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THE EFFECT OF WASTE TYRE RUBBER ON MECHANICAL PROPERTIES OF NORMAL CONCRETE AND FLY ASH CONCRETE

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ABSTRACT: Waste tyre rubber is one of waste material, which is produced excessively worldwide every year. The disposal of this rubber has a major problem in the environment as its decomposition takes a long time and also produces environmental pollution. One of the alternative solutions is to use the scrap waste tyre rubber as a partial replacement of natural aggregate in concrete. This paper presents the experimental study on the effect of waste tyre rubber in the form of crumb rubber as a partial fine aggregate replacement on normal and fly ash concrete. The content of fly ash in the fly ash concrete was 15 % by replacing the cement weight. A total of 60 concrete cylinders were cast and tested to evaluate its compressive and splitting tensile strength. The use of crumb rubber from the waste tyre in both normal concrete and FA concrete is 5%, 10%, 15%, and 20% based on fine aggregate volume. The results show that rubberized concrete has low workability, compressive and tensile strengths but has greater crack resistance when compared with ordinary concrete. The more percentage of crumb rubber on both the rubberized normal concrete (RNC) and the rubberized fly ash concrete (RFAC) result in a higher decrease in compressive and tensile strengths of the concrete. Compared to RNC, RFAC has a higher strength in each crumb rubber content due to the presence of fly ash. From this study, it is recommended to use the crumb rubber as a fine aggregate replacement with the maximum content of 10% and 15% on normal concrete and fly ash concrete, respectively.

Keywords: Concrete, Waste tyre rubber, Fly ash, Workability, Compressive strength, Tensile strength

1. INTRODUCTION

Most building components are made of concrete because concrete has high compressive strength and it's durable. Aggregate is one of the materials used in concrete mixes obtained from nature and also artificial.

The utilization of industrial waste is one of the alternative solutions to replace some of the natural aggregates in concrete mixtures, such as waste tyre rubber [1]. It has been known that disposal of waste tyre rubber has become a major environmental problem, because the production of rubber increases every year, and it is not easily biodegradable [2-3]. According to Indonesian manufacturers association (APBI) data, around 20.48 million waste tyres were produced in Indonesia in 2017, an increase of 2.95% from the previous year.

One of the alternative solutions is the use of scrap waste tyre rubber (crumb rubber) in concrete, to replace some of the natural aggregates. The use of crumb rubber from the waste tyre as a replacement for aggregate has great potential in construction because the waste tyre is one of the cheap, abundantly available sources and easy to be found for free [4-5].

The results obtained by Abdullah et al [6] are quite promising where improvement in some properties is identical with normal concrete in terms of its strength. It has been suggested that with a few adjustments and modifications, the use of crumb rubber may be beneficial for sustainable construction.

However, waste tyre rubber has a low elastic modulus so that it increases concrete ductility but reduces mechanical properties of concrete such as compressive strength, tensile strength, and flexural strength [7]. The compressive strength of rubberized concrete can be increased by adding pozzolanic material to the concrete mixture. Pozzolan is a material containing silica or silica and aluminum which when reacting chemically with calcium hydroxide at ordinary temperatures forms a binding nature [8-9].

Fly ash is one of the pozzolan materials to be added to concrete. Fly ash is the coal combustion residue ash in the power plant. These materials contain high levels of silica so that it can be used as cement replacement materials to increase the compressive strength of concrete [10-11].

This experimental study focused on the investigation of the effect of the partial replacement of fine aggregate by crumb rubber on the mechanical properties of normal concrete and fly ash concrete. The normal concrete and fly ash concrete contain crumb rubber, hereafter they refer to rubberized normal concrete (RNC) and rubberized fly ash concrete (RFAC), respectively.

2. MATERIAL

2.1 Cement

In this experiment, the cement used in producing the rubberized concrete is Ordinary Portland Cement (OPC) produced by a cement factory in Padang, Indonesia.

2.2 Coarse Aggregate

Aggregate used is locally 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 %

2.3 Fine Aggregate

Aggregate used is locally available aggregate with a maximum size of 4.75 mm. The properties of fine aggregate are given in Table 2.

Table 2 Properties of fine aggregate.

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

2.4 Water

The water used is fresh portable which is free from acid and organic which is used for mixing and maintaining (curing) concrete.

2.5 Waste Tyre Rubber

This material is obtained from recycled tyres, which is manually cut first, and then it was manufactured by special mills in which big rubbers change into smaller torn particles (crumb rubber), as shown in Figs. 1-3. The crumb rubber produced the same size as fine aggregate having a maximum size of 2 mm (Fig. 4). In this study, the crumb rubber was used as a partial replacement of fine aggregate (sand) volume in the concrete.

