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EXPERIMENTAL INVESTIGATION ON THE USE OF CRUMB RUBBER AS PARTIAL REPLACEMENT OF COARSE AGGREGATE IN CONCRETE INCORPORATING CEMENT REPLACEMENT MATERIALS

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ABSTRACT: Concrete is a material widely used in building construction, which has several characteristics, including its ease of casting and high compressive strength. Concrete mixed with scrap used tires is expected to reduce the density of concrete and produce low-cost concrete. While waste from used tire material is very easy to find, this material is difficult to decompose naturally. This study aims to investigate the effect of using crumb rubber as a partial substitution of coarse aggregates to mechanical properties of concrete incorporating cement replacement materials, such as fly ash and silica fume. Test specimens are cylinders with a diameter of 15 cm and a height of 30 cm, with variations in the addition of the crumb rubber by 5%, 10%, 15%, and 20% of the volume of coarse aggregate. The target of concrete quality (f'c) is 25 MPa at the age of 28 days. The crumb rubber concrete is tested for slump, compressive strength, and tensile strength. The results show that the slump of crumb rubber concrete decreases with the increase in crumb rubber content. In addition, the use of crumb rubber as partial replacement of coarse aggregate in normal concrete, fly ash concrete, and silica fume concrete decreases the engineering properties such as compressive and tensile strength.

Keywords: Concrete, Crumb Rubber, Fly Ash, Silica Fume, Concrete Properties

1. INTRODUCTION

Waste tires are the largest contributor of waste in the world. They are made up of materials that cannot be decomposed by organisms (non-biodegradable) and that are persistent and will not rot. In Indonesia, scrap tires are widely available and easy to find [1]. In addition, the number of motorized vehicles in Indonesia increases in number, resulting in a significant increase in scrap tires. These waste tires must be handled properly and immediately. If waste from rubber tires continues to be left without reuse, it will have a negative impact on the environment.

Some ways to manage this waste tire include burning (vulcanized) or recycling it into rubber powder. In addition, the new utilization of waste tires is to substitute material for coarse aggregates in concrete mixtures. Scrap tires are cut into small pieces and are then mixed into a concrete mixture to be used as the partial replacement of the coarse aggregate. The use of waste rubber tire pieces in this concrete is expected to produce low-cost concrete with an acceptable strength of the concrete.

The experimental study [2] attempted to know about the mechanical properties of rubberized concrete with and without fly ash. The result showed a big difference in the properties of both the rubberized concretes. The compressive strength and tensile strength of fly ash rubberized concrete were higher than those of normal rubberized concrete.

The waste tire is grinded and reduced into smaller particles before replacing aggregate in concrete. Mechanical grinding at ambient is used to produce chipped rubber, which is used as coarse aggregate [3]. The waste tire has been used as crumb rubber to partially replace fine aggregate in concrete [4,5]. However, few cases show where waste tires are used in the form of chips to replace coarse aggregate in concrete due to the high reduction in strength [6,7].

Many researchers have explored the effect and optimal use of crumb rubber as coarse aggregate replacement in normal concrete. However, the effect and optimal use of crumb rubber as coarse aggregate replacement in fly ash concrete and silica fume concrete have never been previously studied.

The addition of crumb rubber to the concrete mixture decreases density because cavities emerge with the increase of crumb rubber. To deal with this, a pozzolanic material such as fly ash is needed to help reduce the cavities in the crumb rubber concrete mixture. Currently, the number of fly ash in Indonesia continues to grow in line with the development and growth of the manufacturing industry as well as the increasing need for electricity supplied by coal-fired power plants. Fly ash produced from coal-fired power plants alone in 2021 is estimated to reach 12 million tons, and in 2027, it is projected to reach 16.2 million tons [8]. The use of high volumes of fly ash and other supplementary cementing materials in construction reduces the production cost of concrete [9].

Another additional pretreatment to reduce the cost of production is with chemicals such as magnesium oxychloride cement and Portland cement blended with slag and silica fume. The use of silica fume results in high resistance to sulfates, acids, and chlorides. Silica fume is incorporated to provide a denser interface between the cement paste and rubber aggregate [10]. The study shows that the mechanical properties of concrete containing rubber aggregate are enhanced, and the rate of strength loss is diminished by silica fume addition.

