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THE EFFECT OF POLYPROPYLENE FIBERS ON COMPRESSIVE AND SPLIT TENSILE STRENGTH OF LIGHTWEIGHT CONCRETE

Mufti Amir Sultan [1], Abdul Gaus [1], Muhammad Taufiq Yudasaputra [1], Zulham Lambado [2], Ilman Nofiyanto Hi Bayan [3]

[1] Department of Civil Engineering, University of Khairun, Ternate, Indonesia
[2] Student of the Civil Engineering Master's Program, University of Khairun, Ternate, Indonesia
[3] Student of the Civil Engineering Department, University of Khairun, Ternate, Indonesia

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Corresponding Author

Mufti Amir Sultan,
muftiasltn@unkhair.ac.id

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ABSTRACT

This study was carried out to design lightweight concrete, which is enriched with polypropylene fibers using coarse pumice and sand fine aggregates. Lightweight concrete specimens were classified into distinct groups based on fibers content employed, namely a control group with 0 kg/m^3 and the experimental incorporating 0.1 kg/m^3, 0.3 kg/m^3, 0.5 kg/m^3, and 0.7 kg/m^3 varying quantities of polypropylene fibers. Subsequently, after a curing period of 28 days, the hardened concrete test was conducted on cylinder specimens measuring 150 mm x 300 mm. The consistency of the fresh concrete mixture was tested using the Abrams cone test, which revealed a decrease in the workability of fibers-reinforced concrete with an increase in fibers volume in the mixture. The test aimed to determine the effect of polypropylene fibers on compressive and tensile strength of lightweight concrete. The optimal compressive and split tensile strength was observed at fibers volume fraction of 0.5, to obtain 7.84 MPa, or 56.68% increase in compressive strength, and 2.12 MPa or 42.86% rise in tensile strength. Based on compressive and split tensile strength obtained from this study, concrete was classified as highly lightweight structural concrete, which served as an insulator.

Keywords: Lightweight Concrete, Fibers-Reinforced Concrete, Pumice, Compressive Strength, Spilt Tensile Strength

1. INTRODUCTION

Based on seismic zoning, a significant portion of Indonesia is located within earthquake-prone regions making the meticulous selection of building materials a crucial endeavor. This importance arises from the fact that these structures bear the primary permanent load of a building. The considerable weight of this permanent load exacerbates the vulnerability of the structure to seismic forces, increasing the

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risk of potential collapse. In order to address this issue, opting for lightweight concrete emerges as a strategic choice. By reducing the overall weight of the building, the cumulative impact of earthquake-induced loads can be mitigated, ultimately leading to enhanced safety measures. Moreover, the benefits of this method extend to the foundation of these structures. The reduced weight of the building places less stress on the capacity of the foundation to support vertical loads. Strength of lightweight concrete is generally 25 to 35% lower than that of the conventional type Bindu et al. (2022) .

Lightweight concrete is commonly described as having a volume weight that does not exceed 2000 kg/m^3 Kabay & Aköz (2012). However, this definition varies across different regions worldwide. For instance, in the United States, lightweight concrete is defined by a volume weight range of 1440 to 1840 kg/m^3 ACI 318-02. (2014). In Japan, the specific volume weight value is not specified, rather, it depends on the use of lightweight aggregates for both coarse and fine aggregates. Concrete regulations in Norway states that lightweight type has a maximum compressive strength of 85 MPa, and it is permissible to use any type of aggregate. This includes a combination of lightweight and natural aggregates, but the volume weight should not exceed 1200 kg/m3. In Australia, lightweight concrete is classified based on a volume weight of less than 1800 kg/m^3 for its constituent aggregates Clarke (2005). According to ACI 213R guidelines, structural lightweight concrete is defined as a 28-day concrete with strength of 17 MPa and a density range of 1120 to 1920 kg/m^{3}ACI 213R. (2014). In Indonesia, lightweight concrete is characterized by a volume weight of less than 1850 kg/m^3.

