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Physical and Mechanical Properties of Autoclaved Aerated Concrete (AAC) as Partial Fine Aggregate in Concrete

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Abstract: Fine aggregate is the crucial component in the concrete production for construction projects. AAC is a green and eco-friendly building material. that is very sustainable. Nowadays, the uses of AAC in Malaysia is in a great demand due to rapid urbanization of development that needs to implement the quality of AAC aggregate properties Therefore, the fine aggregate partial replacement in the concrete mixture was autoclaved aerated concrete (AAC). The primary aim of this study was to determine the physical properties of concrete, such as workability and density, as well as mechanical properties like compressive strength. The autoclaved aerated concrete (AAC) was crush to produce AAC aggregate as the partial sand replacement in concrete. Both properties of concrete will be tested. There were five concrete mixtures with AAC aggregates as the replacement of sand were prepared and tested. The mixture of concrete was partially replaced by 0%, 10%, 20, 30% and 40% of AAC aggregates with concrete grade of 30. After 7 and 28 days of curing, 30 specimens of concrete cubes with dimensions of 100mm × 100mm ×100mm were prepared and ready to be tested for compressive strength. The compressive strength of concrete mix with autoclaved aerated concrete aggregate was higher at the specimen age of 28 days, indicating that it was the ideal concrete design. The allowable addition of AAC aggregate in the concrete mix should not be greater than 20%. Besides, the optimum workability of concrete was at the range of 20 to 40% of AAC aggregate while the density was 2300kg/m^3. Thus, the AAC was suitable to be used for replacing fine aggregate in producing of concrete due to its properties.

Keywords: Autoclaved Aerated Concrete, Fine Aggregate Replacement

1. Introduction

Due to the sheer rapid development of society, the economy, and the acceleration of urbanization worldwide in the twenty-first century, resource and environmental issues have become increasingly prominent [1]. Construction waste management in Malaysia was becoming a serious issue because of the rapid development in the construction industry. [2] mentioned that the biggest construction wastes,

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it was anticipated that a vast quantity of autoclave aerated concrete (AAC) waste would be produced in recent years. Concrete is a very crucial building material to construct a strong and rigid structure on earth that is globally used for construction material [3]. Therefore, the leftover or autoclaved aerated concrete (AAC) waste is suitable to be used as an aggregate in the admixtures of concrete. This solution of reusing the AAC as aggregate replacement in concrete could lessen the risk of environmental problems and improves the sustainable development. From a sustainable standpoint, effective construction waste management should prioritize by recycling or reusing it which it can benefits both environmental protection and resources conservation [4]. Hence, the sustainable disposal of these wastes in the production of structural and nonstructural concrete is recognized as the best approach for mitigating their negative environmental effects [5].

There is concern about how to improve construction practices to reduce their negative effects on the natural environment. In Malaysia, stream mining is the most important source of sand as it reduces transportation expenses. Excessive sand removal can have a big impact on a stream's natural equilibrium. Stream mines disrupt the sediment mass balance downstream and produce channel changes that extend far beyond the extraction site, in addition to interfering with the continuity of sediment migration in the river system. As a result of growing environmental awareness, experts have conducted numerous tests to develop a sustainable building that uses less sand in concrete production.

The major objective of this study is to determine the physical properties of concrete such as slump and density. The study was conducted by replacing the Autoclaved aerated concrete (AAC) as the partial fine aggregate in concrete mix by containing 0%, 10%, 20% 30% and 40% of AAC crushed into fine aggregate. The determination of mechanical properties of concrete such as compressive strength of concrete was carried out after curing 7 and 28 days by using compressive strength machine. Five different percentage of AAC as partial fine aggregate have will have three cube specimens each are compress under a load 140kg/cm^2 per minute until it fails to obtain the compressive strength. The target design strength of concrete is 30MPa.

2. Literature review

2.1 Sustainable construction

Sustainable construction is a strategy for the engineers in the industrial corresponds to achieving the sustainable development in the future. The resources obtained from [6] proven that the construction industry's sustainability principle, which includes:

- Nurturing people’s and users’ health and safety as well as making sure the productivity of built environment with nature.
- Minimizing the destruction towards the environment and its resources.
- Considering the project's societal and environmental benefits and costs.
- Enhancing the quality of services and buildings while also boost social cohesion.
- Evaluating the project's societal and environmental benefits and costs.