Fig. 1 Waste tyre

Fig. 2 Cutting process of waste tyre

Fig. 3 Special mills to crush the waste tyre and produce the crumb rubber

Fig. 4 Crumb rubber used in this experiment

2.6 Fly Ash

Fly ash is one of the pozzolanic materials that contain a high level of silica. Fly ash is the residue generated in combustion and comprises the fine particles that rise with the flue gases. This material was obtained from ash coal residue in the Sijantang's power plant in Sawahlunto, Indonesia. Fig. 5 shows the material of fly ash that is used as a cement replacement material in this study. The chemical compositions of fly ash are given in Table 3.

Fig. 5 Fly ash.

Table 3 Chemicals composition 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

3. EXPERIMENTAL WORK

3.1 Mix Design

The mix design of the concrete is calculated based on ACI 211.4 R-93 [12] with targeted strength of 25 MPa. There are two variations of concrete, normal rubberized concrete (NRC) and rubberized fly ash concrete (RFAC) with a control mix for each variation. The content of fly ash in fly ash concrete was 15% being partially replaced with the cement weight.

Table 4 Mix proportions of NRC

Material	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Cement (kg/m^3)	391	391	391	391	391
Sand (kg/m^3)	725.6	689.3	653.0	616.8	580.5
Split 5/10 (kg/m^3)	217.7	217.7	217.7	217.7	217.7
Split 10/20 (kg/m^3)	870.7	870.7	870.7	870.7	870.7
Water (kg/m^3)	234.6	234.6	234.6	234.6	234.6
Rubber (%)	0	5	10	15	20

Table 5 Mix proportions of RFAC.

Material	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Cement (kg/m^3)	332.4	332.4	332.4	332.4	332.4
Sand (kg/m^3)	725.6	689.3	653.0	616.8	580.5
Split 5/10 (kg/m^3)	217.7	217.7	217.7	217.7	217.7
Split 10/20 (kg/m^3)	870.7	870.7	870.7	870.7	870.7
Water (kg/m^3)	234.6	234.6	234.6	234.6	234.6
Rubber (%)	0	5	10	15	20
Fly Ash 15 % (kg)	58.6	58.6	58.6	58.6	58.6

The crumb rubber was added into both NRC and RFAC mixtures as a replacement of fine aggregate volume at different ratios 0%, 5%, 10%, 15%, and 20%. The mix proportions of NRC and RFAC mixtures with different crumb rubber content are given in Tables 4 and 5.

3.2 Specimen Preparation

A total of 60 concrete cylinders were cast and tested, consisting of 30 cylinders for compressive strength testing and 30 cylinders for tensile strength testing, as shown in Table 6.

Cylindrical molds with diameter 150 mm and 300 mm height are used in the manufacture of test specimens for the compressive strength and tensile strength test. The specimens are cast with 0%, 5%, 10%, 15%, 20% content of crumb rubber on normal, and fly ash concrete. All specimens were cured in a humidity room and tested on the 28 days.

Table 6 Number of concrete specimens

Type of concrete	Number of Concrete	
	Compressive	Tensile
NRC	15	15
RFAC	15	15

3.3 Testing of Specimens

A slump test was carried out for all concrete mixtures to measure the workability of concrete. The slump test was conducted based on ASTM C 143 [13] in the Material and Structural laboratory, Andalas University (Fig. 6).

Fig. 6 Slump test on the concrete mixtures

The compressive strength test on cylindrical specimens was tested based on ASTM C 39-99 [14], and the tensile strength testing of cylindrical specimens based on ASTM C 496-86 [15]. Both tests were conducted by using Universal Testing Machine (UTM) at the Building Material and Soil Mechanics Laboratory at Padang State University, Padang, Indonesia. Figs. 7 and 8 show the cylindrical specimens under compressive and splitting tensile testing.

Fig. 7 Compressive test on cylindrical specimen

Fig. 8 Splitting tensile test on cylindrical specimen

4. RESULTS AND DISCUSSION

4.1 Workability

The workability of the RNC and RFAC concrete was measured using a slump test. Table 7 shows the results of the slump test for RNC and RFAC with different crumb rubber content. As seen in Table 7, the slump test result of both RNC and RFAC indicates that the workability decreases with the increase of crumb rubber content. At 5% crumb rubber content, the decrease in the slump on

RNC and RFAC was 6.67% and 12.50%, respectively. Then, the slump gradually decreases for the rubberized concrete with 10% and 15% crumb rubber content. The lowest slump of both RNC and RFAC was observed at 20% crumb rubber content, they are 2 cm and 2.5 cm respectively, which has a decrease of 71.43 % and 64.29%, respectively compared with the control mixes.

Although the slump value decrease with the increase of rubber content, it still gave a workable mix when compared with the concrete without a rubber and met the minimum slump for building constructions in Indonesia [16] except for RNC with 20% rubber content.

