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Flexural toughness of concrete with aggregate substitution (steel fiber, crumb rubber and tire chips)

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Abstract. Concrete is a construction material that has been used widely in various constructions. For constructions located in seismic areas, require a material that behaves ductile during an earthquake. To obtain ductile concrete behavior, it can be substituted materials such as steel fiber and waste rubber tires. This study aims to determine the flexural toughness of concrete with steel fiber and waste rubber tires substitution. Specimens with dimensions of 100 x 100 x 400 mm with the substitution of 0%, 2.5%, 5%, and 7.5% of Dramix Steel Fiber; 10%, 20%, and 30% of crumb rubber and tire chips. The greater amount of steel fibers in the concrete, the greater value of flexural toughness. The substitution of 7.5% steel fiber, increasing the value of flexural toughness three times than the control specimens. While the number of crumb rubber and tire chips are variations, giving a value of varying flexural toughness. Flexural toughness achieved optimum value for substitution of 10% crumb rubber, where the energy absorption is 6386.225 Nmm.

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1. Introduction

Concrete is a construction material that has been used widely in various constructions. For construction located in earthquake-prone areas, it requires content that can create plastic concrete mechanisms before the collapse. It is intended in the event of the collapse of the concrete. The concrete is still able to withstand the load continuously even though conditions in the crack, so it is still possible to do a rescue act. Therefore, need a way to handle the problem such as by adding reinforcement or using substitute materials to reduce the brittle nature of concrete.

Material substitution is a material that can replace concrete material either coarse aggregate, fine aggregate, cement and other materials such as steel fibers, inorganic waste and others. Steel fiber is a fiber that is produced through the process of withdrawal (cold drawn) with grooves on the end that provide optimal bonding to the concrete. The addition of angled steel fibers into the concrete provides ductility and high load bearing capacity. It also provides resistance to cracking, energy absorption, resistance to impact, a quick and easy application and solutions that are much more effective and economical.

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The use of solid waste as a substitute for concrete aggregate in recent years has increased as a promising solution for reducing solid waste is inorganic. One of inorganic waste is waste rubber tires. Scrap tire rubber is a waste of a motor vehicle wheel of a car or truck. This waste is growing every year, in European scrap tires in 2004 reached 3:25 million tons per year, whereas in the United States

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in 2003 approximately 3.75 million tons per year and in Japan in 2004, around 1 million tons per year [1] so that should be utilized as concrete material. The use of rubber waste in construction, such as [2]:

- In locations requiring anchoring vibration such as the foundation for the machine that possess high vibration
- In locations that are resistant to strong shocks
- Can be applied as retaining an earthquake, but further research is still needed.

To overcome the continuous dumping of waste material, this research also uses Portland Composite Cement. Fly ash is an environmental pollutant industrial which is a by-product from coal-fired power plants. Some cement factories undertake a project to produce the blended cement containing fly ash cement to reduce CO₂ emissions from the production of cement clinker, to reduce the consumption of raw materials such as limestone and clay, and to contribute a cleaner environment through the recycling of waste materials such as fly ash. The incorporation of fly ash in blended cement such as Portland composite cement achieves ecological benefit and material saving [3].

According to Balaguru and P. Shah [4], the main reason for the addition of fiber in the concrete is to increase the energy absorption capacity of the matrix, which can be determined on the area under the stress-strain curve or behavior in relation load and deflection of an element or commonly called flexural toughness. Meanwhile, with the addition of waste tire rubber can improve the performance of concrete. The performance improvements such as better impact resistance, improved tensile strength, concrete ability to dampen vibration waves, down the nature of heat/noise, and increase resistance to aggressive materials (acidity and salt).

Based on the description above, by utilizing the advantages of each material, the study aims to determine the flexural toughness of concrete with steel fiber and waste rubber tires substitution. In the case of bending, the area under the load-deformation curve was used to estimate the energy absorption capacity or toughness of the material. Increased toughness also means improved performance on fatigue, impact and impulse loads.

2. Experimental programme

A laboratory study was undertaken to determine the flexural toughness of concrete with steel fiber, crumb rubber and tire chips.

2.1. Materials used

Portland Composite Cement (PCC) conforming to SNI 15-7064-2004 from a single lot was used for the entire investigation. Portland composite cement used in this paper is produced by Indonesia cement manufacture and readily available on the market.

