does not suffer cracks, the condition of the fibres in concrete is assumed to be homogeneous, but when cracks begin to occur, the fibres will bridge the cracks and begin to support tensile stress which provides an increase in the capacity of concrete to withstand loads due to tensile in crack conditions (Buratti, et al., 2011).

The stages of FRC failure are schematically shown in Figure 1 and are summarized as follows. Cracks in the cement matrix are formed. Then, there is debonding and sliding between the fibre and the matrix, fibres bridge cracks, the fibre suffers frictional sliding then experiences anchor deformation and finally the fibre is pulled. The potential for the fibre to fail when pressure is applied, the term failure occurs at the final stage when the fibre is no longer able to withstand the pressure that occurs.

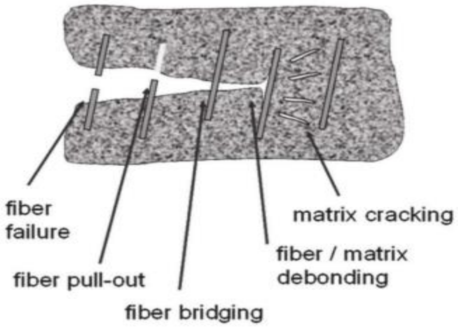

Fig. 1. Scheme of the Working Mechanism of Fibre as Reinforcement
(*Source*: ACI 544.4R, 2018)

Polypropylene fibre is fine filaments made from plastic which has hydrophobic properties, that is, it does not absorb water. In some cases, adding water to fibre concrete aims to increase its workability, but can cause a decrease in compressive strength. Based on research by Kung (2015), it was concluded that adding polypropylene fibre with a content of 0.9 kg/m3 to concrete can increase the tensile strength of concrete by up to 33.14% compared to concrete without fibre. Polypropylene fibre has two forms shown in Figure 2, monofilament fibre and film fibre, this research used film fibre.

Fig. 2. Monofilament fibre (left), film fibre (right)

PFRSCC has mechanical properties which are the qualities and capabilities possessed by concrete. Compressive strength is the ability of concrete to withstand compressive loads until its failure. The compressive strength of PFRSCC will be higher than conventional concrete because it has a different mixture composition due to the addition of polypropylene fibre, superplasticizer and silica fume to obtain the required workability. The compressive strength of PFRSCC obtained at 7 days, 14 days, and 28 days was 39.8 MPa, 52.0 MPa, 63.7 MPa respectively (Long, et al, 2014). In general, the split tensile strength value of concrete is around 3-8 MPa or 1/8 of the compressive strength value (Chandra, 2015). Concrete containing polypropylene fibres increases compressive strength and tensile strength better than normal concrete (Karimipour, et al, 2021). The polypropylene fibres in SCC behave as reinforcement which can provide tensile stress to the concrete with the result that the concrete is able to have high ductility. The bending strength of a beam is a result of the strain that arises due to external loads. If the load increases, deformation will occur and the increase in strain will result in cracks appearing due to bending along the span of the beam (Suryani A, et al, 2018). The use of polypropylene fibres and silica fume in the SCC mixture can increase the flexural strength value. The modulus of elasticity is the ratio of the stress and strain values in concrete. The addition of polypropylene fibres is known to increase the elastic modulus value, although not significantly (Suryawan, 2014). According to ACI 318-89, the elastic modulus value can be taken by comparing 45% of the maximum stress to the strain that occurs under that stress condition.

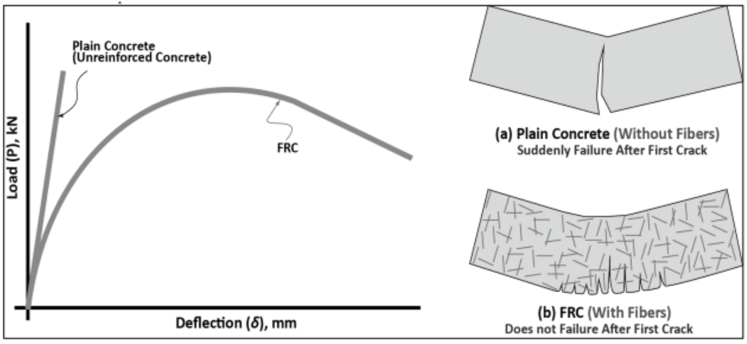

Fig. 3. Flexural toughness of FRC and plain concrete
(*Source*: Hamad dan Sidozian, 2019)

Toughness is defined as the ability of concrete to resist the opening of cracks where the material is able to absorb energy and deform plastically without breaking. The toughness behaviour of plain concrete without reinforcement with FRC can be seen in Figure 3. The toughness of FRC concrete is described in the area under the load-deflection curve, plain concrete occurs failure without plastic deformation while FRC suffers plastic deformation before failure. Cracks that occur in plain concrete propagate quickly and have wide openings, while in FRC the cracks are held in place by fibres so that the cracks do not propagate.

2. Methodology

Research on the effect of polypropylene fibre on self-compacting high-performance concrete was carried out by testing the mechanical properties of the concrete and structural beams under bending loading made using PFRSCHPC mix with mixture proportions referring to research on UHPC with steel fibre (Oesman, et al. 2022), then compared to SCHPC as control concrete. The research began with material preparation, including preparation of a combination of natural sand and crushed stone that passed a 4.75mm sieve. Material testing is carried out as a basis for making PFRSCHPC mixtures and control concrete. The PFRSCHPC mixture is the same as the control concrete, SCHPC, but the control concrete does not contain polypropylene fibre.