2.2 History of autoclaved aerated concrete (AAC)

Autoclaved aerated concrete (AAC) or else named as autoclaved lightweight concrete or aerated cellular concrete is popularly known as environmentally friend and environmentally certified green construction materials available in the construction industries [7]. It was introduced commercially in Sweden in 1923 spread ever since to 40 countries worldwide including in Europe, approximately 15 million m^3 of AAC were now manufactured 100 production sites per year [8]. It was widely used in various of commercial, industrial, and residential applications for over 90 years in Europe, 40 years in the Middle East, and 25 years in the United States and Australia. According to estimates, AAC now accounts for more than 40% of all construction in the United Kingdom and more than 60% of construction in Germany [9]. Based on [10], the Code and Specification of the Masonry Standard Joint Committee (MSJC) were the design provisions of AAC.

It is now extensively utilized in numerous countries for non-structural and structural elements. AAC is designed and built as blocks for infill wall construction or as reinforced panels and beams for roofs, floors, lintels, or walls to allow faster development [11]. Table 1 was the property of AAC block obtain from the construction industry for this experiment.

Table 1: The property of AAC block

Property	Value
Length and height	800mm × 200mm
Thickness	100 – 200mm
Dimensions and Tolerance	±2mm
Dry Density	500 – 730 kg/m^3
Working density	650 – 910 kg/m^3
Compressive strength	3.0 – 5.5MPa
Thermal conductivity, K	0.24 W/mK

2.3 Mechanical Properties of AAC

2.3.1 Compressive strength

AAC is a brittle material with a very low strength that ranges from 1.8 MPa to 4.0 MPa when the density is between 300 kg/m^3 and 600 kg/m^3 [12]. The compressive strength of foam concrete decreases linearly as the concrete density decreases. Several factors influence the strength of foam concrete, including the cement-to-sand ratio, the water content of the mix, the type of sand, the particle size distribution, and the foaming agent. According to the EN 772-1, the compressive strength must not be lower than 80% mean value of the declared value or 90% of the characteristic declared value [13]. It was shown by [14] that AAC has lower compressive strength with a value of 2-6 MPa if compared to normal-weight concrete.

2.4 Physical properties of AAC

2.4.1 Slump or workability of AAC

A foam concrete’s drying shrinkage can be up to 10 time more than the regular weight concrete in order to compensate for the lack particles by Srinu. Autoclaving has shown that the reduce shrinkage by 12-50% if compared to moist-cured concrete. According to researches, the response to a shift in the mineral content of the concrete, autoclaving been shown to substantially reduce drying shrinkage by 12–50% when compared to moist-cured concrete.

2.4.2 Density of AAC

According to [13], the net density of AAC masonry is commonly lower than 1000 kg/m^3. AAC block has a lower density compared to normal weight concrete [14]. When water infiltration is a concern, concrete with a density of 1000 kg/m^3 or higher is normally used to fill cellars or build roof slabs. There were two types of weight: light and heavy. Lightweight is defined as less than 1700 kg/m^3, while heavyweight is defined as more than 2000 kg/m^3.

2.5 Previous findings on AAC as aggregates

In Table 2 will show the summary of previous findings from other authors regarding on the properties of concrete that contains AAC as aggregate replacement. The table below will explain the density, slump or workability and compressive strength of AAC aggregates as sand replacement in concrete. This shall give an evidence or support on these studies by replacing AAC as partial fine aggregate with various percentages in the concrete mixtures.

Table 2: Summary of previous findings

Authors	Title	Findings
[15]	Effect of Using Recycled Lightweight Aggregate on the Properties of concrete	Applying recycled concrete hollow blocks as coarse and fine aggregate instead of natural aggregate results in a concrete mix with a compressive strength that is 74% lower than that of standard concrete. The use of recycled lightweight concrete as a replacement for coarse and fine aggregate at 100% resulting the compressive strength range is 2.5 – 1.51 N/mm^2 that is below the present research values.
[16]	Properties of concrete containing foamed concrete block waste as fine aggregate replacement	In general, the addition of the use of crushed foamed concrete waste as a partial replacement for fine aggregate affects the workability of the concrete mix. As the percentage of foamed concrete waste used as partial sand replacement increases, so does the slump read of the concrete.
[17]	Investigation some properties of recycled lightweight concrete blocks as a fine aggregate in mortar under elevated temperature	Without a segregation or bleeding observed during mixing and casting, the density of mortar decreased as the proportion of lightweight concrete blocks aggregate increased. The density decreased by 6.3% and 12.3% for 10% and 20% replacement respectively due to the very low density of lightweight concrete blocks, which ranges between 400 and $800kg/m^3$. The use of a mixture of a different waste material as a partial replacement for fine aggregate based on their densities.
[18]	Influence of Fly Ash and Recycled AAC Waste for Replacement of Natural Sand in Manufacture	They show that increasing the partial replacement of ground sand with AAC waste content from 0% to 100% raises the dry volume density of the sample. When compared to the control sample, the sample that replaces up to 100 % of ground sand with AAC waste has the highest volume density, which is only 11.99% higher (100% natural sand). As the proportion of AAC waste replaced by ground sand increases, the compressive strength decreases.