Pumice, lightweight and porous volcanic rock, presents an intriguing option for producing lightweight concrete. This natural material can potentially reduce the overall weight of concrete while maintaining satisfactory strength, making it suitable for various construction applications. The concept involves using pumice as both coarse and fine aggregates in concrete. It is found in various countries, such as Japan and New Zealand Liu et al. (2015). In Indonesia, this stone is distributed in Jambi, Lampung, West Java, Banten, Yogyakarta, West, and East Nusa Tenggara, as well as North Maluku, specifically on Tidore Island Sultan et al. (2021).

This distinctive rock is characterized by its light color and high porosity. It is a type of igneous rock formed from explosive volcanic eruptions. This rock is often referred to as volcanic glass silicate due to the presence of foam originating from glass-walled gas bubbles during its formation. Pumice is widely used as lightweight concrete aggregate and an abrasive material in various industrial products. Its high porosity allows it to float on water. The rock exhibits high vesicular properties, containing numerous cells formed from the expansion of the gas foam trapped within. The abundant pore spaces enclosed by thin, delicate walls contribute to its exceptionally low density. Generally, pumice has a density of less than 1, enabling it to remain afloat on water effortlessly. It is found as fragments or debris within volcanic breccias. Common minerals found in pumice include feldspar, quartz, tridymite, and cristobalite Rashad (2019).

Pumice possesses the essential physical characteristics required for functioning as concrete aggregate, offering a compelling option as lightweight alternative. It fulfills the requirements of lightweight concrete and significantly reduces the structural load, leading to smaller foundation designs Suseno et al. (2021). Pumice-aggregate concrete is usually used in earthquake-resistant buildings, particularly where thermal resistance is a primary criterion, as well as in areas prone to acid rain Muralitharan & Ramasamy (2015). When used as a coarse aggregate, pumice substantially contributes to the overall reduction in concrete weight, thereby categorizing it as lightweight Mushtaq Khan & Sachar (2022). In cases where pumice substitutes for coarse aggregate, compressive strength is slightly reduced compared to standard concrete. This necessitates the incorporation of additives to maintain adequate strength levels. However, this type of concrete typically exhibits lower volume weight than regular concrete mixes Idi et al. (2020). The integration of pumice into concrete formulations involves partial substitution for coarse aggregate. The replacement of pumice up to a threshold of 50% maintains tensile, compressive, and flexural strength levels comparable to conventional concrete. Once the replacement surpasses 50%, its strength experiences a gradual decline. As a result, replacing 50% of aggregate with pumice proves effective for structural purposes, while the 60% to 100% replacement range is only suitable for non-structural applications. It was concluded that due to its concrete-like properties, pumice can effectively serve as lightweight aggregate. The outcome also meets the specified criteria for lightweight concrete production Numan et al. (2021). Lightweight concrete with varying strength grades and unit weights can be produced by combining pumice aggregate with an air-entraining agent admixture. This type of concrete falls short of meeting strength requirements for load-bearing structural elements Manzoor et al. (2018). The use of 100% pumice coarse aggregate tends to decrease compressive and flexural strength of reinforced concrete beams Sultan et al. (2021).

In order to address this issue, it is imperative to explore innovative solutions, such as the incorporation of fibers into concrete mixture. Numerous studies have been conducted to enhance concrete properties, particularly its toughness. The use of fibers has been proven to enhance the mechanical properties and durability of concrete. Many studies have been conducted to investigate the performance and advantages of fibers-reinforced concrete in recent decades Annamaneni & Pedarla (2023), Biradar et al. (2020), Geremew et al. (2021), Gupt & Dulawat (2020), Khan & Ali (2019), Nkomo et al. (2022), Wang et al. (2023), Zhang & Li (2013). Furthermore, steel, glass, polyethylene, polypropylene, polyvinyl alcohol, polyester, basalt, and natural fibers, are commonly used in concrete materials. These fibers serve three main benefits in concrete compositions, namely reducing cracking, providing reinforcement, and enhancing toughness.

2. MATERIAL AND METHOD

This study was based on an experimental method and involved the use of several materials. Portland Type 1 cement and water were used as the binding and mixing materials. The composition also included pumice sand fine and coarse aggregates. In addition, polypropylene fibers were introduced as an additional component in the mixture.

