The combination of conventional Roller-Compacted Concrete (RCC) with the substitution of fly ash for fine aggregate replacement

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Abstract. This study aimed to investigate the characteristics of roller-compacted concrete when fine aggregate is replaced with fly ash. The investigation focused on assessing workability, compressive strength, flexural strength, and split tensile strength of the concrete mixtures. Four testing methods were employed, including the slump test for workability assessment, the compression test for determining compressive strength, the flexural test for evaluating flexural strength, and the split tensile test for measuring split tensile strength. The fly ash used in this project was sourced from the powerplant in Malaysia. Various fly ash contents, specifically 0%, 55%, 65%, and 75%, were utilized to replace the fine aggregate. The concrete mixtures were subjected to water curing for 7, 14, and 28 days before testing. Following the mixing process using a concrete mixer, the mixtures underwent a slump test to evaluate their workability. It was observed that the workability of the concrete decreased as the percentage of fly ash used to replace the fine aggregate increased. Mixtures with fly ash exhibited zero slump, while the control mixtures displayed true slump. Subsequently, compression, flexural, and split tensile tests were conducted after 7, 14, and 28 days of water curing. In terms of compression strength, an increase in fly ash content resulted in higher compressive strength in the concrete mixtures. The mixture with 65% fly ash content demonstrated the highest compressive strength at 49.84 MPa. Regarding flexural strength, the concrete with 75% fly ash content exhibited the highest value, measuring 5.45 MPa. However, for split tensile strength, the concrete without fly ash content showed the highest value at 8.84 MPa compared to other mixtures, indicating that the fly ash content exceeded the optimum amount for the mix design. In summary, the concrete mixtures with fly ash displayed

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several advantages, but their suitability depends on the specific type of construction.

1 Introduction

The roller-compacted concrete (RCC) is basically a concrete mixture which is compacted by vibratory rollers and hardened and consists of a stiff mixture of aggregate, cementitious materials, and water. RCC will form a zero slump when it is laid together and compacted with the soil and rockfill elements and has been developed for research of the design of the buildings.

Studies show the effect of global warming and environmental issues due to the usage of conventional concrete which using standard cement as the concrete mixtures [1][2][3]. The standard cement mixtures are produced using limestone as the main ingredient. The excessive quarrying of limestone will affect the balance of environmental systems especially the caves and hills which are the main source of limestone.

To overcome this issue, the usage of fly ash in concrete is very encouraged. Fly ash produced more strength in concrete structure and released lesser heat to the environment [4] [5]. Fly ash is the output of coal-fired electric and steam generating plants. By utilizing the waste from the power generation plants, which is fly ash, the cost for the concrete will be lesser and the impact to the environment will be reduced. The testing for strength of roller-compacted concrete with fly ash will impact on environment. The concrete with fly ash gives more durability compared to normal concrete mixtures [6] [7]. Using fly ash in concrete mixtures is a major improvement in construction sustainability.

According to the literature reports, using fly ash (FA) in civil engineering is now required [8] [9]. The amount of free lime in the ash limits how much cement FA can substitute. In addition to its chemical makeup, the amount of glassy phase present, the temperature at which coal or lignite burns, the specific surface area (SSA), and other factors affect FA's reactivity. A pozzolanic substance is FA. Pozzolanic materials are those that have little to no cementing action on their own but, when combined with lime and water, form insoluble cementitious compounds. Pulverized fuel ash, also known as FA, is generated because of coal-fired power plants, and is added as a mineral to cement and concrete. When pulverized coal is blown into the furnace's burning chamber, its combustible components-primarily carbon, hydrogen, and oxygen-ignite at about 1500 degrees Celsius (2700 degrees Fahrenheit). At this temperature, non-combustible minerals like quartz, calcite, gypsum, pyrite, feldspar, silicates, and others melt and condense into minute liquid droplets. The droplets brought by the burning zone's flue gases are quickly cooled to form tiny, spherical glassy particles. Solid particles are removed from flue gases using mechanical and electrical precipitators, also known as baghouses. FA refers to the ash particles that "fly" away from the furnace with the flue gases. It is anticipated that using industrial waste products like fly ash (FA) in building projects will significantly benefit humanity by protecting the environment and enhancing the concrete's properties [10][11]. Broadly used in concrete, fly ash improves the workability of zero slump concrete and helps to lower the hydration temperature in mass concrete.

