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The Effect of Polypropylene Fiber and Steel Fiber on Geopolymer Concrete

Niza Widiana[1, a)], Iman Satyarno[2, b)], Suprapto Siswosukarto[3, b)]

[1,2,3] *Master Program in Civil Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta*

[a)] Corresponding author: nizawidiana1@mail.ugm.ac.id
[b)] imansatyarno@ugm.ac.id
[c)] suprapto.siswosukarto@ugm.ac.id

Abstract. Geopolymer concrete, which uses fly ash as a cement substitute, is one of the environmentally friendly alternatives to traditional cement concrete. To prevent premature cracking of the concrete, this study investigated the addition of polypropylene fiber, steel fiber (dramix), and a combination of both fibers. Three variables were studied: the addition of polypropylene fiber by 0%, 0.40%, 0.80%, and 1.2%; steel fiber of 0.25%, 0.50%, 0.75%, and 1.00%; and the combination of polypropylene fiber and steel fiber (0.4%P;0.50%D), (0.8%P;0.75%D), and (1.2%P;1.00%D) of the weight of the concrete. Beam specimens measuring 10x10x50 cm were prepared for each percentage of fiber usage, and two beam trials were conducted. The geopolymer concrete in this study had a NaOH and Na2SiO3 ratio of 2:1 and a constant concentration of 10 Molar. The Flexural Strength Test was carried out on the concrete at the age of 28 days. The highest average flexural strength of geopolymer concrete was observed without fiber addition (σl = 78.77 kg/cm2), with 0.80% polypropylene fiber (σl = 50.50 kg/cm2), and with 0.25% steel fiber (σl = 68.87 kg/cm2). The combination of both fibers (P0.4%; D0.25%) resulted in a flexural strength of σl = 65.34 kg/cm2. However, the results showed poor workability, which affected the decrease in flexural strength. By increasing the ratio A from 0.35 to 0.45, the geopolymer concrete mix improved workability and achieved the highest average flexural strength of geopolymer concrete with 0.8% polypropylene fiber (σl = 80.107 kg/cm2).

Keywords: geopolymer concrete, polypropylene, steel fiber, flexible strength test.

INTRODUCTION

Portland cement production is a significant contributor to air pollution and greenhouse gas emissions, which are major factors in global warming. Geopolymer concrete, which uses fly ash as a substitute for cement, is a promising environmentally friendly alternative to traditional cement concrete. However, like traditional concrete, geopolymer concrete is prone to cracking, particularly under bending loads. To prevent premature cracking, polypropylene fiber and steel fiber (dramix) were added to the concrete. These fibers can improve the strength of geopolymer concrete and reduce the occurrence of cracking, particularly under bending loads. This study aims to investigate the influence of adding different amounts of polypropylene fiber, steel fiber (dramix), and a combination of both fibers on the flexural strength of geopolymer concrete, through concrete bending strength tests.

Alkaline solutions composed of fly ash or husk ash can be utilized as a binder, and a chemical reaction known as polymerization occurs during the mixing of these materials, producing geopolymer as the binder. To produce geopolymer concrete, a paste is required to fill the fine aggregate, which becomes a mortar. The mortar is then used to fill the coarse aggregate, producing concrete [1]. Previous research found that a 10M concentration of NaOH and a ratio (A) between the weight of the alkaline solution and the weight of fly ash of 0.35 resulted in the maximum tensile strength after 28 days[2]. Additionally, the flow of mortar increases as the ratio A increases[3], Therefore, this study utilizes the ratio used in this study is 0.35 and 0.45.