Previous studies revealed that the use of recycled waste in the production of new concrete raises significant concerns about the quality of the concrete produced. To maintain the desired mechanical properties, the strengthened methods were used, such as hemp fiber rope (HFR) [11], glass fiber chopped strand mat (FCSM) sheets [12], hemp-fiber-reinforced polymer (HFRP) composites [13], and comparison LC-GFRP (low-cost glass-fiber-reinforced polymer) with carbon/sisal fiber-reinforced polymer [14].

This study shows that an alternative way of recycling tires by incorporating them into concrete based on evidence gathered from published literature. This study aims to investigate the effect and the optimal use of crumb rubber as coarse aggregate replacement in normal concrete, fly ash concrete, and silica fume concrete.

2. RESEARCH SIGNIFICANCE

Currently, the increasing use of used tire rubber is an environmental problem and there are not many effective methods to recycle this waste. The finding of this study can be used as a reference to produce economical crumb rubber concrete as compared to ordinary concrete with an optimum proportion of crumb rubber and additional cement replacement materials. The low-cost concrete was obtained because this concrete used the products of waste tire that are cheap, even cost-free. This study can also be used as balancing the desired mechanical properties with the sustainability benefits of using waste tire is a key consideration in the development of the use of crumb rubber as partial replacement of coarse aggregate in concrete.

3. MATERIAL

3.1 Cement

The cement used in this study was Ordinary Portland Cement (OPC) produced by PT Semen Padang in Indonesia.

3.2 Coarse Aggregate

Coarse aggregate is the crushed stone used for making concrete. The aggregate used was local aggregate with a maximum size of 20 mm. The properties of coarse aggregate are given in Table 1.

Table 1 Properties of coarse aggregate

No	Parameter	Value
1	Specific Gravity	2.41
2	Absorption	5.9 %
3	Fine Modulus (FM)	3.40
4	Water Content	1.99 %

3.3 Fine Aggregate

Fine aggregate/sand is an accumulation of grains of mineral matter derived from the disintegration of rocks. It is distinguished from gravel only by the size of the grains or particles but is distinct from clays, which contain organic materials. For this study, fine aggregate used was locally available aggregate with a size of less than 4.75 mm, as shown in Table 2.

Table 2 Properties of fine aggregate

No	Parameter	Value
1	Specific Gravity	2.54
2	Absorption	3.0 %
3	Fine Modulus (FM)	2.85
4	Water Content	1.83 %

3.4 Water

The water used for the mixture and curing of concrete was fresh potable water, which was free from acid and organic.

3.5 Rubber Aggregates

The absorption of natural rubber by the domestic industry in 2019 was 659,754 tons, and the tire industry was the industry that absorbed the most natural rubber with a composition of 42%, followed by tire retreading (16%) and footwear (14%) [15]. The material is obtained from recycled tires, which are manually cut first before it is manufactured by specific mills where big rubbers are turned into smaller torn particles (crumb rubber) with a maximum size of 20 mm, as shown in Fig.1.

In this study, the variation of 5%, 10%, 15%, and 20% crumb rubber was used as a partial replacement of coarse aggregate volume in the concrete. Properties of rubber aggregate are detailed in Table 3.

Fig.1 Crumb rubber used in the experiment

Table 3 Properties of rubber aggregate

No	Parameter	Value
1	Specific Gravity	0.73
2	Absorption	0 %
3	Bulk Density	0.5283 g/cc

3.6 Silica Fume

Silica fume (SF) is highly reactive due to its high proportion of nanocrystalline SiO_2 and the large surface area. Previous research [16] found that the effect of silica fume in the mixture can improve the compressive strength, splitting tensile strength, and elastic modulus of the mixture. In this study, 10% silica fume as a partial replacement of cement was used in order to review the effect of silica fume on the mechanical properties of crumb rubber concrete. Table 4 shows the material forming of silica fume.