Crushed stone (maximum size of 20 mm, fineness modulus of 6.61) and river sand (fineness modulus of 2.56) conforming to SNI 03-1968-1990 were used as coarse aggregate and fine aggregate, respectively. Table 1 shows the physical properties of the aggregate.

Table 1. Physical properties of aggregates.

Property	Crushed Stone	River Sand
Specific Gravity	Oven Dry	2.61
	Saturated Surface Dry	2.64
Water absorption, %	1.21	1.01

Type of steel fiber used in this study is Dramix Steel Fiber manufactured by companies Bakaert Belgium. Dramix Steel Fiber has a length of 60 mm, a diameter of 0.75 mm and an aspect ratio of 80 with a Young's Modulus of $\pm 210\,000$ N / mm. Minimum dosage dramix steel fiber is 10 kg per m³.

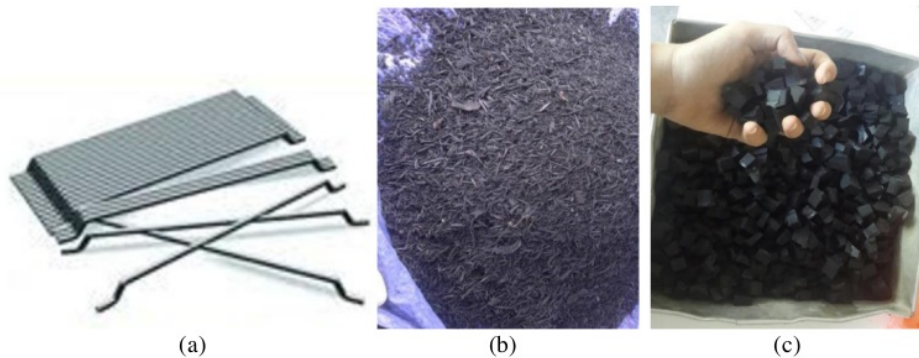


Figure 1. (a) Dramix Steel Fiber, (b) Crumb Rubber and (c) Tire Chips.

Tire Chips serves as a substitute for coarse aggregate. To get this kind of rubber waste, required cutting rubber tire former two-time process, all of which was done by using cutting machines. In the process of cutting the rubber is first obtained measure 300-430 mm. In the second process shrink to 100 -150 mm. Then do cutting process with the cutting machine to obtain Tire Chips sizes range between 13-76 mm.

Crumb Rubber⁸ serves as a replacement of fine aggregate. Where the crumb rubber particle size ranging from 4.75 mm (sieve No. 4) to less than 0.075 mm (sieve No. 200). Crumb Rubber is processed using a particular machine where the rubber⁹ tires are still large sized converted into small pieces. There are three methods used for making Crumb Rubber, namely cracker mill process, granular process, micro mill process. Each of these methods produces crumb rubber size different. Micro mill process to produce crumb rubber measuring 0.075 to 0.475 mm.

2.2. Variables of the study

Three types of concrete mix design, as shown in Tables 2 and 3. The concrete variables as follows:

- Coarse aggregate substitution by dramix steel fiber amounted to 2.5%, 5% and 7.5%
- Coarse aggregate substitution by crumb rubber amounted to 10%, 20% and 30%
- Fine aggregate substitution by tyre chips amounted to 10%, 20% and 30%

Table 2. Mix design of steel fiber concrete (kg/m³).

Type of concrete	Normal Concrete	Dramix Concrete 2.5%	Dramix Concrete 5%	Dramix Concrete 7.5%
Water	197.63	197.63	197.63	197.63
Cement	427.08	427.08	427.08	427.08
Fine aggregate	646.44	646.44	646.44	646.44
Coarse aggregate	1022.65	1019.05	1015.55	1011.84
Dramix steel fiber	-	10.68	21.35	32.03

Table 3. Mix design of rubberized concrete (kg/m³).

Type of concrete	Normal Concrete	Crumb Rubber Concrete 10%	Crumb Rubber Concrete 20%	Crumb Rubber Concrete 30%	Tire Chips Concrete 10%	Tire Chips Concrete 20%	Tire Chips Concrete 30%
Materials	(NC)	(NCR-10)	(NCR-20)	(NCR-30)	(NTC-10)	(NTC-20)	(NTC-30)
Water	230.82	230.82	230.82	230.82	230.82	230.82	230.82
Cement	450	450	450	450	450	450	450
Fine aggregate	547.36	492.62	437.88	383.15	547.36	547.36	547.36
Coarse aggregate	931.58	931.58	931.58	931.58	838.42	745.26	652.10
Crumb rubber	-	20.72	41.45	62.17	-	-	-
Tire Chips	-	-	-	-	42.57	85.14	127.71

The prism size of 100 x 100 x 400 mm³ was prepared for bending test. The number of samples at each testing age was three. The specimens were demoulded after 24h and immersed curing in freshwater at 27°C until 28 days for testing. Prism tests conducted with the static load by two points loading until the prism collapsed. For deflection measurements was performed by installing LVDT (Linear Variable Displacement Transducer) at bottom midspan beam for two positions, as shown in figure 2.

