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Analysis of Flexural Strength in Reinforced High-Sterength Concrete Beams with Macro-Polypropylene Fibers Additives

Sadvent M Purba, Darryl Manoj Kumar, Kevin Aprilio Wibowo
Faculty of Science and Technology, Pelita Harapan University, Tangerang, Indonesia
sadvent23@gmail.com; 01021210019@student.uph.edu; kevin.wibowo@uph.edu

Abstract—High Strength Concrete (HSC) possesses high compressive strength however relatively low resistance against tensile forces and cracking forces. The application of steel rebar in Reinforced Concrete aids in tackling tensile stresses however the brittle nature of HSC is still present. The incorporation of fiber materials such as polypropylene fibers into the concrete mix is an innovation done to improve tensile strength, flexural strength, post-cracking strength and crack resistances. This study aims to analyze the effect of addition of macro-polypropylene fibers at volume fractions 0.5%, 1.0%, and 1.5% on the compressive strength of HSC cylinders as well as flexural strength, deflection, and crack resistance of HSC reinforced beams. The methodology of this study includes the determination of HSC mix design incorporating macro-polypropylene fibers to form High Strength Macro-Polypropylene Fiber Reinforced Concrete (HSMPFRC), compressive strength testing of cylinders, design and preparation of reinforced concrete beams, flexural strength testing and comparative analysis of test results. Results showed an increase in compressive strength for fiber dosages 1.0% and 1.5% in comparison to control, with the highest increase for a dosage of 1.5%. Flexural strength test results showed increases for all fiber dosages compared to control, with a dosage of 1.0% creating the highest flexural strength. This study concludes that compressive and flexural strength improves the compressive, flexural strength and crack resistance of HSC cylinders and reinforced beams respectively. However, the effect on deflection and cracking patterns is not as conclusive.

Keywords : Macro-Polypropylene Fibers; Flexural Strength; High Strength Concrete; Reinforced Concrete Beams

1. INTRODUCTION

Concrete is the most widely used construction material in the world. [1] With this in consideration, innovations in concrete technology become increasingly important as global demand for infrastructure increases. [2] For large scale projects, the application of High Strength Concrete (HSC) is advantageous as it allows for reductions in member cross sections and extensions in span lengths. HSC does have weaknesses mainly relatively low tensile strength [3][4] The application of steel rebar in Reinforced Concrete (RC) helps aid in sustaining tensile stresses in structural elements, however the high compressive strength of HSC increases brittleness making the concrete more prone to cracking. The presence of cracks contributes to defects and faults within concrete structures and exposes rebar to corrosion as noted by [5].

An innovation becoming increasingly popular to tackle these issues is Fiber Reinforced Concrete (FRC) in which the introduction of short discontinuous fibers into the concrete mixture with the goal of increasing the mechanical properties of the concrete as well as its crack resistance. Fibers are also capable of contributing towards post-crack performance of structural elements in flexure [6].The mechanism of FRC is described in detail within ACI 544.4R. During flexure, as the concrete in the tension zone crack, fibers perform bridging action preventing further crack propagation and begin to carry tensile stress. This capability is known as the residual tensile strength of the FRC, which is taken a parameter that contributes to the nominal flexural strength within Hybrid Fiber Reinforced Concrete (HFRC) with both fiber and steel reinforcement. High dosages of fibers may also lead to strain hardening in FRC in which the residual stress exceeds the stress during initial tensile rupture of the concrete.[7]The effectiveness of fibers within FRC is dependent on factors such as mechanical properties, geometry, material, dosage, and distribution of fibers within the concrete mix. Polypropylene fibers are a common variety of synthetic fibers used in concrete mixes due to their low density, availability and versatility. fibers[8][9]. There are generally two main varieties of polypropylene fibers as defined under BS EN 14889-2, micro-fibers and macro-fibers depending on their diameter. Macro-polypropylene fibers are generally more suited for structural applications due to their enhanced mechanical properties over micro-fibers and also their ability to prevent crack propagation beyond the micro crack state [10][11][12].

Several studies have analyzed the effect of incorporating macro-polypropylene fibers into normal and high strength concrete mixtures[13].Studied the propertiesof high strength concrete at a target compressive strength of 60 MPa with incorporation of macro-polypropylene fibers at volume percentages of 0.5%, 1.0% and 1.5%. Compressive strengthhad a slight increase of 3.4% between the control sample with no fiber and 1.5% sample. Flexural strength had an increase of 29.3% from the control sample at the optimum percentage of 1.0%, while flexural strength decreased slightly afterwards at 1.5% with only a 25.9% increase from the control sample[10].Evaluated of flexural strength of FRC with volume fractions of 0.5%, 1.0% and 1.5% of macro-polypropylene fibers, results showed slight increases in first peak strength however consistent improvement in post crack performance and flexural toughness upon increasing the fiber percentage from 0.5% to 1.5%[14].Studied the mechanical properties and load deflection of lightweight concrete with addition of both micro and macro-polypropylene with various percentages. Two mixes were prepared and analyzed with 0.44%and0.66% volume fraction of macro-polypropylene fiber. Flexural strength test results showed an increase flexural toughness index

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upon increasing fiber dosages, 17.84 and 19.76 kN.mm for both volume fractions percentages respectively [15].Evaluated the influence of addition of macro-polypropylene fibers at volume fraction percentages of 0.5% and 1.0% at two grades of concrete 45 MPa and 50 MPa. Results for hardened state properties for 45 MPa and 50 MPa showed increases in flexural tensile strength for both dosages in comparison to the control sample with no fibers. The increase in percentage from 0.5% to 1.5%, caused an increase in residual flexural strengths as well as toughness.

