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The Performance of Aluminium Dust as Sand Replacement in Concrete Mixture in terms of Compressive Strength and Water Absorption

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Abstract

The objectives goal from this research are to examine the feasibility of using aluminium dust as a potential sustainable source of natural sand for concrete production to address environmental issues resulting from sand exhaustion in the construction industry. The research examines the impact of different proportions of aluminum dust in 30 cubes of sample concrete to test the mechanical characteristics which are water absorption, durability, compressive strength, and workability at a percentage concentration of 5%, 10%, 15%, and 20%. The findings showed that the slump test decreased in workability with slump values dropping from 33mm (control cube) to 15mm (20% AD), the aluminium dust makes low workability on fresh concrete due to bubble formation. For the hard concrete test, it was found that the density also decreased with increasing aluminium dust in concrete, with significant cracking at 10% replacement and above. Water absorption improved at 5% replacement but cannot achieve concrete grade 30Mpa. Compression strength was decreased when replacement aluminium dust in concrete, which aluminium was a lesser calcium hydrate led to compression strength decreased. The findings suggest that up to 5% aluminium dust replacement in concrete need to add another material or additives to support compressive strength and durability, such as silica fume or fly ash, to enhance the development of calcium silicate hydrate in the concrete mixture.

1. Introduction

A large number of countries actively apply concrete as one of the key construction materials. However, it is needed to underline that supply of the natural sand is limited and creating a severe threat to the ecology. It has the worst impact in terms of environmental effects as it entirely alters the face of ecospheres through desertion of their original nature, displacement in river basins or coastlines, and erasure from natural habitats. Also, it pollutes soil, disrupts the water table and undermines species richness. Since the demand for concrete is increasing each year all over the globe, proper environmental interventions for the natural sand must be sought [1]. Additionally, there are researchers about recycling management that has stated about the fact that they find out that 28.7% of 12,400 tons of aluminum are wasted to be dust, so which is 3,559 tons of aluminium dust are wasted per year [2]. If aluminum dust is disposed of in a landfill, it will cause serious environmental pollution because the AD product is high in calcium oxide, sodium chloride, and aluminum oxide [3]. The project aims to reduce environmental pollution and increase sustainability in building processes by repurposing this plentiful waste material into concrete.

This study involved mixing the concrete mixture with aluminium dust. Materials for aluminium dust may be obtained from Sandakan, Sabah that make aluminium door and window frames. Activities such as grinding and cutting aluminium produce aluminium dust. The scale dimension will measure each sample cube at 100 mm x 100 mm x 100 mm, and the studies will be conducted in the concrete laboratory of the University Tun Hussein Onn Malaysia branch in Pagoh, Johor. The experiment focuses on the impact on compressive strength throughout 7 to 28 days. With an emphasis on the viability and advantages of incorporating aluminium dust into concrete for make more economical and environmentally friendly building techniques, this study attempts to shed light on cutting-edge building materials. By proving that using aluminium dust in concrete mixtures is feasible and effective, the study offers insightful information that can guide real-world construction projects' practical applications, benefiting all parties involved and promoting sustainable infrastructure development.

1.1 Properties of Aluminium Dust

1.1.1 Physical Properties of Aluminium Dust

Aluminium dust consider is a lightweight material with a density of approximately 2.7 g/cm^3, making it suitable for reducing structural weight [9]. Its particle size ranges from 0.04 to 125 µm, contributing to a high surface area-to-volume ratio, and enhancing dispersion and reactivity [10]. Aluminium dust is non-magnetic, reducing electromagnetic interference (Subramanian, 2010). Density variations in dust aluminium, ranging from 38.62% to 52.68% of its theoretical maximum, result from porosity and processing differences [11].

1.1.2 Chemical Properties of Aluminium Dust

Aluminium waste contains metal oxides, carbides, nitrides, and alumina, with SiO_2 + Al_2O_3 + Fe_2O_3 content exceeding 72.8%, surpassing ASTM C-618 standards for pozzolanic materials [13]. The presence of $Al(OH)_4$ within the silica matrix reduces alkali-silica reaction (ASR) and enhances durability [12]. Aluminium waste also extends the setting time of concrete, beneficial in hot-weather applications [14]. Additionally, aluminium dust are similar to aluminium fabric waste, with a high carbon content of approximately 94%, strengthens concrete and improves corrosion resistance.