Additionally, fly ash can set retard, which is crucial for RCC dam applications. It is well known that fly ash affects the mechanical characteristics and longevity of RCC mixtures. In addition to physically filling pores, fly ash also refines capillary pores, ITZ, and lowers the concrete's permeability by reacting with calcium hydroxide, which is released during cement hydration [12].

2 Methodology

For the experimental study, three different mix designs of well graded fly ash in concrete were prepared which is 0%, 55%, 65%, and 75%. The classification of concrete mix design as shown in Table 1. Then, they were mixing with cement, gravel and water with control mix, mix design 1, mix design 2 and mix design 3 as shown in Table 2. All mixing then were tested by slump test with ASTM C143 standard and the compressive strength test with ASTM C 109's test method.

Portland cement is the most extensively used type of cement in the world as a key component of concrete. It's a complex formation ingredient made from heating and milling a limestone and clay or limestone and shale mixture into a grey powder. Ordinary Portland Cement (OPC) Type I that complies with the ASTM Standard Specification for Portland Cement (ASTM C150) will be used in this research. Aggregates are inert granular materials such as gravel, sand or crushed stone that are used in concrete along with water and Portland cement. Aggregates are separated into two types, accounting for 60 to 75 % of the total volume of concrete. Fine aggregates normally pass through a sieve with a 4.75mm opening. River sand that fulfils ASTM C33 (ASTM, 2055i) criteria will be used as the fine aggregate. Coarse aggregates, retains on a sieve with a 4.75mm opening. As the coarse aggregate, a 20 mm nominal size aggregate that meets ASTM C33(ASTM, 2055i) criteria will be used.

Table 1. Classification of concrete mix design.

Mix Designation No	Fine Aggregate (%)	Fly Ash (%)
Control Mix	100	0
1.0	45	55
2.0	35	65
3.0	25	75

Table 2. Control Mix, Mix design 1.0, Mix design 2.0 and Mix design 3.0.

Mix Design	Cement **(kg)**	Water **(kg)**	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**	**Fly Ash (kg)**
Control Mix	7.88	3.94	13.80	24.64	0.00
1.0	7.88	3.94	6.21	24.64	7.59
2.0	7.88	3.94	4.83	24.64	8.97
3.0	7.88	3.94	3.45	24.64	10.35

36 samples for each mixture were prepared by slicing into dimensions of 100 x 100 x 100 mm cube samples will be used to cast. For each mixture, different proportions will be utilized, and the cubes will undergo wet curing at room temperature. Concrete cubes that had been cured for 7, 14, and 28 days were examined for compressive strength, with 3 cubes tested for each age. During the test, an axial load will be applied to the cube sample, which will gradually increase until the cube sample can no longer withstand it.

3 Results and discussions

The results obtained for the slump test were tabulated in Table 3. The goal of the slump test is to determine whether the concrete mix, which was made in the lab or on the construction site as it was being built, is consistent or workable. Concrete slump tests are carried out from batch to batch to guarantee that the concrete is of a consistent quality throughout the construction process. In accordance with standard of BS 1881: Part 102: 1983, this testing is the simplest, cheapest, and quickest method to figure out the concrete workability.

The highest slump obtained was 40mm which was from the controlled concrete mix where there was no replacement of fly ash in the mixture. Furthermore, three other mix designs with partial replacement of fine aggregate with well graded fly ash showed as expected, the increase in fly ash content will make the workability of the concrete to be lower and produces zero slump [13] [14] [15]. The difference between the control and the concrete with fly ash is very big where the slump height for the control mix is 40mm meanwhile the slump height for the concrete with fly ash is in the range of 0-5mm only. The higher the content of the fly ash, the lower the workability of the concrete.

Table 3. Slump test for fly ash concrete.