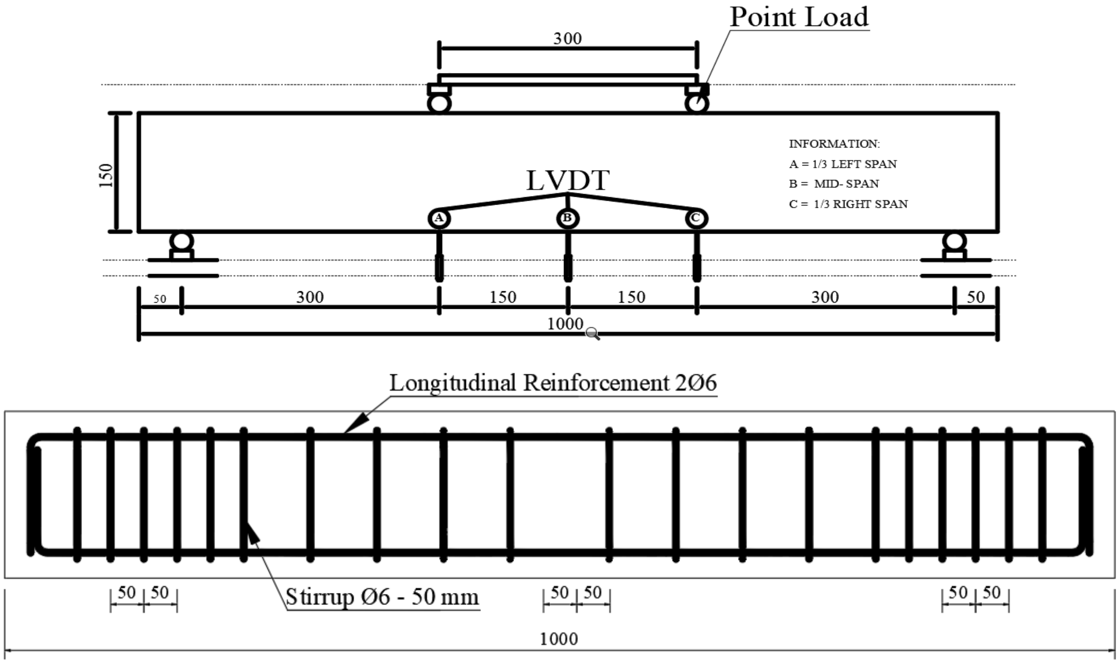

Fig. 4. Set up of loading of the beam specimens.

Fresh concrete testing is carried out using the flow table method referring to ASTM C1437-07. The optimum flow value to be achieved is 250 mm, so the addition of water will be done gradually and carried out until the flow value is met. Making test specimens for PFRSCHPC and SCHPC consists of specimens for compressive strength tests (SNI 03-1974-1990), tensile strength tests (SNI 03-2491-2002), flexural strength (ASTM 78) modulus of elasticity test (ASTM C 469-1994), and testing on beams under bending load with dimensions of 100 x 100 x 500 mm. The curing method is carried out by standard water curing. Testing of beam specimens was carried out under bending loads with third-point loading using a loading frame with a capacity of 80 kN at the age of 28 days. To obtain deflection data, LVDTs were installed on the right and left 1/3 of the span and the middle of the span. The deflection that occurs in the beam will be recorded by the data logger. Testing will be stopped when the beam element collapses. Figure 4 shows set up of loading of the beam specimens. Things that will be observed during the test include the working loads and deflections that occur in the middle of the span and the crack patterns that occur until failure. The results of testing the application of PFRSCHPC and SCHPC beam structural elements under bending will be processed and analyzed by making a graph of the relationship between load and deflection. From the graphs created, the maximum load and load immediately before failure and deflection occur in each of these conditions. Apart from that, the graph can be used to determine the behavior of beam structural elements under bending loads, including maximum load, stiffness, toughness, ductility, and crack patterns.

3. Result and Discussion

3.1. Material Testing

Before making the concrete mixture, testing of the concrete constituent materials that will be used is carried out. The test results are as shown in Table 1.

Table 1. Material Testing Result

No.	Test Type	Test Standards	Results
1.	Cement Specific Gravity	SNI 15-2049-2004	3.09 gr/cm^3
2.	Silica Fume Activity		< 2 mm
3.	Specific Gravity of *Silica Fume*		2.14 gr/cm^3
4	***Crush stone***		
	SSD Specific Gravity (saturated surface dry)	SNI 1969-2016 SNI 1970-2016	2.63
	Dry Specific Gravity (bulk)		2.53
	Apparent Specivic Gravity		2.81
	Water Absoption		3.93%
	Sieve Analysis		
	Sieve Size (mm)	ASTM C136-2012	Cumulative Pass
	4.75		99.70%
	2.36		55.85%
	1.18		13.03%
	0.60		4.09%
	0.30		0.79%
	0.15		0.66%
	0.075		0.51%
	Solid Content Weight	SNI 03-4804-1998	1.56 gr/cm^3
	Loose Content Weight		1.44 gr/cm^3
	Grain Content Passing Sieve No.200	SNI 03-4142-1996	4.96%
5	**Natural Sand**		
	SSD Specific Gravity (saturated surface dry)	SNI 1969-2016 SNI 1970-2016	2.50%
	Dry Specific Gravity (bulk)		2.35%
	Apparent Specific Gravity		2.75%
	Water Absorption		6.16%
	Sieve Analysis		
	Sieve Size (mm)	ASTM C136-2012	Passing Cumulative
	4.75		100%
	2.36		100%
	1.18		99.94%
	0.60		68.81%
	0.30		42.40%
	0.15		13.88%
	0.075		4.23%
	Solid Content Weight	SNI 03-4804-1998	1.38 gr/cm^3
	Loose Content Weight		1.25 gr/cm^3
	Grain Content Passing Sieve No.200	SNI 03-4142-1996	3.31%
	Aggregate Organic Subtances	SNI 2816-2014	No. 1