Table 7 Slump test results of RNC and RFAC.

No	Rubber (%)	Slump Test		Percentage of Decrease	
		RNC (Cm)	RFAC (Cm)	RNC (%)	RFAC (%)
1	0	7,5	8	-	-
2	5	7	7	6,67	12,50
3	10	4,5	5	40,00	37,50
4	15	4	4	46,67	50,00
5	20	2	2.5	71,43	64,29

Comparing the slump value between RNC and RFAC in Fig. 9, it shows that the slump value of RFAC mixtures was slightly higher than those of the RNC mixtures in 10 % and 20% crumb rubber content. The presence of fly ash contributed to the increase in the workability of the rubberized concrete.

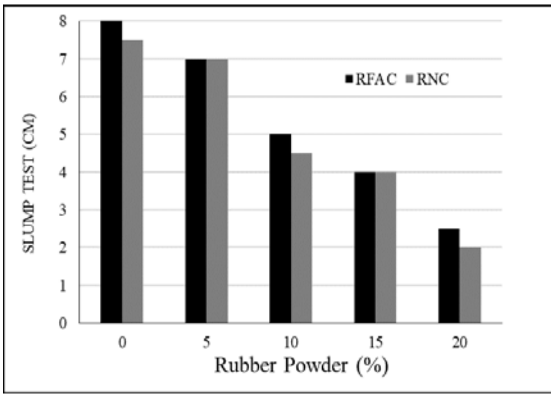

Fig. 9 Comparison of slump test of NRC and RFAC with different rubber content.

4.2 Compressive Strength

Table 8 shows the results of the compressive tests performed on both RNC and RFAC specimens with different percentages of crumb rubber tested on the 28th day.

Table 8 Test result of compressive strength.

No	Rubber (%)	Compressive Strength		Percentage of Decrease	
		RNC (MPa)	RFAC (MPa)	RNC (%)	RFAC (%)
1	0	28.66	29.68	-	-
2	5	22.97	25.87	19.88	12.84
3	10	17.65	23.49	38.41	20.86
4	15	16.29	20.14	43.16	32.14
5	20	7.96	11.56	72.24	61.05

From Table 8, it shows that the compressive strength of both RNC and RFAC decreases with an increase in the replacement level of rubber. A gradual decrease in compressive strength was observed as the percentage of crumb rubber increased. On RNC, the maximum compressive strength of 22.97 MPa was observed with 5 % rubber content, which is almost 20% less than RNC without the rubber. The replacement of fine aggregate with 10% results in a decrease of compressive strength by 20.86%, but the strength is still higher that is almost 23 MPa. While the lowest strength value of 7.96 MPa was observed with 20% crumb rubber content.

For RFAC, the compressive strength also decreases with the increase of rubber content. The strength decreases by 12.84%; 20.86%; and 32.14%; for RFAC with rubber contents of 5%, 10%, and 15% respectively. Although the strength was decreased, the strength value is still more than 20 MPa. While the lowes strength of 11.56 MPa was observed with 20 % rubber content, which is a 61.05% decrease compared with RFAC without the rubber.

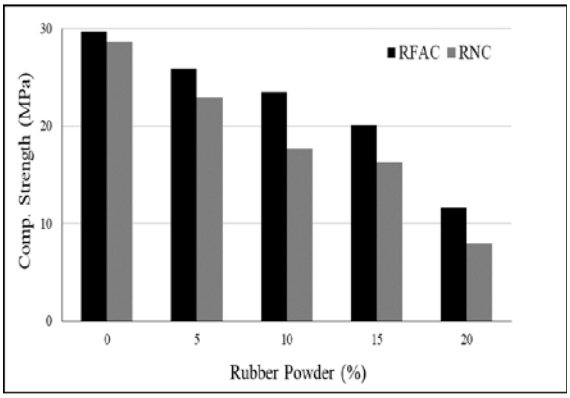

Fig. 10 Comparison of compressive strength between NRC and RFAC with different rubber content.

According to the Indonesian standard for the minimum compressive strength for building [16], the compressive strength of concrete (fc') for building should be more than 17 MPa, so from this study results, it is recommended to use crumb rubber as a replacement of fine aggregate until 10 % and 15 % for RNC and RFAC, respectively.

The comparison of compressive strength between NRC and RFAC with a different variation of crumb rubber content is shown in Fig. 10. As recognized in Fig. 10, the decrease of compressive strength on RNC and RFAC has an almost similar pattern. Compared to RNC, the compressive strength of RFAC slightly higher than those in RNC in each variation of rubber content. Also, the percentage decrease of compressive strength was less than that of RNC with the replacement of sand by rubber from 15 % to 20%.