1.1.3 Mechanical Properties of Aluminium Dust

Aluminium dust positively influences the mechanical properties of concrete, making it more sustainable and durable. It improves workability and extends curing time, particularly in hot weather conditions, with an optimal replacement level of around 20%. Additionally, a 20% aluminium waste replacement reduces water permeability and enhances acid resistance, contributing to the overall durability of concrete [15].

2. Methodology

This study is to expertly conducted laboratory tests to gather precise data about concrete properties. Specifically, the tests on concrete were done to analyze its compressive strength, assess its water absorption, and conduct slump and density tests. The primary objective of this research is to ascertain the efficacy of substituting aluminium dust for sand in concrete mixtures.

In the laboratory, studies were carried out to collect the results on the concrete slump test, density test, water absorption test, and compressive strength test to determine the effectiveness of the usage of aluminium dust in the concrete mixture. The result of this study will analyze to optimize concrete design mixture with sand replacement aluminium dust and to compare it with normal concrete.

2.1 Methodology flowchart

The procedure that needs to be properly planned to accomplish the research predetermined the goals and objectives are depicted in this chart. Figure 3.1 displays the work plan of procedure that was created for this research project.

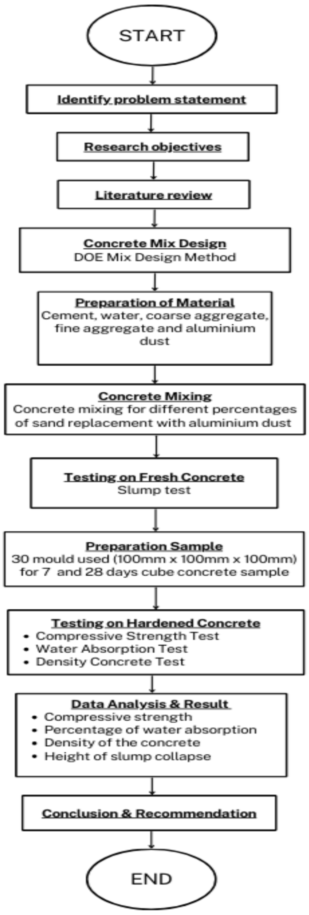

Fig. 1: Flow Chart of Methodology

2.2 Sample Preparation

2.2.1 Concrete Cube Sample

In this study, 30 cubes will be used for testing in the laboratory at 7-day and 28-day intervals. These cube specimens, which are essential components of the study, will be subjected to compression, density, and water absorption tests. A summary of the cube tests carried out at the designated intervals is provided in Table 3.1. In addition, different amounts of aluminum dust in 5%, 10%, 15%, and 20% will be added as a replacement.

Table 1: Sample needed for test

Aluminium Dust Replacement Fine Aggregate Percentage (%)	Number of Concrete Cube	
	7 Days	28 Days
AD (0%)	3	3
AD (5%)	3	3
AD (10%)	3	3
AD (15%)	3	3
AD (20%)	3	3
Total Concrete Cube	**15**	**15**

2.2.2 Concrete Mix Design (DOE Method)

To create concrete with the required qualities, concrete mix designers must precisely calculate the amounts of water, cementitious ingredients, aggregates, and aluminum dust (AD) to add to replacement with fine aggregates in concrete mixture. In this investigation, 30 cube samples of concrete were used with size cube 100mm x 100mm x 100mm. Figure 3.2 shows the proportions of concrete mixed for each amount.