3.2. Concrete Composition

PFRSCHPC and SCHPC mixtures composition are shown in Table 2, but in PFRSCHPC polypropylene fibre is used; meanwhile, the SCHPC did not use fibre. The design of the concrete mixture refers to research by Oesman, et al. (2023). The design of the concrete composition uses Portland Slag Cement (PSC) cement; 1% superplasticizer from total binder; 30% silica fume from total binder; polypropylene fibre is 1% of the total concrete volume; ratio of natural sand to crushed stone 45%: 55%; and a water binder w/b ratio of 0.22.

Table 2. PFRSCHPC composition mixture

Material	Composition
Cement	750.40 kg/m^3
Natural Sand	454.95 kg/m^3
Crush stone	556.05 kg/m^3
Silica fume	321.60 kg/m^3
Superplasticizer	10.72 kg/m^3
Polypropylene fibre	9.10 kg/m^3
Water	225.12 kg/m^3
Binder	1072.00 kg/m^3

3.3. Concrete Workability

Workability of PFRSCHPC fresh concrete tested by a flow table test is carried out according to ASTM C230, as seen in Fig.5. The flow value in this study was set at 250 mm and water was added gradually until the flow value met. In the initial water content required in the concrete mixture composition was 225.12 kg/m^3 with an initial w/b ratio of 0.22. Because the desired flow had not yet been achieved, water was added to the mixture, so that the final water content in the mixture composition after correction was 242.44 kg/m^3 with a w/b ratio of 0.23.

Fig. 5. Flow Table test

3.4. Compressive Strength

The compressive strength of PFRSCHPC and SCHPC was obtained through compressive strength testing according to SNI 03-1974-1990 on aged 7 days, 28 days and 56 days, three test specimens each. The compressive strength test results are listed in Table 3, and Table 4 for PFRSCHPC and SCHPC, respectively.

Table 3. Compressive Strength of PFRSCHPC

No	Test Object Code	Maximum Load (kN)			Compressive Strength (MPa)		
		7 days	28 days	56 days	7 days	28 days	56 days
1	PFRSCHPC 1	290	312	381	36.66	39.48	47.75
2	PFRSCHPC 2	351	358	348	44.61	44.93	44.03
3	PFRSCHPC 3	301	344	312	37.73	43.79	39.16
Average					39.67	42.73	43.65

The test results show that the average compressive strength of PFRSCHPC at 7 days, 28 days, and 56 days is 39.67 MPa, 42.73 MPa, and 43.65 MPa, respectively. This shows an increase in the compressive strength of PFRSCHPC aged 7 days to 28 days by 7.71%, and an increase of 3.05% at the age of 28 days to 56 days.

Table 4. Compressive Strength of SCHPC

No	Test Object Code	Maximum Load (kN)			Compressive Strength (MPa)		
		7 days	28 days	56 days	7 days	28 days	56 days
1	SCHPC 1	330	376	470	41.04	47.11	59.65
2	SCHPC 2	385	392	420	47.19	49.23	53.56
3	SCHPC 3	365	368	477	46.80	46.64	60.86
Average					45.01	47.66	58.02

Meanwhile, test results of SCHPC average compressive strength show that at 7 days, 28 days and 56 days is 45.01 MPa, 47.66 MPa and 58.02 MPa, respectively. This shows an increase in the compressive strength of the aged 7 days to 28 days by 5.89% and an increase of 21.75% at the age of 28 days to 56 days.

The test results show that PFRSCHPC has a lower compressive strength compared to SCHPC at 28 days, that is 4.93 MPa (10.34%). According to Zhu, et al. (2011), the compressive strength of concrete will decrease with the addition of polypropylene fibre due to the influence of porosity.

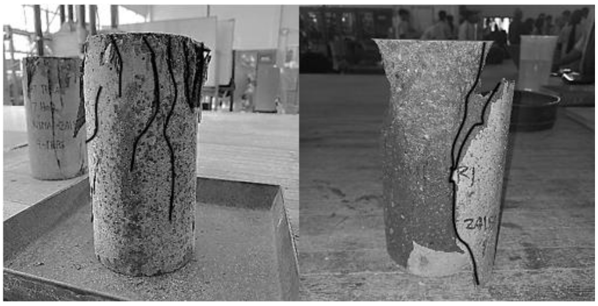

Fig. 6. Crack failure pattern of PFRSCHPC (left) and SCHPC (right)

The failure crack pattern due to compression in PFRSCHPC concrete and SCHPC shows different behaviour. The PFRSCHPC cylindrical specimen with polypropylene fibre content of 1% (left of figure 6) suffered failure with crack pattern extending from the surface. While only hairline cracks occurred at the bottom of the cylinder, the part of the concrete that was almost peeling off was also held in place by fibres so that it did not immediately separate from the concrete. Meanwhile, the SCHPC specimen without fibre (right of figure 6) occurred brittle failure where the cracks that occurred as the applied load increased caused the concrete to separate (spalling) because there was nothing to support it.