The studieslisted above show demonstrable potential and successes in increasing flexural performance of concrete by addition of macro-polypropylene fiber, however, thereremains a lack of research analyzing flexural performance of high strength concrete beams that utilizes both steel rebar reinforcement and macro-polypropylene fibers. Theterm High Strength of Macro-Polypropylene Fiber Reinforced Concrete (HSMPFRC) will be used to refer to the specimens analyzed within this study.

2. RESEARCH SIGNIFICANCE

This analysis aims to study the effect of addition of macro-polypropylene fibers on the compressive strength of high strength concrete cylinders and the flexural strength, deflection, and crack resistance of high strength concrete beams with steel rebar reinforcement. This differs from the previous studies analyzing macro-polypropylene fibers in concrete which mostly do not include the presence of steel rebar. This research will provide further knowledge about the relationship between macro-polypropylene fiber addition and concrete strength and serve as a reference for future research

3. METHODOLOGY

The methodology for this study involves several stages, firstly a literature review on addition of macro-polypropylene fibers in concrete mixture, followed determination and testing of constituent materials, calculations of mix design, preparation of specimens, compressive strength testing, flexural strength testing and analysis of test results.

Constituent Materials

The constituent materials used to produce HSMPFRC cylinder and reinforced beam specimens were Portland Composite Cement, coarse aggregate, fine aggregate, silica fume, superplasticizer, macro-polypropylene fibers, and steel rebar.

1) *Portland Composite Cement (PCC):* Cement used was Portland Composite Cement with specifications in accordance with SNI 7064:2014.
2) *Fine Aggregate:* Washed and sieved Tayan sand originating Kalimantan was used as fine aggregate. This sand was sifted through a no. 4 sieve prior to application to remove any large debris.
3) *Coarse Aggregate:* Crushed stone with varying particle diameter sizes within the range of 10-20 mm, sourced from a quarry in Cilegon, Banten, was used as coarse aggregate.
4) *Silica Fume (SF):* Silica fume used to improve strength and reduce permeability in order to reach high strength targets. This specification of this admixture is in accordance with ASTM C 1240-00 standard.
5) *Superplasticizer (SP):* Sika ViscoCrete-3115N, an aqueous solution of modified polycarboxylate copolymers was used to allow for improved workability.
6) *Macro-polypropylene fibers (MPF):* Macro-polypropylene used was Kratos Macro PP 54 brand, with specifications in accordance with EN 14889-2 Class IIstandard. The specification for this fiber is shown in the table below:

Table 1. Physical Properties of Macro-Polypropylene Fibers

Property	Value	Unit
Density	0.91	g/cm^3
Length	54	mm
Filament Diameter	0.95	mm
Tensile Strength	530	MPa
Elastic Modulus	7200	MPa
Fiber Surface	Embossed	-

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Figure 1. Macro-polypropylene Fiber

1) Steel Rebar: Three different types of steel rebar reinforcement were used for HSMPFRC beams with specifications in accordance with SNI 2052:2017. [16] The table shows the specifications for the steel rebar used:

Table 2. Specification for Steel Rebar Used for HSMPFRC Beams

Reinforcement Type	Diameter (mm)	Surface Pattern	Yield Strength (MPa)
Top Compressive	6	Plain	280
Bottom Tensile	16	Spiral	420
Shear Stirrups	8	Plain	280

Preliminary testing was done for both fine and coarse aggregate to determine material properties such as clay content, moisture content, specific gravity and absorption, as well as particle gradation via sieve analysis.

Equipment

The equipment used for material testing were weighing scales, measuring cylinders, metal bowls, plastic buckets, thermometers, sieves, a sieve shaker machine and an oven.

Preparation of fresh concrete mix required a concrete mixer, a concrete pan, and an Abram's cone to perform slump tests.

Preparation of cylinder specimens required cylinder molds, an angle grinder to polish the molds, a paint brush to grease the molds, and a vibrating table to compact the concrete within the molds.

Preparation of reinforced beams required a bar cutter and bender to cut and bend rebar to required shape, wooden beam formworks fitted with concrete spacers and an electric concrete vibrator to compact the concrete within the formwork.

Plastic buckets were used for curing of concrete cylinder specimens. Thick and moist gunny sacks were draped across beam specimens to maintain moist conditions for effective curing.

Compressive strength testing required a melting pot to melt sulfur which was used to cap cylinders, a concrete cylinder capper, and a digital compression machine to apply axial compressive load to the cylinder specimens.

Flexural strength testing required a bending test machine composed of the following elements. A monitor and controller to control the applied force and steps, an actuator to generate compressive force at the center of the beam, a load cell to measure the applied load, a displacement transducer to measure midspan deflection during flexure and a data logger that combines both sets of data from the load cell and the displacement transducer.

Mix Design

Determination of cement, silica fume, water and superplasticizer proportions was based on the guidelines outlined by [17] in a previous analysis.

Mix designs are originally formulated with the assumption that aggregates are within Saturated Surface Dry Condition as defined within ACI Education Bulletin E1-07. [18]

To account for the actual condition of aggregates, SNI 03-2834-2000 was used to calculate proportion of fine and coarse aggregate based on their respective specific gravities as well as to for correction factors to adjust final amount of water and aggregate based on aggregate material properties such as moisture content and absorption. [19].

