THE EFFECT OF ALUMINUM WASTE ASH ON THE CONCRETE COMPRESSIVE STRENGTH

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Abstract. It was observed by several research that aluminum waste grains can preserve the performance of concrete strength when substituted for sand in the concrete mixture. This paper examines the effects of substituting aluminum waste grains for sand in normal concrete. Aluminum waste grains with grade of IV are unsuitable for use as fine aggregates in normal concrete due to their excessive smoothness. The idea of replacing 0%, 10%, 20%, and 30% of sand with aluminum waste grains with equal proportion, and its ability to be permitted to create zone II gradation. According to the results, introducing aluminum waste grains decreases compressive strength. The average concrete compressive strength after 28 days is 26.20 MPa, whereas the average compressive strength of 10%, 20% and 30% aluminum replacing sand are 17.87 MPa, 15.14 MPa, and 15.35 MPa respectively. Hence, the average compressive strength 10%, 20% and 30% aluminum waste replacing sand dropped by of 31.78 %, 42.17 %, and 60.49% respectively.

Key words: waste content, sand substitution, average concrete strength

1. Introduction

Among the many things that civil engineers look at is concrete. Today, concrete is one of the most used building materials. Concrete is the primary component of structural elements such as foundations, columns, beams, floor plates to foundations, and road pavements (Panditharadhya *et al.*, 2018; Rahmani *et al.*, 2020; Liu *et al.*, 2017; Shabbar *et al.*, 2017; Herting *et al.*, 2018; Kulkarni and Mandal, 2022). The constituents of concrete include cement, coarse aggregate, fine aggregate, and water. These materials' physical characteristics must be understood so that they may be utilized as planning information for concrete mixtures. The final mixture is anticipated to fulfill concrete standards. The quality of the completed concrete must meet the value of the concrete's compressive strength (Elinwa and

Mbadike *et al.*, 2011; Damene *et al.*, 2018; Sanjeev and Nitesh, 2020).

Ashes from the aluminum casting industry fall under the B3 category of toxic and hazardous waste (Mymrin *et al.*, 2018; Sua-Iam and Matkul, 2013; Alzubaidi, 2017; Javali *et al.*, 2017; Reddy and Neeraja, 2016). The majority of the waste ash from aluminum combustion is held in specialized warehouses and is utilized to raise vital river embankments or even repair damaged embankments. The process of stockpiling is conducted in a normal manner, namely by storing the garbage and then stacking it. On the contrary, this can harm the ecology and river ecosystems (Rangan *et al.*, 2005).

This study will examine the mechanical characteristics of aluminum waste ash and its impact when utilized as a partial sand replacement in concrete (Elseknidy *et al.*, 2020; Paktiawal and Alam, 2021; Kumar and Ramamurthy, 2015; Abyzov, 2016, 2017; Font *et al.*, 2017; Busari *et al.*, 2019; Noori *et al.*, 2021). The usage of significant quantities of sand by the community also contributes to environmental degradation. If aluminum waste ash can be utilized to replace a portion of the sand, the environmental damage caused by sand mining will be mitigated. It is believed that this research would reveal the expenses that may be saved by using a variety of waste reduction strategies (Alaneme and Mbadike, 2019; Mohammadyan-Yasouj *et al.*, 2021; Goual *et al.*, 2006; Abyzov, 2017; Hay and Ostertag, 2019; Aadi *et al.*, 2021). This research aims to reduce the usage of common sand for cost-efficient concrete production such done by researcher (Chawakitchareon and Kingthong *et al.*, 2006; Bajare *et al.*, 2011; Meshram *et al.*, 2021; Devadass, 2019; Chindaprasirt *et al.*, 2012; Udvardi *et al.*, 2019; Channa and Saand, 2021; Cristelo *et al.*, 2021; Braz *et al.*, 2019; Onutai *et al.*, 2014, 2015).

Taking into consideration the context and the issue, the aims of this discussion include: 1) Analyzing the mechanical and physical characteristics of industrial waste ash from aluminum casting. 2) Analyzing the determination of the material proportions inside the mix design. 3) Analyzing the effect of substituting ash from aluminum casting industry waste with 0, 10, 20, and 30% of the sand composition on the compressive strength of concrete.