Polypropylene fibers in geopolymer concrete change the failure pattern from brittle to ductile mode and the optimum addition of polypropylene fiber at 0.1%, up to 0.50% of the weight of the concrete[4]. The addition of fiber 0.6 up to 0.9 kg/m^3 can increase the tensile strength by 53.4% up to 98.5% [5]. Optimum addition of steel fiber 0% up to 1% of the concrete weight, geopolymer concrete has an increase in tensile strength up to 75% of ordinary geopolymer concrete. The performance of Fiber Reinforced Geopolymer Concrete showed a significant increase in split tensile strength compared to normal geopolymer concrete without adding fiber. The addition of polypropylene fiber and steel fiber (dramix) is proven to increase the tensile strength and flexural strength of geopolymer concrete with additions at optimum levels. So this research is a development of several previous studies by using 2 types of fiber, namely polypropylene fiber and steel fiber (dramix).

MATERIAL AND METHODS

This study builds upon the previous work of Cornelis [6], which employed a ratio of Rm=1.5, 10M NaOH concentration, a NaOH to Na2SiO3 ratio of 2:1, and an alkali solution to fly ash weight ratio (A) of 0.35 and 0.45. The objective of this study is to evaluate the flexural strength of the concrete after 28 days.

Material Geopolymer Concrete with Fiber

This study used sand from Clereng, Yogyakarta, Indonesia, and fly ash taken from coal combustion waste PT. Paiton, Malang, East Java. The materials test results are shown in Table 1 and Figure 1, and research variables of fiber geopolymer concrete are shown in Table 2 and Figure 2.

TABLE 1. Geopolymer Concrete Materials

Types of material	Specific gravity
Fly Ash Type C	3.280
NaOH	1.251
Na_2SiO_3	1.437
Fine aggregate	2.711
Coarse aggregate	2.549

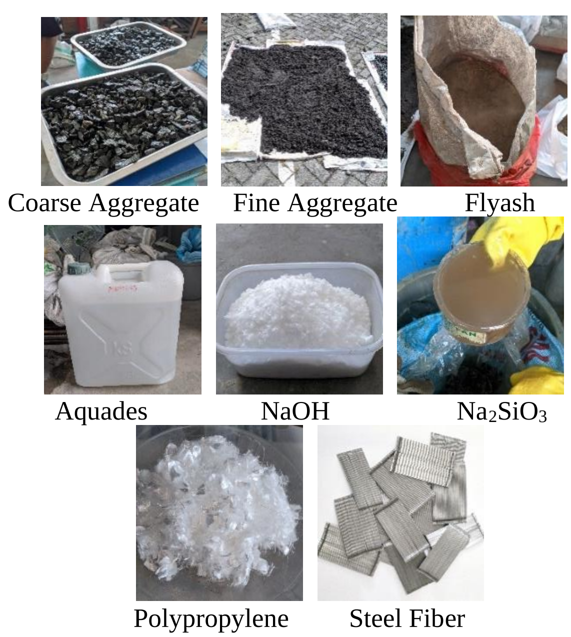

FIGURE 1. Concrete materials

TABLE 2. Research Variables of Fiber Geopolymer Concrete

Variable	Ratio A	Percentage fiber (%)		
		Polypropylene	Steel (dramix)	Polypropylene & Steel (dramix)
Variation	0.35	$P_{0.40\%} = 0.40$	$D_{0.25\%} = 0.25$	$PD_{(0.40\%;0.50\%)} = (0.40;0.50)$
		$P_{0.80\%} = 0.80$	$D_{0.50\%} = 0.50$	$PD_{(0.80\%;0.75\%)} = (0.80;0.75)$
		$P_{1.20\%} = 1.20$	$D_{0.75\%} = 0.75$	$PD_{(1.20\%;1.00\%)} = (1.20;1.00)$
		-	$D_{1.00\%} = 1.00$	-
	0.45	$P_{0.80\%} = 0.80$	$D_{0.50\%} = 0.50$	-
Specimen	Concrete beam specimen			
Test type	Flexural strength test			

