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Mechanical Properties of Concrete Containing Reclaimed Asphalt Pavement (RAP) and Fly Ash as Replacement Materials

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Abstract: Nowadays, a lot of studies have been conducted on waste materials to replace coarse aggregates and cement in producing concrete. Use of the reclaimed asphalt pavement (RAP) and fly ash in the concrete will put on the concept of eco-friendly and also improve the strength of concrete while compared to common concrete that could damage the environment when used too much and costly in the future. In this study, RAP replaced up to 10.00 % of the coarse aggregate, while fly ash replaced up to 9.00 % of the cement in the concrete mixture. The performance of the RAP and fly ash replacement concrete was then compared to that of normal concrete. Based on the result, the closest height of slump to the control sample is at 3.00 % fly ash with 0.00 % RAP aggregate replacement. Furthermore, the maximum water absorption was attained at the replacement ratio of 9.00 % fly ash and 10.00 % RAP, which was 4.09 %. This was due to the distribution of RAP aggregates increasing the voids within the concrete cubes. Besides, the highest compressive strength concrete cube at age 28 days as a percentage of 6.00 % fly ash and 0.00 % RAP aggregate replacement and compressive strength of 29.12 MPa. While the highest compressive strength concrete cube at age 28 days as a percentage of 3.00 % fly ash and 10.00 % RAP aggregate replacement and compressive strength of 30.77 MPa. Hence, the compressive strength was decreased when the percentage of replacement RAP and fly ash increased. Generally, the replacement percentage for fly ash is 10.00 % to 20.00 % acceptable, whereas RAP should not replace coarse aggregates more than 20.00 %. In conclusion, the optimum content for this research of RAP and fly ash are at 10.00 % RAP and 3.00 % fly ash of percentages where its compressive strength results in increases to 30.77 MPa after 28 days.

Keywords: Reclaimed Asphalt Pavement, Fly Ash, Aggregate, Replacement Materials, Concrete

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1. Introduction

Malaysia is one of the countries that has increased total expenditure for road maintenance as they need to maintain a safe, efficient and economical roadway system. Based on [5], this is due to Malaysia having 25 deaths per 100,000 people, which is among the highest in the world, compared to a regional figure of 17.9 deaths per 100,000 people. Since 2004, this has had a negative social and economic impact, with an estimated economic loss of MYR 79 billion. Therefore, this will lead to a significant increase in demand to restore the existing pavement as to decrease the accidents occurring from road pavement problems. Reclaimed asphalt pavement was used as a replacement of coarse aggregate as the RAP materials mix also had the aggregate that was suitable to replace coarse aggregate in concrete. Moreover, rendering to [2] Malaysian palm oil production is expected to reach 15 million tonnes (301,000 barrels per day) in 2005, which is very close to the actual value of 14.96 million metric tonnes recorded by the Malaysian Palm Oil Board (MPOB). Therefore, to save the environment, waste of road maintenance was used as reclaimed asphalt pavement and palm oil waste was used as fly ash for replacement materials in the concrete mix. It is also cost-effective as the waste materials of RAP and fly ash easily get into the industrial waste.

Based on the previous study of [3], the cubes containing 0.00 % of RAP aggregate had the maximum strength among the cubes containing RAP aggregate, with the highest average strength of 28.08 N/mm2 at 28 curing age, according to the results. Moreover, concrete containing 30% RAP aggregate had the maximum strength, followed by concrete containing 50.00 %, and 70.00 % RAP aggregate, with the highest strength of 22.36 N/mm^2 at 28 curing age due to cement hydration. For the fly ash based on the researchers [1], the testing conducted at various times indicates that the compressive strength of concrete mixes decreases as the amount of Fly Ash in the mix increases. It is important to know that the maximum amount of Fly Ash that can be mixed is 45.00 %, and any more than that may not be safe for certain concrete mixtures. In general, as the proportion of fly ash increases, the strength of the concrete increases dramatically from 7 to 28 days, indicating that the early strength of the concrete is lowered as the quantity of fly ash increases. Hence, conferring [6] the use of fly ash recovers the mechanical strength and durability of concrete by modifying the structure and increasing the mechanical strength of the interface area. According [7], once compared to a Portland cement concrete of the same workability, the use of good quality fly ash with high fineness and low carbon content reduces the water demand of concrete. As a result, the use of fly ash should allow the concrete to be produced at a lower water content.