3. Materials and Methods

3.1 Preparation of materials

The materials used to conduct this experiment are consists of five ingredients of concrete. Namely:

i. 0%, 10%, 20%, 30% and 40% of autoclaved aerated concrete (AAC) as partial fine aggregate replacement in concrete (4.75mm±5mm)
ii. Sand (4.75mm±5mm)

iii. Coarse aggregate (10mm)
iv. Ordinary Portland cement (OPC)
v. Water

The water-cement ratio was 2:1 and the mix proportion of concrete was determined as shown in Table 3. During the mixing process, there was an additional of water poured into the mixture to obtain a good result of slump was given in Table 4. DOE method of mix design was attached in Appendix A.

Table 3: The water ratio and mix proportion of concrete

Group	Labelling of samples	Quantity	Cement (kg)	Water (kg)	Fine aggregate (kg)		Coarse aggregate of 10mm (kg)
					Sand	AAC	
		Per m^3	400	215	860		895
		Per trial mix of 0.001 m^3	0.4	0.215	0.86		0.895
A	A1 A2 A3	1st testing of 0.007 m^3	2.8	1.505	6.02	0%	6.265
B	B1 B2 B3	2nd testing of 0.007 m^3	2.8	1.505	5.418	10% = 0.319	6.265
C	C1 C2 C3	3rd testing of 0.007 m^3	2.8	1.505	4.816	20% =0.637	6.265
D	D1 D2 D3	4th testing of 0.007 m^3	2.8	1.505	4.241	30% =0.956	6.265
E	E1 E2 E3	5th testing of 0.007 m^3	2.8	1.505	3.612	40% = 1.274	6.265

Table 4: Addition water in the mixture of concrete

Group	Percentage of crushed AAC as partial fine aggregate replacement	Label of samples	Water for sand (kg)	Water for crushed AAC aggregates (kg)	Water for fine aggregate (kg)
A	0%	A1 A2 A3	0.29	-	0.10
B	10%	B1 B2 B3	0.26	0.18	0.10
C	20%	C1 C2 C3	0.23	0.22	0.10
D	30%	D1 D2 D3	0.20	0.25	0.10
E	40%	E1 E2 E3	0.17	0.28	0.10

3.2 Methods

First, the AAC will be crush by using a jaw crusher machine and then, Los Angeles Abrasion machine was crush into small particles. AAC was sieved to expel debris occur in the materials as well as to get a 5mm size of particles. The mixing of concrete was conducted and ready to be filled into 30 cube specimens with a constant dimension of 100mm × 100mm × 100mm. Before filling, the slump of concrete was conducted. The compressive strength of concrete will be tested by using a compressive strength machine after cured for 7 and 28 days. The cube specimens will be put under pressure of load 140kg/m^3 per minute until it fails to determine the compressive strength. The formula for compressive strength, N/m^2 is express by Force, N per Area, m^2 is in Eq.2:

$$Compressive\ strength, \sigma = \frac{Force}{Volume} Eq. 2$$

The density value was determined by weighing the sample's mass, M and volume, V. The density (kg/m^3) of concrete is calculated by using a formula of mass (kg) per volume (m^3) is express in Eq.1:

$$Density, \rho = \frac{Mass}{Volume} Eq. 1$$

4. Results and Discussions

4.1 Slump test of concrete

The slump test data of concrete was given in Table 5 while the graph showing the height of slump of concrete containing five different percentages of AAC as partial fine aggregate replacement (Figure 4.1). The purpose of conducting slump test was to determine the workability of a concrete containing AAC aggregates.

[16] reported that the percentage of foamed concrete waste used as partial fine sand replacement increases, so does the slump read of the concrete. Based on Figure 1, the height of slump of concrete increases as the amount of AAC aggregates in concrete increases at Group E (45mm) with a percentage of 40% AAC aggregate in concrete. This experiment had proven that [16] research had achieved. During the removal of the slump cone, the concrete shows a true slump in form. The illustration of slump form describes that true slump is considered harsh and lean.