Minimum target compressive strength for the mix design was 41 MPa or higher, in accordance with the defined minimum compressive strength for HSC within ACI 363 1992.[20]

The table below shows mix design for the HSC before correction factors, with the assumption that aggregates are within SSD condition.

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Table 3. HSC Mix Design Before Correction Factors

Material	Value	Unit
w/cm ratio	0.29	-
S/A	38.00	%
Water	174.00	kg/m^3
Portland Composite Cement (PCC)	570.00	kg/m^3
Fine aggregate	633.08	kg/m^3
Coarse aggregate	1032.92	kg/m^3
Silica fume (SF)	30.00	kg/m^3
Superplasticizer (SP)	12.00	kg/m^3

A total of 4 mix designs were prepared and analyzed within this study each with varying volume fraction dosages of macro-polypropylene fibers being added to the mix; CTRL Mix: 0.0% V_f, PF1 Mix:0.5% V_f,PF2 Mix:1.0% $V_f$and PF3 Mix:1.5% V_f.

The table below shows the mix design for the four mix designs of HSMPFRC, with correction factors taken to account.

Table 4. HSMPFRC Design After Correction Factors

Material	Mix Design				Unit
	CTRL	PF1	PF2	PF3	
Water	174.00	174.00	174.00	174.00	kg/m^3
PCC	570.00	570.00	570.00	570.00	kg/m^3
Fine ag.	633.08	633.08	633.08	633.08	kg/m^3
Coarse ag.	1032.92	1032.92	1032.92	1032.92	kg/m^3
SF	30.00	30.00	30.00	30.00	kg/m^3
SP	12.00	12.00	12.00	12.00	kg/m^3
MPF	0.00	4.55	9.10	13.65	kg/m^3

Test Specimens

Two types of test specimens were prepared within this study.

Concrete cylinder specimens with diameter of 10 cm and heights of 20 cm were used to determine the effect of macro-polypropylene fiber on compressive strength. For each of the four mix designs, 6 cylinders were prepared.

Figure 2. Cylinder Specimens

Beam specimens were used to determine the effect of macro-polypropylene fiber on flexural performance with the presence of rebar. For each of four mix designs, 1 beam was prepared. The dimensions of the beam specimen were 15 cm x 25 cm x 100 cm. The bottom tension rebar was composed of 2 Ø16 mm spiral rebars, the top compression rebar was composed of 2 Ø6 mm plain rebars and shear reinforcement were composed of Ø8 mm plain stirrups spaced 100 mm apart. The concrete clear cover was 20 mm. The following figure illustrates the side view of a beam specimen.

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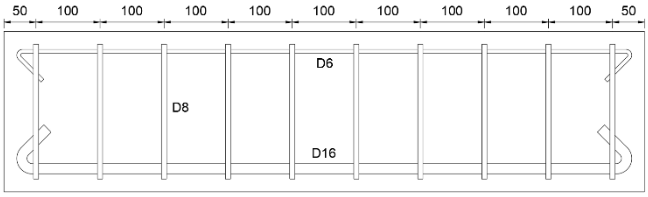

Figure 3. Illustration of Beam Specimen

Preparation of specimens involved several stages described as follows. Material preparation, apparatus preparation, concrete mixing, slump testing, casting, unmolding, labeling, and curing.

Cylinder specimens were cured using the submerged water curing method, in which cylinders were placed in deep plastic buckets and were covered with water. Beam specimens were cured whilst covered with moist gunny sack that were routinely sprayed with a water hose every 24 hours.

Testing of Specimens

Compressive strength testing was performed to determine the maximum axial compressive load that causes failure within the cylinder specimens relative to the compressed area. A total of 6 cylinders were tested for each mix design, with 3 cylinders each being tested 7 days and 28 days after casted.

Cylinders were removed from submerged curing 24 hours prior to testing and were also sun dried 2-3 hours prior to testing. Next, they were weighed, capped and labeled just before testing.

Flexural strength testing was performed to determine the ultimate moment, M_u that causes failure within the beam specimens, to obtain load-deflection relationships and for analysis of cracking during flexure for HSMPFRC beams. A single beam was tested for each mix design at 28 days after casting.

Beam specimens were initially weighed using a load cell. Afterwards they were placed on top of two support pins spaced 900 mm away from each other. Center-point loading was opted for within this study hence, a single loading pin was placed installed at the center of the beam. To measure maximum deflection during flexure, a displacement transducer was placed at the bottom of the beam at its midspan. Cameras were placed on tripods on either side of the beams, to record the beams under flexural loading.

The illustration below shows the setup configuration for flexural strength testing of beam specimens.

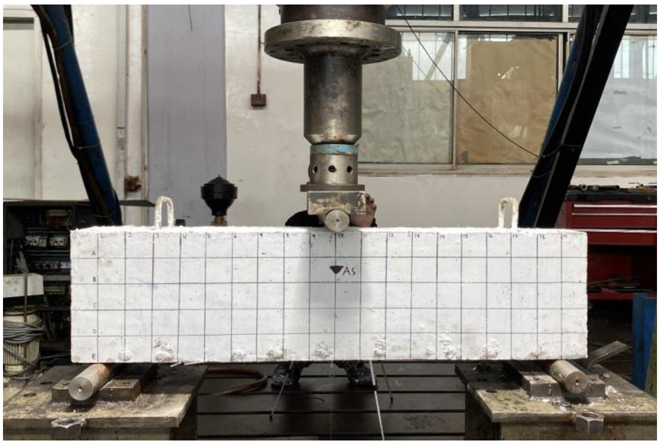

Figure 4. Configuration for Flexural Strength Testing

4. ANALYSIS OF TEST RESULTS

This section will provide detailed analysis of test results for preliminary testing of fine and coarse aggregate as well as test result for HSMPFRC specimens, including slump test results, average density results, compressive strength, flexural strength, deflection, and crack resistance.

