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Effect of Fly Ash as a Partial Substitute for Cement on the Splitting Tensile Strength of Concrete using Recycled Fine Aggregate

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Abstract:- In order to support the environment, sustainable construction is one solution that can be implemented by utilizing construction waste efficiently. Every year, tons of concrete waste is generated and it is necessary to utilize the waste as a recycled material such as recycled aggregate. Production of cement for concrete also increases carbon dioxide (CO2) emissions in the air resulting from factory processing. Fly ash is considered capable of replacing cement as a constituent of concrete since it has pozzolanic properties. Therefore, the splitting tensile strength test has been carried out on concrete made from recycled fine aggregate with the utilization of fly ash as a partial substitute for cement. 0%, 25%, and 50% of fly ash type C were used as a partial replacement for cement, while 0%, 25%, 50%, 75%, and 100% of recycled fine aggregate replaced the natural fine aggregate. Recycled fine aggregates were obtained from parent concrete with a minimum compressive strength of 300 kg/cm^2. The splitting tensile strength of recycled fine aggregate concrete was tested at the age of 28 days. The results showed that the splitting tensile strength decreased with the increase in the percentage of fly ash as a substitute for cement, while the splitting tensile strength increased gradually starting from the use of recycled fine aggregate 0% to 75%.

Keywords: *Fly Ash, Recycled Fine Aggregate, Splitting Tensile Strength*

I. INTRODUCTION

For decades, infrastructure has played an important role in supporting communities. Infrastructure needs are expected to increase continuously in line with the projected population growth. Infrastructure development must be accompanied by the efficient use of materials so that the environment is not polluted. In fact, concrete as one of the most used materials in construction projects has produced more than 25 billion concrete waste which is rarely utilized optimally [1]. Furthermore, considering the decreasing availability of natural aggregate, the utilization of concrete waste as a recycled material, especially recycled aggregate is one key solution to overcome these problems.

One of the concrete constituent materials that can be obtained by recycling is fine aggregate. Recycled fine aggregate can be collected from concrete waste produced from demolition buildings. Nevertheless, several studies have shown that concrete made of recycled fine aggregate tends to decrease the strength due to some mortar still attached to the surface of the aggregate [2-5]. This causes the recycled fine aggregate to have lower-quality compared to natural fine aggregate, especially its water absorption. Previous research explained that the water absorption of recycled fine aggregate is 15% higher compared to natural fine aggregate [6].

Another way to promote sustainable construction is the utilization of fly ash as a partial replacement for cement. It is because the production of cement can increase carbon dioxide (CO_2) emissions in the air and pollute the environment. Fly ash was chosen because it has similarities to cement in terms of physical and chemical properties. Fly ash is a material derived from coal ash through a combustion process with a grain size that passes the sieve number 325 and has the main content of alumina (Al_2O_3), silica (SiO_2), iron oxide (Fe_2O_3), and calcium (CaO) as well as potassium, sodium, titanium, magnesium, andsulfur in small amounts [7]. When fly ash is added to the concrete mix, fly ash will react chemically with calcium hydroxide formed from the hydration process between cement and pozzolan. Previous studies also explained that fly ash increases the workability, durability, and strength of concrete in the use of a certain percentage of fly ash [8-12]. Hence, it isnecessary to evaluate the effect of fly ash as a substitute for cement and recycled fine aggregate on the tensile splitting strength of concrete to support sustainable construction.

II. EXPERIMENTAL PROCEDURE

A. Materials

To evaluate the physical properties of the concrete constituent materials, material tests were conducted on natural fine aggregate, recycled fine aggregate, natural coarse aggregate, cement, and fly ash.

➢ *Fine Aggregate*

In this research, the recycled fine aggregate was obtained from parent concrete with a minimum compressive strength of 300 kg/cm^2. Table 1 describes the comparison of physical properties between natural fine aggregate and recycled fine aggregate. According to the results, the recycled fine aggregate has a lower bulk of specific gravity SSD than natural fine aggregate, but has higher water absorption. The oven-dry density of recycled fine aggregate is also higher compared to natural fine aggregate.

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Table 1: Physical properties of fine aggregate

Physical properties	NFA	RFA
Oven-dry density (kg/m^3)	1280.08	1357.56
Bulk of specific gravity SSD	2.457	2.335
Water absorption (%)	3.520	9.232

Notes: NFA= Natural Fine Aggregate; RFA= Recycled Fine Aggregate.