***Table 2*: Proportions of concrete mixing**

Aluminium Dust Replacement Fine Aggregate Percentage (%)	Weight of Material in kilogram					Number of Samples	
	Cement (kg)	Fine Aggregate (kg)	AD (kg)	Coarse Aggregate (kg)	Water (kg)	7 Days	28 Days
0%	2.172	4.28	0	6.69	1.26	3	3
5%	2.172	4.066	0.214	6.69	1.26	3	3
10%	2.172	3.852	0.428	6.69	1.26	3	3
15%	2.172	3.638	0.642	6.69	1.26	3	3
20%	2.172	3.424	0.856	6.69	1.26	3	3
Total	10.86	19.26	2.14	33.45	6.30	15	15

2.3 Aluminium Dust Preparation

We intend to lessen dependency on traditional sand resources by utilizing recyclable aluminum resources, such as aluminum dust and debris from aluminum composite panels obtained from the industry-producing aluminum door and window frames in Sandakan, Sabah. With 6month period to gather all the aluminium dust, make sure is enough for use in the study. The findings plan will be carried out at the University Tun Hussien Onn Malaysia Pagoh branch laboratory, to assess the feasibility of using aluminum dust as a substitute finer aggregate material in the manufacture of concrete.

2.4 Laboratory Concrete Test

2.4.1 Slump Test for Concrete

It is important to evaluate the workability of concrete mixes that use aluminum dust in place of sand to guarantee the correct handling test. Workability is defined as the easy way the concrete can be molded, laid, and compacted without separation. The slump test, which is a crucial technique for evaluating the workability of concrete, will be carried out in compliance with BS 1881, Part 102.

***Table 3*: Table shown type of slump**

Type of Slump	Explanation
True Slump	The concrete's primary ability to retain its cone shape is proof that the mixture is cohesive and not overly workable.
Zero Slump	The form of the concrete is fully maintained. This illustrates how incredibly dry the combination is, which makes it perfect for use in road building.
Shear Slump	The top half of the concrete leans to one side and suddenly sinks, suggesting that the mix is cohesive but workable. Before retesting, the combination should be adjusted if it contains excessive amounts of water.

Collapsed Slump	All form is lost as the mixture falls completely. This suggests that there is a need to adjust the water-to-cement ratio to its appropriate level.

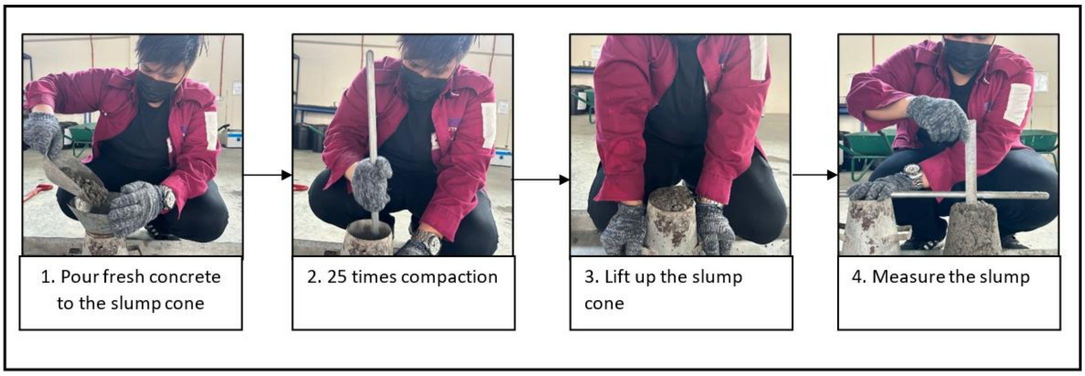

***Fig. 2*: Slump test procedure**

2.4.2 Density Test for Concrete

Accurate measurements of every cube are obtained using high-precision instruments with the following method BS 1881: part 114 density test for concrete, and a delicate balancing mechanism is used to compute each cube's mass accurately. Next, we will use the formula p=m/v to get the density of the concrete cubes, where is ρ as the density (kg/m^3), then m is the cube's mass (kg), and v is its volume (m^3).