Compressive Strength

Testing of compressive strength was done for HSMPFRC cylinder specimens at the age of 7 and 28 days. The table below shows the average compressive strength tested at 7 and 28 days.

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Table 5. Speccification for Steel rebar Used for HSMPFRC Beams

Cylinder Code	Age (Days)	f'c (MPa)	Avg. f'c (MPa)
CTRL-1		18.21	
CTRL-2	7	21.52	21.94
CTRL-3		26.10	
CTRL-4		42.91	
CTRL-5	28	40.87	41.51
CTRL-6		40.74	
PF1-1		24.32	
PF1-2	7	22.66	23.64
PF1-3		23.94	
PF1-4		38.20	
PF1-5	28	34.89	38.20
PF1-6		41.51	
PF2-1		23.30	
PF2-2	7	24.83	24.62
PF2-3		25.72	
PF2-4		41.76	
PF2-5	28	43.04	42.10
PF2-6		41.51	
PF3-1		31.45	
PF3-2	7	34.50	32.08
PF3-3		30.30	
PF3-4		51.95	
PF3-5	28	**52.71**	47.66
PF3-6		38.32	

The graph below shows the percentage change in compressive strength for each fiber concrete mix relative to the CTRL (0.0% Vf) mix tested at 7 days.

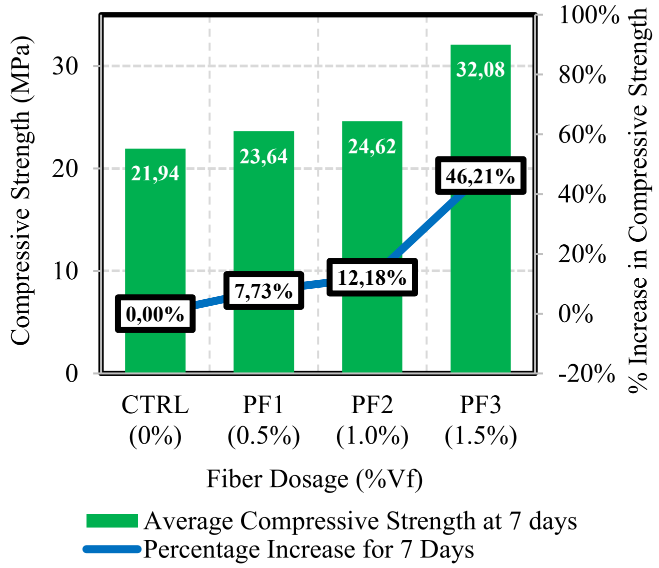

Fig. 5Compressive strength test results at 7 days

The graph below shows the percentage change in compressive strength for each fiber concrete mix relative to the CTRL (0.0% V_f) mix tested at 28 days.

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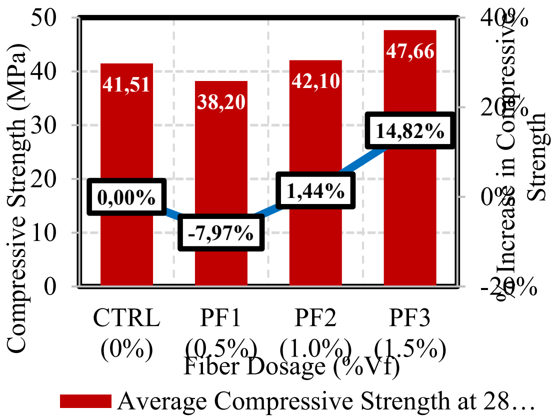

Figure 6. Compressive strength test results at 28 days

Based on the data, the compressive strength of cylinders at 7 days increased with higher fiber dosage, with the PF3 (1.5% V_f) mix showing the highest increase of 46.21% compared to the CTRL mix (0.0%V_f). However, at 28 days, compressive strength initially decreased by 7.97% for the PF1 (0.5%V_f) mix but then improved for the PF2 (1.0%V_f) and PF3 (1.5%V_f) mixes, with PF3 recording the highest increase of 14.82%.

According to [22], polypropylene fibers have a dual potential both enhance and reduce compressive strength. The strength increase at 1.0% and 1.5% fiber dosages may result from the macro-polypropylene fibers bridging gaps and distributing stresses [8], preventing crack propagation and delaying failure.[23]

On the other hand, the strength reduction at 0.5% fiber dosage at 28 days could stem from mixture non-homogeneity, increasing the void ratio and compromising strength [9]. Density data supports this, with the lowest density found at the PF1 (0.5% V_f) mix. Thus, at this lower fiber dosage, the benefits of stress distribution and crack minimization are less evident, while the negative impact of increased voids is more pronounced.

Flexural Strength

Flexural strength testing was achieved through bending test with center-point loading configuration in which reinforced concrete beam specimens with varying macro-polypropylene fiber dosages were tested at 28 days after casting.

The parameters relevant within determination of flexural performance are the applied compressive point load at the center of the beam, P and the deflection at midspan measured from the bottom of the beam. These two variables were combined to produce load deflection graph.

