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The Effect of Waste Flex Banner Fiber on Mechanical Properties of Geopolymer Concrete

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ABSTRACT

This research aims to design a geopolymer concrete mix with the addition of waste flex banner fibre and to study its effects on various physical and mechanical properties of the concrete. The study focuses on the influence of flex banner fibre on the density of geopolymer concrete, workability with a target slump value of 90 mm, and the compressive and splitting tensile strength with flex banner fibre additions of 0.5%, 0.75%, and 1.0% by weight of fly ash. The research method involves curing the concrete in water for 7, 14, and 28 days. The results indicate that the addition of flex banner fibre increases the density of geopolymer concrete, achieving an optimal density of 2462.83 kg/m³. This study also shows that the workability of the flex banner fibre mix in geopolymer concrete meets the target slump value of 90 mm at a 0.75% fibre addition. As the fibre percentage increases, a significant reduction in slump value occurs. At 0.5% fibre content, the slump value decreases to 110 mm, while at 1% fibre content, the slump value drops to 53 mm. The addition of flex banner fibre improves the mechanical properties of geopolymer concrete. The compressive strength of geopolymer concrete with 0.75% fibre addition increases by 4.19%. Furthermore, the optimal splitting tensile strength is achieved with a 0.61% flex banner fibre addition.

Key words: *compressive strength, flex banner fibre, fly ash, geopolymer concrete, split tensile strength.*

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INTRODUCTION

Concrete is the most widely used construction material in the world, both for the construction of high-rise buildings, bridges, roads, dams and other public infrastructure. Concrete was chosen because it has a combination of advantages in the form of high mechanical strength, resistance to various environmental conditions, ease in the formation process, and relatively low production costs compared to other construction materials. However, despite its advantages, the use of conventional concrete has a significant impact on the environment. One of the main causes is the production of Portland cement, which is the main component of concrete. The Portland cement production process produces large amounts of carbon dioxide (CO_2) emissions. According to various studies, the cement industry is responsible for around 7-8% of total global CO_2 emissions every year. This has encouraged various efforts to reduce dependence on Portland cement through technological innovation and the use of alternative materials that are more environmentally friendly (Lubis & Putri, 2024).

The negative effects of the concrete making process involving Portland cement material have been proven. The United States Department of Energy highlights that by 2015, global carbon emissions could increase by 50% more than 1997 levels. This accumulation will lead to an increase in global mean temperature (GMT) in the 21st century to 5.8°C as high as today's temperatures if current emission rates continue. However, on the other hand, there is research on alternative binders other than Portland cement, namely binder technology with alkali activators. This alkali activator can react with materials that have high Si and Al contents through a polymerization process, which is now known as geopolymer (Wijaya et al., 2019).

Geopolymer concrete is a type of concrete that uses natural materials as a binder, with high silica and alumina content (Davidovits, 2009). This chemical process occurs in the alumina and silica content which reacts with an alkaline solution as a substitute for the concrete mix binder. The chemical reaction that converts normal concrete into geopolymer concrete is shown in Figure 1.

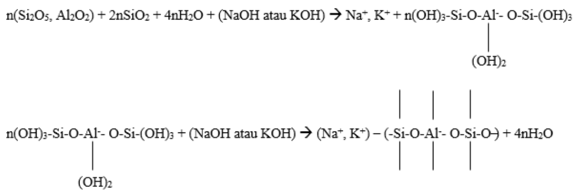

Figure 1. Chemical reaction of geopolymer concrete

Geopolymer concrete has quite good strength, but there are still shortcomings when compared to conventional concrete (Frias, 2015). Especially in terms of tensile strength, the way to increase the strength of geopolymer is by adding fibre. The selected fibre must adapt to environmental conditions and economic aspects. One type of fibre that can be used to increase the strength of concrete is fibre from banner waste. Concrete that comes from banner waste fibre is called fibre concrete.

Fibre concrete is concrete that contains fibre added to strengthen and increase the concrete's resistance to cracking. Several types of fibre commonly used in fibrous concrete include steel fibre, polypropylene fibre, carbon fibre, and others (Sunarwadi et al., 2023). Concrete that comes from banner waste has a slippery surface characteristic similar as plastic, equipped with nylon fibre. This characteristic serves to strengthen the vinyl structure. Banners are made from vinyl and nylon fibre. Vinyl has sufficient hardness and strength as a construction material, while nylon, also known as polyamide, has excellent stretchability when used as a fibre.