3.5. Split Tensile Strength

Split tensile strength test were carried out on the PFRSCHPC and SCHPC specimens according to SNI 03-2491-2002 at the age of 28 days, three test specimens each. The test results show average for the splitting tensile strength of PFRSCHPC of 4.33 MPa, and average the splitting tensile strength of SCHPC of 1.95 MPa. Thus, PFRSCHPC has a greater spilt tensile strength, with a difference of 2.38 MPa (122.05%) compared to SCHPC. Thus, the addition of polypropylene fibre has an influence in increasing the split tensile strength of the concrete. Figure 7 shows the condition of PFRSCC and SCHPC after split tensile strength testing. After being loaded, PFRSCHPC specimens did not split into two parts like the SCHPC specimens. This is because there are fibres that prevent the crack from widening. Thus, cracks only occur on the surface, in other words, failure in the SCHPC specimens occur brittlely.

Fig. 7. Failure pattern after splitting tensile test of PFRSCHPC (left) and SCHPC (right)

3.6. Flexural Strength

Flexural strength testing was carried out on PFRSCHPC and SCHPC test specimens according to ASTM 78 of, three test specimens each. The results of the PFRSCHPC flexural strength test can be seen in Table 5 and the SCHPC flexural strength in Table 6.

Table 5. Flexural Strength of PFRSCHPC

No.	Specimen	Flexural Load (kN)	Flexural Strength (MPa)
1	PFRSCHPC 1	18.34	8.86
2	PFRSCHPC 2	18.52	8.80
3	PFRSCHPC 3	18.92	9.27
Flexural Strength Average			8.98

Based on the tables, the average flexural test results of PFRSCHPC specimens at 28 days were 8.98 MPa, and the average flexural strength of SCHPC was 6.29 MPa, meaning that the flexural strength of PFRSCHPC was greater than SCHPC at 2.69 MPa (42.77%). This shows that polypropylene fibre has the effect of increasing the flexural strength of the concrete.

Table 6. Flexural Strength of SCHPC

No.	Specimen	Flexural Load (kN)	Flexural Strength (MPa)
1	SCHPC 1	12.52	6.27
2	SCHPC 2	12.69	6.26
3	SCHPC3	13.16	6.33
Flexural Strength Average			6.29

Figure 8 shows the condition of PFRSCHPC (left) specimens after the testing, it can be seen that the fibres in the concrete work to bridge the cracks. So, the test object does not split after receiving the maximum bending load. Meanwhile, the SCHPC (on the right) specimen split into two parts after receiving the maximum bending load.

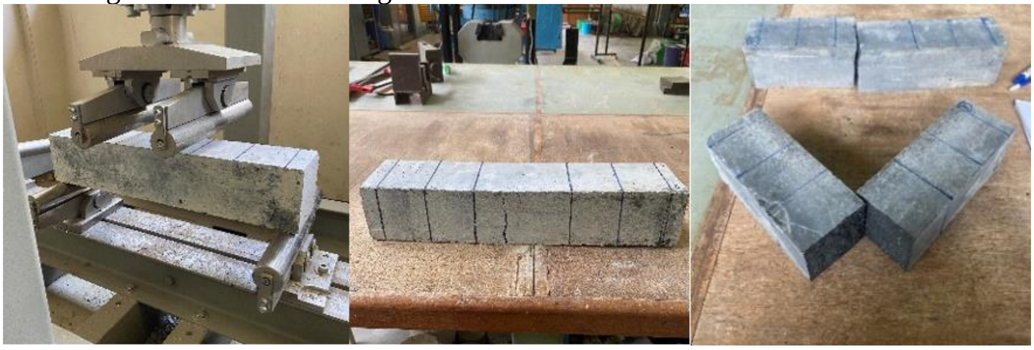

Fig. 8. Failure condition of flexural strength test of PFRSCHPC (left) and SCHPC (right)

3.7. Modulus of Elasticity

The modulus of elasticity test is carried out with the aim of knowing the behaviour of concrete in resisting plastic deflection caused by the working load. Tests were carried out on PFRSCHPC and SCHPC specimens according to ASTM C 469-1994 at the age of 28 days, each with three test specimens. The results of the PFRSCHPC elastic modulus test were found to be 45.51 GPa. Meanwhile, the modulus of elasticity of the SCHPC was 38.79 GPa. Thus, the PFRSCHPC has a greater modulus of elasticity value than the SCHPC 6.67 GPa (17.32%). This shows that polypropylene fibre has the effect of increasing the modulus of elasticity of the concrete.

3.8. Graph of The Relationship Load vs Deflection of Beam Structural Element

The application of the PFRSCHPC mixture to beam elements is carried out to determine its behaviour under bending loads. As a comparison, the beam will also be made with SCHPC mixture. The test was stopped when the beam element failed.

The results of the testing of PFRSCHPC and SCHPC on beam structural elements under bending load are processed and analysed by making a graph of the relationship between load and deflection to determine the behaviour of beam structural elements under bending loads including peak load, stiffness, toughness, ductility, and crack patterns.

3.9. The Effect of Polypropylene Fibre on The Beam Peak Load

The graph in Figure 9 shows the peak load on the SCHPC beam of 23.5 kN at a deflection of 13.74 mm. Meanwhile, the peak load on PFRSCHPC beam is 27.5 kN at a deflection of 36.72 mm. So, by adding polypropylene fibre as much as 1% of the total concrete volume, it can increase the peak load by 4 kN or 17.02% of the peak load of SCHPC beam elements without polypropylene fibre.

