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The Effect of PET Plastic Waste on Crack Pattern of Fly Ash-Rice Husk Ash-Based Geopolymer Concrete

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ABSTRACT

Construction materials are becoming more and more necessary as the times change. When it comes to building infrastructure, concrete is crucial. However, concrete has recently come under fire from environmental conservationists because of its carbon dioxide (CO_2) emissions during the cement-making process, which have been connected to the ozone layer's weakening as a result of global warming. Furthermore, the quantity of organic and industrial waste keeps rising annually. The primary focus in the transition to Indonesia Gold 2045 is the lack of effort in the process of recycling garbage into useful commodities. The purpose of the study is to examine the formation of fractures upon compression of geopolymer concrete samples composed of fly ash and rice husk ash. In this investigation, we included 5% rice husk ash in fly ash-based geopolymer concrete, changed the composition by adding PET plastic fibre at 0%, 0.25%, 0.5%, and 0.75%, and then looked for a crack pattern brought on by compressive fatigue. The cylindrical test specimens, measuring 100 mm by 200 mm, were examined seven and twenty-eight days following moist curing. According to the study's findings, columnar fracture patterns predominated for PET fluctuations of 0.5% and 0.75%, whereas shear and/or cone crack patterns prevailed for PET variations of 0% and 0.25%.

1. INTRODUCTION

These days, concrete—also referred to as standard concrete—is a widely used building material made primarily of rocks (aggregates), water, and Portland cement. Concrete is used extensively in the construction of infrastructure, including as buildings, bridges, highways, and foundations. Second only to water in terms of quantity, concrete is the most widely utilized material by mankind. More than 60% of construction projects in Indonesia use concrete, according to the Ministry of PUPR (2013); concrete is a necessary component of all projects, from the most straightforward to the most intricate. Approximately 8.8 million tons of concrete are consumed worldwide each year, and the need for this material is only going to increase in tandem with the growing demand for basic human amenities. However, the concrete we use has been the subject of constant criticism from environmental environmentalists in recent years. The release of carbon dioxide (CO_2) gas generated during the cement production process is frequently the first item that receives attention. Ozone depletion and global warming are two consequences of this gas's unrestricted atmospheric discharge.

Other materials must be used in place of Portland cement in the concrete-making process in order to lessen the adverse effects that harm the environment while still taking into account the durability of the concrete components. The term "geopolymer," which refers to the creation of non-organic natural materials via the polymerization process, was first used by Professor Joseph Davidovits. components high in silica and alumina are the primary basic components required to make this geopolymer. These elements are found in industrial by-products such as fly ash, which is made from the wastes left behind after burning coal.

In the process of making concrete, fly ash material may react chemically with alkali solutions at specific temperatures to generate a paste that resembles cement. In order to create geopolymer concrete, we combine this paste with aggregate, doing away with the need for further cement. Prior studies on cement material alternatives to fly ash have been carried out by Kosim et al. (2021), Singh et al. (2021), Modesta et al. (2019), and Shah, D. Dhruvin et al. (2020). As one of the biggest consumers of coal, Indonesia surely has fly ash waste, which offers potential for reuse even though there are other materials that are frequently utilized as cement substitutes.

Because of its high silica concentration and pozzolanic qualities, rice husk ash is another pozzolanic material that can partially replace cement in concrete. Concrete can be made more environmentally friendly and stronger by adding rice husk ash. The following are some advantages of building concrete with rice husk ash: Increasing concrete's strength, using less cement to make it more ecologically friendly, the capillary pores in the concrete mixture must be filled.

Strength degradation, in which the real strength cannot be restored to its initial state even after the cracks have been sealed, is a significant issue that must be taken into account when discussing the cracking of reinforced concrete structural parts. Therefore, in order to stop the reinforcement from potentially corroding, we must restrict the breadth and distribution of cracks. As opposed to unprotected structures, like those found in humid regions, by the shore, or in water, the influence of cracks does not deteriorate the reinforcement in covered structures as rapidly.

Since reinforced concrete beams are essentially rods supporting transverse loads, they are generally more likely to crack than other structural components in reinforced concrete projects. The width and dispersion of cracks are influenced by the diameter of the reinforcement; small diameter reinforcement typically results in a relatively small width and gap between fractures, whereas big diameter reinforcement typically results in a relatively large width and gap between cracks. Understanding the mechanism creating fractures in reinforced concrete beam structural elements is essential to addressing the problem.