1) Yielding Moment*:* One parameter observed within this study was the yielding moment, M_y. The yielding point within this context of reinforced concrete beams in flexure refers to the limit of elastic behavior of the tension steel which occurs when the tension rebar begins to yield due to tensile stresses. Beyond the value of M_y, the beam begins to enter plastic behavior. The value for compressive point load at yielding point is referred to P_y.
The formula to calculate yielding moment, M_y, taking to account applied loading and self-weight of the beam is shown below :

$$M_y = \frac{P_y \times L_n}{4} + \frac{q_{sw} \times {L_n}^2}{8} \qquad □□□$$

M_y	yielding moment	kNm
P_y	point load at yielding point	kN
q_{sw}	distributes self-weight	kN/m
L_n	clean span length	m

2) Ultimate Moment*:* Flexural strength is taken to be the ultimate bending moment, M_u, caused by the ultimate applied compressive point load, P_u at the point of failure in combination with self-weight of the beam.
The point of failure is taken to be the point within the load deflection graph just before the value of P begins to decrease from its maximum value.
The formula to calculate ultimate moment at the point of failure, M_u, taking to account applied loading and self-weight of the beam is shown below :

$$M_u = \frac{P_u \times L_n}{4} + \frac{q_{sw} \times {L_n}^2}{8} \qquad □□□$$

M_u	ultimate moment	kNm
P_u	point load at ultimate point	kN
q_{sw}	distributes self-weight	kN/m
L_n	clean span length	m

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3) CTRL Load Deflection Graphs*:* The figures below shows the load deflection graphs for the CTRL beam.

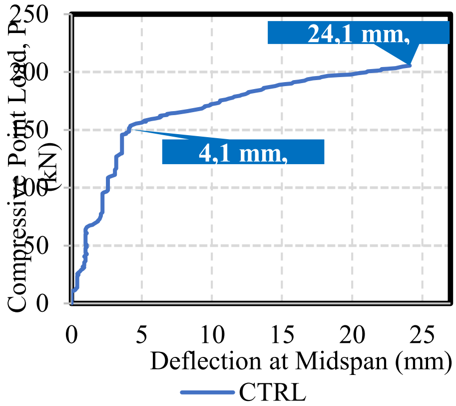

Figure 7. Load Deflection Graph for CTRL Beam

The self-weight for the CTRL beam was 0.92 kN which can be expressed in the form of a distributed load across its length, L of 1 m, q_{sw} with a value of 0.92 kN/m.

Hence, the yielding moment, M_y for the beam specimen is 33.98 kNm and the actual ultimate moment, M_u for the beam specimen is 46.34 kNm.

4) PF1 Load Deflection Graphs: The figures below shows the load deflection graphs for the PF1 beam.

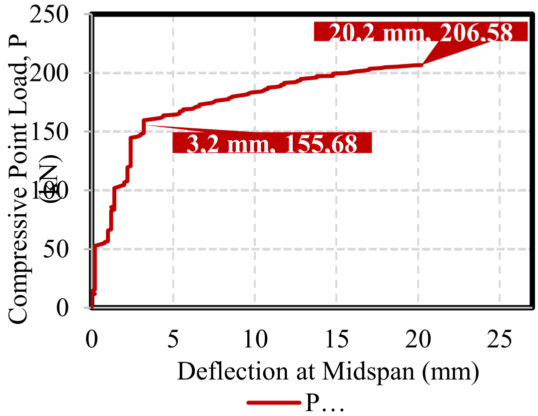

Figure 8. Load Deflection Graph for PF1 Beam

The self-weight for the PF1 beam was 0.93kN which can be expressed in the form of a distributed load across its length, L of 1 m, q_{sw} with a value of 0.93kN/m.

Hence, the yielding moment, M_y for the beam specimen is 35.12kNm and the actual ultimate moment, M_u for the beam specimen is 46.57kNm.

5) PF2 Load Deflection Graphs: The figures below shows the load deflection graphs for the PF2 beam.

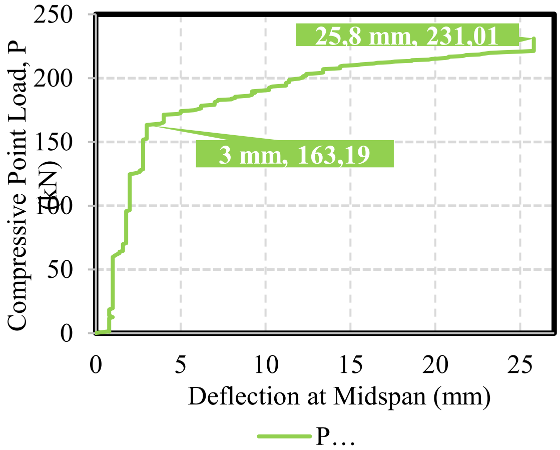

Figure 9. Load Deflection Graph for PF2 Beam

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The self-weight for the PF2 beam was 0.94kN which can be expressed in the form of a distributed load across its length, L of 1 m, q_{sw} with a value of 0.94kN/m.

Hence, the yielding moment, M_y for the beam specimen is 36.81kNm and the actual ultimate moment, M_u for the beam specimen is 52.07kNm.

6) PF3 Load Deflection Graphs: The figures below shows the load deflection graphs for the PF3 beam.