FIGURE 2. Concrete beam specimen

Calculation

Therefore, the geopolymer paste mixture design in this study used the absolute volume calculation method. The calculation of a mixture of paste, mortar, and concrete can be based on the absolute volume proportion and each material making up the mixture in 1 m^3[6]. In this study, the ingredients for a mixture of geopolymer-fly ash paste consisted of class C fly ash (FA), sodium hydroxide (SH), and sodium silicate (SS). Theoretically, if the volumetric ratio of FA: SS: SH is known and the total solid volume is 1 m^3, then the calculation of the proportion of the pasta mixture based on the absolute volume method can be done using Equation (1) below:

$$\frac{W_{fa}}{Gs_{fa}\gamma_w} + \frac{W_{ss}}{Gs_{ss}\gamma_w} + \frac{W_{sh}}{Gs_{sh}\gamma_w} = 1m^3 \quad (1)$$

The design of the geopolymer mortar mix is closely related to the parameter (Rm), namely the ratio between the absolute volume of the paste (Vp) and the absolute volume of the fine aggregate cavity (Vr_{agh})[6]. For this reason, the mortar mixture composition was designed by varying the parameter Rm. If the ratio of Rm and Vr_{agh} is known, then the weight of fly ash (Wfa), weight of sodium silicate solution (Wss), and weight of sodium hydroxide solution (Wsh) required in $1m^3$ of geopolymer mortar mixture can be calculated by Equation (2) below:

$$\frac{W_{fa}}{Gs_{fa}\gamma_w} + \frac{W_{ss}}{Gs_{ss}\gamma_w} + \frac{W_{sh}}{Gs_{sh}\gamma_w} = Rm\ Vr_{agh} \quad (2)$$

If Rm, Rb, Vr_{agh}, and Vr_{agk} are known, then the weight of fly ash (Wfa), weight of sodium silicate solution (Wss), weight of sodium hydroxide solution (Wsh) required in 1 m^3 of geopolymer concrete mixture can be calculated by Equation (3) below:

$$\frac{W_{fa}}{Gs_{fa}\gamma_w} + \frac{W_{ss}}{Gs_{ss}\gamma_w} + \frac{W_{sh}}{Gs_{sh}\gamma_w} = R_m\ Vr_{agh}\ R_b\ Vr_{agk} \quad (3)$$

Design of Geopolymer Concrete Composition

Referring to previous research this geopolymer concrete used a ratio of Rm=1.5, R set constant at 2.0, 10 Molarities NaOH concentration by testing the flexural strength of concrete aged 28 days to produce optimal flexural strength [7]. The calculation of geopolymer paste is designed based on the following calculation stages and is shown in Table 3 and Table 4.

a. The NaOH concentration was set at 10M
b. Ratio by weight of sodium silicate to sodium hydroxide (R = set constant at 2.0)
c. The ratio of the weight of the alkaline solution to the weight of the fly ash (A = set constant at 0.35)
d. Determination of the weight of the constituent ingredients in $1m^3$ pasta.

The calculation of geopolymer mortar is designed based on the following calculation stages and is shown in Table 5 and Table 6.

a. Ratio by weight of sodium silicate to sodium hydroxide (R = set at 2.0)
b. The ratio of the weight of the alkaline solution to the weight of the cementitious.
c. Calculating the void volume of fine aggregate (Vr_{agh})
d. The absolute ratio of geopolymer paste volume to fine aggregate void volume (Rm) is set at 1.5.
e. Determination of the weight of fly ash, NaOH, and Na_2SiO_3 in $1m^3$ of mixed mortar.
f. Determination of the weight of fine aggregate in $1m^3$ of mortar mix.

The calculation of geopolymer concrete is designed based on the following calculation stages and is shown in Table 7 and Table 8.

a. The NaOH concentration was set at 10M
b. Ratio by weight of sodium silicate to sodium hydroxide (R = set constant at 2.0)
c. The ratio of the weight of the alkaline solution to the weight of the cementitious (A = set constant at 0.35)
d. Calculating the void volume of fine aggregate (Vr_{agh})
e. Calculating the void volume of coarse aggregate (Vr_{agk})
f. The absolute ratio of geopolymer paste volume to fine aggregate void volume (Rm) is set at 1.5.
g. The absolute ratio of geopolymer paste volume to coarse aggregate void volume (Rb) is set at 1.5.
h. Determination of the weight of fly ash, NaOH, and Na_2SiO_3 in $1m^3$ of geopolymer concrete mixture.
i. Determination of the weight of fine aggregate in $1m^3$ of geopolymer concrete mix.
j. Determination of the weight of coarse aggregate in $1m^3$ of geopolymer concrete mix.