According to a number of researchers, the categorization of concrete is often based on its specific gravity and compressive strength (Chhorn *et al.*, 2018). Specific gravity and compressive strength based on its specific gravity, concrete is divided into lightweight concrete (Damene *et al.*, 2018), normal concrete, and heavy concrete (Mardani-Aghabaglou and Ramyar, 2013). The specific gravity of light concrete is less than 1800 kg/m^3, that of regular concrete is 2400 kg/m^3, and that of heavy concrete is greater than 3200 kg/m^3. Concrete is classified as low-strength concrete, medium-strength concrete, and high-strength concrete based on its compressive strength. Low-strength concrete has a compressive strength below 20 MPa, and medium- and high-strength concrete have compressive strengths between 20 and 40 MPa, respectively, the remarks included additionally (Susilorini and Sambowo, 2011).

Aluminum waste ash is trash or leftover from the burning of metal including aluminum from many types of commodities destined for casting into aluminum ingots for sale to factories producing pans (Anwar and Hafidz,

2019) and also investigated by other research such as (Alaneme and Mbadike, 2019; Braz *et al.*, 2019; and Onutai *et al.*, 2015).

2. Methods

The chemical composition of aluminum waste ash is indicated in the Table 1 and the fineness in Table 2.

Table 1. Aluminum waste ash content.

No.	Chemical compound	content (%)
1.	Silica oxide (SiO_2)	4.9
2.	Aluminum oxide (Al_2O_3)	69.39
3.	Iron oxide (Fe_2O_3)	1.96
4.	Calcium oxide (CaO)	3.2
5.	Magnesium oxide (MgO)	8.33
6.	Titanium oxide (TiO_2)	1.9

Table 2. The fineness of waste ash for sieve No. 200.

No. sieve	Weight (gr)	Sieve+specimen	Specimen (gr)
200	345.1	444.9	99.8
Pan	432.4	432.6	0.2
Total weight			100
Percentage of passing sieve No. 200			0.2%

2.1 The gradation

The results of the aluminum waste ash gradation test conducted in the laboratory are displayed in Table 3.

Table 3. Aluminum waste ash gradation.

Sieve diameter (mm)	% Retained	% Cumulative retained	pass
38.1	-	-	100
19.2	-	-	100
9.5	-	-	100
4.75	-	-	100
2.76	0.15	0.15	99.85
1.18	1.8	1.95	98.05
0.6	0.1	2.05	97.95
0.3	93.2	95.25	4.75
0.15	0.05	95.3	4.7
Pan	4.7	100	0.0
Fineness number	1.95		

The fineness modulus of aluminum waste ash is calculated as (95.3 + 95.25 + 2.05 +1.95 + 0.15)/100= 1.95.

And it can be said that aluminum waste ash has a fineness number of 1.95 that meets the standards of ASTM C33, for fine aggregate about 1.5–3.8 (Fig. 1).

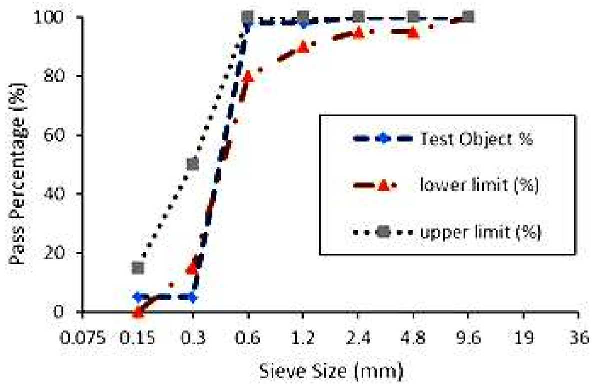

Fig. 1. Aluminum waste ash gradation.

The aluminum waste ash truly interacted with the NaOH solution used in the test, as determined by the results of assessing the organic content of the waste ash. The chemical reaction between a combination of NaOH solution and aluminum waste ash creates heat and water turbidity that cannot be seen visually, as well as assessing the organic content of sand.