This research aimed to investigate mechanical properties of Reclaimed Asphalt Pavement (RAP) aggregate as replacement materials of coarse aggregate and Fly Ash (FA) as replacement materials of cement in the concrete mix. The samples of reclaimed asphalt pavement were collected with the Sime Darby, Pagoh while the fly ash at the Jerantut, Pahang. Next, to evaluate the optimum percentage use of Reclaimed Asphalt Pavement (RAP) aggregate as replacement materials of coarse aggregate and Fly Ash (FA) as replacement materials of cement in the concrete mix. Finally, to observe the compressive strength of concrete mix containing Recycled Asphalt Pavement (RAP) and Fly Ash (FA) compared it with normal concrete (the control) for this research. The expected results for this research is the RAP and fly ash will have strength as good as the normal concrete. In the future research, the recommended replacement percentage for fly ash is 10.00 % to 20.00 %, whereas RAP should not replace coarse aggregates more than 20.00 %.

2. Methodology

2.1 Materials Preparation

2.1.1 Cement

The cement used for each mix in this research was Ordinary Portland Cement (OPC) and in accordance with the standards prescribed by MS 522 Part 1: 1997. The cement crystallizes in the presence of water, forming calcium silicate hydrate (CSH) and calcium hydroxide ($Ca(OH)_2$), which has a strong crystalline bond structure. Besides, cement is a binder to components in concrete due to its bonding agent nature when wet.

2.1.2 Fine Aggregate

In this study, the fine aggregate or sand that was used in this test was sand that passes as the requirement needed for concrete mix. Usually, the sand used consists of the unmilled type. This sand should be free of contaminants and in a clean condition.

2.1.3 Coarse Aggregate

Coarse aggregate is composed of granite elements and this mortar must not contain pieces of clay exceeding 1.00 % by weight. This coarse aggregate must have an appropriate shape, and the maximum size of this aggregate used in this study is in the range of 20 mm.

2.1.4 Fly Ash

Fly ash taken from oil palm plantations around the Jerantut district is utilized as a replacement material in the concrete mix. A total of fly ash that are 3.00 %, 6.00 %, and 9.00 % of the weight of the cement used is included in the mix as an additive to the prescribed mixture. In the previous study, the researchers usually did the research on the higher percentages such as 15.00 %, 25.00 %, 35.00 %, 45.00 %, 55.00 %, and 65.00 % of fly ash. Hence, this research to observe whether 3.00 %, 6.00 %, and 9.00 % of fly ash can give the same strength of concrete compared to normal concrete.

2.1.5 Crushing Reclaimed Asphalt Pavement (RAP)

The Reclaimed Asphalt Pavement (RAP) that is gained from a Sime Darby, Pagoh is generally in a huge shape. Thus, the RAP should be crushed into a particle size of the coarse aggregate because it can be easier to use in the concrete mixture. This work was completed with the help of a CBR hammer and a hammer. The RAP used in this test was a replacement of coarse aggregate in the concrete mix.

2.1.6 Water

Water used in concrete mixes must be from a clean and approved source. In addition, the water used should be free from contaminants such as floating solids, organic matter, and so on. Therefore, in this study, tap water is used in the concrete mix.

2.2 Sample Preparation

2.2.1 Concrete Cube Sample

The amount of concrete cubes samples that will be used in this project were 48 concrete cubes for 7 and 28 days as represented in Table 1. In this test, the cube samples will be used for the density test, water absorption test, and compression test. Each concrete cube sample used in this test is 100 mm x 100 mm x 100 mm in size. The concrete cube sample will be in the curing tank provided by the laboratory for 7 and 28 days. This curing process has a significant impact on the strength and durability of concrete. Hence, each concrete cube sample needs to do the curing process before doing another test based on their reasonable period. Moreover, Reclaimed Asphalt Pavement (RAP) was used to replace coarse aggregate in concrete mixes with percentages of 10.00 % of RAP while Fly Ash (FA) will be used as replacement materials with the percentage of 3.00 %, 6.00 %, and 9.00 % of fly ash.

