The Effect of Crumb Rubber as a Substitute for Fine Aggregate in Lightweight Concrete with Addition of Fly Ash

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Article Info

Article history:

Accepted March 10, 2024
Approved April 10, 2024
Published April 29, 2024

Keywords:

Concrete, Crumb rubber, Compressive strength, Flexural strength.

ABSTRACT

In the construction industry, concrete is an important component often used as a building material. Coarse and fine aggregates constitute the majority of concrete content. Although some researchers have previously replaced aggregate with concrete, advances in industry and time have also made it possible to replace aggregate with waste. The impact of fine aggregate substitution in a 20 MPa quality concrete mixture with a crumb rubber content of 25% and 50% was investigated in this research. The research method used was experimental in the laboratory, where cylindrical test objects with a quality of 20 MPa were made. Variations in the content of crumb rubber substituted with fine aggregate are 25% and 50%. The performance of concrete mixtures with crumb rubber was tested using concrete compressive strength aged 3, 7, 14, 21 and 28 days, while the flexural strength was tested using beam-shaped specimens aged 28 days. Based on test findings, the concrete compressive strength test was reduced by 58.85% at a crumb rubber content of 25% and by 78.73% at a crumb rubber content of 50%. Meanwhile, the flexural strength of concrete decreased by 23.66% and 49.23% for concrete with crumb rubber content of 50% and 25% crumb rubber, respectively. This means that crumb rubber can be used in concrete mixes for non-structural purposes

Available online at http://dx.doi.org/10.36055/fondasi

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1. INTRODUCTION

Indonesia's industrial development is currently excellent and yields high-quality goods. In order to boost economic growth and raise the standard of living for the Indonesian people, industrial activity is an essential component of development [1]. In the construction industry, concrete is a crucial component and is frequently utilized as a building material. Concrete has several benefits, including its high compressive strength, greater environmental resilience, affordability, versatility in shape variations, and relative fire safety. Concrete does, however, have several disadvantages such as a very high specific gravity, brittle characteristics, and low tensile strength [2, 3]. The reinforcing and filling material known as aggregate makes roughly 60% to 80% of the volume of concrete. As a result, aggregate is among the components that most affect the characteristics of concrete; for instance, it can affect the concrete's weight. One of the developments is the production of lightweight concrete, which is achieved by substituting some of the coarse or fine aggregate [4]. Several earlier researchers have replaced the aggregate in concrete; however, because of advancements in science and industry, waste materials including fly ash, bottom ash, crumb rubber, and plastic waste can also be used in place of aggregate [5-7].

Without adequate management, waste tires, a byproduct of urbanization, will unavoidably put an enormous amount of burden on the environment. There are now two primary ways to dispose of tires, which make environmental problems for the tire industry as a whole: either burning or accumulating in agricultural land [8]. Lately, there has been an increase in demand for crumb rubber, a recycled substance created from End-of-Life Tires (ELTs). Rubber is created as a byproduct of crushing and sifting used tires, and as a result, a number of experiments have been carried out to enhance the material cycle where rubber becomes the resource needed in another production [9]. An effective method for pulverizing tires into small pieces or crumbs for use in the concrete industry has been suggested by researchers. Utilizing chipped or crumb rubber in place of some of the natural material, recycled concrete has the potential to use an incredible amount of waste tires. Additionally, the usage of river sand or gravel is reduced by novel substitutes for natural aggregate, which reduces the environmental effect of the concrete industry and lowers the probability of natural disasters brought on by excessive extraction. [10,11].

Previous studies have investigated the usage of crumb rubber in concrete, as mentioned by Roychand et al. (2020) [12]. Depending on the size of the crumb rubber that is produced, coarse or fine aggregate may also be substituted with crumb rubber, according to Roycand et al. (2020) [12]. Research on the usage of crumb rubber as a sand substitute has been conducted in Indonesia by Setiaji et al. (2021) [13] and Nugroho et al. (2022) [14]. 0–20% of the weight of sand is substituted, and the concrete design quality is between 17 and 20 MPa. The study's findings indicate that while concrete's modulus of elasticity tends to rise in comparison to conventional concrete, using sand as a substitute of crumb rubber will reduce the concrete's compressive strength value. According to literature reviews, crumb rubber has been used in sand substitutes between 0 and 20% of the total. However, there is no information available about the usage of crumb rubber in amounts greater than 20%. Thus, in a concrete mixture with a quality of 20 MPa, the impact of substituting fine aggregate with 25% and 50% crumb rubber will be investigated in this study.