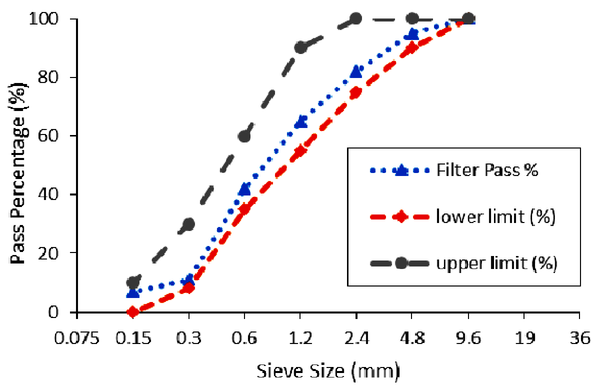

Fig. 2. Gradation of 90% sand + 10% aluminum waste ash.

On a 0.3 mm sieve, the predominant grain size remains. Due to the gradation of ash entering zone IV, mixing with common sand is required to enter a good gradation zone, namely between zones I and II. In this case, the author attempts to use aluminum waste ash in proportions as high as 10% (Fig. 2), 20% aluminum waste (Fig. 3), and 30% of the proportion of sand (Fig. 4).

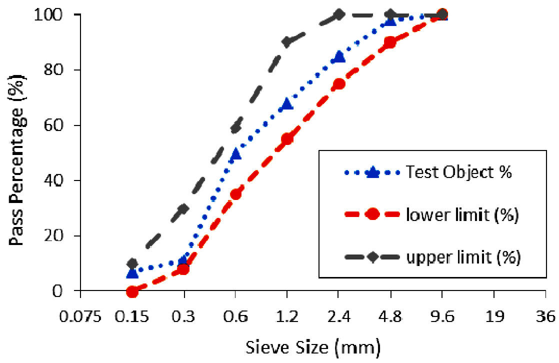

Fig. 3. Gradation of 80% Sand + 20% aluminum waste ash.

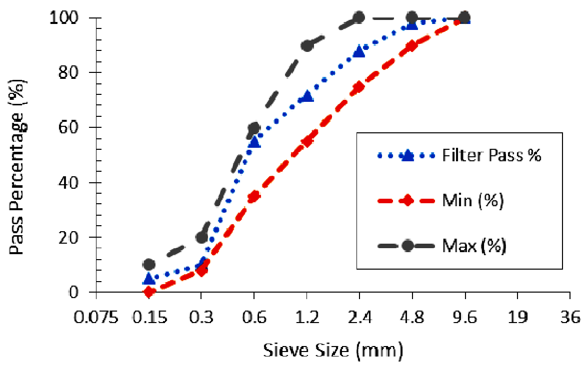

Fig. 4. Gradation of 80% Sand + 20% aluminum waste ash.

The fine aggregate of natural sand from Lumajang is coarse-grained and conforms to the limits of curve line No. 2 according to the Indonesian code SNI 2843:2000. This is because, in order to achieve a higher compressive strength of concrete, aggregates with coarse and varied grains are required so that the resulting concrete is cost-effective and easy to work with. Variable aggregate sizes result in narrow pore volumes and a dense material.

2.2 Miz design

Mix design is required in research to establish the concrete mixture that will be utilized refer to SNI 2834 2000 and SNI 03-2847:2002. The mix design produces data in the form of the mixture's proportion in weight units.

2.3 Concrete Slump

Slump of concrete is the height loss measured at the center of the top surface of the concrete immediately after the slump test mold is lifted in the Indonesian code SNI 1972:2008. The concrete slump value demonstrates the mixture's workability. The workability of a concrete mixture is the ease with which it can be mixed, poured, transported, and compacted. The factors that influence the character of workability, among others, is the slump criteria for concrete structural members (Table 4).

Table 4. Slumps for different structural concrete elements.

Description	Slump (mm)
Walls, foundation slabs and footing	50-125
Unreinforced foundation, Caisson, underground	25-90
Slabs, beams, columns and walls	75-150
Road pavement	50-75
Mass concrete	25-75

In general, laboratory-based quantitative experimental research. In the research being conducted, the physical properties of the concrete's component ingredients and the slump and compressive strength of concrete are being evaluated. This research begins with a literature examination of books, technical standards, and prior studies. This is intended to provide an overview of the research that will be conducted. The research phase was proceeded by producing the materials for the concrete mixture and evaluating the aggregate and aluminum waste ash for their physical properties. The physical properties of fine aggregate are determined by m^3 water content, sieve or gradation analysis, specific gravity and absorption, bulk density and organic content, as well as mud content. Included in the tests used to determine the physical parameters of coarse aggregate are its water content, specific gravity and absorption, density, and hardness. To determine the physical parameters of aluminum waste ash, tests such as water content, sieve or gradation analysis, specific gravity and absorption, as well as organic and sludge content, are performed. The aggregate and aluminum waste ash study results were then examined using parameters according to the set criteria, and the data was recorded as mix design information.