However, the use of 20% crumb rubber content shows the significant reduction of compressive strength for both RNC and RFAC, the strength value is not recommended to be used for real construction. The reasons for the decrease in compressive strength of the rubberized concrete might be due to (a) replacement of hard dense aggregate (sand) by less dense (rubber) aggregate, (b) the lack of proper bonding between rubber particles and cement pastes, as compared to cement paste and sand, which can leads to cracks due to non-uniform distribution of applied stress, and (c) lesser stiffness of the substitute material (rubber).

4.3 Tensile Strength

Tensile strength test results of NRC and RFAC with different content of crumb rubber content are given in Table 9.

Table 9 Test result of splitting tensile strength

No	Rubber (%)	Tensile Strength		Percentage of Decrease	
		RNC (MPa)	RFAC (MPa)	RNC (%)	RFAC (%)
1	0	3.04	3.82	-	-
2	5	2.40	3.27	21.16	14.40
3	10	1.73	2.83	43.34	25.92
4	15	1.63	2.63	46.57	31.15
5	20	1.40	1.87	54.05	51.05

The tensile splitting strength reduces as the volume of rubber increase in both RNC and RFAC. On NRC, the percentage reduction of tensile strength with the addition of 5% rubber was about 21.16 % than that of the control mix. The reduction in tensile strength with 10% and 15% rubber content was 43.34 % and 46.57%, respectively. The minimum splitting tensile strength by adding 20% crumb rubber is 1.40 MPa, which is a 54.05% decrease as compared to NRC without crumb rubber.

For RFAC, the maximum splitting tensile strength was observed with 5% rubber content, which is 14.40 % lower than that of the RNC control mix, while the minimum splitting tensile is 1.87, which 51.05% decreases, as compared to one without the rubber. Fig. 11 shows the comparison of the tensile strength of NRC and RFAC with a different variation of crumb rubber content.

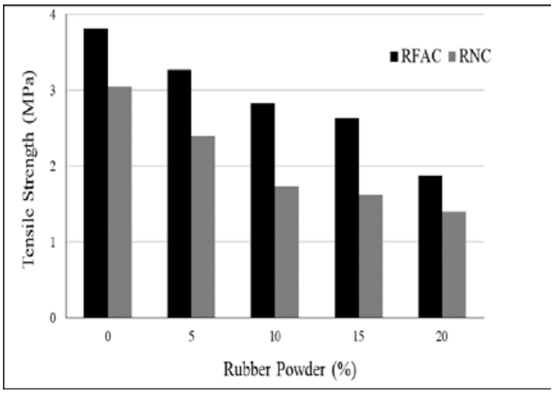

Fig. 11 Comparison of splitting tensile strength of NRC and RFAC with different rubber content.

Fig. 11 shows that both RNC and RFAC have an almost similar tendency in decreasing the tensile splitting strength. However, RFAC has slightly higher tensile splitting strength in each rubber content compared to the RNC control mix.

The reasons for the decrease in splitting tensile strength of both RNC and RFAC with the increase of rubber content might be due to the weak bond between cement pastes and rubber. So the interface zone between rubber and cement may act as a micro-crack which leads to accelerating concrete breakdown.

During the experiment, it is observed that the concrete without rubber exhibited more brittle failure while the rubberized concrete did not show brittle failure under compression loading. For RNC and RFAC, the number and size of crack appeared were lesser than their control mixes. This indicates that rubberized concrete has greater crack resistance compared to concrete without a rubber.

5. CONCLUSION

1. Replacement of crumb rubber for fine aggregate in normal and fly ash concrete caused a reduction in concrete mechanical

properties such as workability, compressive and tensile strengths, but has greater crack resistance compared with the control mixes.

2. The compressive strength was gradually decrease for the addition of 5%, 10% and 15 % crumb rubber, that are 19.88%, 38.41%, 43.16%, respectively for RNC and 12.84%, 20.86% 32.14%, respectively for RFAC. Meanwhile, the use of 20% crumb rubber content on NRC and RFAC shows a significant reduction in compressive strength, which is not recommended to be, used for construction.
3. The tensile strength of both RNC and RFAC decrease by the increase of crumb rubber content. The decrease of tensile strength with 5%, 10%, and 15% that are 21.16%, 43.34%, 46.57%, respectively for RNC and 14.4%, 25.92%, 31.15%, respectively for RFAC, while the highest decrease occurs when the addition 20% crumb rubber, that is around 54.05% and 51.05% for RNC and RFAC, respectively.
4. Based on this study, it is recommended to use the crumb rubber as a fine aggregate replacement on normal concrete and fly ash concrete with the maximum content of 10% and 15%, respectively, in which the compressive strength results of that rubberized concrete still can be used for normal concrete application in Indonesia standard (fc' > 17 MPa).

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