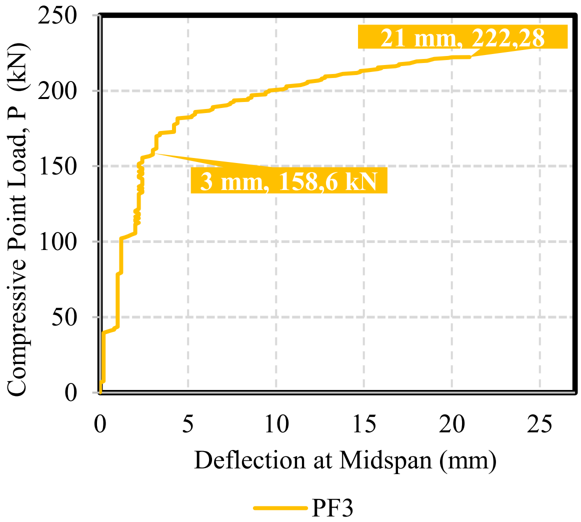

Figure 10. Load Deflection Graph for PF3 Beam

The self-weight for the PF3 beam was 0.94kN which can be expressed in the form of a distributed load across its length, L of 1 m, q_{sw} with a value of 0.94kN/m.

Hence, the yielding moment, M_y for the beam specimen is 35.78kNm and the actual ultimate moment, M_u for the beam specimen is 50.11kNm.

7) Comparative Analysis of Flexural Strength: Comparisons of flexural strength between beam specimens was done based on the ultimate moment, M_u, calculated previously.

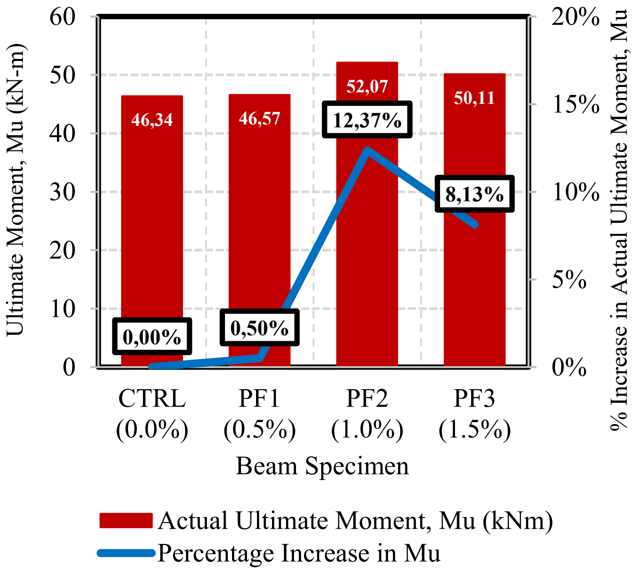

Figure 11. Ultimate Moment for Beam Specimens

The results from flexural strength testing displayed increases in ultimate moment, M_u sustained by the beams with fiber content in comparison to control beam without fiber. This increase may be attributed to the capability of the fibers in providing residual tensile strength in the concrete within the tension zone after initial cracking occurs. [7] Aside from this, these increases may also be attributed to the fiber's influence towards the compressive strength of the concrete.

The smaller increase in ultimate moment for the PF1 ($0.5\%V_f$) beam in comparison to the PF2 ($1.0\%V_f$) and PF3 ($1.5\%V_f$) beams may be attributed to the lower fiber dosage of only 0.5% by volume, leading to insufficient stress distribution and reduced compressive strength. Another factor is the potential for strain hardening in the FRC, which typically requires fiber dosages exceeding 9 kg/m³ for macro-synthetic fibers. [7] The fiber dosages for the PF2 and PF3 beams exceeds this needed threshold, however the PF1 dosage does not.

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The reliability of the results of flexural strength testing are also limited by several factors namely a small sample size of only one beam for each mix design. Aside for this, there is potential for human error within various stages throughout the preparation and testing of beam specimens such as during the mixing, casting, and set-up processes.

Deflection

The effect of addition of macro-polypropylene fiber on deflection was analyzed within this study by the examination of two variables which are deflection at yielding point and deflection at ultimate load.

1) Yielding Point Deflection: Maximum deflection at yielding point was taken to be the value of deflection during which the moment reaches the yielding moment, M_y.

The values of maximum deflection at yielding point for each beam specimen as well as percentage increase in this deflection relative to the control beam is shown in the following figure.

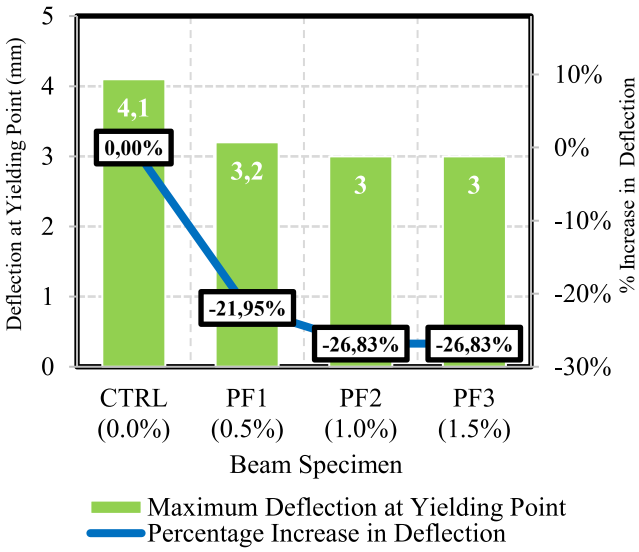

Figure 12. Deflection at Yielding Point for Beam Specimens

2) Deflection at Ultimate Load: Ultimate deflection was taken to be the value of deflection at the point of ultimate load at failure.