This research is proceeded with a mix design to determine the number of concrete mixture proportions. The outcomes of the mix design calculations serve as the foundation to produce concrete. Then, a cylindrical test object is utilized to produce concrete. The initial inspection is the slump test, which is performed when all the ingredients are combined. The purpose of the slump test is to determine the workability of the mixture, and if the required slump value is met, the test object is prepared for printing and testing for the density of fresh concrete and the air content of the concrete.

The printed test object is then extracted from the mold within 24 to 8 hours of the pouring process into the mold. The specimens were submerged until they were about 7, 14, 21, and 28 days old. In addition, the submerged specimens were raised 24 to 8 hours before to measuring the compressive strength of the concrete. To calculate the price comparison of 1 m^3 of concrete mixes, the results of the compressive strength test will be assessed with the appropriate application and compared with the expenses for the production of quality ordinary concrete.

2.4 Water cement ratio (w/c)

The value of the water cement ratio (Fig. 5) is determined by Table 5.

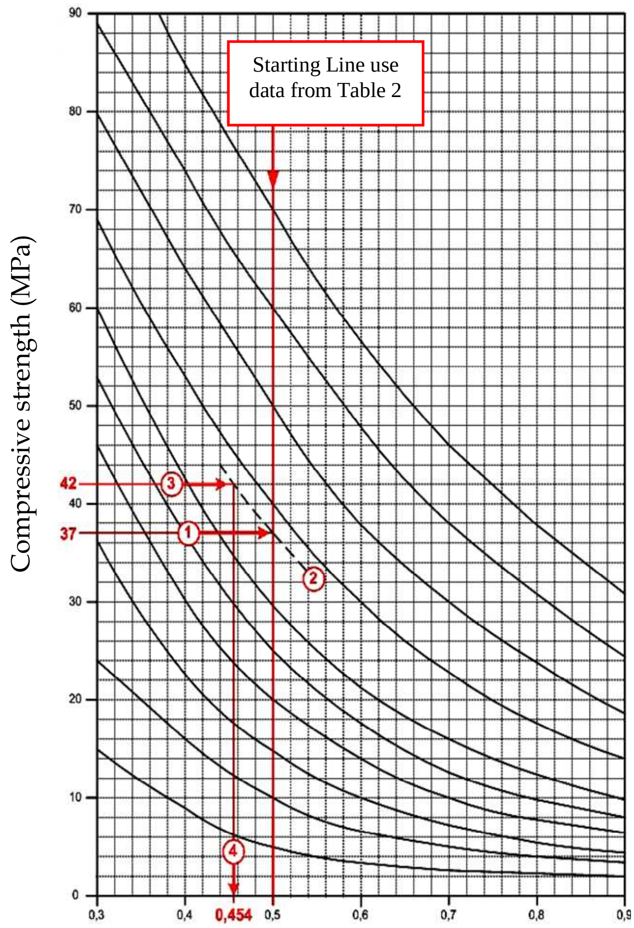

Fig. 5. Compressive strength of specimen and w/c.

2.5 Aggregate relative density

The relative density of aggregate is determined by the proportion of fine aggregate to coarse aggregate multiplied by the specific gravity. The specific gravity is computed after determining the sand content (Fig. 6), and the coarse aggregate percentage may be computed after determining the sand proportion.

2.6 Coarse and fine aggregate: grain size and content

The maximum aggregate grain size used in the concrete mix is 20 mm and to determine the proportion of sand in the concrete (Fig. 6).

Table 5. Estimated compressive strength of concrete.