Research on the use of plastic banner waste (PVC) as an additional material in concrete mixes highlights the importance of testing compressive strength and split tensile strength. Compressive strength testing was chosen because concrete is known as a material with high compressive strength, so any variations in additional materials can affect its pressure characteristics. This testing is critical to ensuring that concrete mixed with PVC fibre continues to meet the quality standards required for structural applications.

Meanwhile, split tensile strength tests are carried out because concrete has weaknesses in resisting tensile forces. The addition of PVC fibre in the concrete mix has the potential to increase resistance to cracking by distributing stress more evenly within the concrete structure. PVC fibre is expected to function as a barrier to micro cracks, thereby improving concrete's resistance to indirect tensile forces. Therefore, these two tests provide a comprehensive picture of the mechanical performance of concrete with the addition of plastic banner waste and ensure its suitability in sustainable and long-lasting construction applications.

Research on concrete reinforced with plastic fibre generally focuses on its mechanical properties such as compressive strength, bending and splitting tensile strength of concrete. However, studies on the impact resistance and toughness of concrete are still limited. Bayasi and Zeng (1993) found that polypropylene (PP) fibre with a length of 12.7 mm could increase the impact resistance of concrete up to a fibre content of 0.5% of the concrete volume, but decreased at higher levels. Foti (2011) also reported that the use of PET strips in concrete increases ductility and prevents total failure of the structure. Additionally, Soroushian et al. (1992) found that recycled plastic fibre can increase impact resistance until the fibre aspect ratio reaches 50, before finally decreasing due to changes in fibre distribution in concrete. Therefore, further research is needed to comprehensively understand how PVC fibre can affect the impact resistance of concrete.

This research aims to evaluate the use of flex banner waste as an additional material in the form of fibre in geopolymer concrete mixtures. Specifically, this research examines the effect on the compressive strength and split tensile strength values of geopolymer concrete with the addition of flex banner waste fibre.

RESEARCH METHOD

This research examines geopolymer concrete that does not contain cement, with the addition of flex banner waste fibre. The main aim of this research is to reduce dependence on Portland cement in making concrete, while improving the strength of concrete through the addition of fibre.

Materials

The materials used in this research include aggregate (sand and gravel), fly ash, alkali activator solution consisting of sodium hydroxide and sodium silicate, and water. The physical properties of the aggregate are shown in Table 1 below.

Table 1. Physical properties of aggregate

Physical Properties	Coarse Aggregate	Fine Aggregate
Specific Gravity	2.55	2.55
Unit weight	1.45	1.44
Absorption	2.61	2.74
Crushing Value	19.65	-
Fineness Modulus	7.75	3.17

Geopolymer concrete is a type of concrete that uses a different binder than conventional concrete. The binding material for geopolymer concrete is an alkali activator, namely an alkali solution such

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as Sodium Hydroxide (NaOH) with Sodium Silicate (Na_2SiO_3), which is used to activate chemical reactions between aluminosilicate materials (such as fly ash or slag) and alkali. Chemical reactions form a solid matrix in geopolymer concrete.

The fly ash used comes from Lontar PLTU waste (Figure 2). Based on the results of the X-Ray Fluorescence (XRF) test carried out by the Chemical Research Center, BRIN Puspitek Serpong, fly ash from steam powerplant (PLTU) Lontar contains SiO_2, Al_2O_3 and Fe_2O_3 with a total of 81.8%. This shows that the fly ash used in this study can be categorized as class F fly ash according to ASTM C 618, because the amount of $SiO_2 + Al_2O_3 + Fe_2O_3$ exceeds 70%.

Figure 2. Fly ash and waste banner fibre

The fibre material used in this research comes from banner/banner waste which is composed of vinyl and nylon fibre (Figure 2). In this research, waste PVC banner fibre have ratio of length and diameter (*L/D*) = 50/3 = 16.33. The optimal length-diameter ratio for PVC banner waste fibre reinforcement is 15-20. For many purposes applications, *L/D* ratios of approximately 15 to 20 have been shown to achieve effective distribution and increase composite strength.