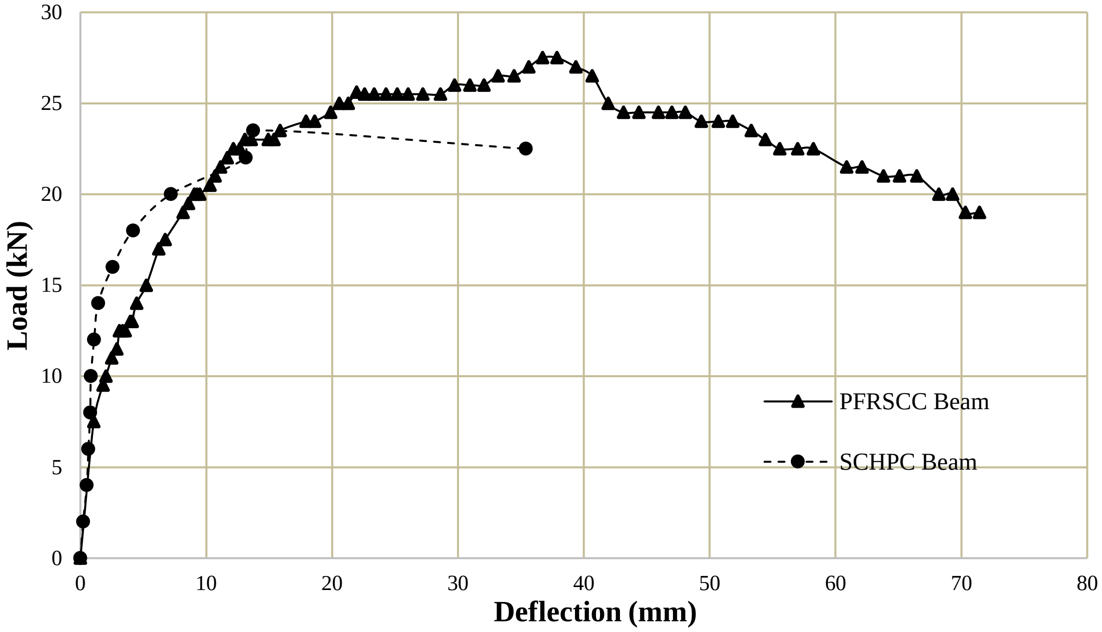

Fig. 9. The graph of the relationship between load and deflection of beams

3.10. The Effect of Polypropylene Fibre on The Beam Stiffness

Figure 9 also shows the stiffness of the SCHPC and the PFRSCHPC beams. The initial stiffness (EI^{st}) of the SCHPC and the PFRSCHPC beams were found to be 9.93 kN/mm, 5.32 kN/mm, respectively. Meanwhile, the value of non-linear stiffness (EI^{nd}) for the SCHPC and the PFRSCHPC beams were found to be 4.31 kN/mm, 2.21 kN/mm, respectively. Therefore, the stiffness of the SCHPC beam was greater with an increase of 86.79% for initial stiffness, and 94.77% for non-linear stiffness compared to the PFRSCHPC. The stiffness of the SCHPC beam is stiffer than PFRSCHPC beam. This is due to the presence of polypropylene fibre distributed so that it can bridge cracks that occur when loaded and increase the elasticity of the PFRSCHPC beam.

3.11. The Effect of Polypropylene Fibre on The Beam Stiffness

The graph in Figure 10 shows the ductility of SCHPC beam at midspan. The yield load (P_{yield}) and deflection (δ_y) are determined using the Li et al. (2013) energy balance method, by cutting the linear line on the curve into areas A1 and A2 of equal size. Point A on the curve shows the displacement results, then from that point B is known as the yield point, yield load. Based on the graph in Figure 10, the yield load (P_{yield}) is 20 kN with a deflection (δ_y) of 7.19 mm; and the ultimate load (P_{ult}) is 23.5 kN with a deflection (δu) of 35.38 mm; so that a ductility of 4.9 is obtained.

