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UTILIZATION OF CONCRETE WASTE AS AN AGGREGATE SUBSTITUTE AND THE ADDITION OF DENIM FABRIC FIBERS TO ENHANCE COMPRESSIVE AND FLEXURAL STRENGTH OF CONCRETE (AS AN IMPLEMENTATION OF CONCRETE TECHNOLOGY COURSE)

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Abstract

Concrete is one of the construction materials used in building structures, bridges, roads, and others. The material components that make up concrete consist of fine aggregates (sand), coarse aggregates (gravel), water, and cement. However, the drawbacks of concrete include low tensile strength, heavy weight, high sound reflection, and difficulty in reshaping after it has been formed. Adding fibers is one way to increase the flexural strength of concrete. This study aims to determine the utilization of concrete waste and the addition of denim fabric fibers in improving the compressive strength and flexural strength of concrete, using fiber lengths of 100 mm and widths of 5 mm with fiber addition of 1% and 2%. The test results at 28 days show the compressive strength values of control concrete, concrete with 1% fiber proportion, and 2% fiber proportion are 10,27 MPa, 8,3 MPa, and 5,44 MPa, respectively, with the optimum compressive strength being 10,27 MPa for the control concrete. Therefore, none of the compressive strengths reached the design compressive strength of 40 MPa. The flexural strength values from the tests are 3,52 MPa, 4,32 MPa, and 2,98 MPa, with the optimum flexural strength being 4,32 MPa at the 1% fiber proportion. The flexural strength values range between 34,27% to 54,77% of the compressive strength values.

Keywords: Compressive Strength, Denim Fabric, Fiber Concrete, Flexural Strength, Waste Concrete

Introduction

The Government Regulation of the Republic of Indonesia Number 27 in 2020 on waste management specifically states that "waste is the residue of human daily activities or natural processes in solid form." Based on this, waste management can be carried out through reduction and handling methods. A concept gaining traction in the construction industry is green concrete, which incorporates waste materials into its composition by applying the 4R principles: Reduce, Refurbish, Reuse, and Recycle (Megasari et al., 2016).

Various types of buildings use concrete as a construction material because concrete has advantages such as ease of production, fire resistance, and durability (Ahmad et al., 2024). However, the drawbacks of concrete include low tensile strength, heavy weight, high sound reflection, and difficulty in reshaping after it has been formed (Mufida, 2023). Improving concrete properties can be achieved through several methods, including upgrading the quality of the concrete materials and incorporating additives such as liquids or fibers. One way to improve the compressive strength of concrete is by adding fibers (Catur et al., 2022).

Meanwhile, waste problems, especially inorganic waste, are a major issue requiring serious attention because this type of waste does not decompose quickly. Another type of waste that can damage the environment, aside from plastic waste, is used clothing waste. Globally, clothing waste reaches 92 million tons of clothing that is no longer fit for use (Dory, 2018). One type of used clothing waste is denim waste. The largest producers of denim waste globally are generally countries with large textile and fashion industries. Some countries known for high denim production and generating large amounts of denim waste include China, India, Bangladesh, Turkey, and the United States. Denim production generates between 40 and 65 liters of waste per kilogram of denim (Periyasamy & Periyasami, 2023).

Construction waste materials, such as leftover concrete, come from excess concrete produced during the ready-mix concrete production process or manually produced concrete (Site Mix). Waste material is part of the material that is not used in the implementation construction project and not being part of the building. So that the more waste material there is, the less efficient the use of materials in the project (Aji Kurniawan et al., 2024). This excess concrete is often discarded, which can decrease the aesthetic value of disposal areas and potentially pollute the environment (Ishaq et al., 2021). The utilization of concrete waste as a concrete mix can be applied on-site with a percentage of 50% or half the weight of the total coarse aggregate, with a concrete mix ratio of 1:2.5:3.3:5.

The increased use of concrete in construction projects has driven the demand for concrete materials. This has led to large-scale mining of stones used as components in concrete production, which can eventually reduce the availability of concrete materials. Several studies have been conducted to find alternative concrete materials sourced from natural elements. Many studies have been carried out to find alternatives to natural concrete materials with other materials. The critical factors in identifying green concrete are the amount of Portland cement substitute, manufacturing process and method, performance, and sustainability impact (Sudarsono et al., 2023). Therefore, this research study focuses on the utilization of concrete waste as a substitute for aggregates and the addition of denim fabric fibers to improve the compressive and flexural strength of concrete.