2.1. AGGREGATES

Pumice sand fine and coarse aggregates were sourced from the Goto quarry in North Maluku. The gradation of the fine aggregate in Zone I. Meanwhile, pumice coarse aggregate in Zone I (max 40 mm). The visual representation of the texture of both aggregates is shown in Figure 1.

2.2. POLYPROPYLENE FIBERS

Polypropylene fibers possess water-repellent properties and are resistant to alkali, chemicals, and chlorides. In this study, polypropylene fibers were cut to a length of 12 mm. The amount of fibers used was based on volume fraction for concrete mixture, namely 0.1 kg/m^3, 0.3 kg/ m^3, 0.5 kg/ m^3, and 0.7 kg/ m^3. In contrast, the control specimens were prepared without the use of polypropylene fibers (0%). Figure 2 shows the visual representation of polypropylene fibers used in this study.

Figure 1

Figure 1 The Texture of Fine Aggregate and Coarse Aggregate

Figure 2

Figure 2 Polypropylene Fibers Used in this Study

2.3. SPECIMENS

Cylinderical-shaped concrete specimens were used for the assessment of compressive and split tensile strength. These cylinders were characterized by a diameter and height of 150 mm and 300 cm. The testing took place once the specimens reached 28 days of curing, with a total of 90 samples involved in the analysis.

3. RESULTS AND ANALYSIS

3.1. SLUMP TEST

The slump value of fresh concrete was examined to ensure the required workability. In this study, the planned slump value falls within the range of 60 to 80 mm. The slump value of concrete without fibers was approximately 75 mm, whereas that of the first fibers-reinforced concrete mixture decreased from 65 mm at a volume fraction of 0.1 to 20 mm at a volume fraction of 0.7, as shown in Figure 3.

Figure 3

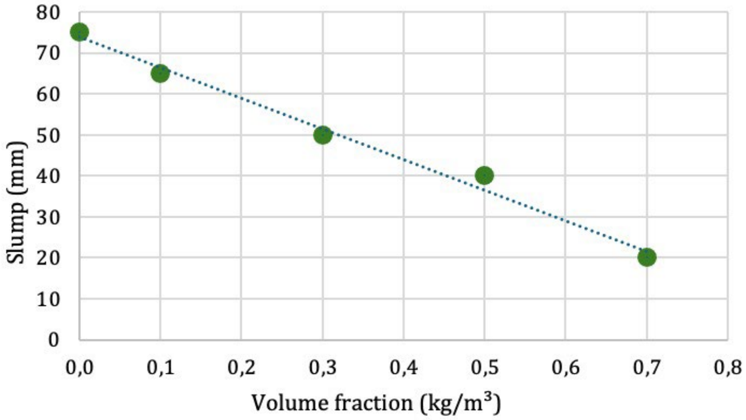

Figure 3 Concrete Slump to Polypropylene Fibers Volume Fraction

Figure 3 shows that an increase in fibers volume fraction within fibers-reinforced concrete mixture requires more water. The decrease in fibers-reinforced concrete workability with an increased volume fraction of polypropylene fibers in the mixture is due to the significant frictional resistance generated between polypropylene fibers and concrete particles Hasan et al. (2019).

3.2. VOLUME WEIGHT OF FIBERS-REINFORCED CONCRETE

The volume weight of polypropylene fibers-reinforced concrete after 28 days of curing is shown in Figure 4. Lightweight concrete without polypropylene fibers exhibits the highest density value of 1505 kg/m^3. Meanwhile, concrete with polypropylene fibers has the lowest value, recorded at 1129 kg/m^3, thereby classifying it as lightweight concrete.