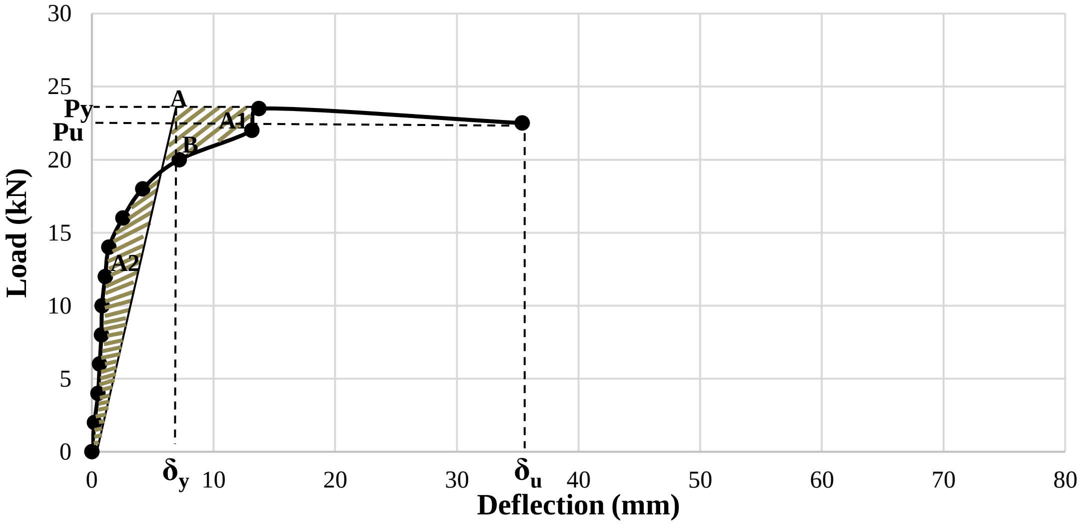

Fig. 10. The graph of SCHPC beam ductility

However, the graph in Figure 11 shows the ductility of PFRSCHPC beam at midspan. Based on the graph in Figure 11, the yield load (P_{yield}) is 22.5 kN with a deflection (δ_y) of 12.65 mm; and the ultimate load (P_{ult}) is 27.5 kN with a deflection (δu) of 71.43 mm; so that a ductility of 5.65 is obtained.

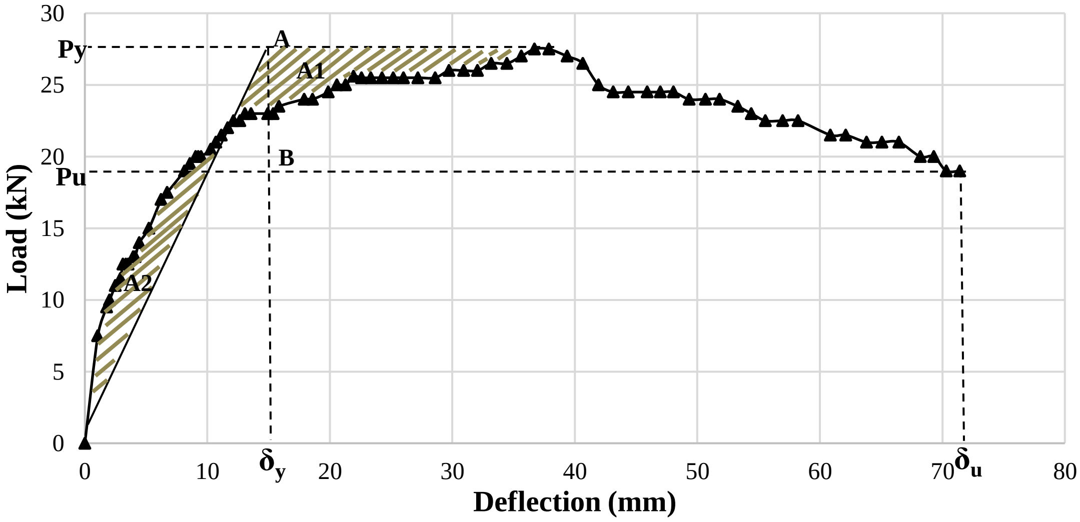

Fig. 11. The graph of PFRSCHPC beam ductility

The ductility of the SCHPC beam is 4.92, while the ductility of the PFRSCHPC beam is 5.65. The ductility of PFRSCHPC beam is higher than SCHPC beam with an increase of 0.73 (14.75%). This shows that polypropylene fibre contributes to the beam in increasing the ductility because of the polypropylene fibre bridging system when cracks occur. The fibres that are evenly distributed in PFRSCHPC beam can bridge cracks that occur in areas where there is no reinforcement. So that, when loaded the beam experiences an extended deflection after the elastic condition before reaching the ultimate load which causes an increase in ductility.

3.12. The Effect of Polypropylene Fibre on The Beam Toughness

The graph in Figure 12 and Figure 13 show PFRSCHPC and SCHPC beam toughness curves. The curves is divided into two areas. The ascending curve shows the energy absorption, and the descending curve shows the dissipation energy.