Research Methods

The research method used is the experimental method, utilizing test specimens in the form of cylinders with diameter of 82 mm and height 150 mm and beams with dimensions of 10 cm x 10 cm x 30 cm, with the addition of denim waste fibers measuring 100 mm x 5 mm. The test specimens will undergo compressive strength and flexural strength testing at the age of 7 days and 28 days. This research is conducted at the Building Materials Laboratory of the Faculty of Engineering, Universitas Negeri Jakarta, located at Jalan Rawamangun Muka Number 1, East

Jakarta, and at the Laboratory of the Technical Materials and Goods Compliance Assessment Management Unit, Cempaka Putih, Central Jakarta.

The number of test specimens used in this study is three samples for each compressive strength and splitting tensile strength test of concrete at 7 days and 28 days, so the total number of samples is 28. This study consists of several procedures, including the preparation stage, preparation of concrete waste and denim waste materials, material inspection stage, concrete mix design stage, mixing stage, concrete slump test stage, test specimen fabrication stage, specimen curing stage, and testing of compressive and flexural strength of concrete.

Research Results and Discussion

The experiment was conducted by using concrete waste as a substitute for aggregates with the addition of denim fabric fibers at concentrations of 1% and 2%. The results of the study include testing of the concrete components, calculation of the concrete mix proportions, calculation of the concrete slump, testing of concrete mass, and testing of compressive and flexural strength of the concrete.

Cement Test Results

In this study, the cement used was Portland cement type I. The preliminary test results of the cement showed a value of 3.1 g/ml. It was concluded that the tested cement meets the required standards and can be used as a concrete component based on SNI 15-2531-1991, with the specification of 3.15 ± 0.5 g/ml.

Results of Fine Aggregate Test

Sebelum Before use, the fine aggregate is first washed with water until clean and free from mud, then dried until it reaches the SSD (Saturated Surface Dry) condition.

Table 1. Results of Preliminary Fine Aggregate Testing

No.	Type of Test	Requirements	Test Results
1.	Mud Content	(SNI S-04-1989-F)	8,731%
2.	Organic Substances	≤ color indicator no.3 SNI 2816:2014	No. 1
3.	Specific Gravity and Absorption a. Apparent specific gravity b. Specific gravity at SSD condition c. Dry specific gravity d. Water absorption	SNI 03-1970-1990	a. 2,953 gr/cm^2 b. 2,523 gr/cm^2 c. 2,314 gr/cm^2 d. 8,919 gr/cm^2
4.	Fine Aggregate Gradation Modulus	SNI ASTM C136:2012	4,736
5.	Moisture Content	SNI 1971:2011	5,487 %

Results of Coarse Aggregate Testing

Before use, the coarse aggregate is first washed with water until clean, then dried until it reaches the SSD (Saturated Surface Dry) condition.

Table 2. Results of Preliminary Coarse Aggregate Testing

No.	Type of Test	Requirements	Test Results
1.	Coarse Aggregate Gradation Modulus	SNI ASTM C136:2012	8,576
2.	Specific Gravity and Absorption a. Apparent specific gravity	SNI 1969:2008	a. 2,978 gr/cm^2

	b. Dry specific gravity c. Specific gravity at SSD condition d. Water absorption		b. 2,065 gr/cm^2 c. 2,366 gr/cm^2 d. 14,732 gr/cm^2
3.	Moisture Content	SNI 03-1971-1990	5,186 %

Denim Fabric Fibers

The denim fabric fibers used in this study were obtained from discarded clothing that was cut. The testing of denim fabric fibers was conducted at the Testing, Inspection, and Product Certification Unit Laboratory for Industry, Trade, Cooperatives, and Small and Medium Enterprises of the DKI Jakarta Province, with the following results.

Table 3. Results of Denim Fabric Tensile Test

No.	Type of Test	Test Results	Method
1.	Fabric Width, m	1,49	SNI ISO 22198:2010
2.	Fabric Weight, gram/m	471	SNI ISO 3801:2010 Method : 5
3.	Tensile strengts of fabric, per 2,5 cm -Warp direction, N -Elongation % -Weft direction, N -Elongation %	 623 23,04 319 48,93	SNI 0276:2009 Method : 5.3.3
4.	Fabric stiffness Average length Curvature, cm - Warp direction -Weft direction Flexural strength, mg.cm -Warp direction -Weft direction Modulus Curvature, kg/cm2 -Warp direction -Weft direction	 2,06 1,20 277,2 55,2 9,7 1,9	SNI 314-2017
5.	Composition -Cotton, % -Polyester, % -Spandex, %	 78,2 20,5 1,3	SNI ISO 1833-1:2011 SNI ISO 1833-12:2011

Concrete Mix Design Calculation

The concrete mix design calculation refers to SNI 7656:2012 regarding the Guidelines for the Selection of Normal Concrete, Heavy Concrete, and Mass Concrete. The planned compressive strength of the concrete is 40 MPa with a slump value of 75 mm - 100 mm, and the percentage of denim fabric fibers is 1% and 2%, with the following proportions of concrete components.