According to a number of research findings, the use of fly ash and the incorporation of PET plastic fibres into geopolymer concrete demonstrate a promising trend in the breakdown of coal waste, which continues to be Indonesia's most formidable weapon as a power plant. Furthermore, the trend of increasing compressive strength at ideal levels is aided by the usage of Indonesian plastic, which is the second-largest contributor globally. Experiments on the compressive behaviour, and in particular the cracking pattern, of materials made of fly ash and rice husk ash, to which PET plastic fibres are added as an extra material for geopolymer concrete, are therefore essential.

2. RESEARCH SIGNIFCANT

The components of geopolymer concrete, which consists of an alkali activator and fly ash mixture, are the same as those of regular concrete. Coarse aggregate, fine aggregate, and water make up geopolymer concrete. We combine NaOH with Na_2SiO_3 after dissolving it in distilled water. Geopolymer concrete generally has a high slump value, but it hardens quickly, making it less workable. In the first four hours, this concrete can reach a 70% compressive strength despite having a high slump value. Fly ash mixed with an alkali activator takes time to react and solidify, just like cement. While setting time on fly ash is significantly influenced by the class of fly ash used, the fly ash to alkali activator ratio, and the molarity level of the alkali activator used, setting time on cement is influenced by the kind of cement and the amount of water used. Thus, this study examines the performance of geopolymer concrete including fly ash, rice husk ash, and PET plastic waste in combination with NaOH and Na_2SiO_3. A crack pattern resulting from a monotonically applied compressive stress characterizes the performance of the geopolymer concrete under consideration.

3. MATERIALS AND METHOD

3.1 Fly Ash

Fly ash for this study was supplied by the PLTU in Punagayya Village, Bangkala District, Jeneponto Regency. The results of the fly ash physical properties test are displayed in Table 1. A specific gravity value of 2.1 was attained. In the meantime, 90% of the fly ash passed filter no. 200, according to the findings of the sieve analytical study.

The chemical makeup of fly ash is shown in Table 2 according to the XRD test results. One kind of waste produced by burning coal is fly ash. Fly ash is classified into three classes (class N, class F, and class C) by ASTM C618-05. Class-N and class-F compounds have a minimum SiO_2, Al_2O_3, and Fe_2O_3 content of 70%, whereas class C compounds have a composition of 50% to 70%. The findings of chemical characteristic tests clearly show that class C fly ash was used in the study.

Table 1. Physical properties of fly ash

No.	Material characteristics	Results of inspection
1	Specific gravity	2.1
2	Sieve analysis	90% pass sieve No. 200

Table 2. Chemical properties of fly ash

No.	Material characteristics	Results of inspection
1	SiO_2 (%)	30.72
2	Al_2O_3 (%)	16.27
3	Fe_2O_3 (%)	8.73
4	$SiO_2 + Al_2SO_3 + Fe_2O_3$ (%)	55.72
5	CaO (%)	26.16
6	SO_3 (%)	4.22

3.2 Rice Husk Ash

Rice husk ash, a pozzolanic substance that can be used in place of cement, is used in this study. Gowa Regency burns the waste from rice mills to create rice husk ash. The results of testing the physical and chemical properties of rice husk ash are displayed in Tables 3 and 4.

Table 3. Physical properties of rice husk ash

No.	Material characteristics	Results of inspection
1	Specific gravity	2.36
2	Water absorption of fine aggregate	172.78%

Table 4. Chemical properties of rice husk ash

No.	Material characteristics	Results of inspection
1	SiO_2 (%)	92.93
2	Al_2O_3 (%)	1.18
3	Fe_2O_3 (%)	0.33
4	P_2O_5 (%)	0.79
5	CaO (%)	0.45
6	SO_3 (%)	0.64
7	K_2O (%)	1.30

3.3 PET Plastic Waste

A PET (polyethylene terephthalate) plastic bottle, which is made of a lengthy chain of ethylene monomers (IUPAC: ethene), will be used in this investigation. Ethene's chemical structure is --CH2-CH2—n, denoted by the symbol C2H4. Two CH2 groups are joined by a double bond, and polyethylene is created when ethene is polymerized.