The sieve analysis of natural fine aggregate and recycled fine aggregate are described in Table 2 and Table 3. The size distribution between natural fine aggregate and recycled fine aggregate must be adjusted so that the recycled fine aggregate size distribution match the existing natural fine aggregate size distribution. Therefore, based on the cumulative pass data obtained, the size distribution of recycled fine aggregate and natural fine aggregate have similar distribution zone. The fineness modulus of recycled fine aggregate and natural fine aggregate were 3.725 and 3.440, respectively.

Table 2: Sieve analysis of natural fine aggregate

Grain size (mm)	Cumulative percent passing (%)
0.149	1.303
0.297	13.828
0.59	26.553
1.19	51.152
2.38	75.752
4.76	87.425
9.5	100

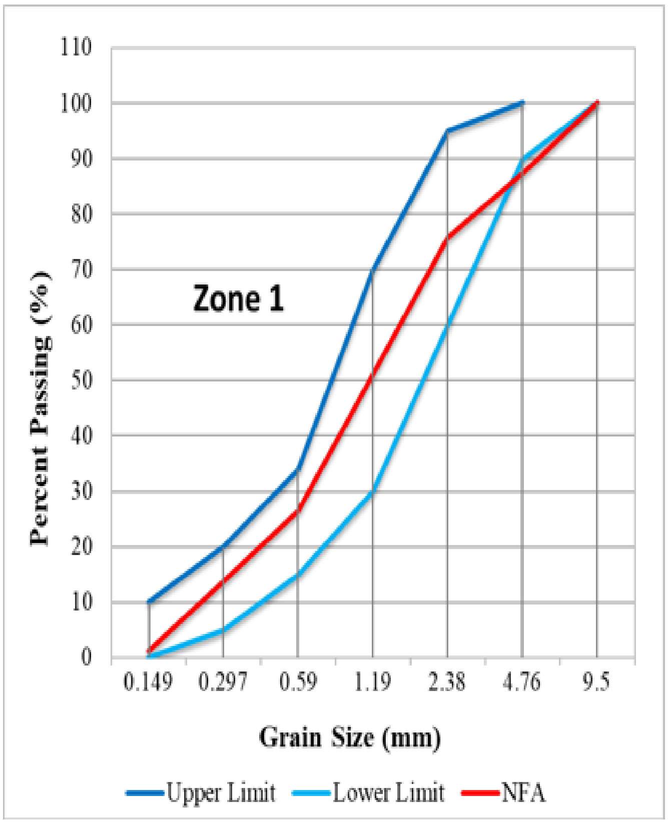

Fig. 1: Natural fine aggregate grain size distribution

Table 3: Sieve analysis of recycled fine aggregate

Grain size (mm)	Cumulative percent passing (%)
0.149	3.372
0.297	10.720
0.59	18.923
1.19	36.387
2.38	67.388
4.76	90.740
9.5	100

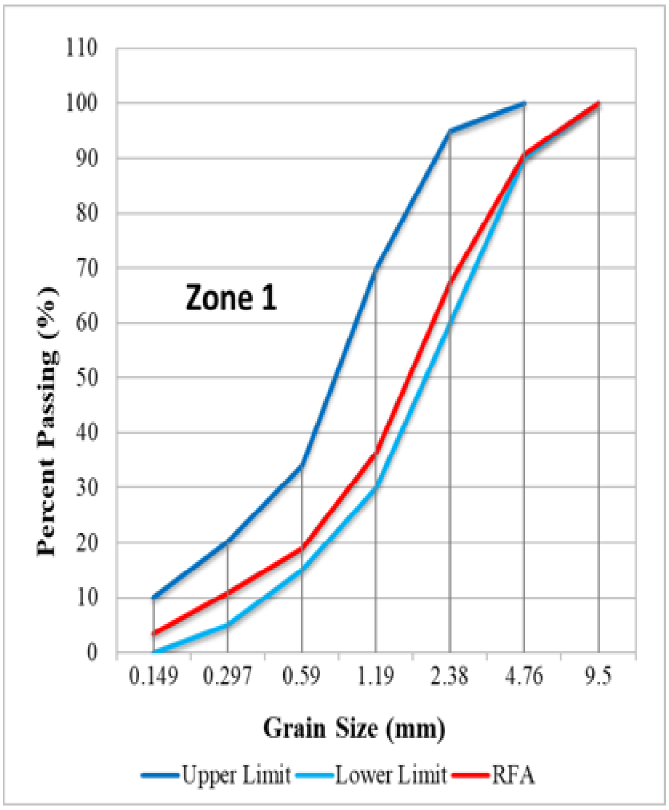

Fig. 2: Recycled fine aggregate grain size distribution

- *Coarse Aggregate*

Natural coarse aggregates were used in this study. Physical properties testing and sieve analysis of natural coarse aggregate were also tested. The result for the physical properties of natural coarse aggregate are shown in Table 4.