**Figure 2.** Two-point bending test.

2.3. Method for Determining Flexural Toughness

As reported by ACI Committee 544 on Fiber Reinforced Concrete, the appropriate way to determine the toughness indexes is with the following ratios;

$$It = \frac{\text{area under the load - deflection graph until the load reaches zero for fiber composite}}{\text{area under the load - deflection graph until it reaches zero load to plain matrix}}$$

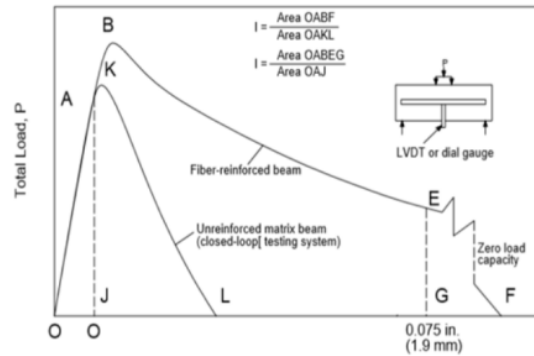


Figure 3. The definition of toughness and toughness indices according to ACI [4].

3. Results and discussion

Overall, the relationship between load and deflection shows tend to form a linear line. This is due to the higher the load applied, the greater the deflection value until it reaches the maximum bending conditions before the sample finally collapsed. Table 4 shows the bending test result for all variation.

In this study, specimens control and rubberized concrete showed no crack when carrying the load and immediately fracture. This indicates that the test specimen is brittle. Whereas for steel fiber specimen showed cracks and no fracture that indicate the test specimen is ductile.

Table 4. Modulus of rupture.

Age (day)	Modulus of Rupture (N/mm ²)										
	Dramix Steel Fiber				Rubberized Concrete						
	NC	2.5%	5%	7.5%	NC	Crumb Rubber			Tire Chips		
						10%	20%	30%	10%	20%	30%
28	3,516	3,748	3,904	4,738	3,192	3,735	3,237	3,270	2,769	1,917	1,980
	3,346		4,461	4,936	3,713	3,663	3,639	2,727	3,063	2,796	1,752
	3,381	3,747	4,367	4,086	3,211	3,690	2,664	3,009	2,837	2,712	2,142
Average	3,414	3,747	4,244	4,586	3,318	3,696	3,18	3,002	2,889	2,475	1,958

Table 5. Correlation between load, deflection and flexural toughness.

Variation	Sample 1			Sample 2			Sample 3		
	Load	Deflection	Flexural	Load	Deflection	Flexural	Load	Deflection	Flexural
	N	mm	toughness	N	mm	toughness	N	mm	toughness
Normal Dramix	11720	0.399	2173.21	11156	0.157	2134.68	11270	0.455	2148.25
Dramix 2.5%	12494	0.601	3966.51				12490	0.655	3887.96
Dramix 5%	13014	0.663	4320.06	14870	0.597	4245.88	14557	0.61	4398.80
Dramix 7.5%	15794	1.066	6527.67	16454	0.76	6759.34	13621	0.772	6516.60
Normal Rubber	10640	1.072	4343.79	12378	0.824	4352.48	10704	0.618	4406.58
Crumb Rubber 10%	12450	1.072	6479.68	12210	0.935	6213.12	12300	1.102	6294.73
Crumb Rubber 20%	10790	0.674	3348.35	12130	0.63	3501.85	8880	0.59	3334.38
Crumb Rubber 30%	10900	0.656	3241.26	9090	0.564	3223.36	10030	0.694	3219.16
Tire Chips 10%	10290	0.994	4277.77	12480	0.952	4218.65	9920	0.868	4258.18
Tire Chips 20%	6390	0.628	2881.29	9320	0.742	2770.82	9040	0.662	2857.44
Tire Chips 30%	6600	0.656	2139.15	5840	0.612	2121.06	7140	0.689	2196.88

Flexural toughness, with the addition of dramix steel fiber up to 7.5% in the concrete are shown in figure 4. The larger volume of dramix steel fibers in the concrete, the greater energy absorption (flexural toughness). But the addition of Dramix 2.5% and 5% did not significantly increase the

energy absorption. This is because more and more fiber in the cracked regions will increasingly provide resistance to cracking itself until fiber break or detached from the mortar. The substitution of 7.5% steel fiber, increasing the value of flexural toughness three times than the control specimens.