PET is a brown plastic made from petroleum. PET plastic's mechanical characteristics include strength, great flexibility, a slightly greasy surface, and a slight transparency. It is extremely resistant to chemical compounds at 600°C. This kind of plastic also has a specific gravity of 0.91 to 0.94 gr/cm^3, is easy to produce, dissolves readily in mixes, and offers good protection against water vapor.

3.4 Coarse Aggregate

For mixing, crushed stone that ranges in size from 10 to 20 mm is used as the coarse aggregate. With a maximum particle size of 40 mm, this coarse aggregate meet both the upper and lower bounds for the mixing gradation. The findings of the analysis of the properties of coarse aggregates are displayed in Table 5.

Table 5. Physical properties of coarse aggregate

No.	Material characteristics	Results of inspection
1	Fineness modulus	7.00
2	Sludge content (%)	3.10
3	Solid condition volume weight (kg/litre)	1.52
4	Loose condition volume weight (kg/litre)	1.37
5	Apparent specific gravity	2.71
6	Dry specific gravity	2.68
7	Saturated surface dry specific gravity	2.69
8	Water absorption (%)	0.40

Analysis of the coarse aggregate material's properties shows that its mud content is below the required levels, requiring aggregate washing to lower the mud content and get it ready for repurposing in the mixing of geopolymer concrete. Furthermore, neither the solid nor the loose conditions' volume weights satisfy the established requirements, so a better way to handle and store coarse aggregate material must be used. To avoid excessive contamination and quality degradation, this procedure must be carried out in a dry environment. To improve the qualities of concrete, we also use additives like retarders and superplasticizers.

3.5 Fine Aggregate

The fine aggregate's physical properties are shown in Table 5. As the fine aggregate, we utilize silica sand from Pinrang Regency. The loose volume weight of the fine aggregate material does not match the established requirements, according to an examination of its properties. Therefore, an improved approach for handling and storage is required when using fine aggregate material. To avoid excessive contamination and quality degradation, we must make sure that this procedure is carried out in a dry environment. To improve the qualities of concrete, we also use additives like retarders and superplasticizers.

Table 6. Physical properties of fine aggregate

No.	Material characteristics	Results of inspection
1	Fineness modulus	2.40
2	Sludge content (%)	4.60
3	Solid condition volume weight (kg/litre)	1.44
4	Loose condition volume weight (kg/litre)	1.32
5	Apparent specific gravity	2.56
6	Dry specific gravity	2.43
7	Saturated surface dry specific gravity	2.48
8	Water absorption (%)	2.1
9	Organic content	No. 2

3.6 Compressive Strength

This research performed density testing in compliance with ASTM C138/C138M 17a and slump testing in compliance with ASTM C143/C143M-00 to evaluate the qualities of fresh concrete. The force (P) exerted on the concrete's surface (in newtons) divided by the surface area (in millimetres squared) is the formula that determines how strong concrete is. Megapascals (MPa) and square millimetres are the units of measurement.

$$\sigma = \frac{P}{A} \tag{1}$$

3.7 Crack Pattern

One of the most often utilized building materials is concrete. We cannot completely rule out the probability that its application will fail. Concrete cracking is one of the possible failures. Without collapsing, a concrete building may separate or crack. Crack patterns vary from one another under field circumstances. This phenomenon is caused by variations in tensile stress brought on by loads, moments, and shear. Cone destruction, cone and split destruction, shear cone destruction, shear destruction, and destruction parallel to the vertical axis (columnar) are the five categories of concrete crack patterns identified by SNI 1974:2011.

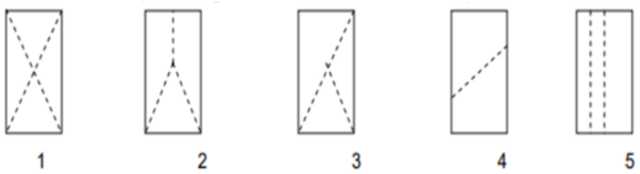

Figure 1. Types of crack patterns in cylindrical test objects

SNI 1974:2011 provides picture descriptions for a number of crack pattern varieties, including:

a) Figure 1: Cone destruction shape
b) Figure 2: Cone and split destruction shape
c) Figure 3: Cone and shear destruction shape
d) Figure 4: Shear destruction shape
e) Figure 5: Columnar destruction shape