Table 5: Slump test data

Group	Percentage of AAC aggregate	Number of samples	Height of slump, (mm)
A	0%	3	28
B	10%	3	30
C	20%	3	36
D	30%	3	41
E	40%	3	45

For 10% and 20% of AAC aggregate, the slump height value was 30mm and 36mm. As a result, the degree of workability of concrete for 10% was low while 20% was medium respectively. Besides, the smallest value of the height of slump was 28mm at 0% of crushed AAC aggregate. The degree of workability was considered lower if compared to 40% crushed recycle AAC aggregates. Thus, the amount of concrete containing 40% of AAC as partial fine aggregate replacement was the most suitable for the production of concrete in construction work.

From the result, the AAC aggregate as fine aggregate can contribute to the production of new concrete. As the percentage of AAC aggregate used as fine aggregate in the concrete mixture increased, so did the degree of workability. The larger quantity of porosity was the cause of slump height was getting higher that allows more water to be absorbed. This happened because of the physical properties of AAC has a numerous of voids present in it. If there was no slump occurs during the slump testing, it was recommended to add a small amount of water consequently to avoid dry mixes.

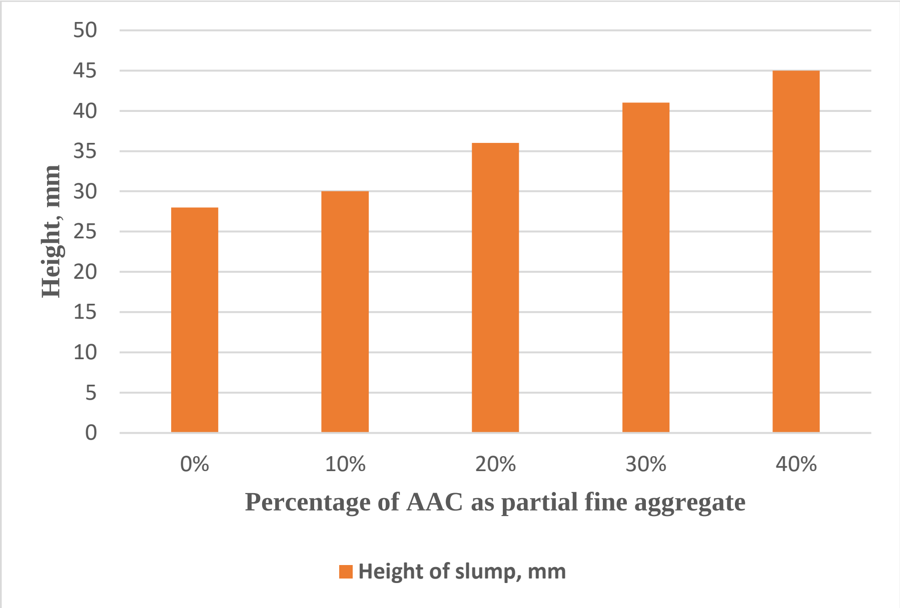

Figure 1: Height of slump

4.2 Density test of concrete

In Table 6 was the outcome of density test of concrete obtain from the experiment. The reading average of density of concrete can be seen clearly by referring Figure 2.

Table 6: Density data

Group	Percentage of AAC aggregate	Number of samples	Density of concrete, (kg/m^3)		Average of density, (kg/m^3)
A	0%	3	A1	2310	
			A2	2260	2277
			A3	2260	
B	10%	3	B1	2300	
			B2	2300	2300
			B3	2300	
C	20%	3	C1	2300	
			C2	2260	2277
			C3	2270	
D	30%	3	D1	2230	
			D2	2210	2227
			D3	2240	

E	40%	3	E1	2170	
			E2	2200	2173
			E3	2150	

From the graph below indicates the highest reading of density was Group B (10%) with a value of 2300kg/m^3 while the lowest density was Group E (40%) with a density value of 2173kg/m^3. The differences between the highest and lowest density were only 127kg/m^3. Group B has the highest density due to large amount of water added during the mixing of admixture which can be referred in Table 3.2. According to [17] research, the density of mortar dropped as the quantity of lightweight concrete blocks aggregate increased, with no segregation or bleeding seen during mixing and casting. Thus, the greater amount or percentage of AAC as partial fine aggregate in concrete, the lower the density of concrete.