Table 4: Natural coarse aggregate physical properties

Physical properties	NCA
Oven-dry density (kg/m^3)	1398.95
Bulk of specific gravity SSD	2.505
Water absorption (%)	4.236

Note: NCA= Natural Coarse Aggregate.

Table 5 describes the sieve analysis of natural coarse aggregate. From the test, the natural fine aggregate was in the maximum grain zone of 40 mm. The fineness modulus of natural coarse aggregate reached 7.239.

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Table 5: Sieve analysis of natural coarse aggregate

Grain size (mm)	Cumulative percent passing (%)
4.76	0.29
9.5	2.59
12.7	14.02
19.1	71.75
25.4	99.24
38.1	100

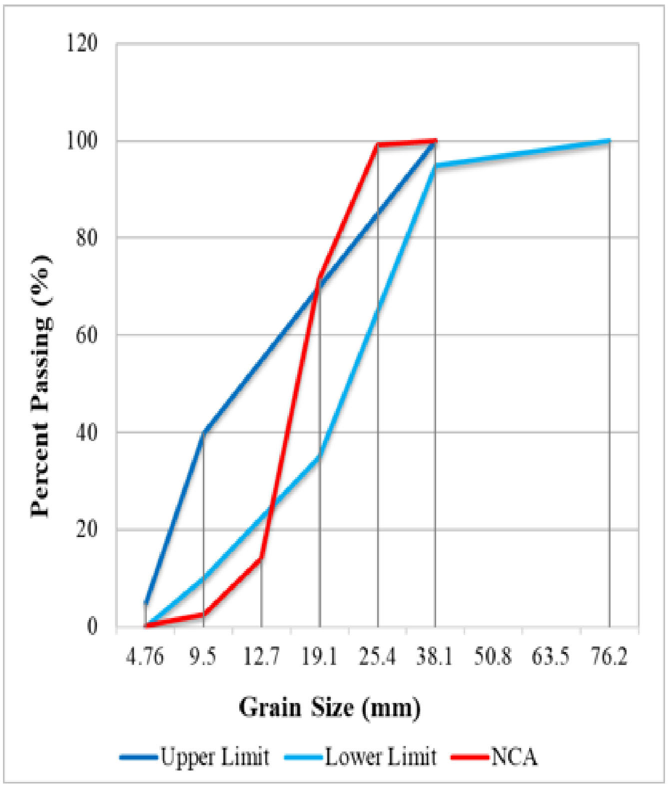

Fig. 3: Natural coarse aggregate grain size distribution

➢ *Binder*

In this experiment, Portland Composite Cement (PCC) and fly ash type C were used as a controlled variable in all mixes. The physical properties of Portland composite cement have satisfied ASTM C595-03, while fly ash was classified according to ASTM C618 which is shown in Table 6.

Table 6: Fly ash classification using XRF method

Properties	Mass (%)		Type C
	E 1180	E 1180 Helium	
CaO	12.8%	20.7%	> 10%
$SiO_2 + Al_2O_3 + Fe_2O_3$	81.71%	64.7%	> 50%

B. Mix Proportion

The mix proportions in this experiment are shown in Table 7. Natural fine aggregate was replaced by 0%, 25%, 50%, 75%, and 100% of recycled fine aggregate, while Portland composite cement was replaced by 0%, 25%, and 50% of fly ash. The water-to-cement ratio was set to 0.39.

