The Effect of Adding Steel Fiber on the Workability and Density of Geopolymer Concrete Mixture

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ABSTRACT

Geopolymer concrete has decent strength, but it is still lower compared to conventional concrete. One way to improve the strength of geopolymer concrete is by adding reinforcing fibers. The fibers used should be suitable for the environmental conditions and economical. One fiber that can be used to enhance the strength of concrete is steel fiber. The addition of steel fiber to concrete can increase its density but may decrease the slump value, which can affect the workability of the concrete. In BGP 1%, the increase from 0% fiber content reaches 3.2%, and in BGP 2%, it reaches the maximum density of 2405.73 kg/m3 with the addition of fiber to geopolymer concrete. From the results, it can be observed that as the density of geopolymer concrete increases, the slump value tends to decrease.

Keywords: geopolymers, steel fibers, workability, density of geopolymers

1. INTRODUCTION

According to data from the Central Statistics Agency (BPS) of Indonesia, the production of steel fibers in Indonesia reached around 476 thousand tons in 2019, an increase from the previous year's production of approximately 459 thousand tons (BPS Indonesia, 2020). Steel fibers are additional materials added to concrete to enhance and improve its strength. Steel fibers can be derived from natural or artificial materials and can be used as an alternative or addition to other materials such as cast iron and reinforcement bars (Lok & Pei, 1998).

In the use of fibers in concrete, the quantity and type of fibers used will affect the mechanical properties and characteristics of the resulting fiber-reinforced concrete (Alani & Aboutalebi, 2013). Therefore, the design of the concrete mixture is needed to produce fiber-reinforced concrete with desired characteristics. investigated the maximum limit that still allows easy mixing in fiber-reinforced concrete, which is the use of fibers with an aspect ratio (l/d) < 100. The limitation of the l/d value is supported by efforts to enhance fiber bond strength by creating fibers with various configurations, such as spiral shapes, crimped shapes, or other shapes, to improve fiber bond strength (Briggs, 1974). Adding fibers to concrete mixtures can cause issues with fiber dispersion and its adequacy in the mixture. The optimal concentration of steel fibers in concrete can vary depending on the fiber type, particle size, and environmental conditions (Krzywiński et al., 2019). In general, adding steel fibers ranging from 0.5% to 2% by weight of the concrete can significantly improve the mechanical properties of the concrete (Salih & Rejeb, 2005).

Adding steel fibers to concrete can increase the density of the concrete but may decrease the slump value, which affects the workability of the concrete. There is still a lack of research examining the effects of adding steel fibers to geopolymers (Centonze et al., 2012). Therefore, research related to the addition of steel fibers to geopolymers is conducted to understand the relationship between workability and the density of the concrete.

2. EXPERIMENTAL PROCEDURES

Mix Design

In this research, the calculation of the geopolymers concrete mix design is based on the SNI 03-2834-2000 standard, which is used for traditional cement mix design. However, for the purpose of this study, the mix design is adjusted to include geopolymers. The steps below outline the process of achieving a molarity of 8 in the geopolymers mix design.

1. The cement-to-water ratio is substituted with fly ash and alkali activator
   After obtaining the composition ratio per cubic meter for normal concrete, the initial step in producing geopolymers concrete is to replace the ratio of cement to water with the ratio of fly ash to alkali activator.
2. The ratio between the alkali activator and fly ash is 1 : 2
   The ratio of alkali activator to fly ash is 1:2, and the calculation results can be seen below on Table 1.

Table 1. Summary of Alkali Activator and Fly Ash Ratios

Total Weight	Fly Ash	Alkali Activator	Coarse Aggregate	Fine Aggregate
2404,80	431,82	215,91	1166,75	590,32

3. The ratio between sodium silicate and sodium hydroxide is 3 : 1
After determining the alkali activator ratio, the next step is to divide the alkali activator ratio into a 1:3 ratio, with 3 parts for sodium silicate and 1 part for sodium hydroxide. The calculated results are presented below. This ratio has been carefully chosen to achieve optimal conditions in the production of geopolymers concrete within the specific context of this research. The calculated results are displayed in the table provided below.