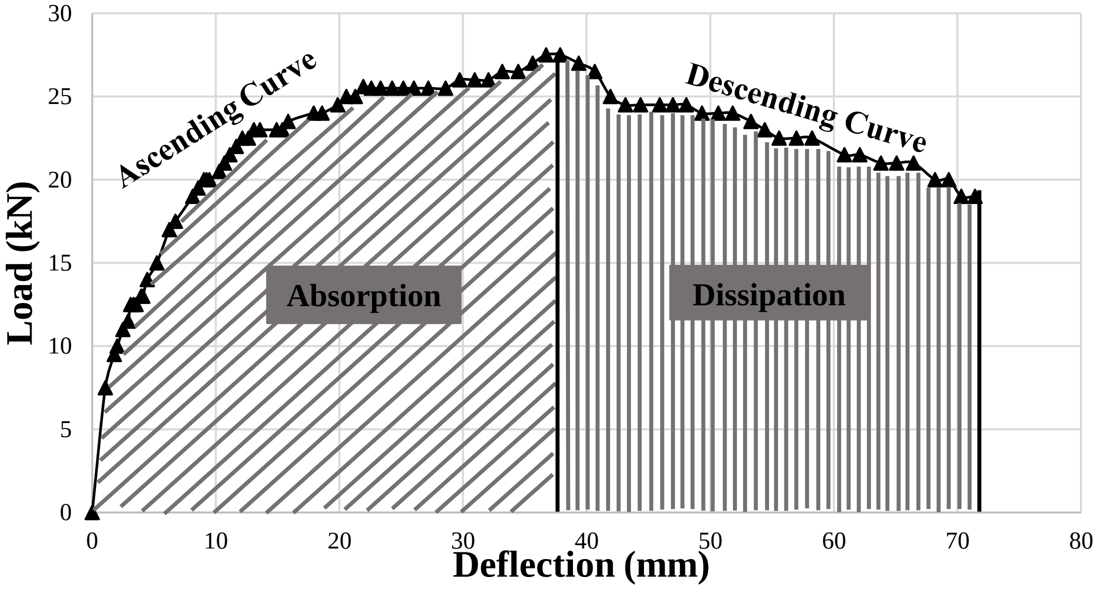

Fig. 12. The graph of PFRSCHPC beam toughness

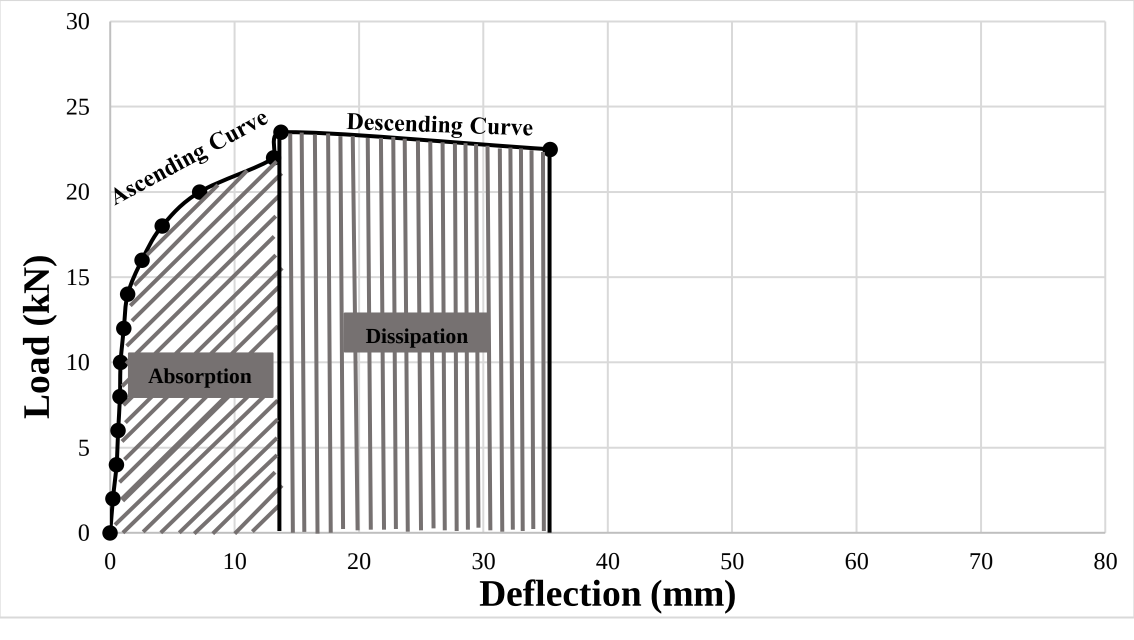

Fig. 13. The graph of SCHPC beam toughness

The toughness is obtained by calculating the total area of absorption and dissipation. The absorption and dissipation areas based on Figure 12 are 875.50 kNmm and 730.58 kNmm respectively, so that the toughness of the PFRSCHPC beam at mid-span is 1606.08 kNmm. However, the absorption and dissipation areas based on Figure 13 are 252.99 kNmm and 497.84 kNmm respectively, so that the toughness of the SCHPC beam at mid-span is 750.83 kNmm.

3.13. The Effect of Polypropylene Fiber on The Beam Crack Pattern Behavior

Figures 14 and 15 show the crack patterns of failure mechanism of PFRSCHPC beam and SCHPC beam, respectively. The crack patterns that occur in the SCHPC beam elements in Figure 58 and PFRSCHPC in Figure 59 have different behavior. The first crack of the initial linear stiffness graph turns nonlinear. In the control concrete, initial cracks occurred when the load was 14 kN with a deflection of 1.41 mm, while in the PFRSCHPC beam elements when the load was 9.5 kN and the deflection was 1.79 mm.

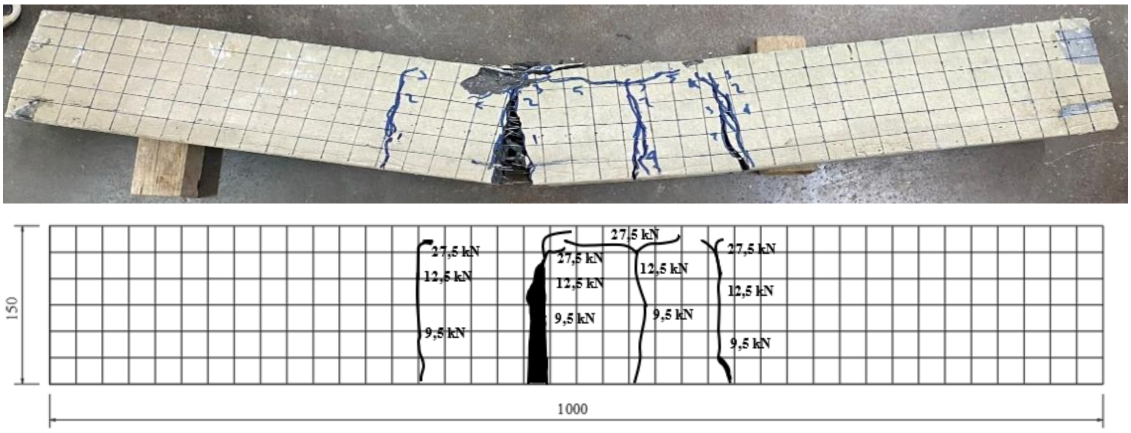

Fig. 14. The crack pattern behavior of PFRSCC beam

The failure pattern that occurs in the SCHPC beam as shown in Figure 15 is through a mechanism that begins with the formation of cracks on the surface in the tensile area of the beam, then the longitudinal reinforcement in the beam elements resists the bending load until it reaches the yield stress; Crack propagation on the compression surface of the beam begins to form before reaching the ultimate load, and then experiences failure of the beam element when it reaches the ultimate load.