Fly Ash (%)	Slump (mm)	Workability	Type of Slump
0	40	Medium	True
55	0	Low	Zero
65	0	Low	Zero
75	0	Low	Zero

Figure 1 shows the compressive strength of different days which is 7,14 and 28 days. Compressive strength of 7 days age was used as an early indication for 28 days strength to determine if any action should be taken if the strength values obtained from the test did not achieve the desired strength. Compressive strength for 14 and 28 days shows an increasing trend for the mix design with replacement of mixing sand with well graded fly ash. However, it shows a slightly decreasing trend compared to 0% of sand replacement. After 28 days of curing, mix design 2.0 with 65% replacement of well graded fly ash as fine aggregate replacement with 49.84 MPa has the highest strength. Nevertheless, Mix design 1.0 and Mix design 3.0 with 55% and 75% replacement of well graded fly ash as fine aggregate replacement managed to achieve a strength of 45.09 MPa and 45.25 MPa, respectively. The targeted design compressive strength for this test was 40 MPa which was achieved by all mix design.

The experiment results are consistent with previous research where a certain percentage of fly ash replacement with fine aggregate showed decrease in compressive strength while others showed an increase in compressive strength. The data also showed that the proportions utilized in the control mix were the correct proportions for producing a strong reinforced concrete, and that the concrete created was strong enough to be used in structural projects. As a result, mix design 2.0 is able to be used in any projects. The percentage of 65% showed a positive on replacing well graded fly ash in concrete.

Table 4. Compressive strength test results (MPa).

Bottom Ash content (%)	Compressive strength (MPa)		
	7 days	**14 days**	**28 days**
0	17.51	37.64	48.98
55	24.54	36.01	45.09
65	29.54	35.36	49.84
75	14.44	27.13	45.25

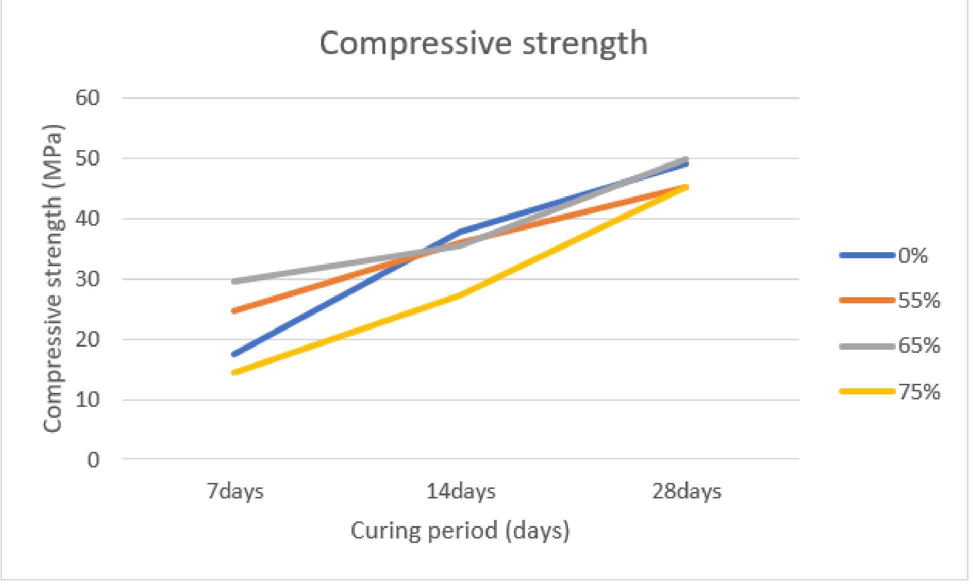

Figure 1. Compressive strength test for 7, 14, and 28 days

The result obtained for the flexural test were composed in Figure 2. Flexural tests evaluate the tensile strength of concrete indirectly. It will test the ability of the concrete to withstand the failure in bending. After experiencing 7 days of curing, the concrete with 75% of fly ash content showed the highest value of flexural strength among all which is 4.9 MPa. While concrete with 65% and 55% both produce 4.58 MPa and 4.51 MPa of flexural strength. The concrete with 0% fly ash content produces 4.06 MPa of flexural strength. After 14 days of curing, the concrete with 75% of fly ash content showing the highest value of flexural strength which is 4.98 MPa. While the concrete with 65% and 55% both produces 4.66 MPa and 4.55 MPa of flexural strength respectively. The concrete with 0% fly ash content produces the lowest value among all which is 4.11 MPa of flexural strength. After 28 days of curing, the concrete with 75% of fly ash content shows the highest value of flexural strength among all which is 5.45 MPa. While the concrete with 65% and 55% both produces 5.39 MPa and 5.06 MPa of flexural strength. The concrete with 0% fly ash content produces 5 MPa of flexural strength, which is classified as the lowest among all.