Table 1. Calculation Results of Sodium Silicate to Sodium Hydroxide Ratio

Total Weight	Fly Ash	NAOH	Na2SiO3	Coarse Aggregate	Fine Aggregate
2404,80	431,82	53,98	161,93	1166,75	590,32

4. Sodium Hydroxide Solution Design
The selected molarity for the sodium hydroxide (NaOH) solution is 8 molar, which will be combined with a total requirement of 1000 grams of NaOH and water, as indicated in Table 3. To achieve the desired outcome of this design, calculations based on the established formula are necessary.

Table 2. Requirement Aquades and NaOh 1000 Gram

	For Preparation 1 kg of SHS		
Molarity	SH Solids (Gram)	Water (Gram)	SHS (Gram)
4	140	860	1000
6	200	800	1000
8	225	745	1000
12	354	646	1000
16	443	557	1000

a. NaOH = SH Solids/1000 x NaOH ………………………………………………………….(1)
b. Aquades = Water/1000 x NaOH …………………………………………………………(2)

The following example presents the calculation of the ratio between water and sodium hydroxide (NaOH) for a molarity of 8, based on the data provided in Table 3.

Afterwards, to acquire a thorough understanding of the material requirements for geopolymers concrete per 1 cubic meter, a detailed summary is presented in Table 4. The table offers vital information on the composition of materials necessary to achieve the correct proportions and ensure optimal performance in the production of geopolymers concrete.

Table 3. Summary of Geopolymer Concrete 1 M^3

Recapitulation of Geopolymer Concrete per 1 m3 (8 Molar)						
Total Weight	Fly Ash	NAOH	Na2SiO3	Air	Coarse Aggregate	Fine Aggregate
2445,02	431,82	161,93 8 Molar	53,98 12,14	40,21	1166,75	590,32

In calculating the material requirements for one mold, the equation for a cylindrical mold with a height of 20 cm and a diameter of 10 cm, based on formula (1), is utilized. This approach is employed to obtain an accurate estimation of the amount of materials needed for each concrete. In calculating the material requirements per mold, the equation for a cylindrical mold with a height of 20 cm and a diameter of 10 cm, based on formula (2), is utilized. This approach is employed to obtain an accurate estimation of the amount of materials needed for each concrete mold of specified dimensions. The equation is as follows on Table 5.

Table 4. Summary of Geopolymer Concrete Material Requirements Per Mold

Material	For One Mold (Kg)
Coarse Aggregate	0,9268
Fine Aggregate	1,8318
Fly Ash	0,6780
Na2SiO3	0,2542
NaOH	0,0210
Air	0,0631

Steel fiber

Steel fiber is utilized as an additional material to enhance the tensile strength and resistance to cracking in concrete, possessing mechanical properties. These mechanical properties of steel fibers are characteristics associated with how steel fibers behave under force or load. They encompass tensile strength, elastic modulus, ductility, and corrosion resistance. Steel fiber serves as a reinforcing material in concrete to enhance its mechanical properties, including compressive strength, flexural tensile strength, and ductility (S. M. Al-Salem, 2019). This study will elucidate the formula in equation 3 necessary for determining the requirement for steel fiber. Figure 1 illustrates the steel fibers utilized.

Figure 1. Steel Fiber

The calculation to determine the steel fiber requirement is given by.

"Steel Fiber Requirements" = $VxPx\rho x1000$ ……………………………………………………………(3)

Which: V = represents the volume of the concrete mold in cubic meters (m^3), P = represents the percentage of steel fiber (%), ρ = represents the density of the fiber in kilogram per cubic meters (kg/m^3)

From the formula as above, the steel requirements are obtained at percentages of 0%, 1%, and 2% respectively stated in Table 6.