Table 4 Chemicals properties of silica fume

No	Composition	Percentage
1	Silicon Dioxide (SiO_2)	90.36
2	Aluminium Trioxide (Al_2O_3)	0.71
3	Iron Trioxide (Fe_2O_3)	1.31
4	Calcium Oxide (CaO)	0.45
6	Sulfur Trioxide (SO_3)	0.41
7	Sodium Dioxide (Na_2O)	0.45
8	Kalium Oxide (K_2O)	1,52

3.7 Fly Ash

Fly ash is a major solid industrial by-product created by the combustion of pulverized coal in thermal power plants. In general, fly ash reduces the water consumption of cement, increases the setting times, reduces the heat of hydration and adds long-term strength to cement products. The 15% fly ash as a cement replacement material used was materialized from the Sijantang's power plant in Sawahlunto, Indonesia. The chemical properties of fly ash are given in Table 5.

Table 5 Chemicals properties of fly ash

No	Composition	Percentage
1	Silicon Dioxide (SiO_2)	51.7
2	Aluminium Trioxide (Al_2O_3)	26.47
3	Iron Trioxide (Fe_2O_3)	9.96
4	Calcium Oxide (CaO)	10.23
5	Magnesium Oxide (MgO)	0.86
6	H_2O	0.16
7	Sulfur Trioxide (SO_3)	0.32
8	Lost in annealing	0.22
9	Sodium Dioxide (Na_2O)	0.18

4. EXPERIMENTAL WORK

4.1 Mix Design

The mix design of the concrete was calculated, referring to ACI 211.1-22 [17] with a targeted strength of 25 MPa and water-cement ratio (WC) of 0.6. The mix proportions of crumb rubber concrete mixtures with different crumb rubber content are given in Tables 6-8.

Table 6 Mix proportions of crumb rubber concrete (CRC)

Material	Composition CR				
	0%	5%	10%	15%	20%
Cement (kg/m^3)	391	391	391	391	391
Fine Aggregate (kg/m^3)	725.6	725.6	725.6	725.6	725.6
Coarse Aggregate (kg/m^3)	1088.4	1034	979.6	925.1	870.7
Water (kg/m^3)	234.6	234.6	234.6	234.6	234.6
Rubber (kg/m^3)	0	54.4	108.8	163.3	217.7

Table 7 Mix proportions of crumb rubber fly ash concrete (CRFAC)

Material	Composition CR				
	0%	5%	10%	15%	20%
Cement (kg/m^3)	332.4	332.4	332.4	332.4	332.4
Fine Aggregate (kg/m^3)	725.6	725.6	725.6	725.6	725.6
Coarse Aggregate (kg/m^3)	1088.4	1034	979.6	925.1	870.7
Water (kg/m^3)	234.6	234.6	234.6	234.6	234.6
Rubber (kg/m^3)	0	54.4	108.8	163.3	217.7
Fly Ash (kg/m^3)	58.6	58.6	58.6	58.6	58.6

Table 8 Mix proportions of crumb rubber silica fume concrete (CRSFC)

Material	Composition CR				
	0%	5%	10%	15%	20%
Cement (kg/m^3)	351.9	351.9	351.9	351.9	351.9
Fine Aggregate (kg/m^3)	725.6	725.6	725.6	725.6	725.6
Coarse Aggregate (kg/m^3)	1088.4	1034	979.6	925.1	870.7
Water (kg/m^3)	234.6	234.6	234.6	234.6	234.6
Rubber (kg/m^3)	0	54.4	108.8	163.3	217.7
Silica Fume (kg/m^3)	39.1	39.1	39.1	39.1	39.1

4.2 Specimen Preparation

A total of 90 cylindrical specimens were produced: 30 specimens of crumb rubber concrete (CRC), 30 specimens of crumb rubber fly ash concrete (CRFAC), and 30 specimens of crumb rubber silica fume concrete (CRSFC), as shown in Table 9. The specimens are cast with 0%, 5%, 10%, 15%, and 20% content of crumb rubber concrete.

All specimens were cured in a humidity room and tested at 28 days' age. The curing conducted for 28 days of the test specimen was carried out in a water bath at the Materials and Structures Laboratory of the Department of Civil Engineering, Andalas University.