Portland Cement type	compressive strength (MPa)			
	Ages (days)			
	3	7	28	29
Type I	19	27	37	45
Sulfate resistant II, V	25	32	45	54
Type III	25	33	44	48

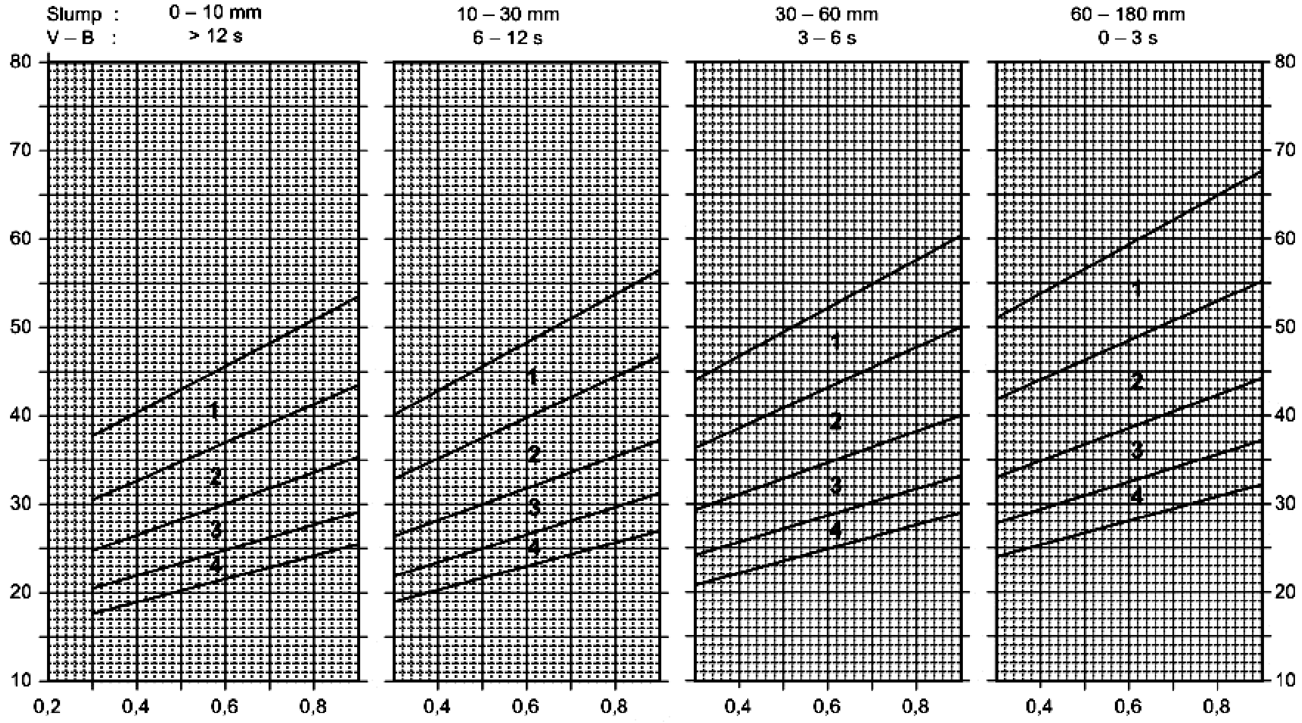

Fig. 6. Content of sand to total aggregate recommended for a maximum grain size of 20 mm.