Table 5. Steel Fiber Requirements

Steel Fiber Requirements (cylinder 10x20 cm)					
Steel Fiber (%)	Volume Fiber (m^3)	Density Fiber (gram)	Requirement Fiber (gram)	Amount of Cylinder (Pcs)	Total Requirements Fiber (gram)
0,50%	0,00000785	7850	61,62	9	554,60
1,00%	0,00001570	7850	123,25	9	1.109,21
1,50%	0,00002355	7850	184,87	9	1.663,81
2,00%	0,00003140	7850	246,49	9	2.218,41
		Total (gram)			5.546

3. RESEARCH METHODOLOGY

In this study, non-cement geopolymer concrete is utilized with a steel fiber blend, and split tensile strength testing is conducted. The objective of this research is to reduce the reliance on Portland cement in concrete mixes while enhancing concrete quality through fiber reinforcement. The variables examined in this study include changes in fiber content and the curing time of geopolymer concrete under room temperature conditions. A mix design is developed to ascertain the tensile strength of geopolymer concrete by determining the appropriate ratios for the concrete mixture.

The research product was developed at the PT Jaya Beton laboratory. There are 45 test specimens to be tested and produced. This testing follows the Procedure for Creating a Standard Concrete Mix Design outlined in SNI 03-2834-2000 as a fundamental guideline for concrete geopolymer's mix design and also SNI 2493-2011 as a reference that explains the Procedures for Making and Maintaining Concrete Test Objects in the Laboratory.

Making geopolymer paste involves several steps. Initially, the NaOH solution is mixed with water for 2 minutes. Next, Na2SiO3 is added to the solution as an activator for 3 minutes. The third step includes mixing the fly ash into the activator solution for 5 minutes, followed by the geopolymer paste mixed with the aggregate.

In prior studies, geopolymer concrete with a NaOH solution concentration ranging from 12M to 14M, subjected to steam treatment at 60℃ for 4 hours, exhibited a significant increase in compression strength values, achieving 17.8% of the targeted compression strength value. The ideal ratio between the weight of Na2SiO3 and solid NaOH falls within 7.5 to 8.5. The optimal steam curing temperature is 60℃ with a duration of 4 hours. The slump value of geopolymer concrete tends to decrease as the NaOH concentration rises (Setiawan et al., 2023).

In this study, the test specimens were treated in two stages. Initially, the concrete was taken out of the mold and oxidized in an oven at 60°C for 4 hours. Subsequently, the concrete was removed from the oven and allowed to rest at room temperature before conducting the test. Figure 2 illustrates the concrete curing process using an oven.

Figure 2. Concrete Treatment Using an Oven at 60°C

Tensile strength testing is a method used to determine the strength of a material by pulling it until damage or failure happens. It represents the maximum force a material can withstand before damage or failure (ASTM C1583-04, 2010).

Split tensile strength is a measure of a material's resistance to breaking when a load is applied at a specific point. It is used in concrete to assess strength and quality and can be determined using a split tensile testing machine.

(SNI 03-2491, 2002) states that the splitting tensile strength of concrete can be measured using a splitting tensile test based on static or dynamic methods. In a static splitting tensile test, the load is applied to the concrete slowly until the breaking point is reached. In the dynamic splitting tensile test, the load is applied to the concrete suddenly and the frequency of the load can be adjusted to obtain information about the dynamic response of the concrete to the load.

Figure 3. Splitting Tensile Strength of Concrete

4. RESULTS

Slump test

In this study, slump tests were conducted before casting the concrete mixture into cylinders. The purpose was to evaluate the workability of the geopolimer concrete prepared for this research. The results of the slump tests can be found in Table 7.

Table 6. Slump Test Results for Fiber Percentage

Steel Fiber	Slump (cm)
0,00%	20
1,00%	7
2,00%	2

From the slump test results, it can be observed that as the percentage of fibers increases, the slump value of the fiber-reinforced geopolimer concrete mixture tends to decrease.