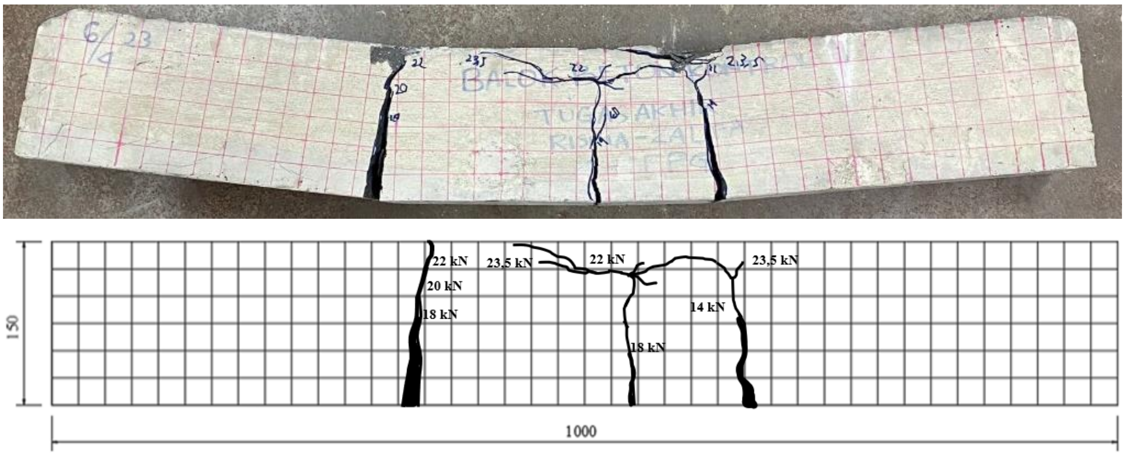

Fig. 15. The crack pattern behavior of PFRSCHPC 3beam

Meanwhile, in the PFRSCHPC beam element, as shown in Figure 15, the mechanism is that failure begins with the formation of the first crack, then spreads and elongated fibers bridge the crack which occurs as the load applied to the beam element test object increases, this can be seen where there are open cracks, some fibers broke. It can be assumed that during the crack elongation process the fibers are compressed and elongated to bridge and inhibit the spread of the crack as the applied load increases until it reaches its maximum limit, the fibers will break and the beam will collapse. However, in this study it is not possible to know directly the mechanism of fiber contribution in bridging cracks because testing was not carried out using a strain gauge.

4. Conclusions

1) The average value of the flow table achieved is set at 250 mm with the water mixture composition being 242.44 kg/m3 and w/b 0.23.
2) The average PFRSCHPC compressive strength test obtained at concrete ages of 7, 28 and 56 days was 39.67 MPa; 42.73 MPa; and 44.04 MPa respectively. The compressive strength is lower than the SCHPC at concrete ages of 7, 28 and 56 days, amounting to 45.01 MPa; 47.66 MPa; and 58.02 MPa respectively. The compressive strength of PFRSCHPC at 28 days is 4.93 MPa (11.54%) lower than SCHPC.
3) The average splitting tensile strength of PFRSCHPC for concrete aged 28 days is 4.33 MPa, while for SCHPC it is 1.83 MPa. Thus, the splitting tensile strength of PFRSCHPC is 2.38 MPa (122%) higher than SCHPC. This is because the fibres contained in concrete are able to absorb the energy provided by tensile loads and bridge cracks in the concrete; so that the concrete does not suddenly crack or break.
4) The modulus of elasticity of PFRSCHPC at 28 days of concrete is 45.51 GPa; Meanwhile, the modulus of elasticity for the SCHPC was 38.79 GPa.
5) The flexural strength of PFRSCHPC at 28 days of concrete is 8.98 MPa; while the flexural strength of the SCHPC was 6.29 MPa. This shows that the flexural strength of PFRSCHPC is 42.77% higher than the flexural strength of SCHPC.
6) The maximum load generated by the PFRSCHPC and SCHPC beam elements are 27.5 kN at a deflection of 36.74 mm; and 23.5 kN at a deflection of 13.74 mm, respectively. So, the addition of Polypropylene fibre can increase the load by 17.02%
7) The initial stiffness of the PFRSCHPC and SCHPC beam elements are 5.32 kN/mm and 9.93 kN/mm, respectively. SCHPC beam elements have initial stiffness 86.79% greater than PFRSCHPC.
8) The ductility of the PFRSCHPC and SCHPC beam elements are 5.65 and 4.92, respectively. Therefore, the ductility of PFRSCHPC beam elements increases 14.75%. This is due to the influence of Polypropylene fibres in bridging cracks in concrete so that deflection extension occurs after the elastic condition and before the ultimate load is reached causing the ductility to increase.
9) The toughness of the PFRSCHPC and SCHPC beam element were 1606.08 kN.mm, 750.83 kN.mm, respectively. Therefore, the toughness of PFRSCHPC beam elements increases 14.75%.

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