2. METHODS

Concrete is tested in the Concrete Laboratory, Faculty of Engineering, Tridinanti University, and concrete samples are made as part of this research using laboratory testing methods. The material is divided from the former Musi 2 River in Palembang City, with a maximum size of 20 mm. Ogan Komering Ilir Regency's Tanjung Raja area provides the fine aggregate needed in the work. The maximum aggregate size of 20 mm is specified in ASTM C-33 for the coarse aggregate gradation employed, which falls under Gradation No. 67. The gradation results are displayed in Figure 1. The fine aggregate gradation illustrated in Figure 2 corresponds to ASTM C-33's Gradation Number 2, also known as Medium Sand. Portland cement type 1 Baturaja product is the cement used as binding material. A recycling plant in the Malang City region provides the crumb rubber used for the production of chopped vehicle tire waste [15]. The sieve analysis test results for sand and crumb rubber are displayed in Table 1, where the sand particle size and the crumb rubber particle size (Figure 3) are nearly identical. Sand particles have a maximum size of 4.75 mm, while crumb rubber particles have a maximum size of 0.6 mm. The fly ash used comes from coal burning at PT. Pupuk Sriwijaya (Pusri) Palembang (Figure 4). Fly ash is used as a cement substitute at 15% of the cement weight. Before the fly ash is used, it is first oven-treated at 110ºC for 24 hours and the results are sieved until it passes sieve No. 200 (0.075 mm) [16]. The percentages of fly ash and crumb rubber utilized in the concrete mixture with a design quality of 20 MPa varied in the test specimens that were created. The amount of sand needed in the Job Mix Design computation for regular concrete is replaced by 0%, 25%, and 50% of crumb rubber.

Table 1. Comparison of sand gradations with crumb rubber

Sieve Size	% Cumulative Passed	
(mm)	Sand	Crumb Rubber
19	100.00	100.00
12.5	100.00	100.00
9.5	100.00	100.00
4.75	99.47	100.00
2.36	98.95	100.00
1.18	88.42	100.00
0.6	39.37	76.55
0.3	10.42	21.81
0.15	1.47	11.14
0.075	0.00	1.12
Pan	0.00	0.00