Table 4. Proportion of Concrete Components

Component Materials	Proportion of Concrete Components			Amount
	Control (kg)	1% (kg)	2% (kg)	
	27 Samples			
Cement (kg)	0,407	0,407	0,407	1,221
Water (kg)	0,171	0,171	0,171	0,513
Fine Aggregate (kg)	0,459	0,459	0,459	1,377

Coarse Aggregate (kg)	0,964	0,964	0,964	2,892
Denim Fabric Fiber		0,020	0,040	0,060
Total Weight for 1 Cylindrical Concrete Sample		1,667		
Total Weight for 1 Beam Concrete Sample		7,2		

Slump Test

The slump test, or fresh concrete test, is conducted after the mixing of concrete components. The reference for this test is SNI 1972:2008. The planned slump value in this study is 75 mm – 100 mm.

Table 5. Slump Test Results

No.	Test Specimen	Slump Value
1.	Waste Concrete	10 mm
2.	Fiber Concrete 1%	85 mm
3.	Fiber Concrete 2%	42 mm

Test Specimen Mass

The test specimens are weighed first before conducting the compressive strength test and flexural strength test.

Table 6. Test Specimen Mass at 7 Days

Test	Samples	Fiber Proportion		
		Control (Kg)	1% (Kg)	2% (Kg)
Compressive Strength	1	1,738	1,784	1,674
	2	1,53	1,744	1,758
	3	1,748	1,75	1,738
Average		**1,672**	**1,759**	**1,723**

Table 7. Test Specimen Mass at 28 Days

Test	Samples	Fiber Proportion		
		Control (Kg)	1% (Kg)	2% (Kg)
Compressive Strength	1	1,83	1,752	1,788
	2	1,488	1,75	1,822
	3	1,682	1,724	1,686
Average		**1,667**	**1,742**	**1,765**
Flexural Strength	1	6,2	6,5	6,6
	2	6,1	6,3	6,1
	3	5,9	5,9	6,2
Average		**6,067**	**6,233**	**6,3**

Compressive Strength Test of Concrete

The compressive strength test is conducted to obtain the compressive strength value of the concrete test specimens, which have been designed with the mix design. The reference used for this test is SNI 1974:2011. The compressive strength of the concrete is obtained by dividing the maximum load received by the test specimen by its cross-sectional area. In the testing stage, the cylindrical test specimen is capped on the surface to be loaded to make it flat. The test is conducted on specimens with ages of 7 days and 28 days, with a total of 18 samples.

Table 8. Compressive Strength Test Results of Concrete (7-Day Test Specimens)

Test Specimen	Samples	Compressive Strength (MPa)	Average Compressive Strength (MPa)	28-day Compressive Strength Conversion (MPa)
Control Concrete	1	11,37	8,97	13,8
	2	5,82		
	3	9,71		
Fiber Concrete 1%	1	6,03	5,58	8,58
	2	5,29		
	3	5,42		
Fiber Concrete 2%	1	3,53	4,22	6,49
	2	4,74		
	3	4,41		

Table 9. Compressive Strength Test Results of Concrete (28-Day Test Specimens)

Test Specimen	Samples	Compressive Strength (MPa)	Average Compressive Strength (MPa)
Control Concrete	1	9,93	10,27
	2	12,94	
	3	7,93	
Fiber Concrete 1%	1	7,22	8,43
	2	9,03	
	3	9,03	
Fiber Concrete 2%	1	5,29	5,44
	2	6,63	
	3	4,41	

Flexural Strength Test of Concrete

The flexural strength test of concrete is conducted to determine the flexural strength value of the concrete test specimens that have been designed in the mix design, with a total of 9 samples. The reference used for this test is SNI 4151:2014. The flexural strength of the concrete is obtained from the maximum load that causes the test specimen to break. The average flexural strength test results for each variation range from 2.98 MPa to 4.32 MPa.