Mix design is carried out by referring to Indonesian Standards (SNI 7656 – 2012) with a characteristic compressive strength target of 25 MPa. In this research, 5 mix design was proposed, namely BGSS 0 (with zero fibre), BGSS0.5, BGSS0.75 and BGSS1 (for concrete with 0%, 0.5%, 0.75%, and 1% banner fibre respectively). The weight of flex banner fibre in each mixture are calculated based on the following equation:

$$(V \times P \times \rho f) \times 1000 \qquad (1)$$

where V is the volume of concrete, P is the percentage of fiber (0.5% - 1%), dan ρf is the unit weight of banner fibre (i.e = 0.342 kg/m^3). Table 2 shows the material composition of each mixture.

Table 2. Mix design of concrete

Materials	BGSS 0	BGSS 0,5	BGSS 0,75	BGSS 1
Fibre	0	0.00171	0.002565	0.00342
Fly Ash	34.66			
Na_2SiO_3	113.89			
NaOH	12.65			
Water	42.42			
Coarse Aggregate	1,092.01			
Fine Aggregate	766.55			

Research location and duration

The location of this research was carried out at the Civil Engineering Laboratory at Pembangunan Jaya University, using equipment that meets the National Indonesia Standards. The manufacture of test objects was also carried out at the Civil Engineering Laboratory at Pembangunan Jaya University, using methods that had been adapted to Indonesian National Standards

Flowchart and Methodology

Analysis was carried out after data processing, including material tests (coarse, fine aggregate, fly ash) and mechanical properties of geopolymer concrete such as slump, specific gravity, compressive strength and split tensile strength. Figure 3 shows the flow diagram used to conduct this research.

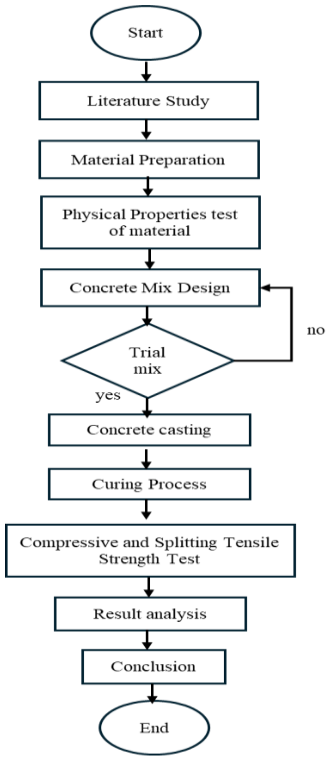

Figure 3. Research flow chart

RESULT AND DISCUSSION

Slump test

Figure 4 shows a graph of slump test results on four types of geopolymer concrete with different variations of non-fibre and mixtures of flex banner fibre variations.

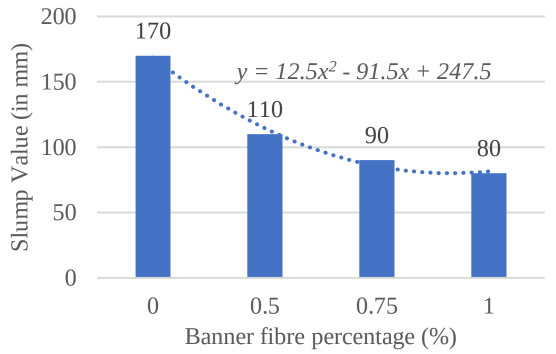

Figure 4. Slump test results

Geopolymer concrete mixture without fibre (0% fibre), the slump value obtained was 170 mm, which shows that the concrete consistency is quite liquid because there are no fibre binding the concrete. As the percentage of flex banner fibre increases, the concrete slump value decreases significantly. With the addition of 0.5% flex banner fibre, the slump value decreases to 110 mm. When the fibre percentage was increased to 0.75%, the slump value further decreased to 90 mm. When adding up to 1% flex banner fibre, the slump value reaches 80 mm. Overall, the decrease in slump value between 0% fibre and 1% fibre concrete mixtures reached 53%.

Based on existing data, it can be concluded that the addition of flex banner fibre in geopolymer concrete significantly reduces the consistency of the concrete, which is reflected in the decrease in slump value. This shows that the flex banner fibre functions as a filler material that inhibits concrete flow, increases the density of geopolymer concrete, and reduces the workability or ability of the concrete to be processed. Even though the resulting slump value does not meet the mix design target, the addition of flex banner fibre still affects the characteristics of the concrete. Apart from that, NaOH levels also contribute to reducing the workability of concrete, so it is important to pay attention to the influence of flex banner fibre and NaOH levels in designing geopolymer concrete (Setiawan, 2017).