Source: laboratory test results

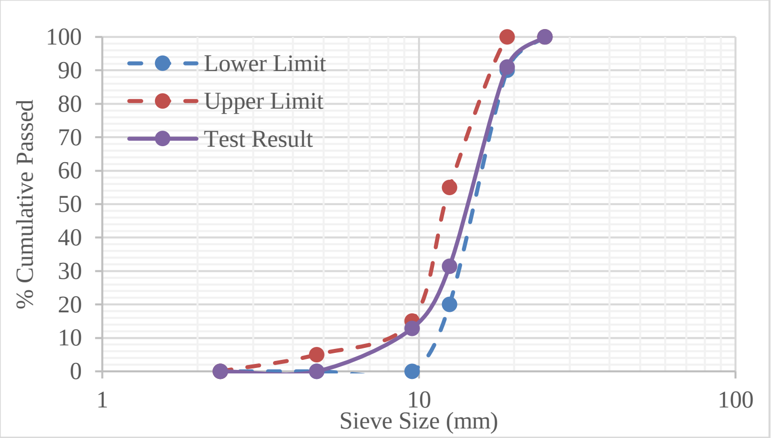


Figure 1. Coarse aggregate gradation results

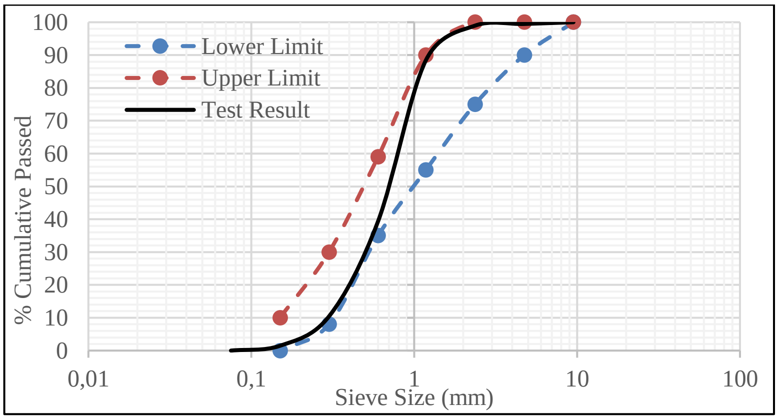
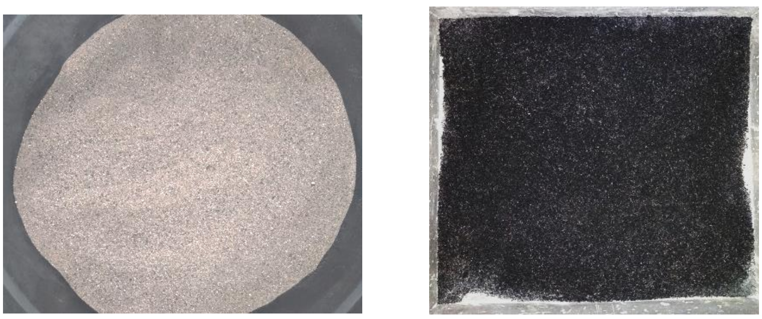


Figure 2. Results of fine aggregate gradation

The changes and quantity of test objects used to get information on concrete's flexural and compressive strengths are displayed in Table 2. There are 6 types of test object samples made, namely: (1) Normal concrete for compressive strength (BN-KTB), (2) Normal concrete for flexural strength (BL-KT), (3) Concrete + 25% crumb rubber + 15% fly ash for compressive strength (BR-25CR-KTB), (4) Concrete + 25% crumb rubber + 15% fly ash for flexural strength (BR-25CR-KT), (5) Concrete + 50% crumb rubber + 15% fly ash for compressive strength (BR-50CR-KTB), and (6) Concrete + 50% crumb rubber + 15% fly ash for flexural strength (BR-50CR-KT). There are 16 cylindrical samples were used for each modification in the compressive strength test of the concrete. In the meantime, three units in the form of 28-day-old beams were tested for each change to determine the flexural strength of the beam. The two-point loading type used in the beam flexural strength test is in accordance with SNI 03-4431-1997 [17].

Table 2. Number of samples created

No.	Sample Codes	Information of sample	Number of Test				
			3 days	7 days	14 days	21 days	28 days
1	BN-KTB	Normal concrete for compressive strength	3	3	3	3	7
2	BL-KT	Normal concrete for flexural strength	-	-	-	-	3
3	BR-25CR-KTB	Concrete + 25% crumb rubber + 15% fly ash for compressive strength	3	3	3	3	7
4	BR-25CR-KT	Concrete + 25% crumb rubber + 15% fly ash for flexural strength	-	-	-	-	3
5	BR-50CR-KTB	Concrete + 50% crumb rubber + 15% fly ash for compressive strength	3	3	3	3	7
6	BR-50CR-KT	Concrete + 50% crumb rubber + 15% fly ash for flexural strength	-	-	-	-	3
Total sample			9	9	9	9	30



(a) **(b)**

Figure 3. (a) Sand material and (b) crumb rubber material

Figure 4. Fly ash from PT. Pusri

3. RESULTS AND DISCUSSION

The test results obtained were in the form of material characteristics testing, concrete mix planning, concrete compressive strength test results and concrete flexural strength test results.

3.1. Aggregate Characteristics Test Results

The outcomes of testing the properties of fine and coarse aggregate are shown in Tables 3 and 4. While the coarse aggregate test results in Table 4 also meet the specifications, the fine aggregate test results in Table 3 meet the requirements in the used specifications. Calculations for concrete mix planning will be made using the findings of these characteristic tests. The results of evaluating crumb rubber particles with the SNI 1964-2008 method are shown in Table 5. The specific gravity of crumb rubber was found to be less than that of fine aggregate SSD, with an average specific gravity value of 0.628, according to these data. The specific gravity of fine aggregate and crumb rubber are comparable at about 1:3.99, which means that 3.99 grams of crumb rubber weighs the same as 1 gram of sand. Calculating the weight of crumb rubber in the concrete mixture involves using this comparison.