Table 1: Calculation Amount of Cube Test for Different Percentages of RAP and FA in 7 and 28 Days

RAP				
Fly Ash	**0%**		**10%**	
Number of Samples	7 Days	28 Days	7 Days	28 Days
0%	3	3	3	3
3%	3	3	3	3
6%	3	3	3	3
9%	3	3	3	3
Total cubes	48			

2.2.2 Design of Concrete Mix

The process of finding the required and specified characteristics of a concrete mixture was known as mix design. The design of the concrete mix is prepared based on the Department of Environment (DOE). This concrete mix will be designed to achieve a compressive strength of 25 N/mm^2 in 28 days and have a total collapse slump test drop between 30 mm to 60 mm. Each fresh concrete needs to do the slump test for each batch of concrete mix. The mechanical tests used in this research were the density test, water absorption test, and compressive strength test. The samples will be examined for mechanical properties after 28 days of the curing process. The compressive strength test will be tested for concrete cube samples for 7 and 28 days after the curing process. The compression machine that will be used in this test with a capacity of 1500 kN to get the compressive strength results whether it has achieved the objective for this research. The further total amount of the materials used for each percentage is tabulated in Table 2.

Table 2: Concrete Mix Design Calculation Amount of Material that Used

Percentage of Fly Ash (%)	Percentage of RAP (%)	Weight of Material (kg)						Number of Samples	
		Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	RAP	Water	7 Days	28 Days
0	0	2.11	0	2.67	9.50	0	1.06	3	3
	10	2.11	0	2.67	8.55	0.95	1.06	3	3
3	0	2.05	0.06	2.67	9.50	0	1.06	3	3
	10	2.05	0.06	2.67	8.55	0.95	1.06	3	3
6	0	1.99	0.13	2.67	9.50	0	1.06	3	3
	10	1.99	0.13	2.67	8.55	0.95	1.06	3	3
9	0	1.92	0.19	2.67	9.50	0	1.06	3	3
	10	1.92	0.19	2.67	8.55	0.95	1.06	3	3
									48

3. Results and Discussions

3.1 Slump Test Data for Fresh Concrete

Slump tests were performed for each percentage of RAP and fly ash used in concrete, as well as for normal concrete. To achieve the workability of fresh concrete, it was based on the procedures outlined

in BS EN 12350-2 (Testing Fresh Concrete: Slump Test). The outcome was documented and is shown in Table 3 below.

Table 3: Results of a Slump Test during the Mixing of Fresh Concrete

Fly Ash (%)	RAP (%)	Slump (mm)
0	0	47
	10	35
3	0	42
	10	40
6	0	38
	10	24
9	0	36
	10	25

Table 3 shows that all of the slumps produced were true slumps. The slump value for normal concrete was 47 mm, which was the highest recorded. While slump for 0.00 % fly ash with 10.00 % RAP, 3.00 % fly ash with 0.00 % RAP, 3.00 % fly ash with 10.00 % RAP, 6.00 % fly ash with 0.00 % RAP, 6.00 % fly ash with 10.00 % RAP, 9.00 % fly ash with 0.00 % RAP, and 9.00 % fly ash with 10.00 % RAP decreased with slump values of 35 mm, 42 mm, 40 mm, 38 mm, 24 mm, 36 mm, and 25 mm, respectively. It was discovered that as the percentage of RAP and fly ash replacement increased, the workability increased due to the strength of fly ash as replacing cement. However, all slump values obtained were acceptable because they were still within the requirement of slump values between 30 mm and 60 mm in concrete mix design, with the exception of 9.00 % fly ash with 10.00 % RAP. However, the closest height of slump to the control sample is at 3.00 % fly ash with 0.00 % RAP aggregate replacement. We can conclude that 3.00 % fly ash and 0.00 % RAP meet and exceed the standard workability of concrete.