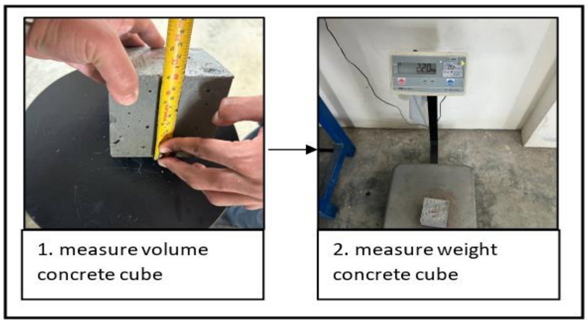

***Fig. 3*: Density test procedure**

2.4.3 Water Absorption Test for Concrete

Measure the increased mass of concrete over time while only the concrete cube was submerged in water, this approach is used to analyze the qualities of concrete in terms of water absorption rate performance. The procedure for this test follows the guidelines outlined in BS 1881: Method of test for assessing water absorption as required under part 122. The calculation water absorption test formula is shown below:

$$Percentage\ of\ water\ absorption = \frac{wet\ mass\ (kg) - dry\ mass\ (kg)}{dry\ mass\ (kg)}\ x\ 100 \tag{1}$$

Fig. 4: Water absorption test procedure

2.4.4 Compressive Strength Test for Concrete

Compressive strength is the ability of a given material or structure with regard to surface load so that it does not break or change its shape when the load is applied. Most materials are normally elongated when pulled and shortened when pressed with force. This test is defined in accordance with in BS 1881: Section 116 explains the normal process for analysis of the compressive strength of concrete cubes.

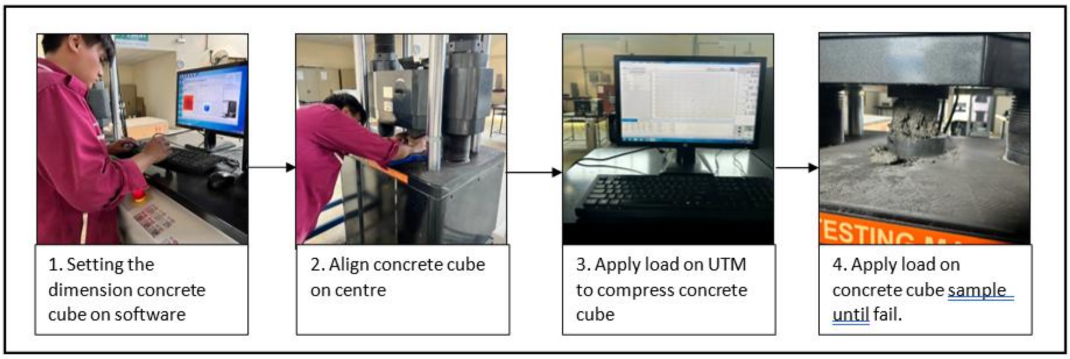

Fig. 5: Compressive strength test procedure

3. Results and Discussion

3.1 Slump Test

From the data presented in Table 4, the collected slump test results with different percentages of aluminum dust replacement, all proportions of the slump test may be categorized as a true slump. All samples possess a low workability in the range of 25-50 mm.

Table 4: Table shown the result of slump test

Sample	Collapse Height (mm)	Type of Slump	Degree of Workability
AD (0%)	33	True slump	Low
AD (5%)	21	True slump	Low
AD (10%)	17	True slump	Low
AD (15%)	17	True slump	Low
AD (20%)	15	True slump	Low

Figure 4.1 demonstrates that during the slump value of sand replacement to aluminium dust has dropped, the proportion of AD has grown. Aluminium content in concrete has been established to reduce the slump when it is increased in percentages of aluminium in concrete, as noted by different researchers. Aluminium in the form of powder, dross, or waste from composite panels, is found to accelerate the rates of hydrogen gas and lead to increased stiffness of the concrete mix, affecting its workability. Aluminium waste in higher dosages increases the rate of bubble formation and decreases workability, causing results in a large slump decrease [4][5].