Table 5. Flexural strength test results (MPa).

Bottom Ash content (%)	Flexural strength (MPa)		
	7 days	**14 days**	**28 days**
0	4.06	4.11	5.00
55	4.51	4.55	5.06
65	4.58	4.66	5.39
75	4.90	4.98	5.45

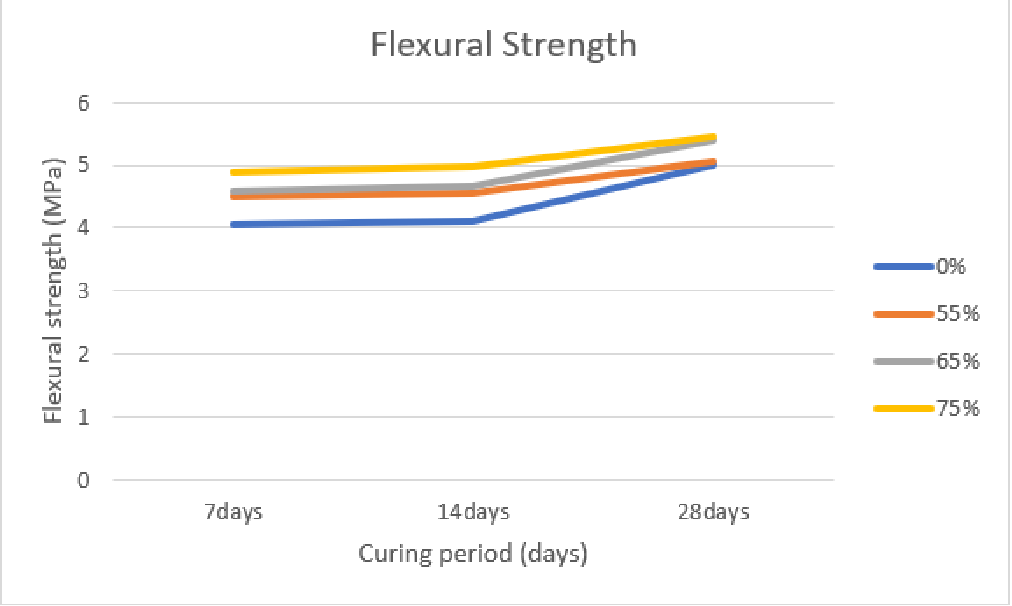

Figure 2. Flexural Strength Test for 7, 14 & 28 Days.

Meanwhile Table 6 shows the split tensile strength of different days which is 7,14 and 28 days. The split tensile test is an indirect way of evaluating the tensile test of concrete where the specimen, which is in cylindrical shape is laid horizontally and the force applied on the cylinder radially on the surface which causes the formation of a vertical crack along its diameter. After curing for 7 days, the concrete with 0% fly ash content produces the highest split tensile strength compared to others which is 5.39 MPa. The split tensile strength for concrete with 65% of fly ash content is 4.13 MPa while for concrete with 75% and 55% both produces 3.91 MPa and 3.03 MPa respectively. After curing for 14 days, the concrete with 0% of fly ash content shows the highest value of split tensile strength which is 8.42 MPa. Then, the concrete with 75% fly ash content produces 6.5 MPa of split tensile strength and the concrete with 65% and 55% both produces 5.3 MPa and 5.26 MPa respectively. After experiencing curing for 28 days, the concrete with 0% fly ash content produces the highest split tensile strength compared to others which is 8.84 MPa. The split tensile strength for concrete with 75% of fly ash content is 6.98 MPa while for concrete with 55% and 65% both produces 6.16 MPa and 33.41 MPa respectively.