Based on comparison with other research, the slump flow test shows that the addition of polypropylene fibre can reduce the slump flow value. This decrease occurred because polypropylene fibre inhibited the free flow of aggregate. As the polypropylene fibre content increases, the slump flow value decreases. This supports the conclusion that flex banner fibre have a similar ability in reducing the workability of concrete mixes (Susdiyanti et al., 2017).

Unit weight

Figure 5 shows the results of concrete specific gravity measurements. Based on SNI 2847:2019, normal concrete has a specific gravity between 2155–2560 kg/m³, with a general range of 2200–2400 kg/m³. The test results show that the addition of flex banner waste fibre to geopolymer concrete contributes to an increase in specific gravity in each hardening period. The highest specific gravity was found in 28 days old concrete with 1% fibre content, namely 2462.83 kg/m³, an increase of 2.83% compared to concrete without fibre (2394.9 kg/m³). At 0.5% and 0.75% fibre content, the specific gravity reaches 2401.27 kg/m³ and 2441.61 kg/m³ respectively. This increase shows that flex banner fibre can increase concrete density by filling empty spaces between mix particles, reducing porosity, and strengthening bonds between materials, resulting in a denser concrete structure.

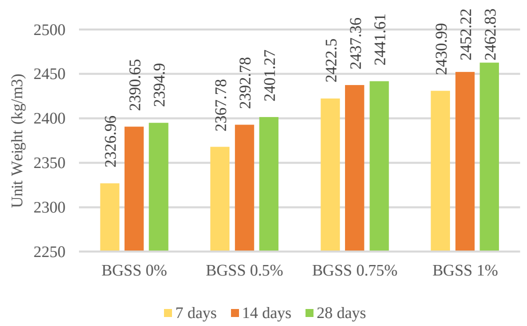

Figure 5. Unit weight of specimens

In addition, flex banner fibre, which has a higher density than other concrete materials, also increases the total mass of concrete. However, fibre content that is too high can reduce workability and potentially cause segregation if the mix design is not adjusted properly. Therefore, the addition of fibre requires optimal proportions to obtain a balance between density and concrete workability.

Previous research also supports these results. According to Ghifari (2023), concrete with the addition of flex banner fibre has a higher specific gravity than concrete without fibre. Normal concrete with a fibre content of 0.7% shows a significant increase in specific gravity compared to concrete without fibre. Setiawan (2017) emphasized that adding waste fibre to concrete can increase the overall density of concrete, while Alahmari et al. (2023) stated that geopolymer

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concrete has a density comparable to conventional concrete, namely around 2200–2400 kg/m³, depending on the composition of materials such as fly ash, aggregate, and water-binder ratio.

Compressive strength test

The compressive strength results for concrete shown in the Figure 6 illustrate the development of compressive strength values, starting from concrete without flex banner fibre to concrete with the addition of 1% flex banner fibre.

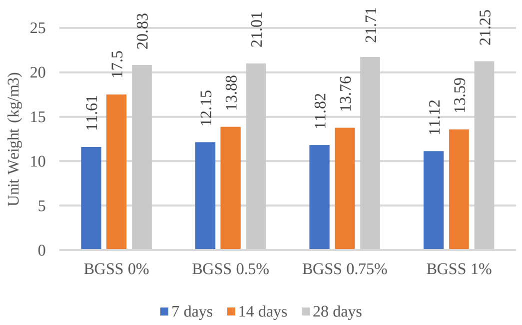

Figure 6. Compressive strength of concrete at 7, 14, and 28 of days

Based on Figure 6, increasing the percentage of flex banner fibre affects the compressive strength of concrete at various ages. At 7 days of age, the highest compressive strength (12.15 MPa) was achieved with 0.5% fibre, while at 1% fibre there was a decrease of 1.03 MPa due to an imbalance in fibre distribution. At 14 days, the compressive strength of the concrete increased to 13.88 MPa with the optimal fibre content remaining 0.5%. Higher fibre content (0.75% and 1%) actually reduces compressive strength due to the potential for fibre agglomeration and reduced homogeneity of the mixture.

