NUMERICAL ANALYSIS STUDY OF THE EFFECT GEOPOLYMER CONCRETE COMPRESSIVE STRENGTH ON DUCTILITY OF REINFORCED CONCRETE BEAMS

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Abstract: *Geopolymer concrete that has polymer formwork is very likely to be used as reinforced concrete material with several advantages. The advantages of geopolymer concrete when compared to portland cement concrete are: resistant to acidic environments (corrosion resistance), better bond strength of reinforcement with concrete material, stable at high temperatures, higher fracture energy. Previous experimental studies found that the tensile strength, bond strength, and fracture energy of geopolymer concrete were better, leading to the hypothesis that the ductility value of geopolymer concrete was better than portland cement concrete. The identification of ductility values based on the compressive strength of concrete will be carried out in research using the finite element method using the 3D ATENA program. Several specimens with compressive strength of 25 MPa, 30 MPa, 35 MPa, 40 MPa, and 45 MPa were compared with their ductility values. The results showed that the 25 MPa specimen had the highest ductility value is 5.33, while the lowest ductility value is 45 MPa specimen is 3.39.*

Keywords: *Geopolymer concrete, compressive strength, finite element analysis, ductility*

INTRODUCTION

The estimated production of carbon dioxide gas produced by the cement production industry is 5% of the total carbon dioxide gas emissions [1]. Experts and researchers have long developed fly ash material technology as a substitute for cement, one of which is binder technology using alkaline activator. Alkali activators can react with materials containing high Al and Si through a polymerization process or currently called geopolymers [2]. Pozzolanic materials that have similar characteristics to Portland cement are another option to replace the use and demand for Portland cement by 20% – 30% in concrete [3]. Fly ash is one of the pozzolanic materials used as a cement substitute. It has a spherical shape, amorphous, with a diameter ranging from 20 μm – 25 μm [4]. The use of this geopolymer material is very promising as an environmentally friendly material, the tensile strength is better than portland cement [5]; [6], resistant to acid environments (corrosive resistant) [7], the adhesive strength of concrete to geopolymer reinforcement material is better than portland cement [8]; [9], as well as stable at high temperatures [10]. The fracture energy value of geopolymer concrete is higher than portland cement in experimental tests [11].

The ductility of reinforced concrete structures is an urgency that must be investigated more deeply, because the need for reinforced concrete structures that can withstand deformation to absorb energy due to existing loads (ductile) is very important. The displacement ductility of an element is generally defined as the ratio of the ultimate deformation to the first yield deformation. The non-brittle collapse provides a longer time when it collapses so as to provide better comfort and safety when elements with high ductility are applied to the building. Equation 1 below is a formulation to find the value of the displacement ductility of the structure [12].

$$\mu\Delta = \frac{\Delta u}{\Delta y} \quad (1)$$

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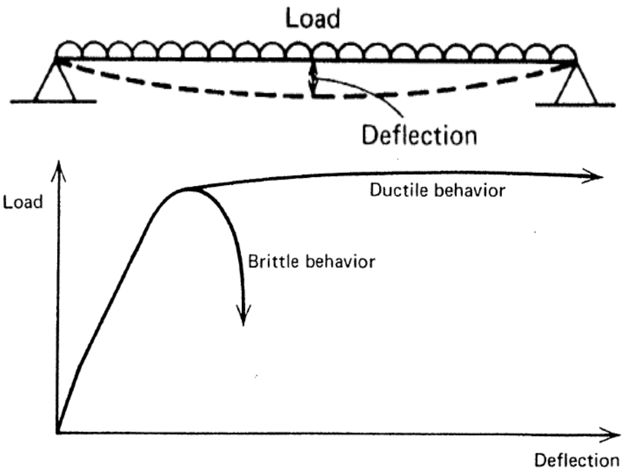

Figure 1 Comparison of ductile and brittle behavior in reinforced concrete beam structures [12]