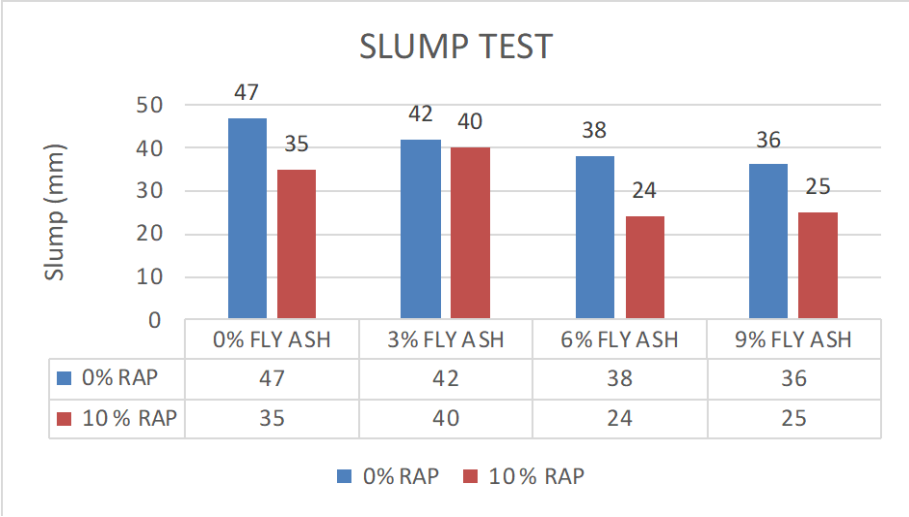

Figure 1: Graph of Slump Test in the Different Percentages of the RAP and Fly Ash

According to Figure 1, normal concrete has a slump value of 47 mm. It shows that the percentage of RAP and fly ash has increased while the slump value of fresh concrete has decreased. The slump test appearance of this lowering slump value is due to RAP and fly ash that gives higher water immersion values than normal concrete. This condition occurs due to RAP and fly ash which absorbs water at a higher rate than coarse aggregate and cement. Hence, the higher the percentage of RAP aggregate and

fly ash replace by coarse aggregate and cement in the concrete mixture, the lower the workability of fresh concrete.

3.2 Density Test Data for Concrete Cubes

The average density of concrete cubes was determined using 3 cubes aged 7 and 28 days. Complete density test results with various percentages of RAP and fly ash are shown in Figure 2.

As presented in Figure 2, the replacement ratio of RAP and fly ash increased due to the average density of concrete cubes decreased. Normal concrete cube samples had an average of density 2322 kg/m^3. As soon as the percentage of RAP and fly ash replacement materials reached 10.00 % and 9.00 % respectively, the average density of concrete cubes dropped to 2197 kg/m^3. Based on [8], the most appropriate concrete density was generally between 2300 kg/m^3 and 2500 kg/m^3 with a minimum value of 2000 kg/m^3. From the average results, the density of concrete that contains replacement materials of RAP and fly ash has reached the necessity of the concrete density. As a result, all percentages of RAP and fly ash containing samples are classified as normal concrete.