4. RESULTS AND DISCUSSION

4.1 Mixtures Design of Geopolymer Concrete

In the geopolymer concrete, 10 M sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) were employed as alkali activators. Na_2SiO_3 to NaOH had a ratio of 2. The ratio of pasta to total aggregate was 6:5, and the ratio of FA to alkali activator was 69:31. For every change, 5% volumes of RHA were used in place of FA. Additionally, to enhance the bending capabilities, PET plastic measuring 1-3 mm in width and 2.5 cm in length was added at 0%, 0.25%, 0.50%, and 0.75%, respectively. These additions are referred to as SN, SA, SB, and SC. The composition of geopolymer concrete is displayed in Table 7. Three standard cylinder specimens, each 100 mm in diameter and 200 mm in height, were cast and tested following seven and twenty-eight days of moist curing.

Table 7. Composition of geopolymer concrete (kg/m^3)

Code	Fly Ash	RHA	Coarse aggregate	Fine aggregate	Alkaline activator		Retarder	SP	PET
					10 M NaOH	Na_2SiO_3			
SN	857.68	45.14	654.55	436.36	135.42	270.85	1.81	9.03	0
SA	857.68	45.14	654.55	432.91	135.42	270.85	1.81	9.03	3.45
SB	857.68	45.14	654.55	429.46	135.42	270.85	1.81	9.03	6.90
SC	857.68	45.14	654.55	426.01	135.42	270.85	1.81	9.03	10.35

4.2 Slump Test

For every fresh geopolymer concrete mixture change, we performed slump testing. To ascertain the concrete mixture's workability level, we require the slump value. The test results are shown as follows in Table 8:

Table 8. Slump test

No	PET percentage variation	Slump (cm)
1	0%	60
2	0.25%	64
3	0.50%	67
4	0.75%	58

The fresh concrete slump test, as shown in Table 8, demonstrates a tendency of increasing PET variance from 0% to 0.50%, followed by decreases in PET variation from 0.75% to 0.50%. After creating concrete samples, we find that the slump value is between 50 and 75 cm, and PET changes of 0%, 0.25%, 0.50%, and 0.75% satisfy the intended slump flow requirements according to ACI 1611M-05. Meanwhile, the slump value rises with a percentage increase of 6.72% and 5.51% when PET 0.25% and 0.5% are added, respectively, and falls with a percentage loss of 15.52% when PET 0.75% is added.

4.3 Density

The strength and concrete hardness of geopolymer concrete are represented by its density. The weight reduction of concrete volume to increase the substitution of PET plastic in concrete is shown in Figure 2. The weight decreases in concrete volume increases with the amount of PET plastic applied. However, adding PET plastic up to 0.75% results in an increase in density. This is because other materials were not reduced or replaced by the addition of PET plastic.

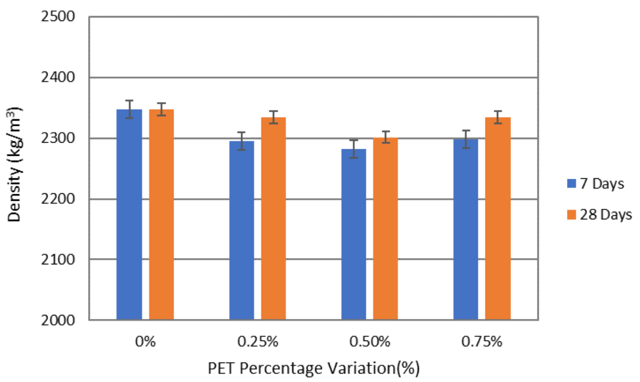

Figure 2. Density of geopolymer concrete

4.4 Compressive Strength

The standard for testing the compressive strength of geopolymer concrete at 7 and 28 days of age is SNI 1974:2011. 0% PET plastic fibre, 0.25% PET, 0.5% PET, and 0.75% PET are the variations that are utilized. The results of the geopolymer concrete compressive strength test are displayed in Table 9.