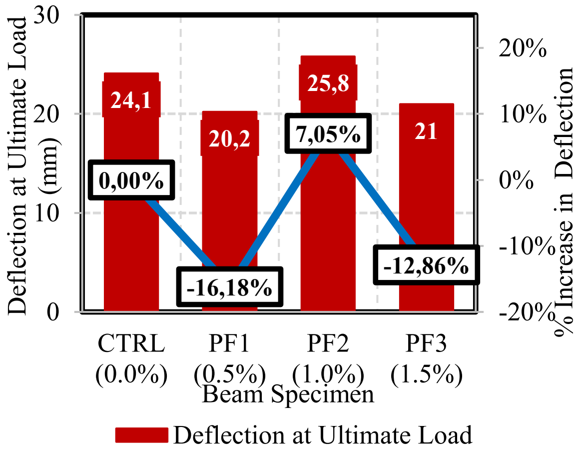

Figure 13. Deflection at Failure for Beam Specimens

The ultimate deflection varied across beam specimens with different fiber dosage. Deflection at failure decreased for the PF1 (0.5% V_f) and PF3 (1.5% V_f) beams. However, the deflection at failure of the PF2 (1.0% V_f) beam increased by 7.05% in comparison to the CTRL (0.0% V_f) beam.

The inconsistency in the ultimate deflections amongst the beam samples show a lack of correlation with parameters determined prior such as density, compressive strength and ultimate moment. Potential imperfections within the beam that become more apparent closer to the point of failure may be the cause behind the lack of consistency in these results.

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Crack Resistance

Analysis of crack resistance of beam specimens was done by comparative analysis of yielding moment, M_y. The figure below shows the yielding moments for each beam sample and the percent increase relative to the CTRL (0.0% V_f) beam.

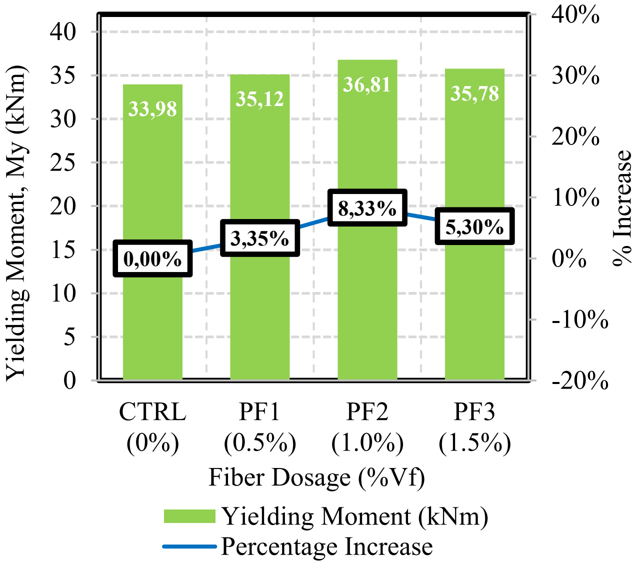

Figure 14. Yielding Moment for Beam Specimens

Results show increases in yielding moment when fiber were introduced into the mix. The highest increase of 8.33% was found to be at the PF2 (1.0% V_f) beam.

These increases are likely attributed to the improved crack resistance of the FRC beams in comparison to the control beam with no fibers. According to the description provided within ACI 544.4R regarding the performance of FRC,crack bridging and minimization of crack propagation allows the fibers to sustain a part of the stress within the tension zone of the beam, reducing the stress sustained by the steel rebar. Hence, the presence of macro-polypropylene fibers extends the yielding point of the steel rebar such that it yields at a higher load. [7]

5. CONCLUSION

From the results obtained throughout this study the following conclusions can be made.Slump value of HSC mix decreased upon addition of macro-polypropylene fibers.Density of HSC mix decreased for the initial addition of macro-polypropylene fiber, however increased when fiber dosage was increased but never reaching the density of the CTRL(0.0% V_f) mix with no fibers.Compressive strength increased with the addition of macro-polypropylene fibers, the PF3 (1.5% V_f) mix produced the highest compressive strength when tested at 7 and 28 days with an increase of 46.21% and 14.82% respectively. The PF1 (0.5% V_f) mix had a slight decrease of 7.97% when tested at 28 days.Flexural strength in terms of ultimate moment increased with the addition of macro-polypropylene fiber. The PF1 (0.5% V_f) beam had the lowest increase of 0.5%. The largest increase of 12.37% was found in the PF2 (1.0% V_f) beam, while the PF3 (1.5% V_f) beam had an increase of only 8.13%.Deflection at yielding point decrease with the addition of macro-polypropylene fibers with the largest decrease of 26.83% found for the PF2 (1.0% V_f) and PF3 (1.5% V_f) beams. Deflection at ultimate load was inconsistently effected by the addition of macro-polypropylene fibers.The crack resistance for beam specimens improved with the addition of macro-polypropylene fibers.Beams with fiber content sustained higher yielding moments during flexure relative to the CTRL (0.0% V_f) beam. The PF2 (1.0% V_f) beam had the largest increase of 8.33%.Recommendations for future research into this topic include increasing sample sizes to improve accuracy of results, flexural strength testing with different loading configuration such as third-point loading, calculating theoretical values for flexural strength to become a basis for comparative analysis and trying out different varieties and dosages of macro-polypropylene fiber.