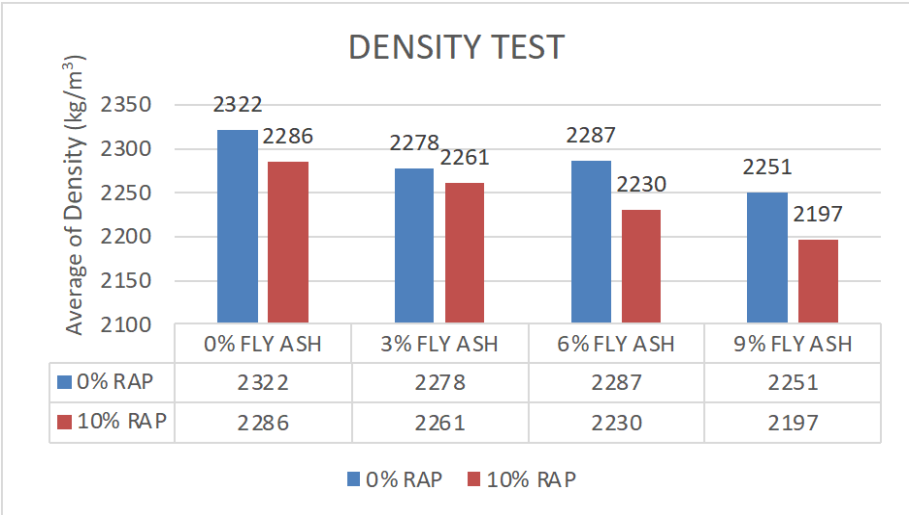

Figure 2: Graph of Density Test in the Different Percentages of the RAP and Fly Ash

3.3 Water Absorption Test Data for Concrete Cubes

The water absorption of concrete is very important because it determines the durability of this building material to weather changes. This test was carried out in accordance with the procedure outlined in BS 1881: Part 122: 1983 (Testing Concrete: Water Absorption Determination Method). In addition, the water absorption test is defined as an increase in the weight of concrete due to water. The low water absorption implies that the concrete is of higher quality and more resistant to weather changes, particularly when exposed to heat and rain. This water absorption test was carried out in which the samples used for this experiment were weighed initially before being submerged in water after cooling for 24 hours. The immersion process was using a curing tank and the time was set at 30 minutes for curing. After that, the wet mass of the concrete cube samples will be taken. The results were then recorded to find the average percentage of water absorption for 28 days.

Figure 3 shows the percentage of water absorption at 28 days which had the different percentages of RAP and fly ash content in each mixture. In this study samples, the particular water absorption percentage increased with the increase in the use of RAP and fly ash materials. The higher RAP and fly ash materials in the sample, the higher the percentage of water absorption rate for the sample of 28 days. The water absorption of normal concrete was 2.51 % which was the lowest percentage compared to the concrete cubes samples that had replacement materials of RAP and fly ash. At the replacement of 6.00

% and 9.00 % of fly ash, the result showed the unchanged value which was 3.34 %. Maximum water absorption was attained at the replacement ratio of 9.00 % fly ash and 10.00 % RAP, which was 4.09 %. This was due to the distribution of RAP aggregates increasing the voids within the concrete cubes. To conclude, the percentage of water absorption increased with the percentage of RAP aggregate and fly ash as the age of the sample increased.

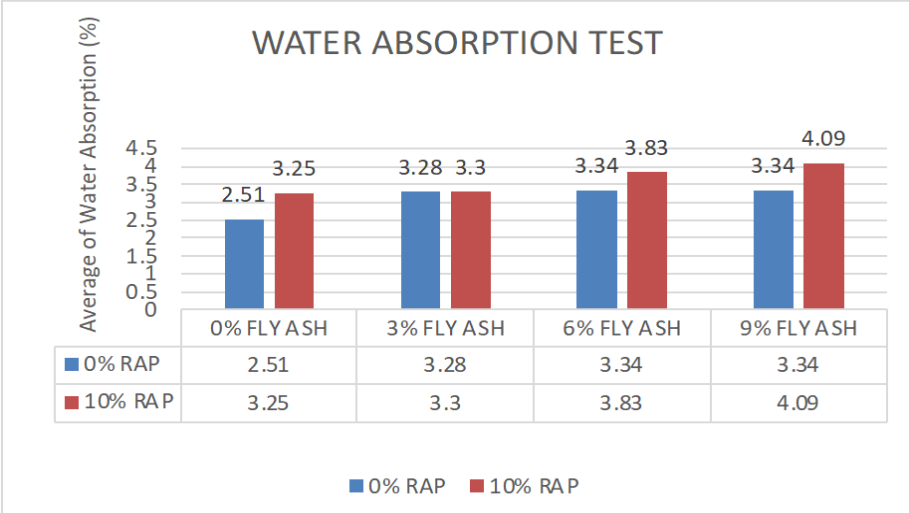

Figure 3: Graph of Water Absorption Test in the Different Percentages of the RAP and Fly Ash