Table 3. Results of testing the characteristics of fine aggregate (sand)

No	Testing	Test Result	Requirement	Test Method
1	Mud Content	1.93%	Max 3%	ASTM C-40-92
2	Organic Substance Content	Murky	Yellow	ASTM C-40
3	Specific Gravity		-	
	a. Dry specific gravity	2.47	-	ASTM C-128-93
	b. Saturated surface dry (SSD)	2.51	-	
	c. Apparent specific gravity	2.57	-	
4	Volume weight	1.364 gr/cm^3	-	ASTM C-29/29M-91a
5	Water content	8.01 %	-	-
8	Water Absorption	1.57 %	-	ASTM C-128-93
9	Fineness Modulus	2.62	1.3 – 3.1	ASTM C-33

Table 4. Results of testing characteristics of coarse aggregate (split)

No	Testing	Test Result	Requirement	Test Method
1	Dry specific gravity	2.44		
2	Saturated surface dry (SSD)	2.51	-	ASTM C-127-68
3	Apparent specific gravity	2.62		

4	Volume weight	1.69 gr/cm^3	-	ASTM C-29/29M-91a
5	Water content	1.1 %	-	-
6	Water Absorption	2.83 %	-	ASTM C-128-93
7	Wear	11.7 %	Max 40%	ASTM C-31-69
8	Aggregate Impact Value	13.2	Max 30%	BS 812: part 3: 1975

Table 5. Crumb Rubber specific gravity test results

Information	Notation	Test Result-1	Test Result-2
Picno weight + sample	W2	34.5	55.2
Picno weight	W1	24.5	45.2
Sample weight	Wt = W2-W1	10	10
Picno weight + sample+water	W3	120.3	137.6
Picno weight +water	W4	123.9	146.8
	W5 = Wt + W4	133.9	156.8
Volume sample	W5-W3	13.6	19.2
Specific gravity	Wt / (Wt+W4-W3)	0.735	0.521
Avg. Specific gravity		0.628	

3.2. Concrete Mix Design Results

The design of the concrete mix refers to the SNI 03-2834-2000 method, where the design quality of the concrete is 20 MPa and the design slump is 25–100 mm, with construction types such as plates, beams, columns, and walls.

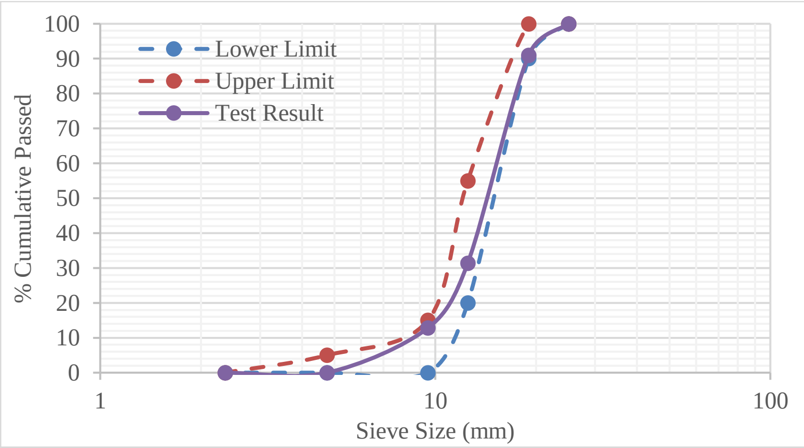


Figure 5. Gradation plan for coarse aggregate

Table 6 is the result of calculating the concrete mix design for each m^3, where the amount of cement required is 325 kg, sand is 655.5 kg, coarse aggregate is 1069.5 kg, and water is 225 liters. The weight of 25% of the sand, or 655.5 kg x 25% = 163,875 kg, can be used to calculate the weight of the crumb rubber that was used. Next, a conversion based on the specific gravity ratio of sand to crumb rubber (1: 3.99) is performed to obtain a quantity of 41 kg of crumb rubber. This calculation is also done for concrete mixtures that contain half of crumb rubber. As a substitute, the weight of fly ash is determined to be 15% of the weight of cement. The intended coarse aggregate gradation in the concrete mixture is shown in Figure 5, where the gradation boundaries are based on ASTM C-33 and the coarse aggregate size is less than 20 mm.