A. Pasta Calculation Design

TABLE 3. Pasta Calculation Design using Ratio A=0.35

Material	Weight		Volume	
Fly ash (W_{fa})	1784.08	kg/m^3	0.544	m^3
Sodium Silicate (W_{ss})	416.29	kg/m^3	0.290	m^3
Sodium Hydroxide (W_{sh})	208.14	kg/m^3	0.166	m^3
Total	2408.5	kg/m^3	1.000	m^3

TABLE 4. Pasta Calculation Design using Ratio A=0.45

Material	Weight		Volume	
Fly ash (W_{fa})	1578.41	kg/m^3	0.481	m^3
Sodium Silicate (W_{ss})	473.52	kg/m^3	0.330	m^3
Sodium Hydroxide (W_{sh})	236.76	kg/m^3	0.189	m^3
Total	2288.7	kg/m^3	1.000	m^3

B. Mortar Calculation Design

TABLE 5. Mortar Calculation Design using Ratio A=0.35

Material	Weight		Volume	
Fly ash (W_{fa})	1135.21	kg/m³	0.346	m³
Fine Aggregate (Wagh)	986.00	kg/m³	0.364	m³
Sodium Silicate(W_{ss})	264.88	kg/m³	0.184	m³
Sodium Hydroxide (W_{sh})	132.44	kg/m³	0.106	m³
Total	2518.53	kg/m³	1.000	m³

TABLE 6. Mortar Calculation Design using Ratio A=0.45

Material	Weight		Volume	
Fly ash (W_{fa})	1004.33	kg/m³	0.306	m³
Fine Aggregate (Wagh)	986.00	kg/m³	0.364	m³
Sodium Silicate(W_{ss})	301.30	kg/m³	0.210	m³
Sodium Hydroxide (W_{sh})	150.65	kg/m³	0.120	m³
Total	2442.29	kg/m³	1.000	m³

C. Concrete Calculation Design

TABLE 7. Concrete Calculation Design using Ratio A=0.35

Material	Weight		Volume	
Fly ash (W_{fa})	676.17	kg/m³	0,206	m³
Fine Aggregate (W_{agh})	587.30	kg/m³	0,217	m³
Coarse Aggregate (W_{agk})	1030.90	kg/m³	0,404	m³
Sodium Silicate(W_{ss})	157.77	kg/m³	0,110	m³
Sodium Hydroxide (W_{sh})	78.89	kg/m³	0,063	m³
Total	2530.97	kg/m³	1,000	m³

TABLE 8. Concrete Calculation Design using Ratio A=0.45

Material	Weight		Volume	
Fly ash (W_{fa})	598.22	kg/m³	0.182	m³
Fine Aggregate (W_{agh})	587.30	kg/m³	0.217	m³
Coarse Aggregate (W_{agk})	1030.90	kg/m³	0.404	m³
Sodium Silicate(W_{ss})	179.46	kg/m³	0.125	m³
Sodium Hydroxide (W_{sh})	89.3	kg/m³	0.072	m³
Total	2485.56	kg/m³	1.000	m³

D. Calculation of Geopolymer Concrete Mixture with Polypropylene Fiber and Steel Fiber (Dramix)

In planning geopolymer concrete mixes with polypropylene fiber or steel fiber (dramix) can be calculated based on the composition of the total weight of geopolymer concrete as follows:

a. Need for polypropylene fiber = % polypropylene x weight of geopolymer concrete (kg/m^3)

b. Need for steel fiber (dramix) = % steel fiber x weight of geopolymer concrete (kg/m^3)

Steps for mixing concrete

The initial step in manufacturing geopolymer concrete is to create a geopolymer binder that has both a set time and optimum compressive strength. The reaction of NaOH 10 M and Na2SiO3 occurs first, and then the activator solution is added to a mixer containing Type C Fly Ash, which is stirred thoroughly. Because the binding time for this method is quite lengthy, the fine aggregate must be added to the mixer immediately after thorough mixing, followed by the coarse aggregate and the fiber. This process results in rapid concrete hardening, necessitating careful attention to ensure homogeneity.