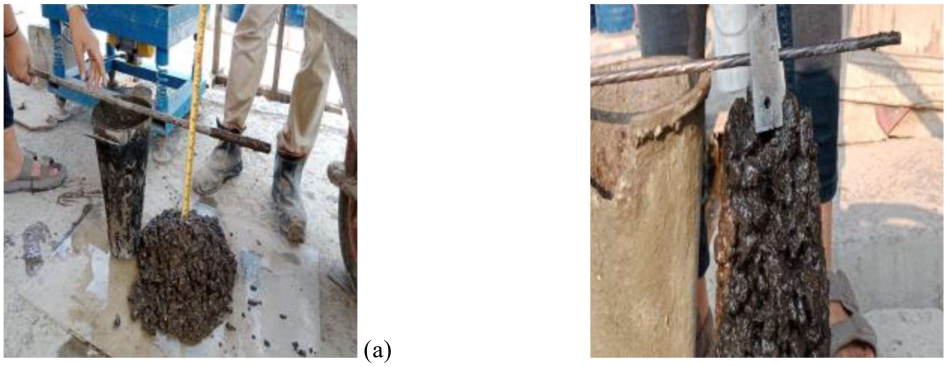
(a) (b)

Figure 4. Slump Testing on Geopolymer Concrete Testing

Figure 5 displays the results of the slump test graph for the three types of geopolymer concrete mixtures with different variations of steel fiber.

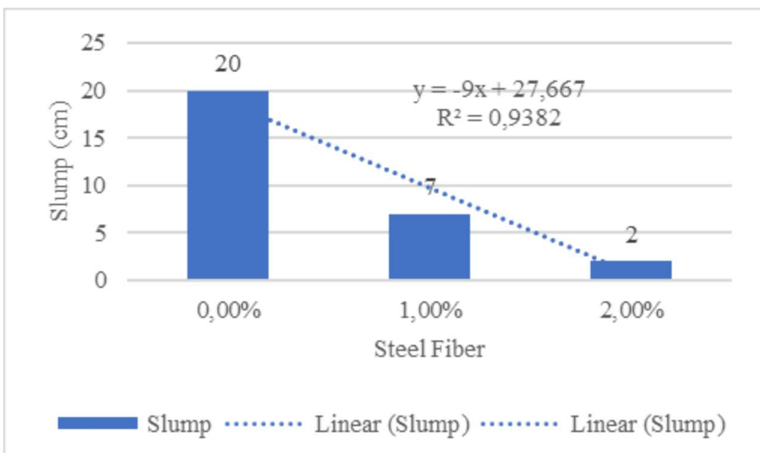

Figure 5. Graph of Slump Test on Steel Fiber Reinforced Geopolymer Concrete

From the observations, it is evident that the concrete slump value is affected by the steel fiber percentage. Adding steel fiber from 0% to 1% resulted in a slump value of 65%, and from 1% to 2% resulted in a slump value of 71.4%. Each 1% increase in steel fiber caused an average 68% decrease in slump, with the optimal slump value identified at 1% fiber content. There is a trend for the slump value to decrease as the steel fiber percentage increases. This can be attributed to the decrease in percentage leading to an increase in water requirement in the concrete mix, resulting in a more fluid mix. Additionally, it can be observed that mixes with higher percentages tend to reach the plastic state or harden more quickly.

The graph depicting the relationship between the steel fiber percentage and the slump value of concrete can be approximated using a linear regression equation, expressed as follows.

$y = -9x + 27{,}667$ ....(4)

In this equation, y represents the slump value of concrete in centimeters (cm), and x represents the percentage of steel fiber. This linear regression equation illustrates the correlation between the fiber percentage and the concrete slump value.