Table 6. Results of concrete mix design

No.	Design plan	Normal Concrete (BN)	BR-25CR	BR-50CR
1	Design Quality (MPa)	20	20	20
2	Slump (mm)	25 -100	25 -100	25 -100
3	Cement (kg/m^3)	325	276.25	276.25
4	Sand (kg/m^3)	655.5	491.63	327.75
5	Split (kg/m^3)	1069.5	1069.5	1069.5
6	Water (lt/m^3)	225	225	225
7	Crumb Rubber (kg/m^3)	-	41	82
8	Fly Ash (kg/m^3)	-	48.75	48.75

3.3. Concrete Compressive Strength Test Results

Compression test equipment is used to measure the compressive strength of concrete at a rate of 2 to 4 kg/cm^2 per second. The concrete sample, which is in the shape of a cylinder, is first weighed to obtain the concrete density result before evaluating the compressive strength of the material (Figure 6). Figure 7 displays the results of the concrete density calculation. After 28 days, the density of normal concrete (BN-KTB) is 2341.75 kg/m^3. In contrast, concrete that contains a 25% substitute for crumb rubber loses 8.63% of its density, while concrete that contains a 50% substitute for crumb rubber loses 15.92% of its weight. This demonstrates that the concrete gets lighter the more crumb rubber is utilized.

Figure 6. Concrete compressive strength testing in the laboratory

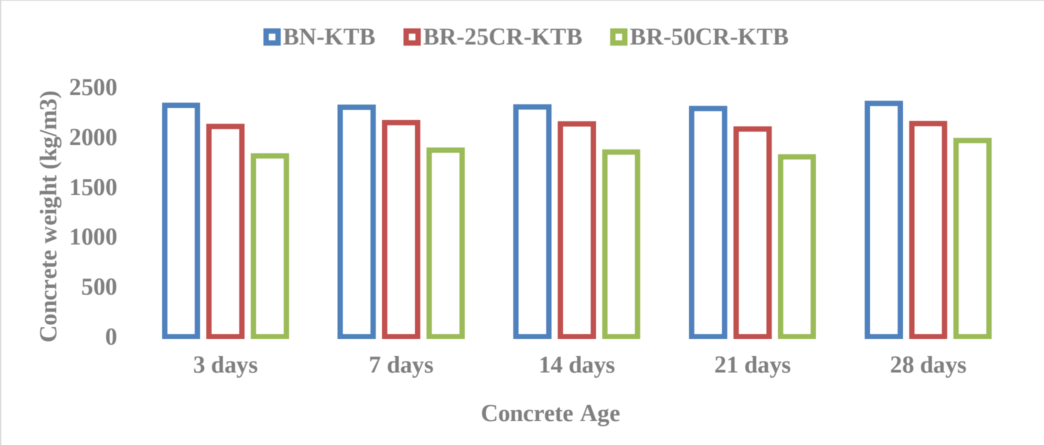


Figure 7. Results of calculating the density of concrete

The concrete compressive strength test results for a range of combinations with curing durations varying from 3 days to 28 days are shown in Figure 8. Figure 8 illustrates how concrete that substitutes crumb rubber for normal concrete has a lower compressive strength value. While concrete with 25% and 50% substitute has a compressive strength of 10.95 MPa and 5.66 MPa, respectively, normal concrete that has been aged for 28 days has a strength of 26.61 MPa. This indicates a 58.85% reduction in BR-25CR-KTB concrete and a 78.73% reduction in BR-50CR-KTB concrete. The study's findings concur with those of Abbara et al. (2022) [18], that indicate that this reduction may occur by 32% to 57%. Reducing the bulk weight and compressive strength of concrete can be achieved by substituting too much crumb rubber. Because perfect bonding between the crumb rubber particles and the cement and water, the particles that make up concrete, does not occur, causing a loss in the concrete's compressive strength. When concrete undergoes exposure to pressure, the stress spreads through the aggregate and mortar until, at a certain pressure, the mortar cracks before the aggregate does, making the concrete incapable of withstanding the pressure.