Table 9 Number of concrete specimens

No	Rubber (%)	CRC Compr.	CRC Tensile	CRFAC Compr.	CRFAC Tensile	CRSFC Compr.	CRSFC Tensile
1	0	6	6	6	6	6	6
2	5	6	6	6	6	6	6
3	10	6	6	6	6	6	6
4	15	6	6	6	6	6	6
5	20	6	6	6	6	6	6
Total		30	30	30	30	30	30

4.3 Testing of Specimens

A slump test was done for all concrete mixtures to measure the plasticity and workability of concrete. The slump test was conducted based on ASTM C 143/C 143M – 15a [18]. The purpose of a slump test was to determine the consistency of fresh concrete and to measure the workability and uniformity of the mix series.

Based on ASTM C 39-05 [19] and ASTM C 496-17 [20] for compressive strength (Fig.2) and tensile strength (Fig.3), respectively, the compressive strength and the tensile strength of the cylindrical specimens were tested using a Universal Testing Machine at the Material, Soil Mechanics and Highway Laboratory, Department of Civil Engineering, Padang State University.

Fig.2 Compressive test on cylindrical specimen

Fig.3 Splitting tensile test on cylindrical specimen

5. RESULTS AND DISCUSSION

5.1 The Workability of the Concrete Mixture

Table 8 shows the results of the slump test for CRC, CRFAC, and CRSFC with different crumb rubber content.

As seen in Table 10, the slump test of crumb rubber concrete (CRC) is evaluated as 13.7 cm, 13.3 cm, 13.0 cm, and 12.8 cm and at the addition of crumb rubber by 5%, 10%, 15%, and 20%. The percentage decrease in the slump test is 2.44%, 4.88%, 7.32%, and 8.54%, respectively with the increase of crumb rubber in the concrete mixture. Furthermore, slump values of crumb rubber fly ash concrete (CRFAC) are 14.1 cm, 13.7 cm, 13.4 cm, and 13.0 cm, with the increase of crumb rubber by 5%, 10%, 15%, and 20%, respectively.

The slump value result of crumb rubber silica fume (CRSFC) indicates that the workability decreases if the crumb rubber content increases. The slump gradually increases for the rubberized concrete from 5% to 20% crumb rubber content. The lowest slump of CRSFC is observed at 20% crumb rubber content (12.8 cm), which decreases by 9.52%, compared with the control mixes.

Although the slump value decreases along with the increase of rubber content, it remains a workable mix when compared with concrete without rubber and meets the minimum slump for building constructions in Indonesia.

Table 10 Slump test results of crumb rubber concrete

Rubber (%)	Slump Test (cm)			Percentage of Decrease (%)		
	CRC	CRFAC	CRSFC	CRC	CRFAC	CRSFC
0	14	14.4	14.1	-	-	-
5	13.7	14.1	13.8	2.44	2.38	2.38
10	13.3	13.7	13.3	4.88	4.76	5.95
15	13.0	13.4	13.1	7.32	7.14	7.14
20	12.8	13.0	12.8	8.54	9.52	9.52

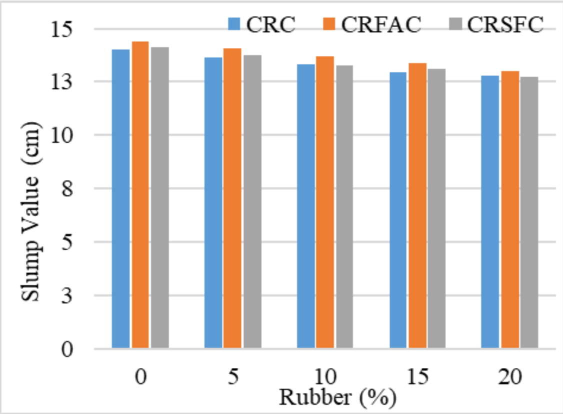

Fig.4 The comparison of slump value of CRC, CRFAC, and CRSFC

The increased crumb rubber in the concrete mixture decreases the plasticity of the rubberized concrete mixture and reduces the workability of the rubberized concrete. The value of the slump is getting lower as the increase of rubber content, as shown in Fig.4. The reason for the low workability is that the rubber particles have a different surface texture and are less dense compared to gravel, which can absorb some of the water in the mix, leading to a decrease in the overall water-cement ratio [21]. In addition, the workability of fly ash concrete (CRFAC) is higher than silica fume concrete (CRSFC) due to its finer particle size and spherical shape, which can improve the flow and ease of handling during construction.