These findings enhance our understanding of how the steel fiber percentage affects the slump characteristics of geopolymer concrete. This knowledge is valuable for adjusting material proportions, designing concrete mixtures, and ensuring quality control of geopolymer concrete mixes based on the steel fiber percentage used.

Density

In this study, the concrete density was determined using a specific formula, and the findings were displayed in a table. The measurement of concrete density was conducted to examine the characteristics of the concrete produced in this research. The results of the concrete density measurement offer insights into the physical properties and quality of the concrete manufactured. Equation 5 is the formula used to calculate the density of the concrete.

$Concrete\ Density = M/V$ ……………………………………………………………………………..(5)

Which: Concrete Density (kg/m^3), M = Concrete weight (kg), V = Concrete volume (m^3)

This formula considers the measured mass of the concrete and the volume of the concrete produced. By using this formula, the density of the concrete can be calculated, indicating the level of density and compactness of the concrete. In this research, density tests were carried out on geopolymer concrete with steel fiber reinforcement at ages 7, 14, and 28 days. The density tests aimed to determine the characteristics of the density of geopolymer concrete mixed with steel fiber at different ages. Table 8 summarizes the density tests conducted on geopolymer concrete with steel fiber reinforcement at ages 7, 14, and 28 days. This formula considers the measured mass of the concrete and the volume of the concrete produced. By using this formula, the density of the concrete can be calculated, indicating the level of density and compactness of the concrete.

On the other hand, density tests were carried out on geopolymer concrete with steel fiber reinforcement at ages 7, 14, and 28 days. The density tests aimed to determine the characteristics of the density of geopolymer concrete mixed with steel fiber at different ages. Table 8 summarizes the density tests conducted on geopolymer concrete with steel fiber reinforcement at ages 7, 14, and 28 days.

Table 7. Density Test Summary

Concrete	Average (Kg/m^3)		
	GCSF 0%	GCSF 1%	GCSF 2%
7 days	2104,7	2259,2	2349,3
14 days	2211,9	2329,1	2316,3
28 days	2273,5	2349,5	2405,7

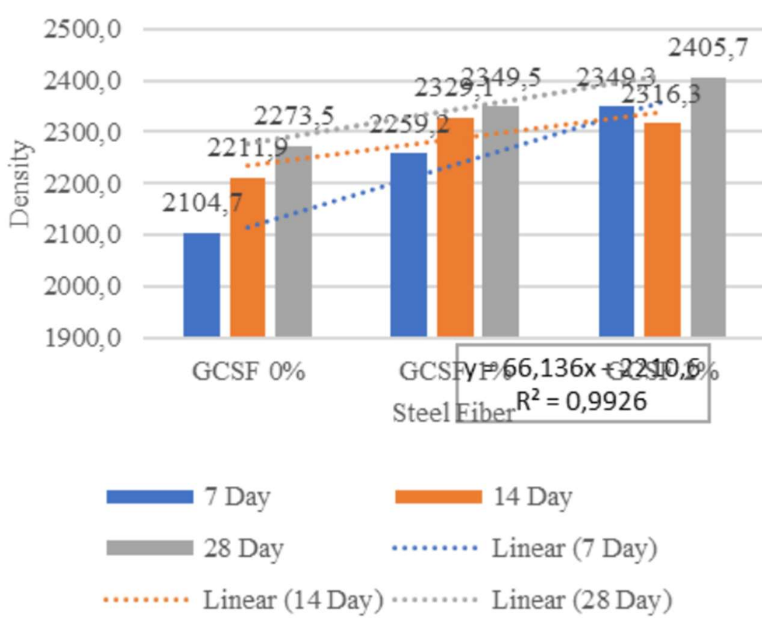

Figure 6. Graph of Comparison of Density with Fiber Addition

According to Standard (Badan Standarisasi Nasional SNI 2847 : 2019, 2019), typical normal weight concrete has a density (concrete density) ranging from 2155 to 2560 kg/m3, with the standard range being 2200 to 2400 kg/m3. The table and graph show that the density of geopolymer concrete with steel fiber reinforcement increases as the concrete ages and the fiber content increases. In BGP 1%, the density rises from 0% fiber content to 3.2%, and in BGP 2%, it reaches a peak density of 2405.73 kg/m3 when fiber is added to geopolymer concrete. This correlation is represented by equation 6.