Table 7: Mix proportion

Mix	Binder (%)		Aggregate (%)	
	PCC	Fly Ash	NFA	RFA
H0F1	100	0	100	0
H0F2	75	25	100	0
H0F3	50	50	100	0
H1F1	100	0	75	25
H1F2	75	25	75	25
H1F3	50	50	75	25
H2F1	100	0	50	50
H2F2	75	25	50	50
H2F3	50	50	50	50
H3F1	100	0	25	75
H3F2	75	25	25	75
H3F3	50	50	25	75
H4F1	100	0	0	100
H4F2	75	25	0	100
H4F3	50	50	0	100

C. Testing Procedure

The test specimens used are a cylinder with a height of 30 cm and a diameter of 15 cm. The specimens were cured according to ASTM C192/C192 M-95 for 7 days. To determine the effect of fly ash and recycled aggregate on concrete, splitting tensile strength was tested at the age of 28 days using a Compression Testing Machine (CTM) according to ASTM C496/C496 M-04.

III. RESULTS AND DISCUSSIONS

A. Fresh Concrete Analysis

To determine the characteristics of fresh concrete, the workability was tested using a slump test method according to the AASHTO T 199-99. The results of the test are explained in Table 8. From the table, the slump test results vary widely from0 cm to 18 cm. When recycled fine aggregate was used in concrete mixtures, the slump test results tend to increase along with the increase in the use of fly ash. In contrast, concrete without recycled fine aggregate showed that the slump test results had no significant changes.

Table 8: Slump test of fresh concrete

Mix	Proportion	Slump (cm)
H0F1	RFA 0%, Fly Ash 0%	13
H0F2	RFA 0%, Fly Ash 25%	11
H0F3	RFA 0%, Fly Ash 50%	16
H1F1	RFA 25%, Fly Ash 0%	6
H1F2	RFA 25%, Fly Ash 25%	12
H1F3	RFA 25%, Fly Ash 50%	15
H2F1	RFA 50%, Fly Ash 0%	2
H2F2	RFA 50%, Fly Ash 25%	17
H2F3	RFA 50%, Fly Ash 50%	13.5
H3F1	RFA 75%, Fly Ash 0%	0
H3F2	RFA 75%, Fly Ash 25%	2
H3F3	RFA 75%, Fly Ash 50%	14
H4F1	RFA 100%, Fly Ash 0%	0
H4F2	RFA 100%, Fly Ash 25%	3
H4F3	RFA 100%, Fly Ash 50%	18

B. Hardened Concrete Analysis

➢ *Splitting Tensile Strength*

The splitting tensile strength was tested at the age of 28 days using a Compression Testing Machine which refers to ASTM C496/C496 M-04. There are two types of analysis, such as analysis of the effect of recycled fine aggregate on the splitting tensile strength of concrete and analysis of the effect of fly ash on the splitting tensile strength of concrete. Fig. 4 andFig. 5 illustrate the graph for both analyses.

Fig. 4 depicts the graph of the effect of increasing the percentage of recycled fine aggregate in the concrete mixture on the results of the splitting tensile strength of concrete. It is shown that the results tend to have the same trend. In fly ash variations of 0% and 25%, the results of the splitting tensilestrength increased when the recycled fine aggregate was used up to 75%. In the 0% fly ash variation, the splitting tensile strength increased by 13.317% from the 0% recycled fine aggregate to 75%, and in the 25% fly ash variation, it increasedby 35.135% from the 0% recycled fine aggregate to 75%. As for the 50% fly ash variation, the splitting tensile strength tendsto fluctuate as the percentage of recycled fine aggregate increases. However, in this variation, the splitting tensile strength increased significantly at 75% recycled fine aggregate percentage calculated from 0% recycled fine aggregate concrete mixture.

Theoretically, natural fine aggregate has better quality than the recycled fine aggregate. However, the experiment results showed that the splitting tensile strength increased to its higher result with 75% recycled fine aggregate replacement. It is because the oven-dry density of the recycled fine aggregate was greater than the natural fine aggregate.