Geopolymer concrete using the fiber mix method is shown in Figure 3.

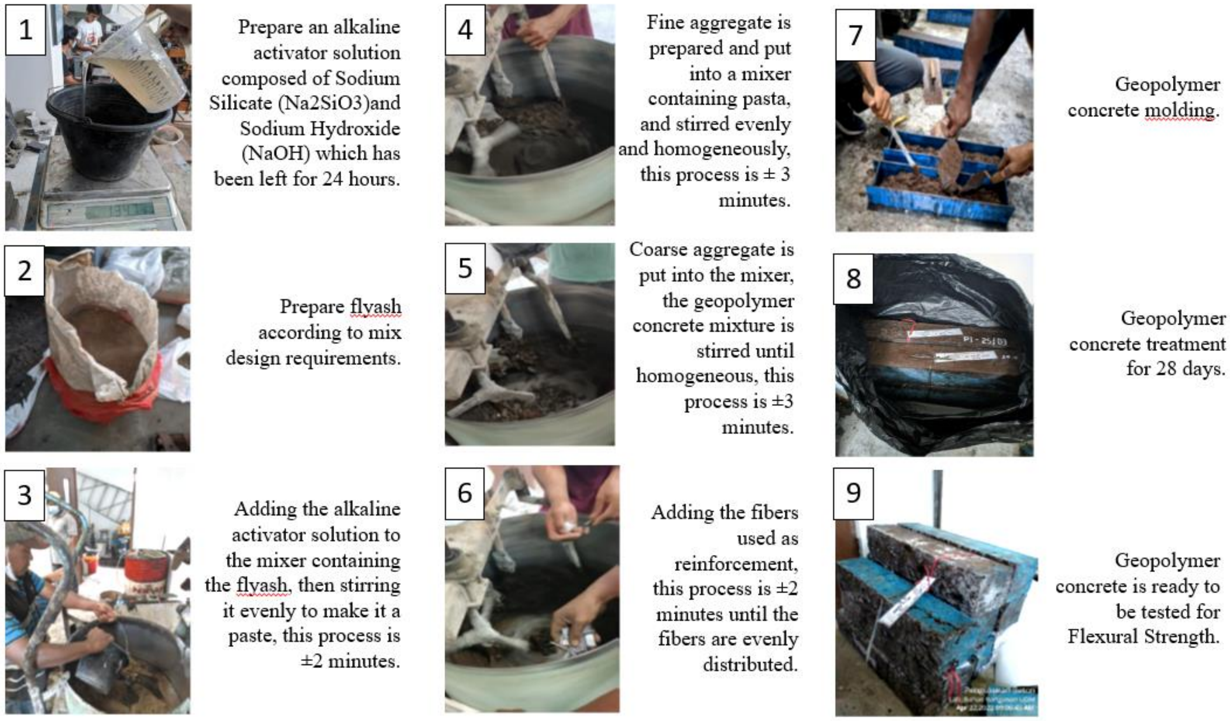

FIGURE 3. Steps for mixing concrete

Flexural strength test

Flexural strength of geopolymer concrete beams was evaluated using the two-point loading method in accordance with SNI 4431:2011 and ASTM C78-02 standards at 28 days of age. The dimensions of the test specimens were measured, as shown in Figure 4, and placed on a support beam in the flexural strength testing machine, as illustrated in Figure 5. The dial testing tool was set to register deflection and load every 0.01 mm and 0.05 KN, respectively. Flexural strength was determined based on the fracture point of the specimen, which could occur either in the center area at 1/3 the distance from the bearing point or outside the center area at 1/3 the distance from the bearing point, and calculated using the formulas specified in SNI 4431:2011, as depicted in Figure 6..