The relationship between the addition of steel fiber and the density of geopolymer concrete.

$y = 66{,}136x + 2210{,}6$ ……………………………………………………………………………………(6)

The comparison of density with slump test

There is a graph comparing density with slump test. This graph and Table 9 are utilized to analyze the correlation between the density of geopolymer concrete and the resulting slump test.

Table 8. Table of Density and Slump Test

Concrete Mix Design	Average (Kg/m^3)		
	GCSF 0%	GCSF 1%	GCSF 2%
Density (kg/m^3)	2273,5	2349,5	2405,7
Slump Test (cm)	20,0	7,0	2,0

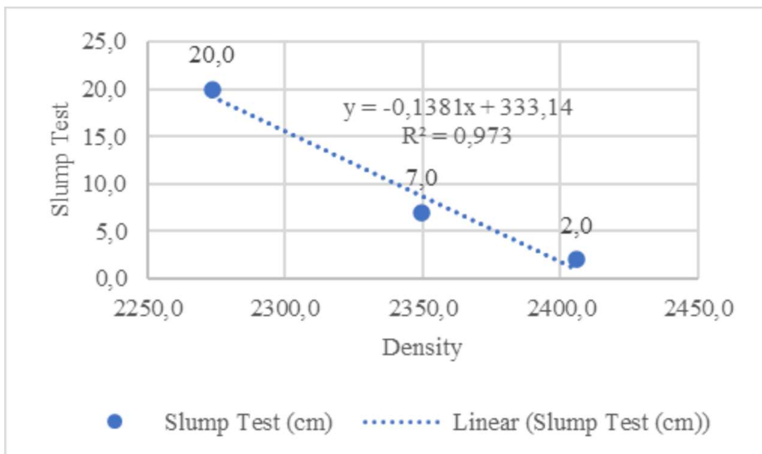

Figure 7. Graph of Slump Test and Density Comparison

Based on the graph provided, it is evident that as the density of geopolymer concrete rises, the slump value decreases. This suggests that higher density results in stiffer geopolymer concrete that tends to be drier. The graph effectively demonstrates the correlation between slump and density in geopolymer concrete mixes with steel fiber reinforcement. This correlation is mathematically represented by equation 7.

The correlation between slump test results and density in geopolymer concrete.

$y = -0{,}1381x + 333{,}14$ …………………………………………………………………………………(7)

In this equation, y represents the slump test value of concrete (MPa), and x represents the density of the concrete (kg/m^3). This linear regression equation elucidates the correlation between the splitting tensile strength and the concrete density. The equation indicates that the inclusion of steel fiber in geopolymer concrete mixtures may influence the slump value. This linear equation enables the estimation of the slump value depending on the density of geopolymer concrete with steel fiber reinforcement.

5. CONCLUSION

Based on the research and discussion on the impact of steel fiber mixture on geopolymer concrete in terms of splitting tensile strength, the following conclusions can be drawn.

1. Adding 1.5% steel fiber to the geopolymer concrete mixture yields the best results in enhancing split tensile strength, with a value of 5.71 MPa. This is further supported by a slump value of 5 cm and a specific gravity of 2383.23 kg/m3. This study demonstrates the significant role of steel fibers in improving the ability of geopolymer concrete to resist splitting tensile forces.

2. The inclusion of steel fiber in geopolymer concrete can enhance splitting tensile strength without notably affecting the concrete's specific gravity. However, the addition of steel fibers may decrease the workability of the concrete, necessitating careful regulation of water mixture proportions.

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