According to several previous experimental studies that have been mentioned, one of the advantages of geopolymer concrete is its tensile strength, fracture energy, and bond strength to reinforcement which is higher in value when compared to portland cement concrete. The brittle failure that occurs in geopolymer concrete blocks with high fracture energy, tensile strength, and adhesive strength values for geopolymer materials means that the energy absorbed by geopolymer concrete will be large and have smaller/fine cracks [11]. In an experimental study on the effect of the ratio of reinforced concrete beams on the ductility of geopolymer reinforced concrete beams. The tensile reinforcement ratio of less than 2% has a higher ductility value than the tensile reinforcement ratio above 2% [13]. Finite element analysis is one of the solutions that analyzing the full behavior of geopolymer concrete and also to shorten the time other experiment.

RESEARCH SIGNIFICANCE

In this study, an analysis using the finite element method will be carried out to identify the flexural ability of geopolymer reinforced concrete beams. Flexural behavior of beam structure is important characteristic, it can be defined through value of ductility. ATENA 3D used as a running program which is specialized for concrete structure analysis, other advantage is even though the analyses described severe cracking, the program never had problems finding non-convergent solution.

METHODOLOGY

The finite element method analysis modeling is carried out with several material parameters which are the main basis for the structural characteristics of reinforced concrete beams. Previous research on the value of bond-slip model, fracture energy, tensile strength, modulus of elasticity, flexural strength, and Poisson's ratio of geopolymer concrete as parameters of material properties. The interaction between reinforcement and geopolymer concrete (bond-slip) is used as an indicator of the bond strength between these materials. The bond-slip indicator was included as a parameter because according to previous experimental studies, the higher the compressive strength of the concrete, the higher the bond strength of the reinforcement to the material [8].

A. GEOMETRY OF REINFORCED CONCRETE MODEL

Modeling and beam geometry to identify flexural properties in the form of ductility values with 4 bending point testing methods as shown in Figure 2.

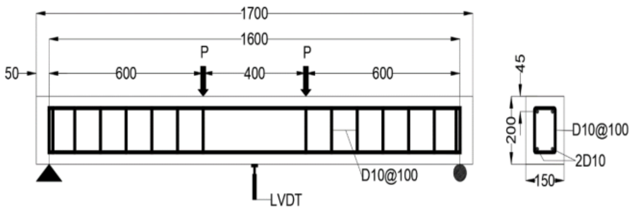

Figure 2 Geometry of reinforced concrete beams and specimen section

The modeling in the ATENA 3D analysis software is carried out by half beams of reinforced geometry from the beam plan because the model object is symmetrical on the vertical axis [14]. Loading modeling with displacement control every 0.001 m above the linear steel plate towards the lower vertical as shown in Figure 3.

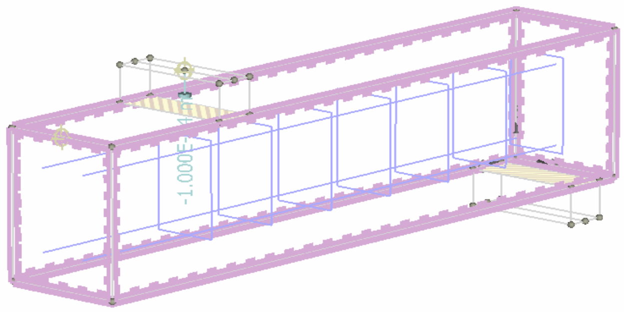

Figure 3 Finite element method beam modeling

Concrete steel reinforcement is modeled as a wire with adhesive strength parameters as shown in Figure 4. Pinned supports are defined on the surface of the beam that cannot move towards the length of the specimen as shown in Figure 5. Roll supports that can move in the longitudinal direction of the specimen are defined on the linear steel at the bottom of the concrete beam reinforced section as in Figure 6.