Table 6. Split tensile strength test results (MPa).

Bottom Ash content (%)	Split tensile strength (MPa)		
	7 days	14 days	28 days
0	5.39	8.42	8.84
55	3.03	5.26	6.16
65	4.13	5.30	3.41
75	3.91	6.50	6.98

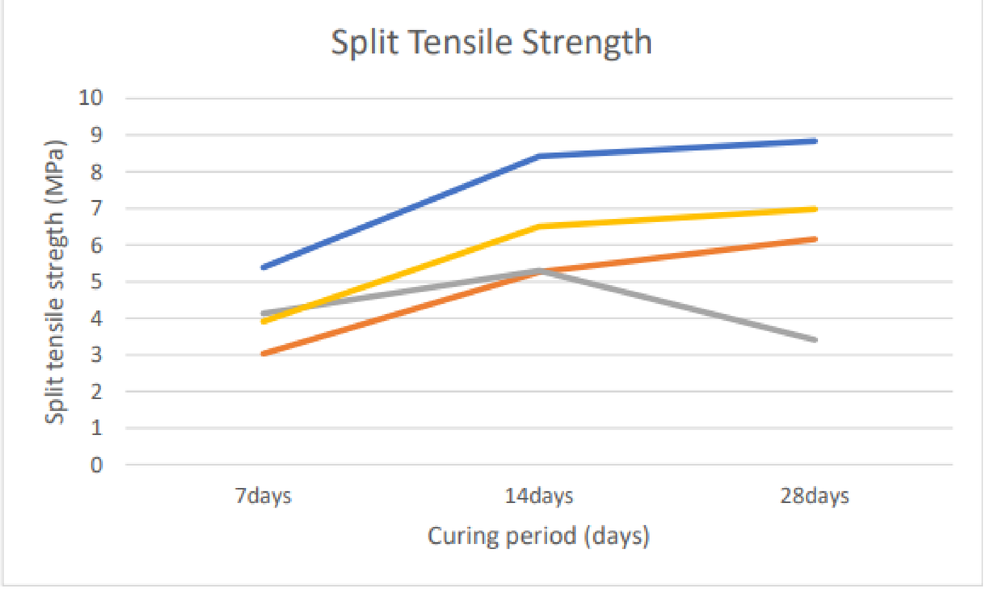

Figure 3. Split tensile strength Test for 7, 14 & 28 Days.

4 Conclusion

In this paper, the effect of using well graded coal fly ash on concrete as a fine aggregate replacement on normal concrete workability was successfully conducted. The conclusion that can be made based on the results obtained in the experiment on the slump test, it is showed that the presence of fly ash reduces the workability of concrete, with samples containing fly ash showing zero slump in comparison to control mixtures that had true slump. This suggests that the workability of concrete decreases as fly ash content increases. For the strength, the results of the compression test, concrete mixtures containing more fly ash produced concrete with greater compressive strength. The concrete mixtures with the highest fly ash content demonstrated the highest compressive strength, which is 49.84 MPa, after 28 days of curing. The compressive strength produced a strength greater than 40 MPa, which was the designated strength. Meanwhile for flexural strength, concrete with a fly ash content of 75% produced the highest flexural strength, according to the results of the flexural test. Comparing the obtained flexural strength to the control mixtures, it is 5.45 MPa. The fly ash playing important role to the concrete strength where it increases the strength of the concrete more than the control mixes although experiencing same type and same period of curing. Finally, the split tensile strength demonstrated that the fly ash causes the concrete cylinder to become weaker than control mixtures. The results demonstrated the strength difference between concrete containing fly ash and concrete lacking fly ash, with the control mixtures achieving split tensile strengths of 8.84 MPa. This is impacted by the excessive fly ash content, which decreased the concrete's split tensile strength.

In conclusion, fly ash may be used in construction in place of fine aggregate because the presence of fly ash will reduce the workability of concrete, making mass concrete structures an appropriate application. Moreover, the compressive strength of the concrete is higher when the fly ash content is higher, and it increases the flexural strength of the concrete. The split tensile strength decreases with the existence of fly ash content in the concrete [10].

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