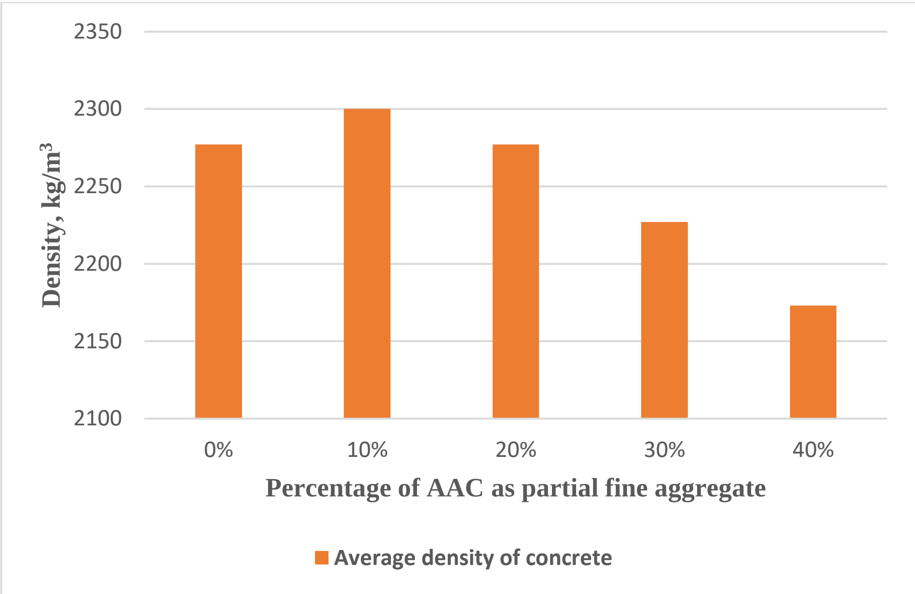

Figure 2: Average density of concrete

4.3 Compressive strength of concrete

Compressive strength containing five different percentage of AAC as partial fine aggregate replacement in concrete were tested after curing for 7 and 28 days. Table 7 and Table 8 represents the compressive strength of concrete for 7 and 28 days after curing. In Figure 3 conveys the graph of average compressive strength vs 7 and 28 days of curing.

Table 7: Compressive strength of concrete after 7 days of curing

Group	Percentage of AAC aggregate	Compressive strength (MPa)		Average of strength, (MPa)
A	0%	A1	21.9	
		A2	20.8	21.5
		A3	21.8	
B	10%	B1	21.9	
		B2	20.4	21.3
		B3	21.1	
C	20%	C1	20.3	
		C2	19.7	20.0

		C3	19.9	
D	30%	D1	19.0	
		D2	19.4	19.2
		D3	19.1	
E	40%	E1	16.9	
		E2	17.2	17.1
		E3	17.3	

Table 8: Compressive strength of concrete after 28 days

Group	Percentage of AAC aggregate	Compressive strength (MPa)		Average of strength, (MPa)
A	0%	A1	23.2	
		A2	31.5	30.5
		A3	36.8	
B	10%	B1	24.6	
		B2	30.6	31.2
		B3	38.3	
C	20%	C1	31.4	
		C2	29.4	30.1
		C3	29.6	
D	30%	D1	26.6	
		D2	30.6	29.1
		D3	30.0	
E	40%	E1	25.3	
		E2	25.5	25.0
		E3	24.1	

From the graph below shows the average compressive strength of concrete at 7 days had the highest value, 21.5 MPa from Group A (0%) while at 28 days was 31.2MPa from Group B (10%). Followed by Group A (0%) and Group C (20%) with a value of average compressive strength of 30.5MPa and 30.1MPa at 28 days after curing. The differences of each strength, Group A and C were 0.4MPa. The ideal concrete strength in this study was from Group C (20%) which was only 0.1MPa differs from the strength design of 30MPa. Therefore, the concrete containing AAC aggregates at 28 days after curing had achieved the desired design strength of C30. This research was proved by [19] stating that curing after 28 days was the ideal design strength of concrete.

The pattern flow of average compressive strength for both 7 and 28 days were getting lower when the percentage of AAC aggregates in concrete increases. The lowest value of average compressive strength for 7 and 28 days were 17.1 MPa and 25MPa respectively. The study of [20] did mentioned the strength was decreasing due to higher demand of water in concrete mixtures. Also, [17] gave an idea that the tendency of lightweight concrete block aggregate to absorb water during preparation may account for the slight decrease in compressive strength. During the mixing process, water was added subsequently as shown in Table 3.2 to obtain a successful slump instead it affects the strength of concrete.