FIGURE 4. Dimensions of the beam test object

FIGURE 5. The placement of the flexural strength test object

FIGURE 6. Concrete flexural strength test

RESULT AND DISCUSSION

The flexural strength test results of geopolymer concrete with an alkaline solution to cement weight ratio of 0.35 revealed a decrease in flexural strength when using polypropylene fiber, steel fiber, or a combination of both, compared to normal geopolymer concrete. This decrease can be attributed to the reduced workability of the concrete mix due to the addition of fibers, leading to segregation and lack of homogeneity. This issue can be addressed by increasing the ratio of the alkaline solution to the weight of cement (A). Therefore, a study was conducted with an increased ratio of alkali to fly ash weight (A) of 0.45.

Flexural Strength Test Results with Ratio A=0.35

The results of the flexural strength test are in Table 9. The highest flexural strength was achieved by normal geopolymer concrete without fiber (P0%) with an average flexural strength result of σl = 78.77 N/mm^2, compared to polypropylene fibrous geopolymer concrete using ratio A=0.35 which only reached the average flexural strength of σl=50.50 N/mm^2, geopolymer concrete using ratio A=0.35 with steel fiber (dramix) reached an average flexural strength of σl=68.87 N/mm^2, and geopolymer concrete with a combination of polypropylene and steel fiber (dramix) using ratio A=0.35 also only reached an average flexural strength of σl= 65.34 N/mm^2. When compared with previous research, the use of 0.025 kg/m^3 of polypropylene fiber shows a flexural strength of 39.10 N/mm^2, while the use of 0.05 shows a flexural strength of 42.00 N/mm^2[8], the addition of steel fiber 0.6 up to 0.9 kg/m^3 can increase the tensile strength by 53.4% up to 98.5%. Fibrous geopolymer concrete (polypropylene, steel) with the use of ratio A of 0.35 in this research experienced a decrease in flexural strength when compared to concrete geopolymer without fiber, this can be caused by the use of ratio A which low resulting in less workability of fresh concrete and segregation in concrete. The decrease in flexural strength then increased the use of the ratio of alkaline solution to the weight of fly ash by A = 0.45.

TABLE 9. Flexural Strength Test Results with Ratio A=0.35

ID sample	P max (N)	Flexural strength (kg/cm^2)	Average Flexural Strength (kg/cm^2)
P(0%)	16900	81.87	78.77
P(0%)	15500	75.67	
P0.40% a	11900	53.87	50.50
P0.40% b	10400	47.14	
P0.80% a	11000	54.45	49.39
P0.80% b	9300	44.32	
P1.20% a	10850	53.45	53.45
D(0.25%) a	12700	64.41	68.55
D(0.25%) b	15500	72.70	
D(0.50%) a	14350	68.52	66.86
D(0.50%) b	14000	65.20	
D(0.75%) a	12450	66.47	64.19
D(0.75%) b	12900	61.93	
D(1.00%) a	15100	68.71	68.87
D(1.00%) b	14550	69.03	
PD(0.40%;0.25%) a	14100	66.51	65.34
PD(0.40%;0.25%) b	13500	64.17	
PD(0.80%;0.50%) a	12000	60.60	57.65
PD(0.80%;0.50%) b	10550	54.71	
PD(1.20%;0.75%) a	14500	68.93	68.93

Figure 7 shows that concrete non-fiber using ratio A=0.35 when given a load can reach a maximum load of 16.90 KN. Figure 8 shows that 0.4% polypropylene fiber concrete using ratio A=0.35 when given a load can reach a maximum load of 11.90 KN. Figure 9 shows that 1.00% steel fiber concrete using ratio A=0.35 when given a load can reach a maximum load of 15.10 KN. Figure 10 shows that polypropylene fiber 0,4% dan steel fiber 0.25% concrete using ratio A=0.35 when given a load can reach a maximum load of 13.50 KN. The dotted line shows the corrected chart. When compared with previous research, the relationship between load and deflection with the addition of polypropylene fiber 0.3 up to 0.9 kg/m^3 with an A ratio of 0.35 when given a load can reach a maximum load of 17.50 KN[9]. The additional fiber reached the maximum load and resulted in deflection so that it could overcome sudden cracks in geopolymer concrete.