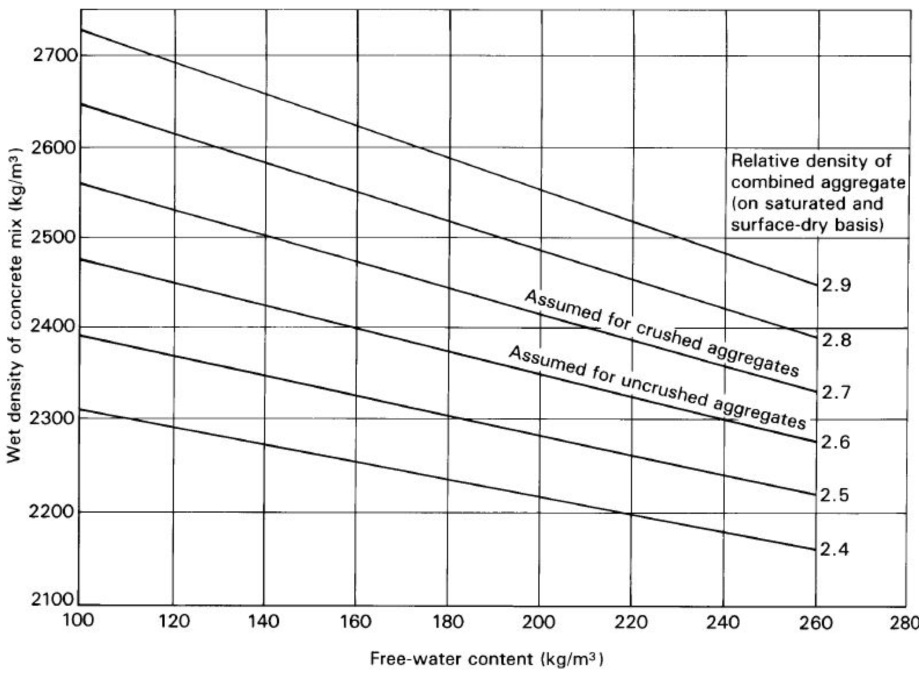

Fig. 7. Estimated wet density of compacted concrete.

2.7 Estimated concrete wet density

After establishing the relative density of the aggregate, it is possible to determine the concrete's density. Based on estimated wet density (Fig. 7), the estimated density of concrete may be determined. The density of concrete is used to estimate the aggregate proportion when the amount of cement, water, and the proportions of coarse aggregate and fine aggregate are known.

2.8 Concrete compressive strength

Concrete's compressive strength is the standard metric for measuring the performance of hardened concrete. The compressive strength of concrete is the load per unit area that causes the test specimen to disintegrate when loaded with a certain compressive force created by machining and executed in a laboratory. Concrete compressive strength calculation in SNI 1974:2011 pertaining to concrete cylinder specimen testing methods.

3. Results and Discussion

1.

3.1 Properties of fine aggregate

Concrete's fine aggregate is composed of Lumajang sand and aluminum waste ash. The characteristics of the two materials were evaluated in the laboratory using the fine aggregate technique. Table 6 displays the outcomes of evaluating the physical qualities of fine aggregate.

Table 6. Properties of sand and aluminum waste ash.

Description	fine aggregate		coarse.
	sand	aluminum waste ash	split gravel ½
Water content (%)	2.15	2.65	1.86
Sludge level (%)	2.17	-	-
Gradation Zone	II	IV	19.5%
Wet density (kg/m³)	1.49	-	1.41
Specific gravity on SSD (gr/cm³)	2.7	1.51	2.74
Absorption (%)	0.975	33.25	1.61
Cement	Cement type I, brand: SG		

3.2 Properties of coarse aggregate

The coarse aggregate was created by crushing stone with a particle size ranging from 10 to 20 mm sourced from Purwosari (Table 6).

3.3 Mix Design

The technique for estimating the percentage of the concrete mixture refers to Indonesian code SNI 2834:2000 regarding Procedures for Determining Normal Concrete Mixtures and SNI 03-2847:2002 and SNI 7565:2012 regarding Procedures for Selection of Concrete Materials (Table 7).

Table 7. Mix design using w/c=0.474.

Specimen restrained at	ingredients	Content (kg) per specimen
Control specimen[b]	FA[a] AWA[a]	3.59 0
10 % AWA and sand[b]	FA[a] AWA[a]	2.78 0.31
20 % AWA and sand[b]	FA[a] AWA[a]	2.09 0.52
30 % AWA and sand[b]	FA[a] AWA[a]	1.52 0.65

[a] FA=fine aggregate; AWA=aluminum waste ash; CA=coarse aggregate

[b] all specimen has constant weight (kg) of cement=2.17; water=1.03 and CA*=6.06

3.4 Compressive Strength

Based on the results of the tests, the specimen data acquired (Fig. 8) can be seen in Table 8.

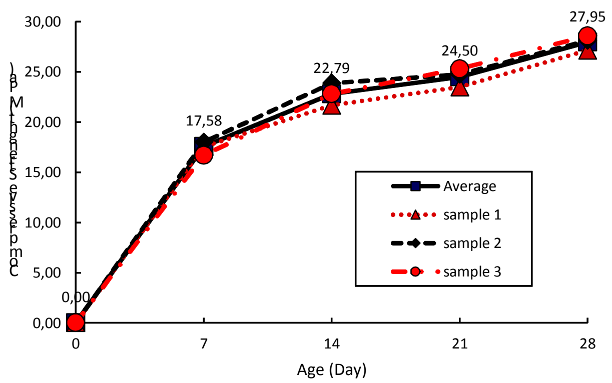

Fig. 8. Concrete compressive strength to age at w/c= 0.474.