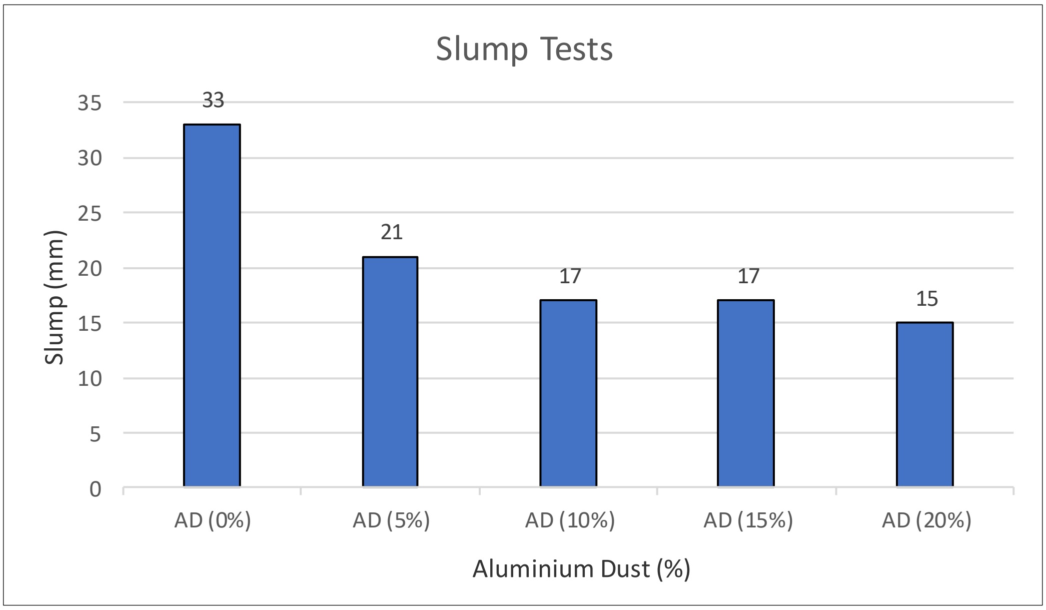

Fig. 6: Slump test result between the different AD percentage

3.2 Density Concrete Test

Based on Figure 4.2, the data showed the concrete density decreased when the percentage of aluminium dust (AD) increased. The incorporation of aluminium powder in the concrete mixture decreases. The concrete's density is because of the aeration of the material, the particle size of the aluminium powder is also another factor because the small size of particles causes a low dosage of the particles for density reduction. This has been due to the formation of gaseous bubbles when aluminium powder reacts with other chemicals within the mix, making the mix porous [5]. Moreover, at 28 days the density for the 10% aluminium dust replacement dropped sharply because concrete which contained this additive developed some cracks during the curing process in the tank.

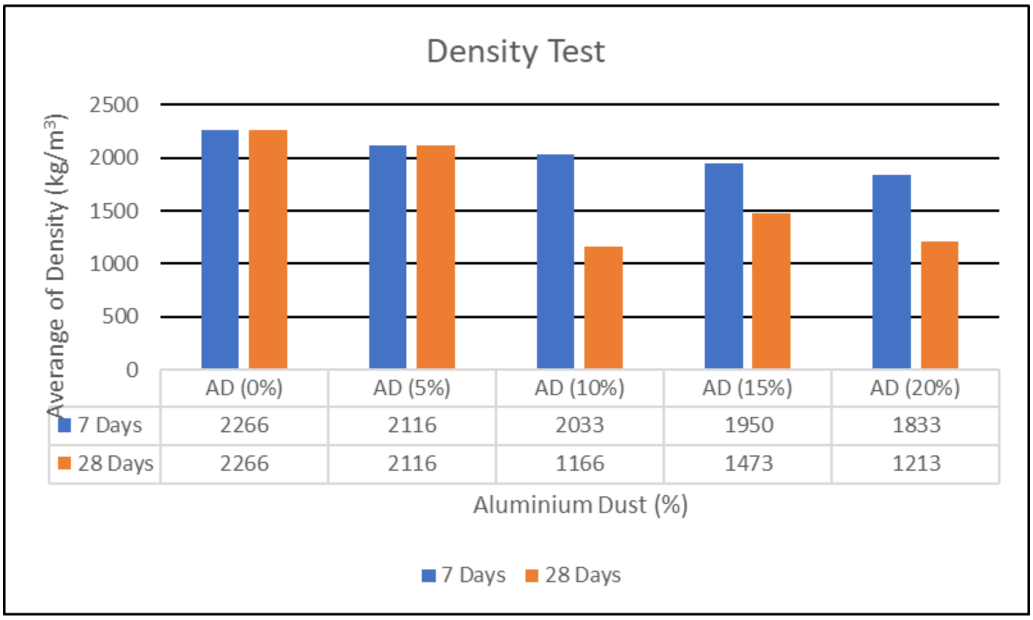

Fig. 7: Graph of density test result for different percentages of the aluminium dust (AD) for 7 days and 28 days