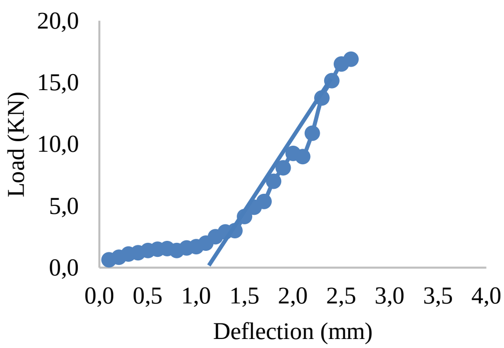

FIGURE 7. Graph of load and deflection relationship of non-fiber using Ratio A=0.35 (P0%)

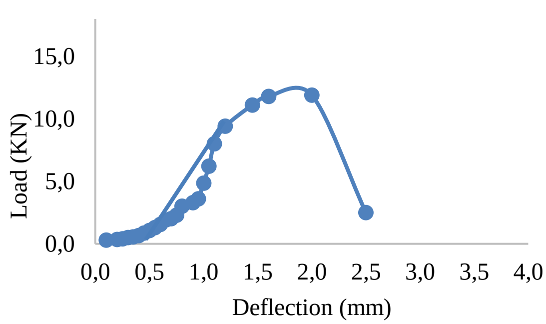

FIGURE 8. Graph of load and deflection relationship of 0.4% polypropylene fiber using Ratio A=0.35 (P0.4%)

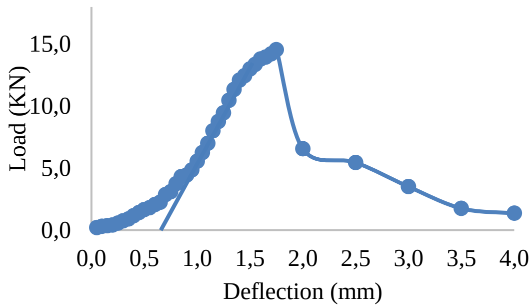

FIGURE 9. Graph of load and deflection relationship of 1.00% steel fiber using Ratio A=0.35 (D1.00%)

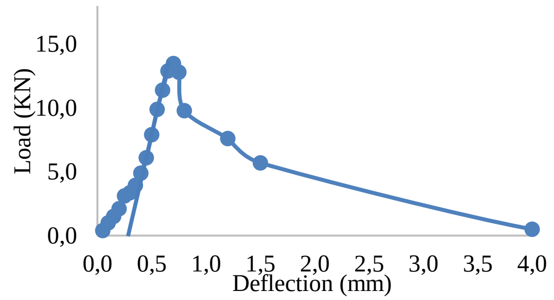

FIGURE 10. Graph of load and deflection relationship of fibrous concrete with a combination of 0.25% polypropylene fiber and 0.40% steel fiber using Ratio A=0.35 (PD(0.40%;0.25%))

Flexural Strength Test Results with Ratio A=0.45

Table 10 shows the results of an increase in the flexural strength test of 0.8% polypropylene fibrous geopolymer concrete using ratio A=0.45 with the highest average σ_l of 80.107 kg/cm^2, and a decrease in flexural strength test of 0.5% steel fiber (dramix) fibrous geopolymer concrete using ratio A=0.45 with the highest average σ_l of 75.467 kg/cm^2. When compared with previous research, flexural strength increases as the percentage of steel fiber increases, the strength increases from 3.22% for 0.25% volume fraction of fibers up to 8.51% for 1% volume fraction. An increase in this ratio A 0.45 is proven to be able to produce the workability of flexible, homogeneous fibrous geopolymer concrete mix, as well as an increase in flexural strength test results. It was concluded that the additional fiber reached the maximum load and resulted in deflection so that it could overcome sudden cracks in geopolymer concrete.