At 28 days, concrete with 0.75% fibre produced the highest compressive strength (21.71 MPa), indicating increased mechanical performance at higher fibre content at maturity. However, 1% fibre content again reduces compressive strength due to increased porosity and reduced bonds between particles. It can be concluded that the optimal fibre content varies according to the age of the concrete: 0.5% for ages 7 and 14 days, and 0.75% for ages 28 days. The addition of flex banner fibre can increase the compressive strength of concrete, but its use must be managed optimally to prevent a decrease in performance due to excess fibre.

As a comparison, research by Setiawan (2017) showed the highest compressive strength in the WPC C mixture with 1% flex banner fibre, an increase of 4.95% compared to normal concrete. However, the WPF A mixture with 0.25% fibre have decrease in compressive strength of up to 16.5%. Siti Nurul Hidayah's research (2019) shows that natural fibre such as hemp in lightweight concrete provide the best results at a level of 0.75%. Polypropylene fibre is also optimal at levels of 0.5%–0.75% to increase the compressive strength of concrete (Hariman Al Faritzie et al., 2023). Hardjasaputra & Ekawati's (2018) research on geopolymer concrete recorded a compressive strength of up to 50 MPa with a mixture of 73% aggregate and 27% fly ash, showing the importance of material proportions in achieving the best performance.

Splitting tensile strength test

Figure 7 shows the results of the splitting tensile strength test of geopolymer concrete, which illustrates the effect of variations in flex banner fibre on the splitting tensile strength value of concrete.

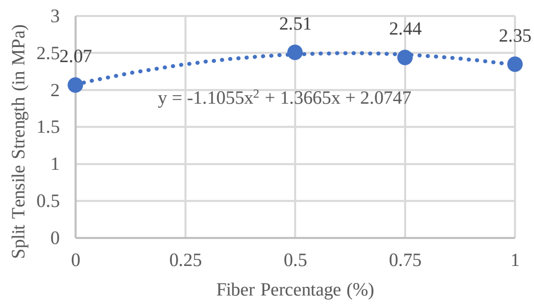

Figure 7. Concrete Split Tensile Strength Growth Rate at 28 Days

Based on Figure 7, geopolymer concrete without fibre (BGSS 0%) has the lowest splitting tensile strength value, which is 2.07 MPa. The graph shows that the highest splitting tensile strength value is achieved in geopolymer concrete with the addition of 0.5% flex banner fibre, which is 2.51 MPa. However, along with the increase in fibre content, the splitting tensile strength value decreases, with concrete with a variation of 0.75% flex banner fibre reaching 2.44 MPa and a variation of 1% flex banner fibre of 2.35 MPa. Thus, it can be concluded that increasing the percentage of flex banner fibre in geopolymer concrete tends to cause a decrease in the splitting tensile strength of concrete. The concrete mixture with the highest splitting tensile strength value is found in the variation of 0.5% flex banner fibre, with a value of 2.51 MPa. This variation shows an increase in splitting tensile strength of 21.25% compared to concrete without the addition of flex banner fibre.

The relationship between the increase in the percentage of flex banner fibre in geopolymer concrete and the splitting tensile strength at the age of 28 days is as follows:

$$y = -1{,}1055x^2 + 1{,}3665x + 2{,}0747 \quad \ldots\ldots\ldots (2)$$

In the equation, to determine the value of x that gives the maximum value of equation (1), the calculus derivative method is used. By differentiating the equation with respect to x, the first derivative is obtained:

$dy/dx = -2\,(1.1055)\,x + 1.3665$.

The maximum point occurs when the first derivative is equal to zero, which results in a value of $x = 0.62$. With a value of $x = 0.62$, then $y = -1.1055(0.62)^2 + 1.3665(0.62) + 2.0747 = 2.49$ MPa is obtained. Thus, it can be concluded that the addition of fibre up to 0.62% is the optimal condition, where geopolymer concrete reaches maximum splitting tensile strength before experiencing a reduction effect due to excess fibre.

CONCLUSSION

The addition of 1% flex banner fibre to 28-day-old concrete increases the specific gravity to 2462.83 kg/m³ (up to 2.83%). The workability of geopolymer concrete mixture with flex banner fibre will decrease with the increase in fibre. Slump of 90 mm at 0.75% content decreases to 80 mm at 1% fibre content. The highest compressive strength of 22.37 MPa is achieved at 0.75% fibre content, an increase of 4.19% compared to concrete without fibre. Meanwhile, the highest splitting tensile strength is 2.51 MPa at 0.50% fibre content, an increase of 21.25%. The regression equation shows the optimum tensile strength value at 0.62% fibre content.

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