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REFERENCES

[1] C. R. Gagg, "Cement and concrete as an engineering material: An historic appraisal and case study analysis," Eng Fail Anal, vol. 40, pp. 114–140, May 2014, doi: 10.1016/j.engfailanal.2014.02.004.
[2] United Nations Environment Programme, 2023 Global Status Report for Buildings and Construction: Beyond foundations - Mainstreaming sustainable solutions to cut emissions from the buildings sector. Nairobi: United Nations Environment Programme, 2024. doi: 10.59117/20.500.11822/45095.
[3] K. Abdelsamie, I. Agwa, and R. Abdel Hafez, "Improving the brittle behaviour of high-strength concrete using keratin and glass fibres," Advances in Concrete Construction, vol. 12, pp. 469–477, Dec. 2021, doi: 10.12989/acc.2021.12.6.469.
[4] H. Constantinescu, O. Gherman, C. Negrutiu, and S. P. Ioan, "Mechanical Properties of Hardened High Strength Concrete," Procedia Technology, vol. 22, pp. 219–226, 2016, doi: 10.1016/j.protcy.2016.01.047.
[5] C. Zhao, Z. Wang, Z. Zhu, Q. Guo, X. Wu, and R. Zhao, "Research on different types of fiber reinforced concrete in recent years: An overview," Constr Build Mater, vol. 365, p. 130075, Feb. 2023, doi: 10.1016/j.conbuildmat.2022.130075.
[6] S. Acosta-Calderon, P. Gordillo-Silva, N. García-Troncoso, D. V. Bompa, and J. Flores-Rada, "Comparative Evaluation of Sisal and Polypropylene Fiber Reinforced Concrete Properties," Fibers, vol. 10, no. 4, p. 31, Mar. 2022, doi: 10.3390/fib10040031.
[7] ACI Committee 544, "ACI 544.4R-18 Guide to Design with Fiber-Reinforced Concrete," 2018
[8] H. Hosseinzadeh, A. MasoudSalehi, M. Mehraein, and G. Asadollahfardi, "The effects of steel, polypropylene, and high-performance macro polypropylene fibers on mechanical properties and durability of high-strength concrete," Constr Build Mater, vol. 386, p. 131589, Jul. 2023, doi: 10.1016/j.conbuildmat.2023.131589.
[9] M. R. Latifi, Ö. Biricik, and A. MardaniAghabaglou, "Effect of the addition of polypropylene fiber on concrete properties," J AdhesSciTechnol, vol. 36, no. 4, pp. 345–369, Feb. 2022, doi: 10.1080/01694243.2021.1922221.
[10] M. Dopko, M. Najimi, B. Shafei, X. Wang, P. Taylor, and B. M. Phares, "Flexural Performance Evaluation of Fiber-Reinforced Concrete Incorporating Multiple Macro-Synthetic Fibers," Transportation Research Record: Journal of the Transportation Research Board, vol. 2672, no. 27, pp. 1–12, Dec. 2018, doi: 10.1177/0361198118798986.
[11] British Standard, "BS EN 14889-2:2006 Fibres for concrete — Part 2: Polymer fibres — Definitions, specifications and conformity," 2006
[12] J. Blazy and R. Blazy, "Polypropylene fiber reinforced concrete and its application in creating architectural forms of public spaces," Case Studies in Construction Materials, vol. 14, p. e00549, Jun. 2021, doi: 10.1016/j.cscm.2021.e00549.
[13] Z. Yao, X. Li, C. Fu, and W. Xue, "Mechanical Properties of Polypropylene Macrofiber-Reinforced Concrete," Advances in Materials Science and Engineering, vol. 2019, pp. 1–8, May 2019, doi: 10.1155/2019/7590214.
[14] D. Altalabani, D. K. H. Bzeni, and S. Linsel, "Mechanical properties and load deflection relationship of polypropylene fiber reinforced self-compacting lightweight concrete," Constr Build Mater, vol. 252, p. 119084, Aug. 2020, doi: 10.1016/j.conbuildmat.2020.119084.
[15] V. Guerini, A. Conforti, G. Plizzari, and S. Kawashima, "Influence of Steel and Macro-Synthetic Fibers on Concrete Properties," Fibers, vol. 6, no. 3, p. 47, Jul. 2018, doi: 10.3390/fib6030047.
[16] Badan Standardisasi Nasional, "SNI 2052:2017 Baja tulangan beton," 2017
[17] A. Jayanandana, M. T. R. Jayasinghe, and C. Hewagama, Design Of High Strength Concrete Mixes. 1997. Accessed: Dec. 09, 2024. [Online]. Available: https://www.researchgate.net/publication/304247619_DESIGN_OF_HIGH_STRENGTH_CONCRETE_MIXES
[18] American Concrete Institute, "ACI Education Bulletin E1-07 Aggregates for Concrete," 2007
[19] Badan Standardisasi Nasional, "SNI 03-2834-2000 Tata cara pembuatan rencana campuran beton normal ," 2000
[20] American Concrete Institute, "ACI 363R-10 Report on High-Strength Concrete," 2010
[21] D. P. M. B. D. J. C. K. D. P. U. dan T. L. PUPR, "Peraturan Beton Bertulang Indonesia 1971 N.l. r 2," 1971
[22] M. R. Latifi, Ö. Biricik, and A. Mardani, "Mechanical and Durability Performance of Macro Polypropylene Fibrous Concrete," Iranian Polymer Journal, vol. 32, no. 9, pp. 1149–1164, Sep. 2023, doi: 10.1007/s13726-023-01193-6.
[23] Z. Deng et al., "A study of tensile and compressive properties of hybrid basalt-polypropylene fiber-reinforced concrete under uniaxial loads," Structural Concrete, vol. 22, no. 1, pp. 396–409, Feb. 2021, doi: 10.1002/suco.202000006