3.4 Compressive Strength Test Data for Concrete Cubes

A compressive strength test is an experiment that is often performed on concrete to determine the strength of the concrete. The test was carried out according to the BS 1881: Part 122: Method for determination of water absorption. Compressive strength tests were carried out on concrete cube samples measuring 100 mm x 100 mm x 100 mm. This test was conducted at 7 and 28 days according to the age of the cube using the Compression Machine Test. The compressive strengths of the concrete cube samples were distinguished through the different percentages of RAP content were 0.00 % and 10.00 % while the percentages of fly ash used were 0.00 %, 3.00 %, 6.00 %, and 9.00 % for samples aged 7 and 28 days. A total of three concrete cube samples were tested and the mean value of the readings was recorded to determine the compressive strength. The results of the compressive strength testing at 7 and 28 days of replacement 0.00 % RAP and 10.00 % RAP were recorded.

Figure 4 showed the compressive strength of concrete cubes with the replacement of 0.00 % RAP. After 7 days and 28 days, the compressive strength of normal concrete was 17.15 MPa and 27.44 MPa respectively. After 28 days, the highest compressive strength value was 6.00 % fly ash which is 29.12 MPa, while the lowest compressive strength value is 3.00 % of fly ash concrete which is 22.32 MPa. This occurred because the concrete did not reach sufficient maturity in 28 days of the curing process. The compressive strength of concrete cubes decreased as the fly ash replacement percentages increased. Besides that, the compressive strength of concrete cubes samples with 3.00 %, 6.00 %, and 9.00 % fly ash replacement were 22.32 MPa, 29.12 MPa, and 25.49 MPa after 28 days respectively. As a result, the minimum compressive strength of concrete is at 7 days which is a percentage of 3.00 % fly ash with a percentage of 0.00 % RAP aggregate replacement with the compressive strength is 16.56 MPa. While the highest compressive strength concrete cube at age 28 days as a percentage of 6.00 % fly ash and 0% RAP aggregate replacement and compressive strength of 29.12 MPa. This compressive strength corresponds to the grade of the design concrete mix.

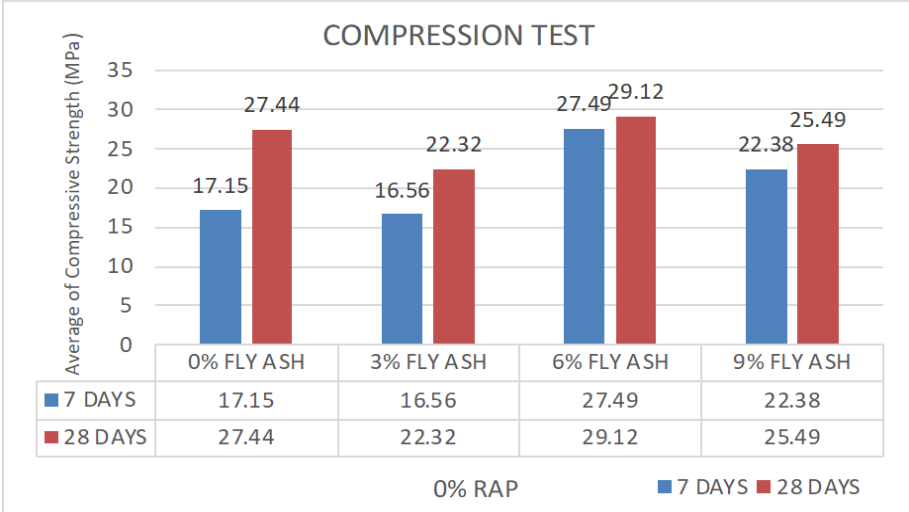

Figure 4: Graph of Compressive Strength Test in the Concrete with Replacement of 0% RAP