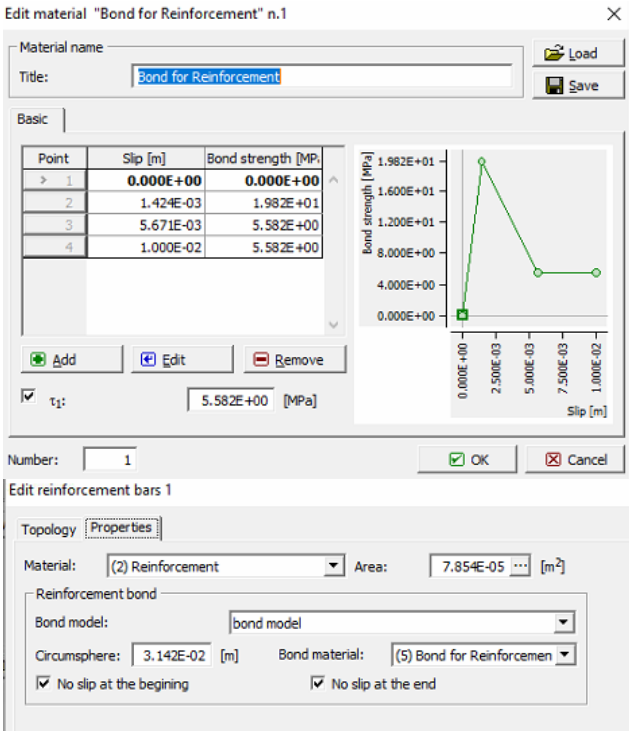

Figure 4 Parameters of bond-slip reinforcement with geopolymer concrete

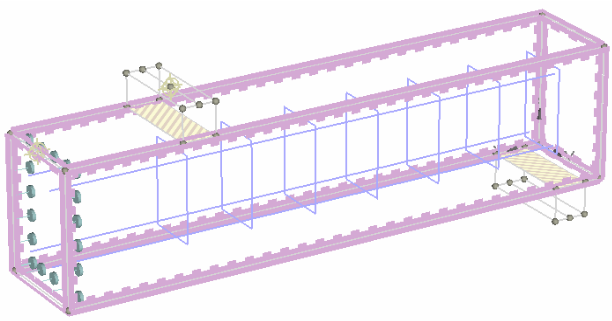

Figure 5 Pinned restrain model

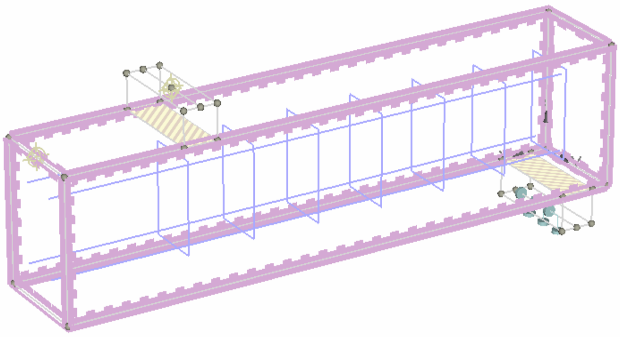

Figure 6 Roll restrain model

B. MODEL VALIDATION

Preliminary modeling was carried out to validate several parameters in the model. Several parameters that become material properties are adjusted to the material properties from Tran's experimental research [22].

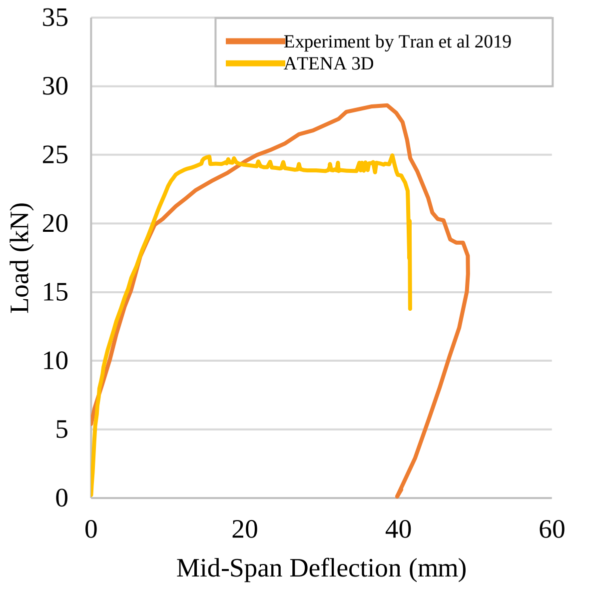

Figure 7 Comparison of load-displacement curve analysis of finite element method and experiment