Fig. 8: The image of evidence of a crack on the test cube at 28 days on above 10% sand replacement with AD

3.3 Water Absorption Test

Based on Figure 7, the findings of the Water Absorption Test for the concrete specimen having concrete made from the replacement of sand by aluminium dust (AD) in different proportions at 7 and 28 days of curing time are shown. The findings also reveal the directionality of the relationship between water absorption and the percentage of aluminium dust, where they are inversely related. In the control sample with 0% AD, the highest values were observed for water absorption of 2.80% at 7 days and 2.41% at 28 days. At 28 days, for 10% above, there was an error in the result because during the curing tank, the concrete cube for 10%, 15%, and 20% was cracked, causing an imperfect size of the concrete cube to make an effect for the weight of the concrete, causing an error for 28 days above 10%. As much as 5% sand is replaced with aluminium dust at 28 days, the water absorption was maintained from the 7-day concrete cube result, it was only 2.41%, which means it has good water resistance for 5% sand replacement with AD in the concrete mixture. Further, previous researchers mention that the use of 5% aluminium waste enhances the water absorption resistance [6].

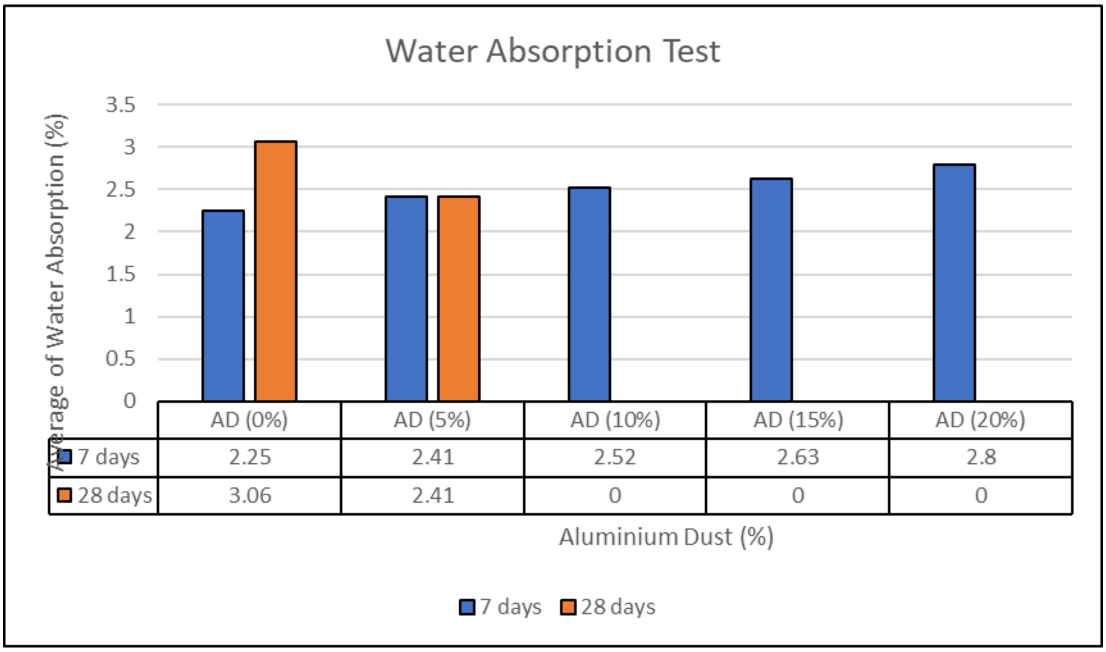

Fig. 9: Water absorption test results with different percentages of aluminium dust in concretes at 7 days and 28 days

Fig. 10: Concrete cube crack during in process of curing tank causes imperfect size for sand replacement AD in 10%, 15%, and 20% at 28 days sample cube