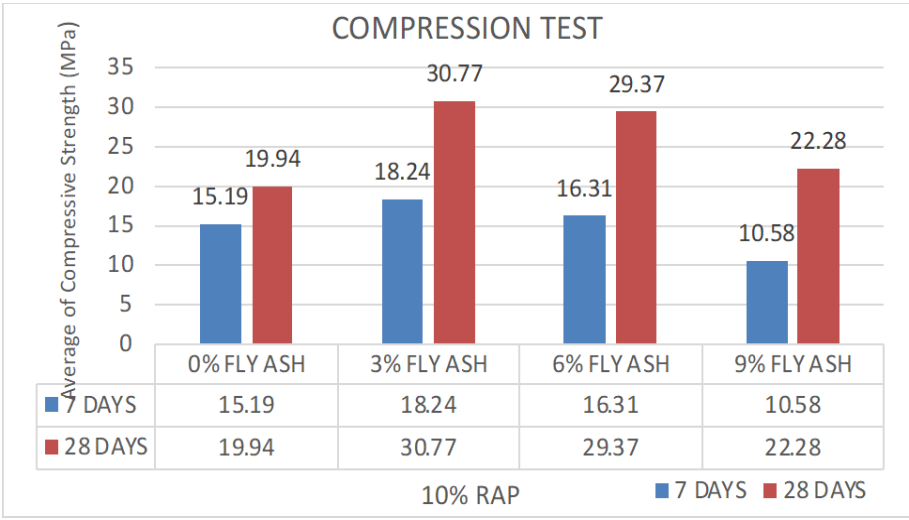

Figure 5: Graph of Compressive Strength Test in the Concrete with Replacement of 10% RAP

Figure 5 showed the compressive strength of concrete cubes with the replacement of 10.00 % RAP. After 7 days and 28 days, the compressive strength of concrete with replacement of 10.00 % RAP was 15.19 MPa and 19.94 MPa respectively, which was lower than normal concrete (control). This is due to normal concrete having the highest compressive strength from the replacement material of RAP was not strong and its strength is not durable compared to the existing coarse aggregates used in concrete mixes. The compressive strength of concrete with replacement materials of 10.00 % RAP decreased due to the increase in percentage replacement of fly ash materials. After 28 days, the compressive strength of concrete with replacement 3.00 %, 6.00 %, and 9.00 % fly ash materials were 30.77 MPa, 29.37 MPa, and 22.28 MPa respectively. Other than that, the minimum compressive strength of concrete is at 7 days which is a percentage of 9.00 % fly ash with a percentage of 10.00 % RAP aggregate replacement with the compressive strength is 10.58 MPa. However, the highest compressive strength concrete cube at age 28 days as a percentage of 3.00 % fly ash and 10% RAP aggregate replacement and compressive strength of 30.77 MPa. Hence, the graph demonstrated that increasing the amount of RAP aggregate and fly ash in the concrete will increase the compressive strength at both 7 and 28 days.

4. Conclusion

It may be deduced from this research that the cube test had achieved the objectives. The mechanical properties of RAP and fly ash containing concrete were measured in terms of slump value, density,

water absorption, and compressive strength. According to the objective, the goal of this research was to decrease the use of natural resources by replacing coarse aggregate and cement in concrete with RAP and fly ash. Overall, it can be concluded that the compressive strength was decreased when the percentage of replacement RAP and fly ash rose. Based on [4], due to the high fineness of the fly ash and the early-age pozzolanic reaction, the compressive strength abilities of the treated fly ash concretes increased the mechanical properties. Moreover, the method of crushing reclaimed asphalt pavement also influences the results of each test performed. Thus, permanent method requirements are to be recognized for reclaimed asphalt pavement to be reused to produce the best test results. It is also advised not to use concrete using RAP material on building sites due to the lowest strength measured. Moreover, [3] utilized that for non-structural purposes such as walkways or playgrounds. Finally, the optimum content for this research of RAP and fly ash are at 10.00 % RAP and 3.00 % fly ash of percentages where its compressive strength results in increases to 30.77 MPa after 28 days. For future research, the recommended replacement percentage for fly ash is 10.00 % to 20.00 %, whereas RAP should not replace coarse aggregates more than 20.00 %.

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