Control the model with previous research to validate that the analysis using the finite element method is appropriate, within the small gap of ductility value, first yield and ultimate displacement between previous experimental and finite element research. Experimental research on beam elements with geopolymer cement concrete material, the first yield displacement is 12.1 mm, the displacement at the ultimate condition is 42 mm, with a ductility value of 3.47. As for the results of the finite element method, the first yield displacement is 11 mm, the displacement at the ultimate condition is 41.27 mm, with a ductility value of 3.74. The comparison of the load-displacement curves and ductility values calculated based on Figure 7 between the analysis of the finite element method and the experiment has a difference of 7.8%.

C. MATERIAL PROPERTIES OF RESEARCH MODEL

The quality of the compressive strength of concrete as a comparison of geopolymer concrete varies, namely: 25 MPa, 30 MPa, 35 MPa, 40 MPa, and 45 MPa. The following are some literacy in order to obtain constitutive model parameters based on several previous studies:

- The compressive stress-strain of concrete follows the calculation procedure of Thorenfeldt's research in a previous study [14]. As for the tensile stress in concrete, it follows the "Crack Band Theory" theory [15].
- Modulus of Elasticity :

$$E_{C-GPC} = -11400 + 4712\sqrt{f'_c}\ [16] \qquad (2)$$

- Poisson's Ratio :

$$\upsilon - GPC = \frac{0.2324}{f'^{\,0.093}_c}\ [17] \qquad (3)$$

- Tensile Strength :

$$f_{ct-GPC} = 0.7\sqrt{f'_c}\ [18] \qquad (4)$$

- Flexural Strength of Concrete :

$$f_{r-GPC} = 0.4398 \times f'^{\,0.7704}_c\ [17] \qquad (5)$$

- Fracture Energy :

$$G_f = (0.0469 d_a^2 - 0.5 d_a + 26) \times (\frac{f'_c}{10})^{0.7}\ [19] \qquad (6)$$

- Description :
  f'c : Concrete Compressive Strength (MPa)
  d_a : Maximum Crushed Stone (7 mm)
- *Bond-Slip Model* Interaction model of reinforcement to concrete:
  Geopolymer concrete bonding model based on previous research by Darwin in 2005 [20] [21].
- The constitutive model for the stress-strain reinforcing steel fins with a diameter of 10 mm, based on the value of the modulus of elasticity (E_s = 200000 MPa), yield strength (f_y = 548 MPa), and tensile strength (fu = 675 MPa). The modulus of elasticity at the time of strain hardening was 0.03 E_s [22]; [23] in accordance with the validation of the previous model. Figure 7 below is a graph of the stress-strain of concrete steel reinforcement.