Unfortunately, this experiment of concrete strength at the ages of 7 days did not succeed the desired target strength design. The reading of compressive strength test of concrete for all groups of specimens were lower than 30MPa. The summary from [21] stating a porous structure of autoclaved aerated concrete waste as aggregates in the admixture contributes to the lower strength of concrete. This is because when the additional little amount of water during mixing the materials, the AAC absorbs the water vigorously. Thus, the amount of water in concrete when mixing should be control.

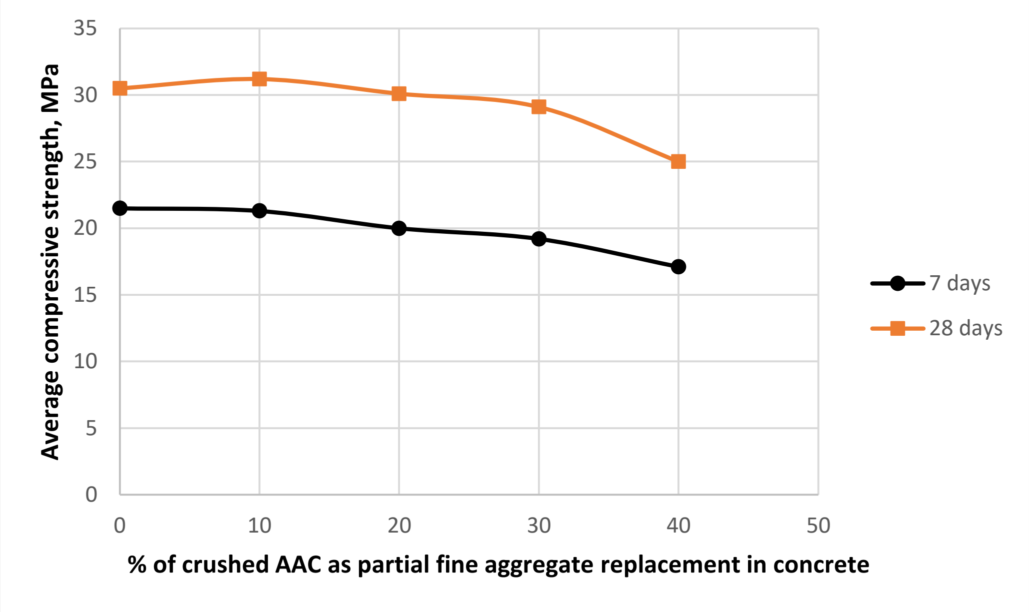

Figure 3: Strength Vs 7 and 28 days of curing

In summary, it can clearly be seen that at the ages of 28 days had the best and optimum desired compressive strength in Group C. This results of study were supported by [19] who proved that at ages of 28 days, the concrete achieved its desired strength. The partial fine aggregate replacement of AAC in the admixture of concrete does affect its compressive strength depending on the amount based on the percentages of AAC aggregates added. This study indicates that the additional of AAC as fine aggregate replacement in concrete mix was allowed to be less than 20%.

5. Conclusion

From the results of the experiment, the objectives of this research were successfully achieved. All the data collected in the expected results prove the AAC block generated from construction and demolition of concrete can be reused or recycle again for another concrete production. In this case, the reduction of using sand in concrete mixes able to sustain the environment as well as construction.

The main objectives of this research are to determine the physical properties of concrete such as slump and density. The degree of workability of concrete is in the category of medium with a maximum height of slump 45mm. Therefore, the type of slum determined is a true slump. The highest density of concrete is at Group B (10%) with a value 2300kg/m^3.

Next, the objective is to study the compressive strength of concrete containing AAC as a fine aggregate. The allowable compressive strength of concrete is must be less than 20% of AAC aggregates. The study of autoclaved aerated concrete (AAC) as fine aggregates that is the partial sand replacement for the concrete mixture is the most inventive, excellent, and sustainable material for construction in the building sectors. There are two aspects requested for further implementation related to this study are as follows:

(a) It is requested to implement or conduct other properties of AAC on the production of concrete such as thermal insulation, thermal conductivity and etc.

(b) It is suggested to use different size of AAC aggregates or percentage of AAC aggregates contain in the concrete which is up to 100%.

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