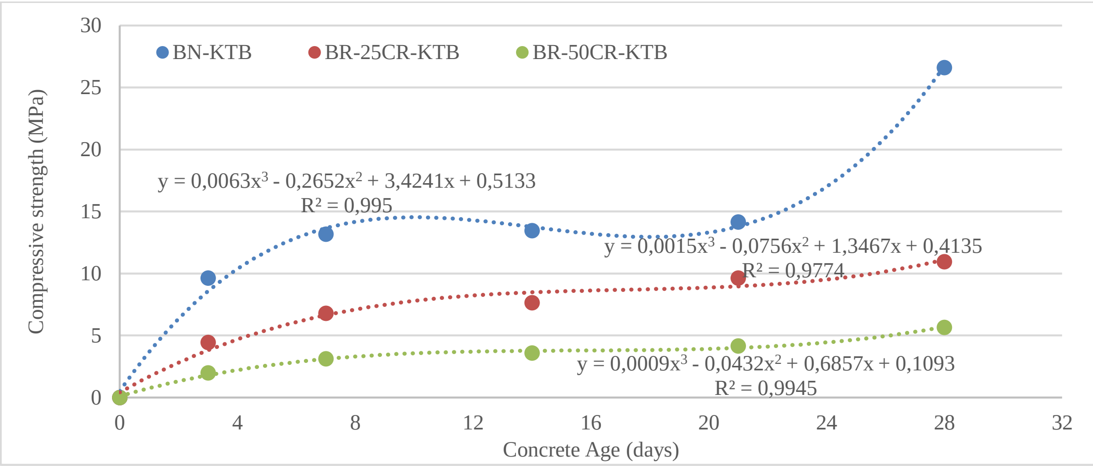


Figure 8. Test results for concrete compressive strength

The crack patterns found in samples BR-25CR-KTB and BR-50CR-KTB are shown in Figure 9, which displays the findings of tests conducted on the compressive strength of concrete. The two samples create different crack patterns, indicating various results. Whereas the crack pattern on BR-25CR-KTB is almost parallel to the sample height, indicating that the stress only spreads in one direction, the crack pattern on BR-50CR-KTB is spread in all directions, indicating that the stress spreads evenly where the mortar and aggregate are able to withstand the pressure applied. only one way and doesn't disperse elsewhere. Because of this, the concrete in BR-50CR-KTB has a very low compressive strength rating when compared to other samples. Another indication is that when testing the compressive strength of the BR-50CR-KTB concrete sample, water was released from the concrete sample when the compressive force was applied. This indicates that the presence of crumb rubber can inhibit the concrete hydration process where water is trapped and does not react to form CSH bonds.

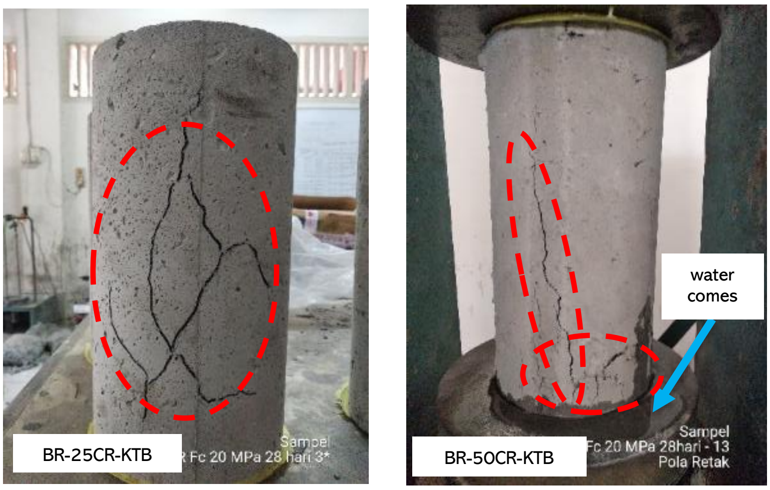


Figure 9. Crack pattern from concrete compressive strength testing

A concrete sample that was 28 days old was disassembled to reveal the sample's interior structure in order to provide evidence for the reason why the compressive strength value of concrete employing crumb rubber decreased. The structure in the broken concrete samples BR-25CR-KTB and BR-50CR-KTB is shown in Figure 10, where it is evident that the crumb rubber particles have been mixed into and distributed throughout the concrete as well as integrated with the mortar. The BR-50CR-KTB sample, however, found that the mortar was extremely fragile and easily broken by hand following identification. The destruction of the mortar is due to the obstruction of the hydration process in the concrete because water is trapped by the crumb rubber particles which are unable to absorb water so that the mortar forms many pores so that it becomes brittle. This observation aligns with the findings of studies by Huang et al. (2020) [19] and Chen et al. (2022) [20], in which microstructural testing using SEM revealed numerous holes in the concrete and inadequate bonds between the crumb rubber. Because of this, fissures in the concrete are immediately visible with mortar (Figure 11). Additionally, Figure 11 demonstrates that there is a space between the mortar and the crumb rubber particles because the crumb rubber's surface is not filled.