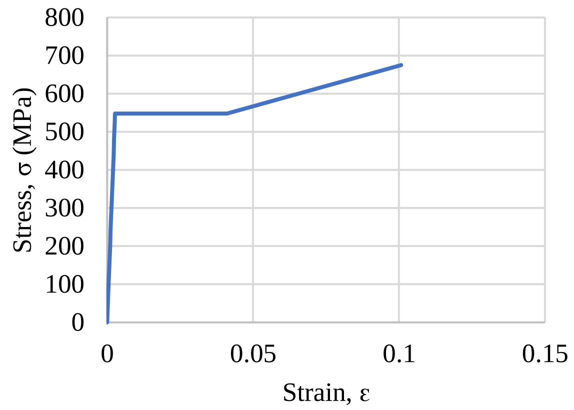

Figure 8 Stress-strain curve of reinforcement

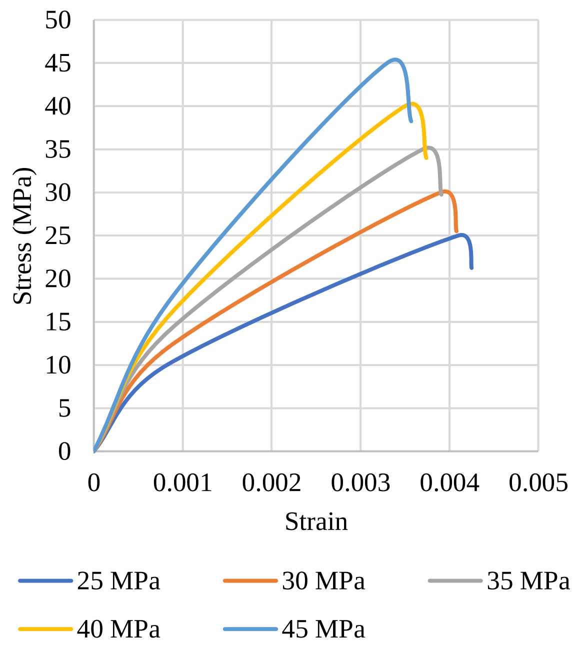

Figure 9 Material model of stress-strain curve of geopolymer concrete in compressive condition

In Figure 9 is the stress-strain parameter of concrete in compression that can behave ductilely in a structure, the greater the strain value, the higher the ductility value. Comparison of the stress-strain curves, it was found that the strain value of the GPC1 specimen had the largest strain value, while the GPC5 specimen had the highest stress. Figure 10 is the stress-strain parameter of concrete under tensile conditions, from the curve it can be stated the type of failure that will occur in reinforced concrete structures. The smaller the strain value of the material, the higher the brittle failure behavior that will be achieved.

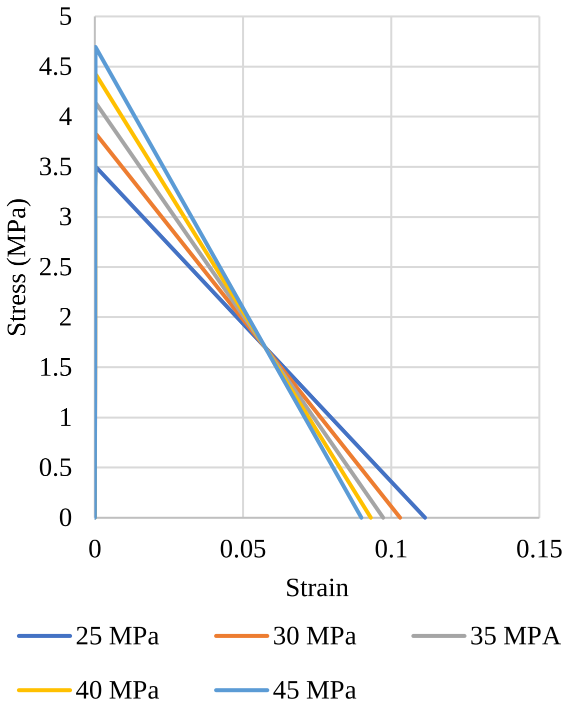

Figure 10 Material model stress-strain curve of geopolymer concrete in tensile condition

The calculation results of several material properties model parameters for the finite element method analysis are listed in Table 1 and Table 2.

Table 1 Material properties parameter model

Beam	f_c' (MPa)	E_c (GPa)	f_{ct} (MPa)	GF (MN/m)
GPC1	25	12.16	3.50	0.0000471
GPC2	30	14.41	3.83	0.0000535
GPC3	35	16.48	4.14	0.0000596
GPC4	40	18.40	4.43	0.0000654
GPC5	45	20.21	4.70	0.0000711

Table 2 Material properties parameter model

Beam	fc' (MPa)	Poisson Ratio	Fr (MPa)
GPC1	25	0.1723	5.2508
GPC2	30	0.1694	6.0427
GPC3	35	0.1670	6.8046
GPC4	40	0.1649	7.5419
GPC5	45	0.1631	8.2583

D. BOND-SLIP PARAMETER

Based on research that has been done that the adhesive strength is considered as a function of the square root of the strength of the concrete, which will be parallel to the tensile capacity of the concrete [20]. The bond-slip parameter is a function curve of how much stress will occur in the reinforcement when there is a displacement/slip that occurs between the reinforcement and the concrete material. Figure 11 is a bond-slip curve, it can be seen that the greatest stress occurs in the GPC5 specimen with the largest compressive strength when compared to other specimens.