Table 9. Compressive strength test

No	Variation	Average of compressive strength (N/mm^2)	
		7 days	28 days
1	SN	21.61	29.84
2	SA	17.47	19.80
3	SB	11.25	16.80
4	SC	14.30	18.86

Fly ash and rice husk ash geopolymer concrete samples had an average compressive strength of 21.61 N/mm^2 after 7 days, with variations in SN, according to the compressive strength test. Additionally, the values for compressive strength with SA variations are 17.47 N/mm^2, with SB variations they are 11.25 N/mm^2, and with SC variations they are 14.30 N/mm^2. The findings indicate a compressive strength of 29.84 N/mm^2 with SN fluctuation at 28 days of age. Additionally, the compressive strength values with SA variation are 19.80 N/mm^2, SB variation is 16.80 N/mm^2, and SC variation is 18.86 N/mm^2.

The table also shows that the SA variation concrete has a higher compressive strength than the other variations at 7 and 28 days of age. In contrast, the SB sample to SC grew by 27.05% after 7 days of an average addition of PET plastic fibre, while the SN sample to SA-SB decreased by 19.19% and 35.58%, respectively. Additionally, at 28 days, the SB sample to SC grew by 10.91%, while the SN sample to SA-SSB decreased by 33.62% and 15.17%, respectively, with an average addition of PET plastic fibre.

Theoretically, the test findings indicate that after every 0.25% PET added, the compressive strength values go downward. The average percentage drop in compressive strength values for the SA and SB variations at 7 and 28 days of age was 27.39% and 24.40%, respectively. In contrast to the SB variation, the SC variant's compressive strength results increased by 27.05% and 10.91%, respectively, defying the anticipated downward trend. The procedure and results of Handayani et al.'s (2021) study are similar because they had difficulties working with the concrete samples. The concrete mixer's restricted capacity made it impossible to produce all of the required PET plastic fibre additions at once, thus the concrete mixture had to be divided into several stages. A single mixing only produced 10 samples.

4.5 Crack Pattern

The compressive strength test results for the geopolymer concrete variation SN are shown in Figures 3 and 4. The crack patterns on each concrete sample after seven and twenty-eight days are also shown in Figures 3 and 4. At 7 and 28 days, the three samples' collapse patterns are shear, cone and shear, and cone and shear failure patterns, respectively, and column, cone and shear, and column failure patterns, respectively.

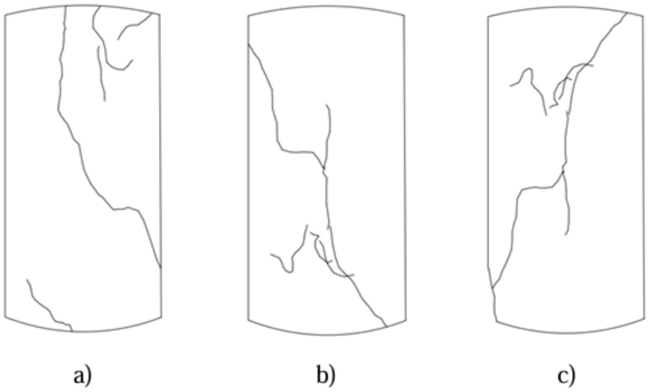
a) b) c)

Figure 3. Crack patterns of SN samples aged 7 days a) SN 1; b) SN 2; c) SN 3

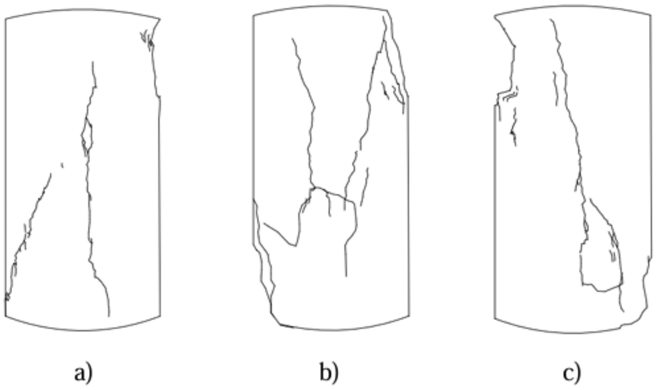
a) b) c)

Figure 4. Crack patterns of SN samples aged 28 days a) SN 1; b) SN 2; c) SN 3

The compressive strength test results for the geopolymer concrete variation SA are displayed in Figures 5 and 6, which also demonstrate how each concrete sample that was aged for seven and twenty-eight days crumbled. The three samples' collapse patterns resemble a cone at 7 days of life, and shear, column, and shear failure patterns at 28 days of age.