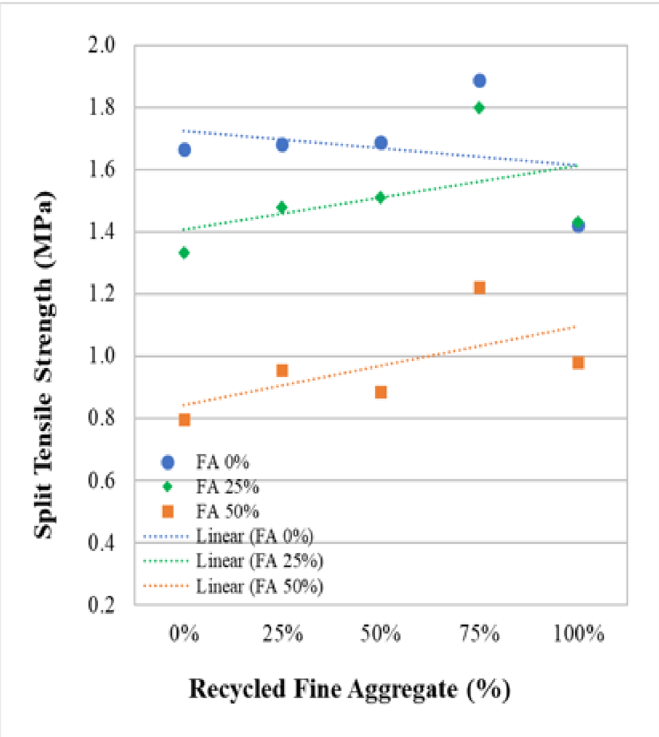

Fig. 4: Effect of recycled fine aggregate on the splitting tensile strength of concrete

On the other hand, Fig. 5 depicts the graph of the effect of increasing the percentage of fly ash in the concrete mixture on the results of the splitting tensile strength of concrete. From the figure, it is shown that the splitting tensile strength tends to decrease as the percentage of fly ash used increases. At the 0% recycled fine aggregate variation, the splitting tensile strength decreased by 52.129% at the 50% fly ash percentage calculated from the 0% fly ash concrete mixture. The splitting tensile strength of the 25% recycled fine aggregate variation decreased by 43.129%, the 50% recycled fine aggregate variation decreased by 47.602%, and the 75% recycled fine aggregate variation decreased by 35.256%. While in the 100% recycled fine aggregate variation, the splitting tensile strength increased by 0.629% at 25% fly ash percentage calculated from the 0% fly ash percentage and again decreased by 31.377% at 50% fly ash percentage.

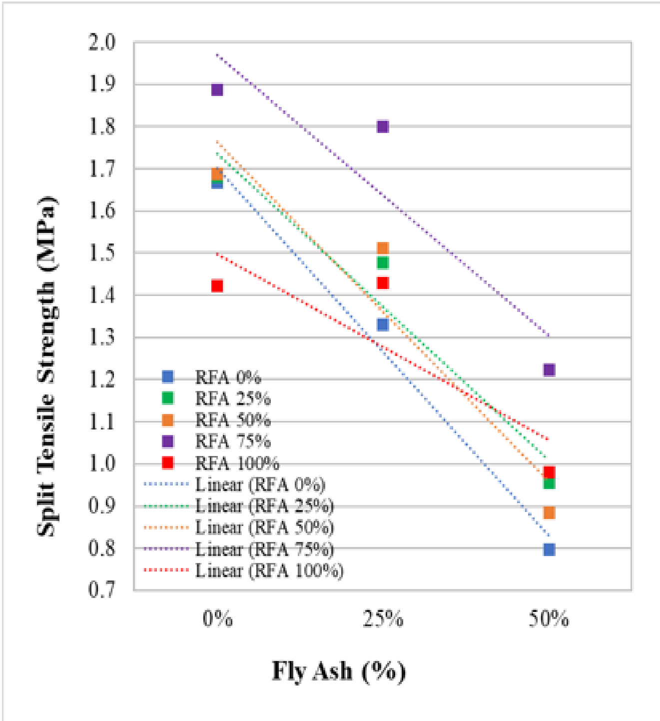

Fig. 5: Effect of fly ash on the splitting tensile strength of concrete

IV. CONCLUSIONS

The splitting tensile test was examined to evaluate the performance of fly ash type C as partial replacement and recycled fine aggregate on concrete. The following conclusions are made from the test results:

- ➢ The increasing use of fly ash percentage in the concrete mixture gradually reduced the splitting tensile strength of the concrete. Except for the 100% recycled fine aggregateand 25% fly ash replacement, the splitting tensile strength increased by 0.629% from the 100% recycled fine aggregate and 0% fly ash composition. These results indicate that the use of fly ash in the 28-day-old concrete mixture was not able to increase the splitting tensile strength of concrete.
- ➢ The splitting tensile strength increased gradually until it reached its highest strength at 75% recycled fine aggregate

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replacement. Recycled fine aggregate mixed in concrete has greater strength than normal concrete because the recycled fine aggregate oven-dry density value used in this study is greater than the natural fine aggregate.

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