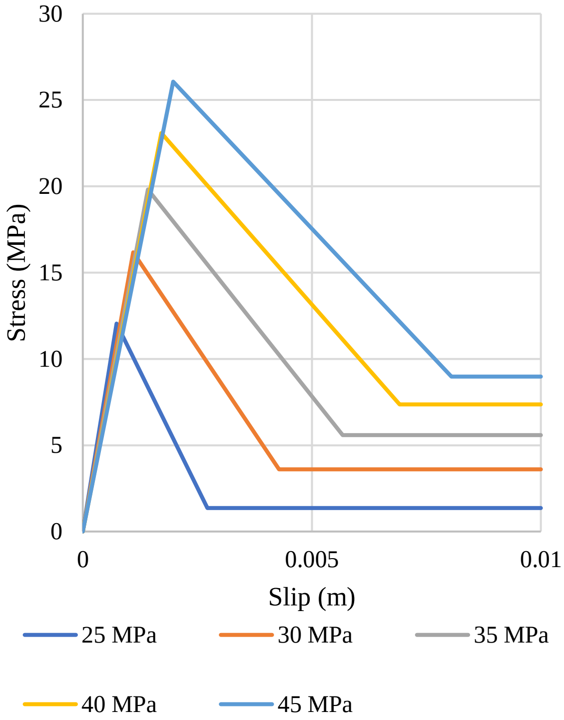

Figure 11 Bond-slip curves parameter model

ANALYSIS AND DISCUSSIONS

The results of the analysis of the finite element method of reinforced concrete beams can be obtained as follows.

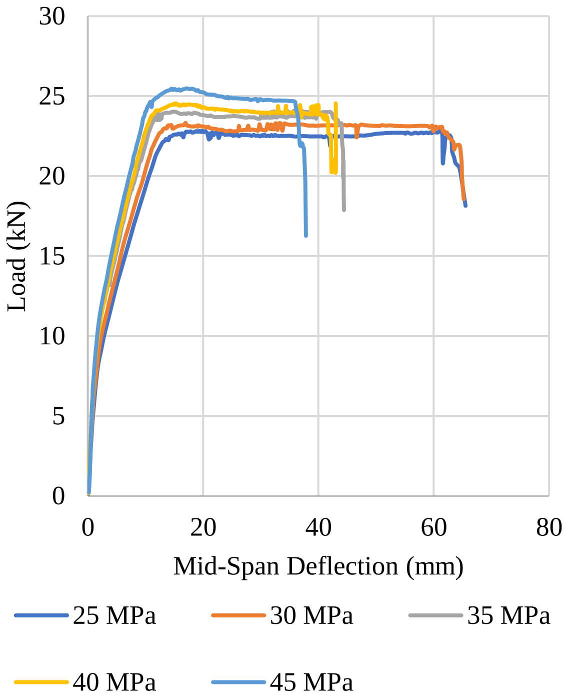

Figure 12 Load-displacement curves

Table 3 Value of load and displacement of first yield and collapse conditions

Beam	*f'c* (MPa)	First Yield		Ultimate	
	MPa	δ (mm)	P (kN)	δ (mm)	P (kN)
GPC1	25	12.10	22.11	64.51	20.44
GPC2	30	13.34	22.98	64.87	20.63
GPC3	35	11.00	23.14	44.36	20.91
GPC4	40	11.56	23.94	42.38	20.97
GPC5	45	11.06	24.31	37.53	21.43