Figure 4

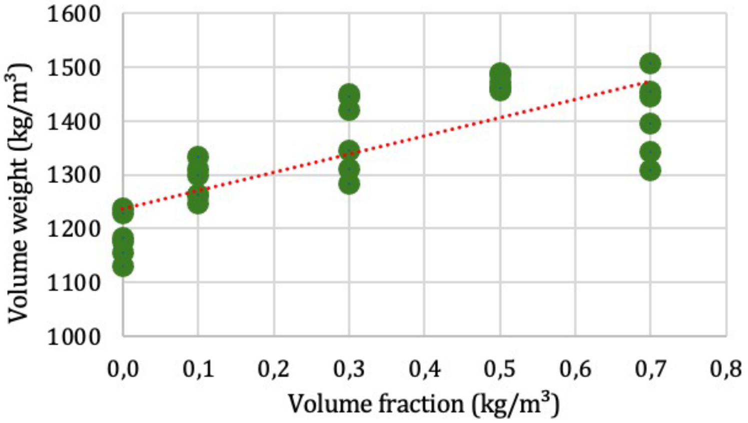

Figure 4 The Volume Weight of Polypropylene Fibers-Reinforced Concrete

3.3. THE EFFECT OF POLYPROPYLENE FIBERS ON COMPRESSIVE STRENGTH

Figure 5 shows that polypropylene fibers tend to affect concrete mixture by enhancing the 28-day compressive strength. The maximum compressive strength of

7.84 MPa was achieved at a volume fraction of 0.5, accounting for 56.68% of strength observed in concrete without fibers. Strength starts to decrease as fibers concentration increases further because higher fibers volume disrupts the compactness of concrete matrix. Based on the test results, the produced concrete falls into the highly lightweight structural concrete category, serving as an insulator Gaus et al. (2022).

Figure 5

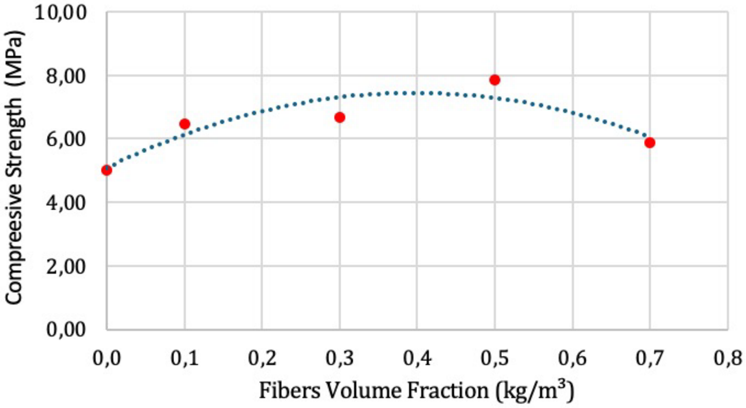

Figure 5 Compressive Strength of Polypropylene Fibers-Reinforced Concrete

3.4. THE EFFECT OF POLYPROPYLENE FIBERS ON SPLIT TENSILE STRENGTH

According to Figure 6, tensile strength starts to increase as fibers volume fraction rises. It reaches a maximum value of 2.12 MPa at fibers volume fraction of 0.5, which is 42.86% higher than tensile strength of fibers-less concrete. The increase in split tensile strength occurred due to two factors, namely the even distribution of fibers within the mixture and the careful selection of fibers proportions. Tensile strength improves primarily because of the bonding mechanism of polypropylene fibers. However, the addition of fibers volume fraction greater than 0.5 leads to a reduction in the bond strength between concrete components, resulting in earlier failure compared to concrete with a lower fibers volume Ahmed et al. (2006).