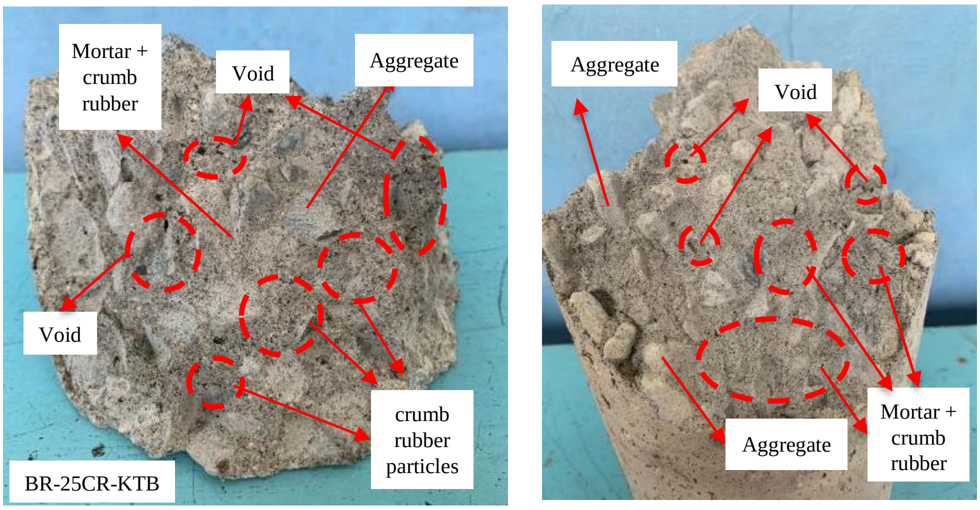
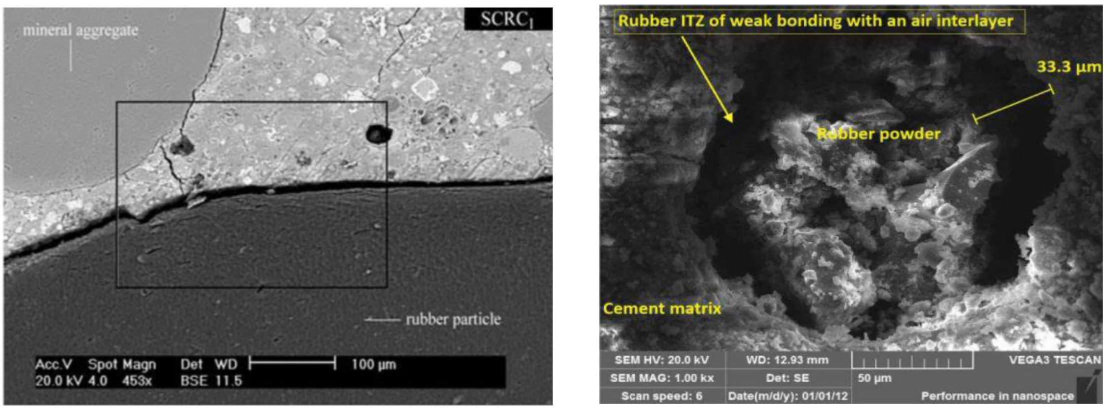


Figure 10. Shape of fractions in the sample



(a) **(b)**

Figure 11. Identification of rubber concrete microstructure (a) Huang, et al (2020) [19] and (b) by Chen, et al (2022) [20].

3.4. Test results for concrete flexural strength

Flexural strength, which is determined by loading a concrete test object that is placed horizontally on the pressing table of the testing machine as represented in Figure 12 [21], is the value of the indirect tensile strength of the test object, which is a block measuring 15 x 15 x 60 cm. The concrete flexural strength test results are displayed in Figure 12, with the calculation results referencing SNI 03-4431-1997. Concrete that uses crumb rubber has the potential to reduce flexural strength when compared to normal concrete; this reduction was obtained by 49.23% for 25% crumb rubber (BR-25CR-KT) and 23.66% for 50% crumb rubber (BR-50CR-KT). This shows that the use of 50% crumb rubber is better than 25% crumb rubber, which means that the crumb rubber particles are able to withstand the bending moment given by the load. According to Roychand et al. (2020) [12], crumb rubber performs better when it comes to giving concrete a high flexural strength. The test object for flexural strength, demonstrated in Figure 14, failed in the middle region at a distance of one-third from the placement point. In comparison to BR-50CR-KT, BR-25CR-KT exhibits a crack pattern that is farther from the center. This indicates that 50% of the crumb rubber particles dispersed in the concrete mortar are strong enough to survive the bending tension applied to it, causing a crack pattern to emerge in the central region beam.