Table 4 Rated load and displacement highest load conditions and rated ductility

	f'_c (MPa)	Highest Load		Ductility
Beam	MPa	δ (mm)	P (kN)	$\gamma\Delta$
GPC1	25	19.36	22.82	5.33
GPC2	30	16.94	23.31	4.86
GPC3	35	36.47	24.10	4.03
GPC4	40	15.12	24.54	3.67
GPC5	45	17.28	25.47	3.39

In Figure 12 the load-displacement curve is presented as a result of the finite element method analysis, it is found that the higher the compressive strength value of geopolymer concrete will be in line with the maximum load that can be carried by the structure according to Table 4 and Figure 13. The higher the value of the compressive strength of concrete, the smaller the strain value, so that it affects the displacement that occurs in the reinforced concrete beam structure. The lower the strain value under compression conditions (Figure 9), the lower the failure displacement that will be achieved in a reinforced concrete beam structure (Figure 12**,** Figure 13).

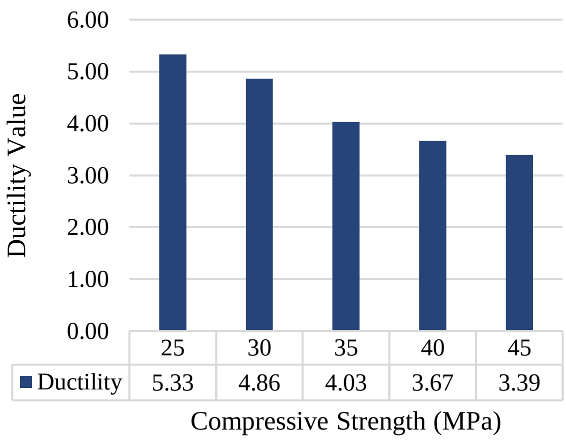

Figure 13 Ductility value of compressive geopolymer concrete

The ductility value will decrease with increasing compressive strength as shown in Table 4, similar to the behavior of portland cement concrete which has properties that become brittle with increasing concrete compressive strength.

The value of the load at the first yield condition will increase with the increase in the compressive strength of the geopolymer concrete in line with the failure load achieved as shown in Table 3. The displacement at the first yield condition for each specimen has a similar value, but with the displacement value at the time of the first yield condition. different collapses. The largest deflection was in the GPC1 specimen with a compressive strength of 25 MPa, which had a difference of 26.98 mm (72%) compared to GPC5 with a compressive strength of 45 MPa.

CONCLUSIONS

Based on some of the discussions above, the following conclusions can be drawn:

1. The stress-strain parameter of concrete in compression conditions which can indicate the ductile behavior of a structure, the greater the strain value, the higher the ductility value. Comparison of the stress-strain curves, it was found that the strain value of the GPC1 specimen had the largest strain value, while the GPC5 specimen had the highest stress.
2. The stress-strain parameter of the concrete under tensile conditions, from the curve, can indicate the type of failure that will occur in the reinforced concrete structure. The smaller the strain value of the material, the more brittle the failure behavior will be, it can be seen from the smaller ductility value.
3. The compressive strength of geopolymer concrete affects the ductility value of the concrete beam structure, the higher the compressive strength value, the lower the ductility value. The following is the ductility value according to compressive strength.
   a. GPC1 25 MPa = 5.33
   b. GPC2 30 MPa = 4.86
   c. GPC3 35 MPa = 4.03
   d. GPC4 40 MPa = 3.67
   e. GPC5 45 MPa = 3.39
4. High ductility values can mean that a structure can absorb energy due to loads and convert it into displacement. The smaller the ductility value of a structure, the more brittle the behavior of the structure will be.
5. The failure behavior of the geopolymer reinforced concrete beam structure will become more brittle with the increase in the compressive strength of the concrete.
6. The GPC 1 specimen has the highest ductility value of 5.33 and the GPC 5 specimen has a ductility value of 3.39. The difference between the two ductility values is 1.95 (57%).

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