5.2 Compressive Strength of Concrete

Fig.5 and Table 11 show the results of the compressive tests performed on specimens with different percentages of crumb rubber tested on the 28th day. The results of the compressive strength of cylinder test specimens with an increase in the replacement level of rubber. The result of the compressive strength of the cylinder test specimen without the addition of crumb rubber in crumb rubber concrete (CRC) is 27.1 MPa. The lowest compressive strength value is 14.59 MPa after being replaced with 20% of the coarse aggregate volume with crumb rubber. Replacement of 5%, 10%, and 15% volume of coarse aggregate with crumb rubber results in the compressive strength of 24.41 MPa, 21.16 MPa, and 17.51 MPa, respectively.

Meanwhile, for crumb rubber concrete containing fly ash (CRFAC), the maximum compressive strength of 27.8 MPa is observed without rubber content, which reaches almost 8.95% more than specimens with 5% rubber content. The replacement of coarse aggregate with 10% and 15% results in a decrease of compressive strength by 19.07% and 31.71%. However, the strength remains higher, that is, 22.5 MPa and 18.98 MPa, respectively. While the lowest strength value of 16.17 MPa is observed with 20% crumb rubber content.

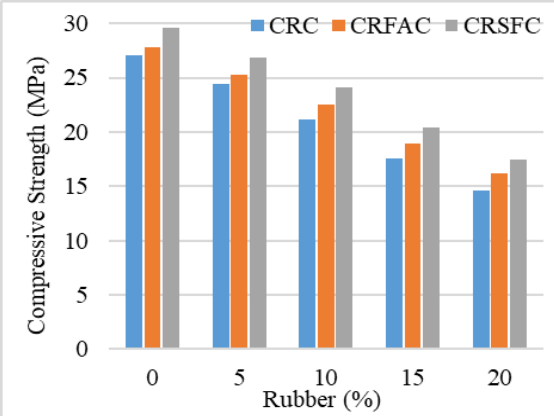

Fig.5 Comparison of compressive strength with different rubber content

Table 11 Test result of compressive strength

Rubber (%)	Compressive Strength (MPa)			Percentage of Decrease (%)		
	CRC	CRFAC	CRSFC	CRC	CRFAC	CRSFC
0	27.1	27.8	29.6	-	-	-
5	24.41	25.31	26.9	9.91	8.95	9.11
10	21.16	22.5	24.06	21.92	19.07	18.72
15	17.51	18.98	20.41	35.38	31.71	31.03
20	14.59	16.17	17.5	46.15	41.83	40.89

For crumb rubber silica fume concrete (CRSFC), the compressive strength significantly decreases with the addition of crumb rubber content by 5%, 10%, 15%, and 20% replacement of coarse aggregate, while the maximum compressive strength is 29.6 MPa without adding crumb rubber content in the concrete mixture. The compressive strength of CRSFC is 26.9 MPa, 24.06 MPa, 20.41 MPa, and 17.5 MPa, and the percentage decreases by 9.11%, 18.72%, 31.03%, and 40.89%, respectively.

The factor responsible for the decrease in compressive strength can also result from the insubstantial bond between the particles of rubber, the replacement of sand (solid) to rubber (soft) aggregate, and the lesser stiffness of rubber [22].

According to Indonesian building standards, the compressive strength of concrete (fc') for a building should be more than 17 MPa. From this study, it is recommended to use crumb rubber as a replacement for coarse aggregate up to 15 %, in which the concrete compressive strength is still more than 17 MPa. The use of 20% crumb rubber content results in a significant reduction of compressive strength for all mixtures, with the concrete compressive strength of less than 17 MPa for CRC and CRFAC. In addition, the compressive strength of silica fume concrete (CRSFC) is higher than fly ash concrete (CRFAC) due to its reactivity and ability to fill gaps in the cementitious matrix.

The comparative results of compressive strength with the previous studies are shown in Fig.6.