Table 10. Flexural Strength Test Results of Concrete

Test Specimen	Samples	Compressive Strength (MPa)	Average Compressive Strength (MPa)
Control Concrete	1	2,92	3,52
	2	4,01	
	3	3,63	
	1	4,57	

Fiber Concrete 1%	2	4,34	4,32
	3	4,06	
	1	3,04	
Fiber Concrete 2%	2	2,81	2,98
	3	3,10	

Analysis of Concrete Compressive Strength

Below are the results of the compressive strength test of concrete at 7 days and 28 days, presented in a graph.

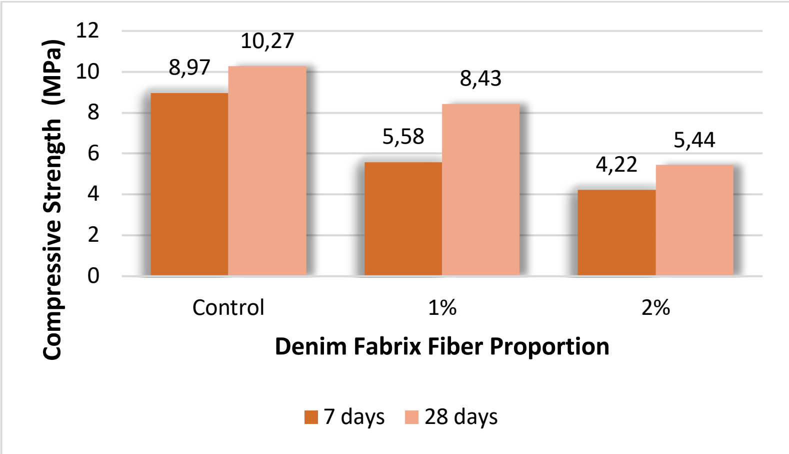

Figure 1. Compressive Strength Value Graph

Based on the graph, at 7 days of concrete age, the 0% variation shows a compressive strength of the control concrete of 8.97 MPa. In the variations with 1% and 2% fiber addition, the compressive strength decreases consecutively. The compressive strength for the 1% fiber addition variation was 5.58 MPa, a decrease of 3.39 MPa from the control concrete without fiber. The compressive strength for the 2% fiber addition variation was 4.22 MPa, a decrease of 4.75 MPa from the control concrete without fiber. At 28 days of concrete age, the compressive strength of the control concrete was 10.27 MPa. For the 1% and 2% fiber proportions, the compressive strength decreased consecutively. The compressive strength for the 1% fiber addition variation was 8.43 MPa, a decrease of 1.84 MPa from the control concrete. The compressive strength for the 2% fiber addition variation was 5.44 MPa, a decrease of 4.83 MPa from the control concrete. At a longer concrete age (28 days), the compressive strength reaches a higher value compared to concrete at 7 days of age. The cement hydration process has been completed, resulting in higher strength. However, the results do not reach the planned compressive strength of 40 MPa. With the addition of denim fabric fibers, the compressive strength decreases further. This may be caused by the poor quality of the fiber mixing, where the non-homogeneous mixing process results in uneven fiber distribution in the concrete, thus reducing the strengthening effectiveness of the fibers. Additionally, mixing in hot weather conditions reduces the amount of water. The mixing time of the concrete will affect its quality; if the mixing is done too briefly, the materials will not mix evenly, which can reduce the bond between the concrete components. On the other hand, overmixing can lead to an increase in concrete temperature, water loss, an increase in slump value, and a reduction in concrete strength (Andika et al., 2021.).

Analysis of Concrete Flexural Strength

Below are the results of the flexural strength test of concrete at 28 days, shown in.

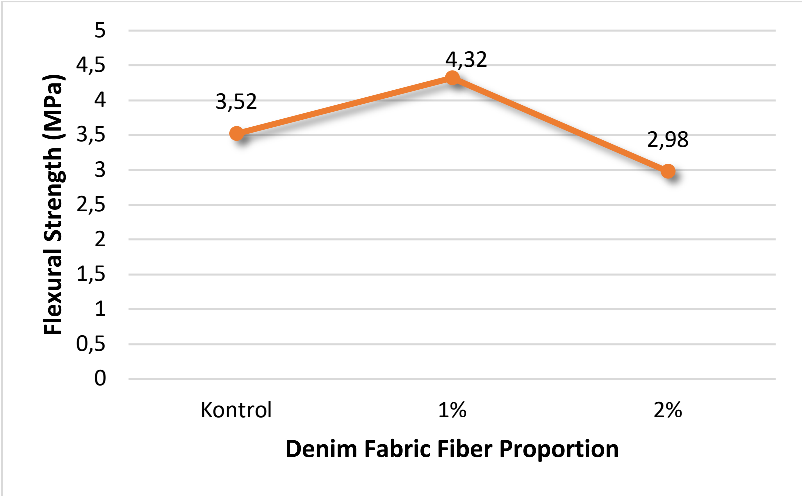

Figure 2. Graph of Concrete Flexural Strength Values

Based on the graph, it can be seen that in the control concrete variation, a flexural strength value of 3.52 MPa was obtained. Then, with the addition of 1% fiber, the flexural strength increased by 0.8 MPa, reaching 4.32 MPa. However, with the addition of 2% fiber, the flexural strength decreased to 2.98 MPa.