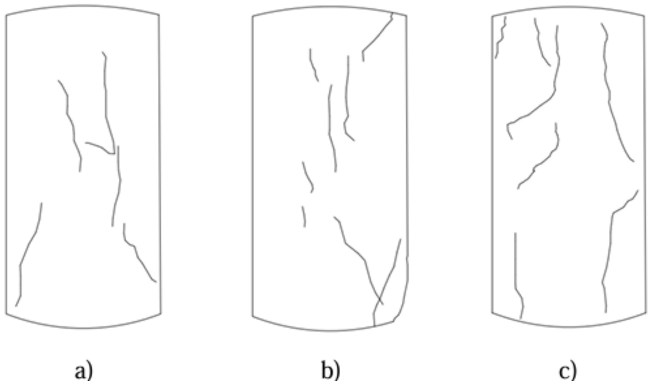
a) b) c)

Figure 5. Crack patterns of SA samples aged 7 days a) SA 1; b) SA 2; c) SA 3

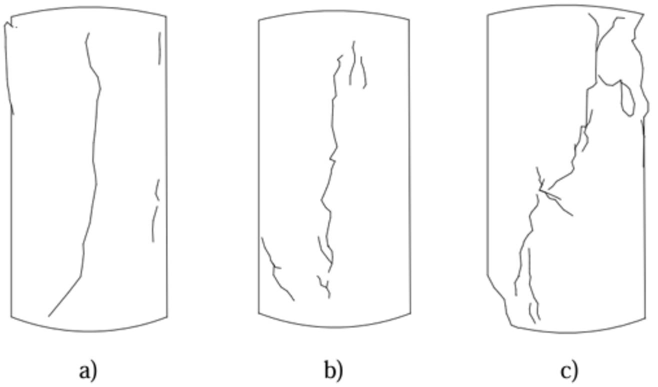
a) b) c)

Figure 6. Crack patterns of SA samples aged 28 days a) SA 1; b) SA 2; c) SA 3

For the compressive strength test of the SB variety of geopolymer concrete, there were two sets of results. The collapse pattern for each concrete sample that was aged for seven and twenty-eight days is displayed in Figures 7 and 8. The three samples' collapse patterns include column, shear, shear collapse pattern at 7 days and column, column, column collapse pattern at 28 days.

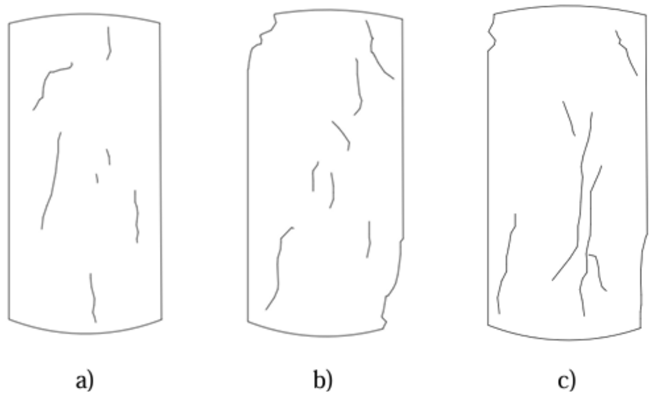
a) b) c)

Figure 7. Crack patterns of SB samples aged 7 days a) SB 1; b) SB 2; c) SB 3

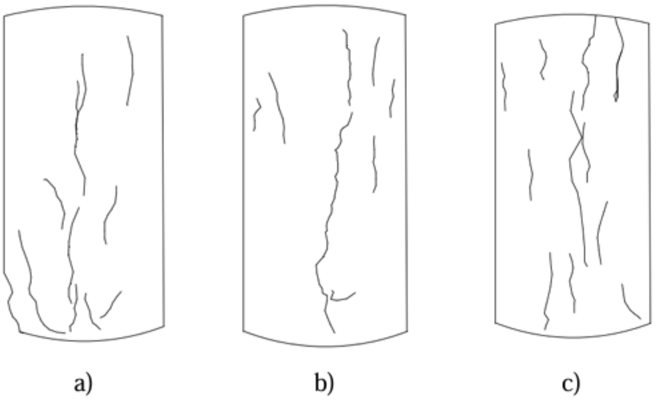
a) b) c)

Figure 8. Crack patterns of SB samples aged 28 days a) SB 1; b) SB 2; c) SB 3

The compressive strength of the SC variation of geopolymer concrete is shown by the test results in Figures 9 and 10. Every sample was aged for seven days and then for twenty-eight days. The three samples' collapse patterns include column, shear, shear collapse pattern at 7 days and column, column, shear collapse pattern at 28 days.