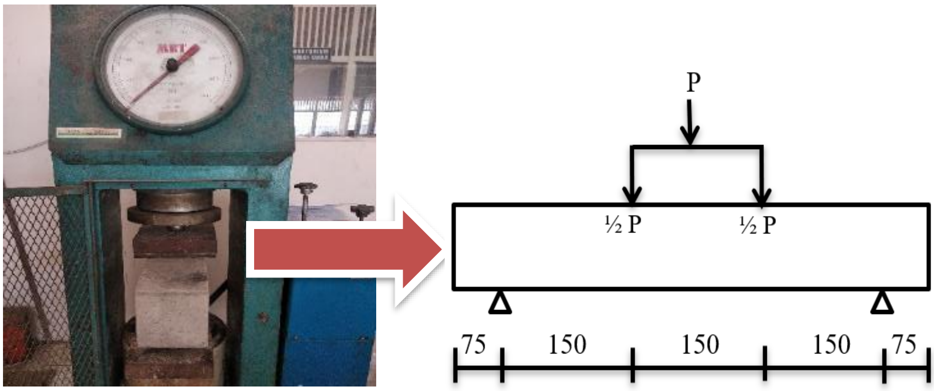


Figure 12. Testing concrete flexural strength in the laboratory

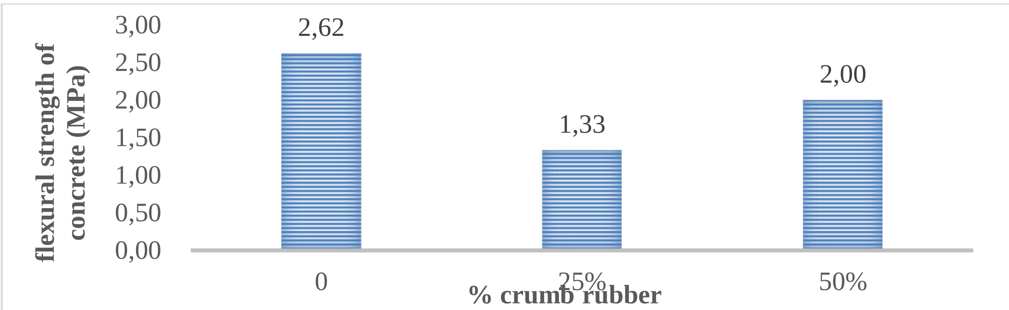
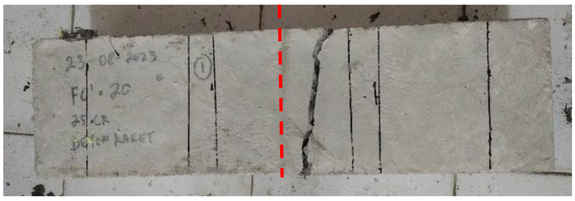


Figure 13. Test results for concrete flexural strength



(a)

(b)

Figure 14. Crack patterns in the results of concrete flexural strength tests (a) BR-25CR-KT and (b) BR-50CR-KT

4. CONCLUSION

Research regarding the effect of using crumb rubber as a substitute for fine aggregate in concrete mixtures has been completed using the method described. Based on the results of the analysis and discussion, it was found that when compared with normal concrete, the weight of the concrete can be decreased by 8.63% for an amount of 25% and 15.92% for a grade of 50% by substituting crumb rubber for fine aggregate. This demonstrates that the ability to lower the weight of the concrete increases with the amount of crumb rubber employed. The compressive strength values of concrete with 25% and 50% content, respectively, decreased when crumb rubber was used as a substitute of fine aggregate, according to the findings of tests conducted on the material. This demonstrates that non-structural concrete can be made using concrete combined with crumb rubber. According to visual results, excessive amounts of crumb rubber can make concrete mortar brittle. This is because the excessive amounts of crumb rubber are unable to interact well with the mortar, preventing the formation of solid bonds between the aggregate, mortar, and crumb rubber particles. The flexural strength of the concrete decreases by 49.23% at a 25% crumb rubber content and by 23.66% at a 50% crumb rubber content, according to the results of the test.

ACKNOWLEDGEMENT

The author would like to thank the Yayasan Pendidikan Nasional Tridinanti (YPNT) for being awarded a research grant in 2023 with contract number: 091/Unanti.A12/LPPM/PI/2023.

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