It can be concluded that the lowest flexural strength was recorded at the 2% fiber addition variation, with a value of 2.98 MPa, and the highest flexural strength was at the 1% fiber addition variation, with a value of 4.32 MPa. The decrease in flexural strength at the 2% fiber addition variation may be caused by several factors. Excessive fiber addition can cause the fibers to be unevenly distributed in the concrete mix, making some parts of the concrete weaker at the points where the fibers are more concentrated. In addition, the non-uniform length and diameter of the fibers added to the concrete mix can disrupt the concrete matrix structure and affect the concrete's ability to resist bending loads.

In the study (Kholis et al., 2022) with the addition of textile waste fibers as fibers in concrete, varying values of compressive strength and flexural strength were obtained. The highest compressive and flexural strengths were found in the concrete mixture with a 6% fabric and 9% glass shard ratio, yielding a compressive strength of 15.592 MPa and a flexural strength of 4.495 MPa. However, in the subsequent variations, the mixture with an 8% fabric and 12% glass shard ratio, as well as the mixture with a 10% fabric and 15% glass shard ratio, showed a decrease in both compressive and flexural strengths, respectively. It can be concluded that an increase in the amount of addition can affect the compressive and flexural strength values of the concrete.

Relationship Between Concrete Compressive Strength and Flexural Strength

Below is an illustration of the compressive strength and flexural strength values of concrete at 28 days.

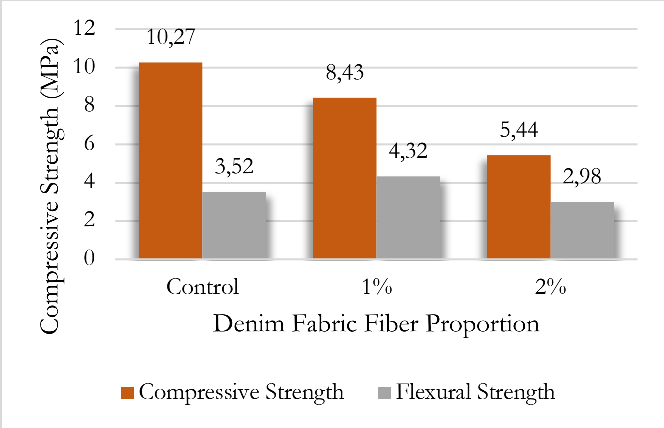

Figure 3. Relationship Between Compressive Strength and Flexural Strength of Concrete at 28 Days

Based on Figure 3, at 28 days of concrete age, the control concrete achieved a flexural strength of 3.52 MPa or 34.27% of the control concrete's compressive strength. With the addition of 1% fiber, the flexural strength value was 4.32 MPa or 51.24% of its compressive strength. With the addition of 2% fiber, the flexural strength value was 2.98 MPa or 54.77% of its compressive strength. From the explanation of these results, it can be concluded that the flexural strength of the concrete ranges from 34.27% to 54.77% of its compressive strength.

Conclusion

Based on the analysis of the research data from the test results, it can be concluded that the incorporation of concrete waste and denim fabric fibers influences both the compressive and flexural strength of concrete. The denim fabric fibers can improve the flexural strength at the fiber addition level of 1%. The maximum compressive strength value was recorded in the control concrete at 28 days of age, which was 10.27 MPa. An increase in the amount of denim fabric fibers in the concrete mixture led to a decrease in the resulting slump value. The optimum compressive and flexural strength values with fiber addition were found at the 1% variation, with compressive strength of 8.43 MPa and flexural strength of 4.32 MPa. The flexural strength test results ranged from 2.98 MPa to 4.32 MPa. Concrete flexural strength generally ranges from 3 MPa to 5 MPa, with flexural strength values ranging from 10% to 15% of its compressive strength. In this study, the flexural strength ranged from 34.27% to 54.77% of its compressive strength. However, all compressive strength test results did not reach the target strength of 40 MPa. The compressive strength of the concrete at 28 days ranged from 5.44 MPa to 10.27 MPa.

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