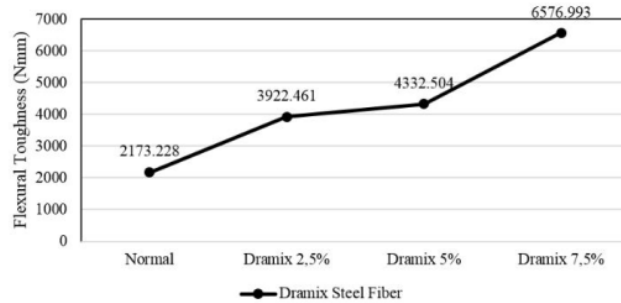


Figure 4. The flexural toughness of dramix steel fiber.

Energy absorption has decreased with the normal concrete to substitution crumb rubber 20% and 30%. Variations in concrete with the addition of tire chips, energy absorption, continued to decline compared with normal concrete. It can be concluded that the optimal energy absorption of rubberized concrete contained in the variation of 10% crumb rubber and the greater the volume of tire chips in the concrete the smaller the energy absorption (flexural toughness) as presented in figure 5. This is because of the dimensions of crumb rubber and tire chips. Crumb rubber has an elongated shape such as fibers which can withstand more tensile strength while tire chips have a shape which resembles coarse aggregate contribution to withstand tensile strength is very small.

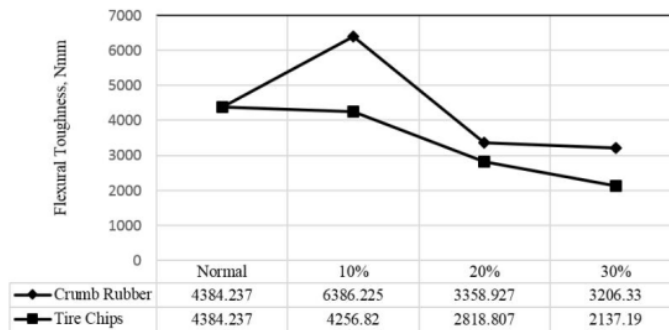


Figure 5. The flexural toughness of rubberized concrete.

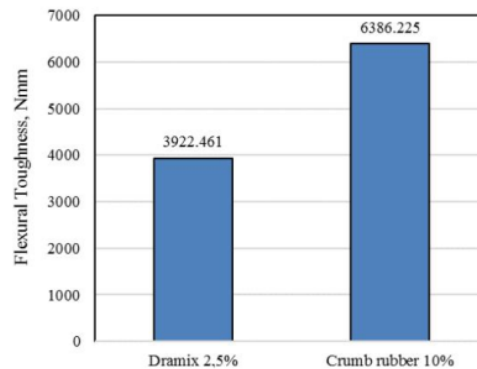


Figure 6. Comparison flexural toughness between dramix 2.5% and crumb rubber 10%.

From a variety of concrete were observed, data described in Tabel 4 and Figure 6 that the concrete with dramix steel fiber of 2.5% and 10% crumb rubber has the same flexural strength, i.e. 3.7 N/mm². The use of crumb rubber 10% resulted in energy absorption (toughness flexural) greater than dramix steel fiber concrete, whereby energy absorption at 2.5% dramix is 3922.461 Nmm and 10% crumb rubber is 6386.225 Nmm.

During testing flexural strength, also observed a pattern collapse occurs. All samples showed the collapse that occurred in the third midspan. This indicates that the test specimen can withstand bending loads and does not cause shear failure.

4. Conclusion

The interim results showed that the greater amount of steel fibers in the concrete, the greater value of flexural toughness. The substitution of 7.5% steel fiber, increasing the value of flexural toughness three times than the normal concrete specimens. Moreover, the optimal energy absorption of rubberized concrete is achieved with 10% crumb rubber. On the other hand, the greater the volume of tire chips/crumb rubber in the concrete, the smaller the energy absorption (flexural toughness) is generated.

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