3.4 Compressive Strength Test

Based on the result of the compressive strength test in Figure 9, the sand replacement aluminium dust in the concrete mixture led to a drop in compressive strength that may have various causes, previous research has stated that the incorporation of aluminium dust in concrete decreases its strength in compression, a reduction rate of 13.62 percent reduction for every one percent increase in the quantity of aluminium dust. Supplemented was attributed to the random dispersion of the dust, which hindered the matrix of concrete. This random orientation means that a dense and compact matrix cannot be formed, some areas contain pores that act as sources of stress under compressive loads [7]. Moreover, a decrease in the calcium in the concrete mixture also led to a decrease in the compressive strength, which aluminium, was a lesser calcium silicate hydrate, the major phase credited with providing strength to concrete [8]. This is because for 10% above sand replacement aluminium dust, it had cracked during the process of curing in the tank, so when the compression test was done, it easily failed. These studies showed that in cement concrete, the aluminium dust reduces the compressive strength and limits sand replacement to 5% aluminium dust.

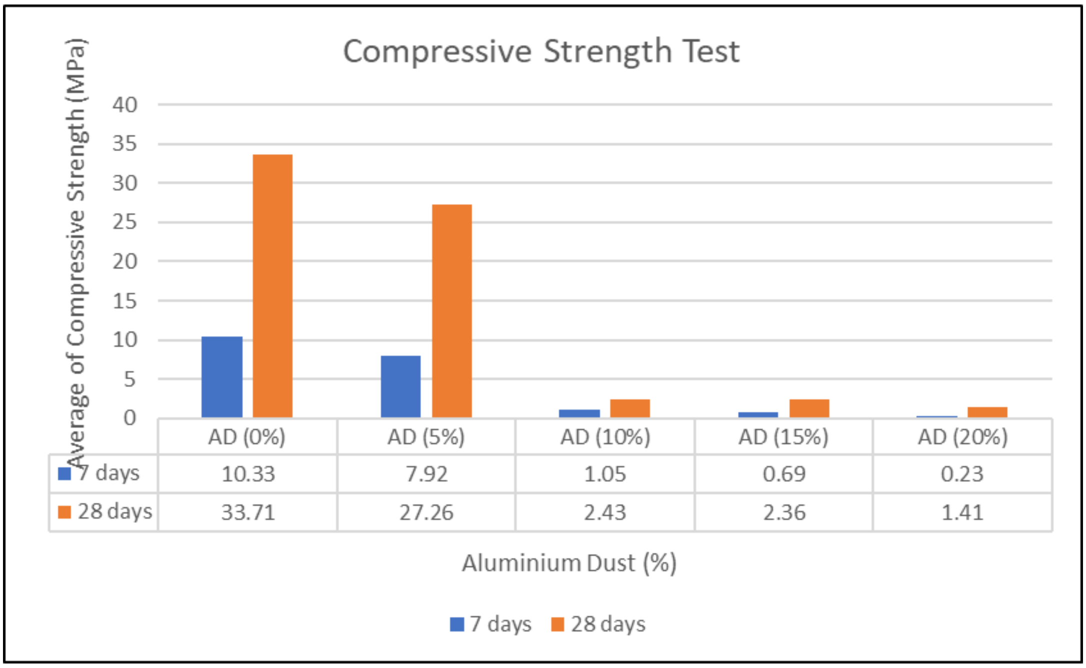

Fig. 11: Graph of compressive strength test result with different percentage of aluminium dust for 7 days and 28 days

4. Conclusion

This study therefore aims at determining the possibility of using partial replacement of fine aggregates in concrete mixtures by Aluminium Dust (AD). It makes it possible to replace the sand with AD decrease sand consumption and recycle aluminium waste to improve the concrete characteristics and make it more appropriate for lightweight construction. The results that establishing AD in place of sand reduced the advanced compressive strength but encouraged prospects in the improvement of water resistance. Further, the results indicate that the optimum dosage of the AD relies upon the nature of the AD and the intended characteristics of the concrete is below 5%. Therefore, this research concludes that the percentage of aluminium dust which can be used as a partial replacement for sand in concrete is a viable and enhanced solution for the sustainable development of constructions but overall aluminium dust characteristics not suitable replacement finae aggregates in concrete mixture.

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