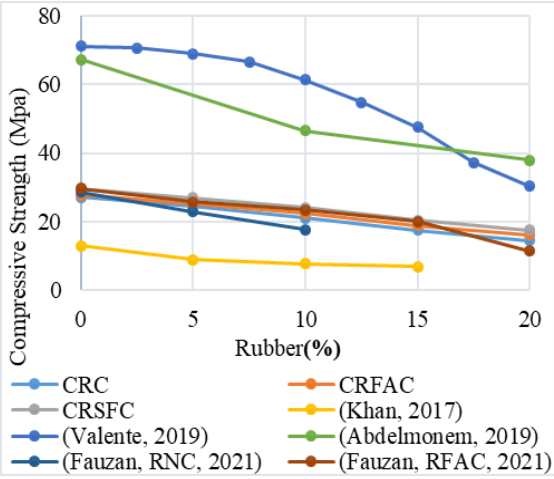

Fig.6 The comparison of compressive strength

From Fig.6, the results of the percentage change in the compressive strength of the specimens tested are lower than that of the previous study's data. The maximum percentage decrease in compressive strength of the test specimens in this study ranges from 40% to 46%, while in the previous studies [22-25], the maximum decrease was 43%-58%.

5.3 Splitting Tensile Strength of Concrete

Tensile strength is a critical characteristic of pavement concrete, and it can prevent serious cracking. The tensile strength of rubber-containing concrete is affected by the size, shape, and surface textures of the aggregate, along with the volume being used, indicating that the strength of concretes decreases as the volume of rubber aggregate increases. The results of tensile strength tests performed on crumb rubber concrete (CRC), crumb rubber fly ash concrete (CRFAC), and crumb rubber silica fume concrete (CRSFC) with variations of crumb rubber as partial replacement of coarse aggregates are shown in Table 12 and Fig.7.

Table 12 Test result of tensile strength

Rubber (%)	Tensile Strength (MPa)			Percentage of Decrease (%)		
	CRC	CRFAC	CRSFC	CRC	CRFAC	CRSFC
0	3.2	3.3	3.8	-	-	-
5	2.59	2.89	3.31	18.92	12.28	12.81
10	2.16	2.43	2.49	32.43	26.32	34.6
15	1.77	2.08	2.17	44.59	36.84	42.78
20	1.3	1.62	1.66	59.46	50.88	56.4

Table 12 shows that the tensile strength reduces as the volume of rubber increases in concrete. For crumb rubber concrete (CRC), the percentage reduction of tensile strength with the addition of 5% rubber is about 18.92% with a tensile strength of 3.2 MPa, higher than the control mix. The reduction in tensile strength with 10% and 15% rubber content is 32.43% and 44.59%, and the tensile strength is 2.16 MPa and 1.77 MPa, respectively. The minimum splitting tensile strength by adding 20% crumb rubber is 1.3 MPa, with a 59.46% reduction as compared to concrete without crumb rubber.

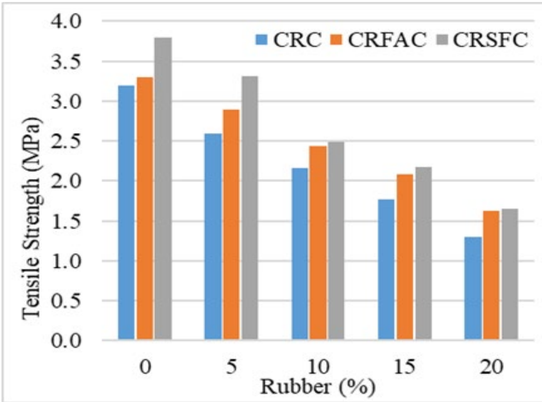

Fig.7 Comparison of splitting tensile strength

Meanwhile, for crumb rubber fly ash concrete (CRFAC), the tensile strength decreases by 12.28%, 26.32%, 36.84%, and 50.88% when rubber is replaced with coarse aggregates with 5%, 10%, 15%, and 20% respectively. The maximum tensile strength obtained is 3.3 MPa for CRFAC with additional rubber of 5%, while the lowest value recorded is 1.62 MPa for CRFAC with the addition of rubber by 20%.