Figure 6

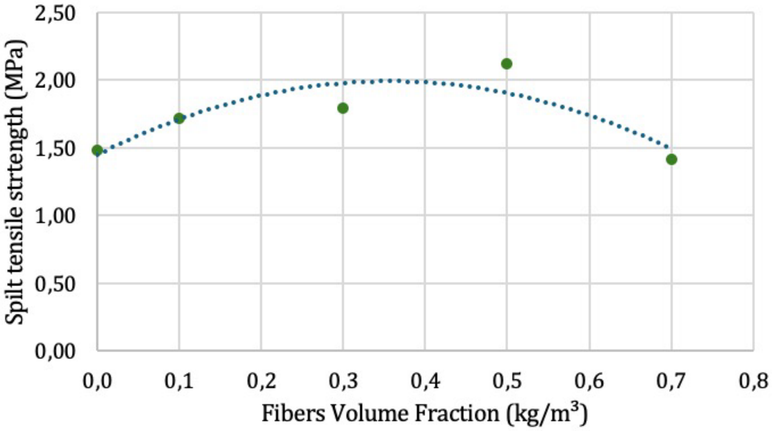

Figure 6 Split Tensile Strength of Polypropylene Fibers-Reinforced Concrete

3.5. RELATIONSHIP BETWEEN COMPRESSIVE AND SPLIT TENSILE STRENGTH

A suitable method for calculating tensile strength of normal concrete, fct, is 0.10f'c < f'ct < 0.2f'c Nawy (2005). Based on Table 1 and Figure 7, the obtained split tensile strength values from the calculations do not align with the theoretical ranges. For instance, tensile strength of normal concrete without fibers is 1.49 MPa, surpassing the projected range of 0.50 to 1.00 MPa. Split tensile strength of concrete with the addition of polypropylene fibers at a volume fraction of 0.1 is 1.72 MPa, exceeding the range of 0.65 to 1.29 MPa. Furthermore, split tensile strength of concrete with the addition of polypropylene fibers at a volume fraction of 0.3 is 1.79 MPa, surpassing the expected range of 0.67 to 1.33 MPa. This trend persists as concrete containing polypropylene fibers at a volume fraction of 0.5 showed split tensile strength of 2.12 MPa, which is above the projected range of 0.78 to 1.57 MPa. Meanwhile, split tensile strength of concrete with the addition of polypropylene fibers at a volume fraction of 0.7 is 1.41 MPa, exceeding the range of 0.59 to 1.18 MPa. The addition of polypropylene fibers to lightweight concrete results in a decrease in compressive strength, albeit not significantly. Split tensile strength of lightweight concrete increases due to the addition of polypropylene fibers. The measured values for each variant surpass the theoretical tensile strength of normal concrete.

Table 1

Table 1 Relationship Between Compressive and Tensile Strength in Concrete

Fibers Fraction (kg/m³)	Compressive Strength (MPa)	Spilt Tensile Strength (MPa)	Tensile Strength (MPa)	
			0.1fct	0.2fct
0.0	5.00	1.49	0.50	1.00
0.1	6.47	1.72	0.65	1.29
0.3	6.67	1.79	0.67	1.33
0.5	7.84	2.12	0.78	1.57
0.7	5.88	1.41	0.59	1.18

Figure 7

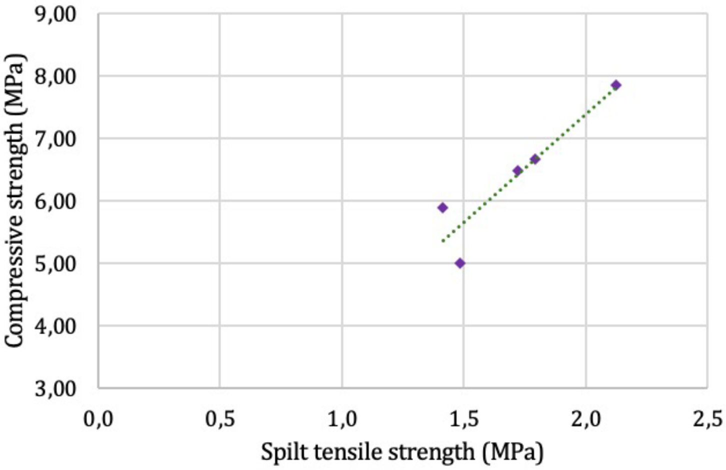

Figure 7 Graph of the Relationship Between Compressive and Split Tensile Strength

4. RESULTS AND ANALYSIS

In conclusion, the analysis of the experimental results and data showed that the volume weight of the obtained concrete ranged between 1129 kg/m^3 and 1505 kg/m^3. Therefore, it was classified as lightweight concrete. The workability of lightweight concrete decreased as the volume fraction of polypropylene fibers in the mixture increased. The optimal compressive and split tensile strength of lightweight concrete occurred at a volume fraction of 0.5 kg/m^3, with values of 7.84 MPa and 2.12 MPa, respectively. These values represented an increase of 56.68% and 42.86% compared to compressive and split tensile strength of fibers-less concrete. The relationship between compressive and split tensile strength of polypropylene fibers-reinforced lightweight concrete exceeded that of the normal type.

CONFLICT OF INTERESTS

None.

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