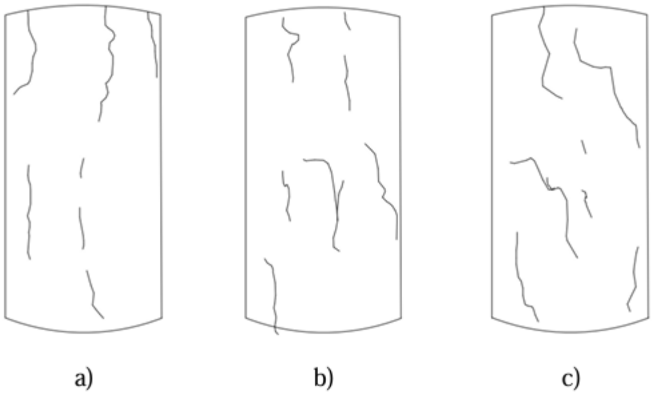

Figure 9. Crack patterns of SC samples aged 7 days a) SC 1; b) SC 2; c) SC 3

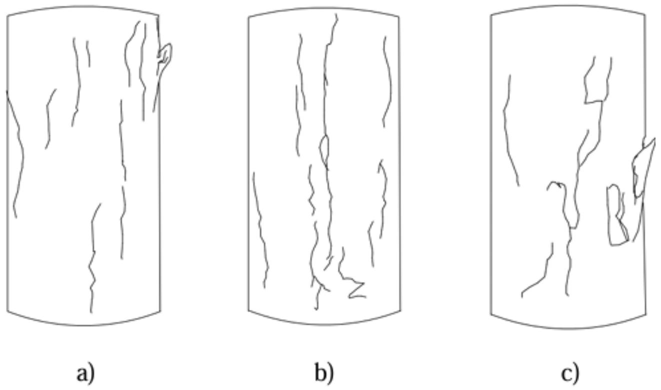

Figure 9. Crack patterns of SC samples aged 28 days a) SC 1; b) SC 2; c) SC 3

When different amounts of PET plastic fibre are introduced to test objects designated SN, SA, SB, and SC, the crack pattern analysis of geopolymer concrete aged 7 and 28 days produces patterned cracks. While the behaviour of PET changes varies, the fracture patterns at 7 and 28 days are comparable. Shear and/or cone cracking predominate for PET 0% and 0.25%, whereas column cracking predominates between PET 0.5% and 0.75%. Neville, AM. (1997) conducted additional research on the crack patterns observed in concrete during a compression test. He discovered that when the concrete is squeezed vertically, friction tries to prevent it from expanding laterally, which results in the shear crack pattern. Columnar cracks are more likely to occur in concrete specimens with lower compressive strength, while this fracture pattern is more prevalent in test specimens with comparatively higher compressive strength.

5. CONCLUSION

In the study, PET plastic fibres with variation codes SN (PET 0%), SA (PET 0.25%), SB (PET 0.5%), and SC (PET 0.75%) were added to the volume of geopolymer concrete, which is manufactured from fly ash and rice husk ash, and the compressive strength test results were examined. Numerous inferences can be made, including:

1. Every variety of geopolymer concrete has good workability, with slump flow values falling within the desired 50–75 cm range.
2. The compressive strength of concrete will grow with age, but the compressive strength value decreases when PET plastic fibres are added to the geopolymer concrete mixture. For every 0.25% PET addition to the SA and SB compositions, the average drop is 24.22%; however, the SC composition increases by 10.91% in comparison to SB.
3. The results of the study showed that shear and/or cone crack patterns were more common for PET variations of 0% and 0.25%, whereas columnar fracture patterns were more common for PET fluctuations of 0.5% and 0.75%.
4. Future researchers must carefully evaluate the best working method to assure exact and faultless craftsmanship and quality, especially in large-scale manufacturing, because geopolymer concrete has a limited mixer capacity and a short setting time.

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