For crumb rubber silica fume concrete (CRSFC), the tensile strength significantly decreases with the addition of crumb rubber content by 5%, 10%, 15%, and 20% replacement of coarse aggregate, while the maximum tensile strength is 3.8 MPa without crumb rubber content in the concrete mixture. The tensile strength of CRSFC is 3.31 MPa, 2.49 MPa, 2.17 MPa, and 1.66 MPa, and the percentage decreases by 12.81%, 34.60%, 42.78%, and 56.40%, respectively. Fig.7 shows that crumb rubber concrete has an almost similar tendency to reduce the tensile splitting strength.

The reasons for such a reduction in strength are probably similar to those affecting compressive strength. The decrease in splitting tensile strength of specimens with the increase in rubber content might be due to the weak bond between cement pastes and rubber. If so, the interface zone between rubber and cement may act as a micro-crack, which leads to accelerated concrete breakdown.

The comparative results of tensile strength with the previous studies are shown in Fig.8.

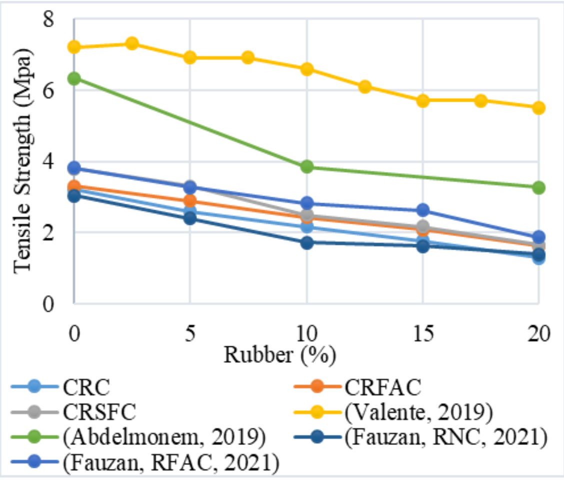

Fig.8 The comparative of tensile strength

Fig.8 shows that the tensile strength value tends to decrease as the crumb rubber content increases in the concrete. The previous studies [22-24] show that the concrete mixture with the highest decrease value ranged from 23% to 49%, while in this study, the highest decrease value ranges from 50% to 60%.

The decrease in the addition of crumb rubber in the concrete mixture results in a significant decrease in the tensile strength of CRC, CRFAC, and CRSFC. The results obtained are in line with the results of the previous studies.

It is possible to use crumb rubber in combination with fly ash and silica fume in the rubberized concrete mixture. The concrete without rubber shows more stiff failure, while the rubberized concrete does not show the same manner under compression loading. For crumb rubber concrete, the number and size of cracks are lesser than their control mixes. This indicates that rubberized concrete has greater crack resistance compared to concrete without rubber. Crumb rubber is a powerful aggregate alternative in concrete Preparation, and it can be used in structures with low seismic intensity.

The addition of crumb rubber in this study resulted in a decrease in the compressive and tensile strength of concrete, but provided positive properties such as increased ductility.

6. CONCLUSION

The results of the experimental investigation have led to the following:

1. Replacement of crumb rubber for coarse aggregate in concrete results in a reduction in concrete mechanical properties such as compressive and tensile strengths. However, they have greater crack resistance compared to the control mixes. Meanwhile, workability does not significantly decrease for crumb rubber addition.
2. The compressive strength gradually decreases for the addition of 5%, 10% and 15% crumb rubber in the range from 9% to 41% for CRFAC and from 9% to 41% for CRSFC with the maximum compressive strength of 29.6 MPa for CRSFC. Meanwhile, the use of 20% crumb rubber content on CRC, CRFAC, and CRSFC shows a significant decrease in compressive strength.
3. For CRC and CRFAC, the use of 5%, 10%, 15%, and 20% of the crumb rubber decreases the tensile strength by 19%-60% and 12%-51%. Meanwhile, it decreases by 12%-56%, respectively, for CRSFC. The maximum tensile strength is 3.8 MPa for CRSFC.
4. This study recommends using crumb rubber as a coarse aggregate replacement on concrete up to 15% for concrete with the target compressive strength of 25 MPa, in which the compressive strength results of that rubberized concrete remain usable for normal concrete application in Indonesian standard (fc' > 17 MPa).

7. ACKNOWLEDGEMENTS

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