TABLE 10. Flexural Strength Test Results with Ratio A=0.45

ID sample	P max (N)	Flexural strength (kg/cm^2)	Average Flexural Strength (kg/cm^2)
P0%	16900	81.87	78.77
P0%	15500	75.67	
P0.80%	13650	72.03	80.11
P0.80%	16750	88.19	
D0.50%	14750	71.66	75.47
D0.50%	15250	79.28	

Figure 11 shows that 0.8% polypropylene fiber concrete using ratio A=0.45 when given a load can reach a maximum load of 16.75 KN. Figure 12 shows that 0.5% steel fiber concrete using ratio A=0.45 when given a load can reach a maximum load of 14.75 KN. The dotted line shows the corrected chart. When compared with previous research, the relationship between load and deflection with the addition of polypropylene fiber 0.3 up to 0.9 kg/m^3 with an A ratio of 0.55 when given a load can reach a maximum load of 27.50 KN[9].

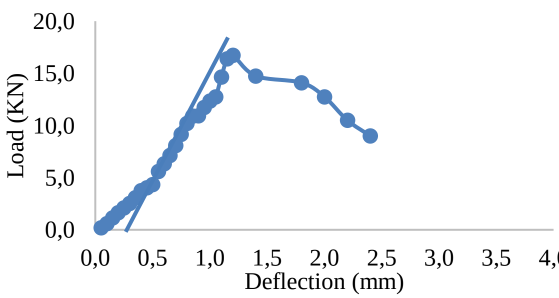

FIGURE 11. Graph of load and deflection relationship of 0.8% polypropylene fiber using Ratio A=0.45 (P0.8%)

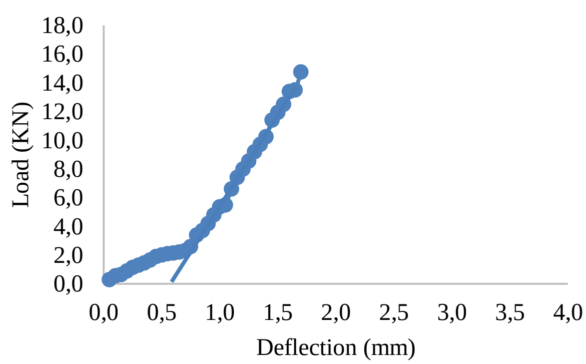

FIGURE 12. Graph of load and deflection relationship of 1.0 % steel fiber using Ratio A=0.45

CONCLUSION

The flexural strength of fibrous geopolymer concrete (polypropylene, steel) with a ratio A of 0.35 was observed to be lower than that of non-fibrous geopolymer concrete. This can be attributed to the low ratio A, which reduces the workability of fresh concrete and leads to segregation. To increase the flexibility, the ratio A was increased to 0.45, which resulted in improved flexural strength. The addition of 0.80% polypropylene fiber enhanced the flexural strength compared to non-fibrous geopolymer concrete. However, the usage of 1.00% steel fiber decreased the flexural strength compared to geopolymer concrete without fiber, indicating that steel fiber is not suitable for use in geopolymer concrete.

The addition of polypropylene fiber of 0.40%, 0.80%, and 1.20% in concrete geopolymer with the use of ratio A = 0.45 showed the best results on polypropylene fiber 0.80% which produces an average flexural strength of, σ_l = 50.503 (kg/cm²) at 28 days of concrete age. The addition of steel fiber of 0.25%, 0.50%, 0.75%, and 1.00% in goop and polymer concrete using ratio A=0.45 showed the best results on 1.00% steel fiber which produces strength the average bending is, σ_l = 68.87 (kg/cm²) at the age of 28 days concrete. Influence addition of fiber to post flexural strength of geopolymer concrete (85% condition) produced the largest deflection in combined fiber geopolymer concrete polypropylene and steel fiber.

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