From the results (Fig. 8), it can be evaluated that the influence of the concrete age with w/c ratio 0.474 on the average of aluminum waste ash (AWA) concrete compressive strength of 7, 14, 21 and 28 days are 17.58 MPa, 23.39 MPa, 23.90 MPa and 27.95 MPa respectively.

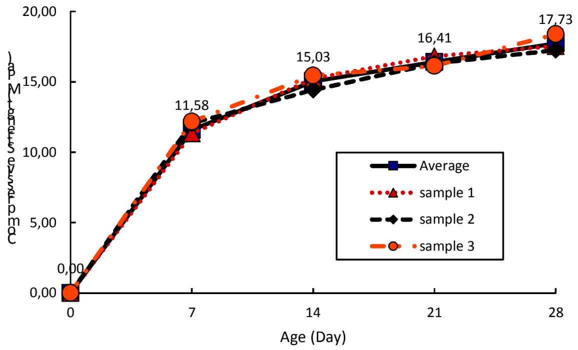

Fig. 9. Compressive strength at 10% AWA concrete (w/c = 0.525).

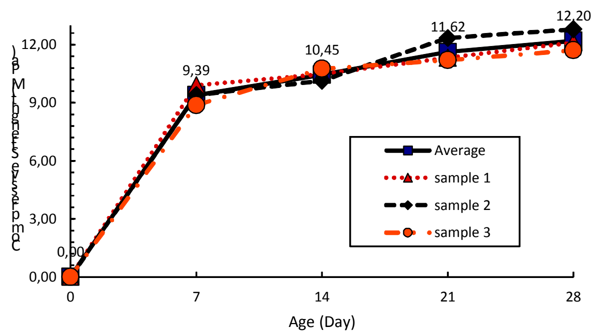

Fig. 10. Compressive strength at 20% AWA concrete (w/c = 0.575).

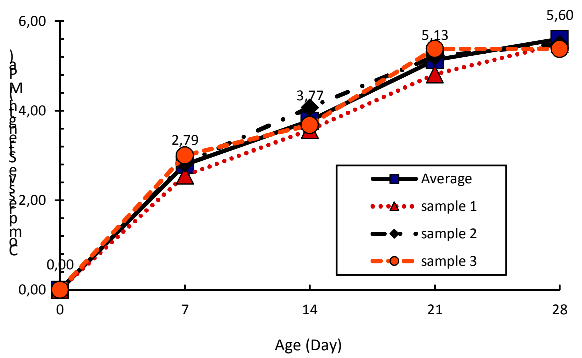

Fig. 11. Compressive strength at 30% AWA concrete (w/c = 0.611).

The influence of aging on concrete containing 10% aluminum ash at w/c ratio as 0.525 is presented (Fig. 9). On the average of compressive strength of 7, 14, 21 and 28 days are 11.85 MPa, 15.03 MPa, 16.43 MPa and 17.73 MPa respectively.

In Fig. 10 and 11, the influence of aging on concrete containing 20% AWA at w/c ratio as 0.575 (Fig. 10) and 30% AWA at w/c ratio 0.611 (Fig. 11) are presented. On the average compressive strength of 7, 14, 21 and 28 days of 20% AWA are 9.34 MPa, 10.41 MPa, 10.88 MPa and 12.20 MPa respectively. While for 30% AWA concrete at 7, 14, 21 and 28 days the compressive strength are 2.79 MPa, 3.77 MPa, 5.13 MPa and 5.60 MPa respectively. Hence at 28 days, the AWA concrete compressive strength does not meet the specified value of 25 MPa.

On the basis of the findings of the compressive strength test of concrete, which have already described (Table 9), it was determined that the compressive strength of concrete containing a combination of aluminum waste ash did not meet the design compressive strength. Significantly lower compressive strength of concrete was directly related to the amount of aluminum waste ash in the mixture.

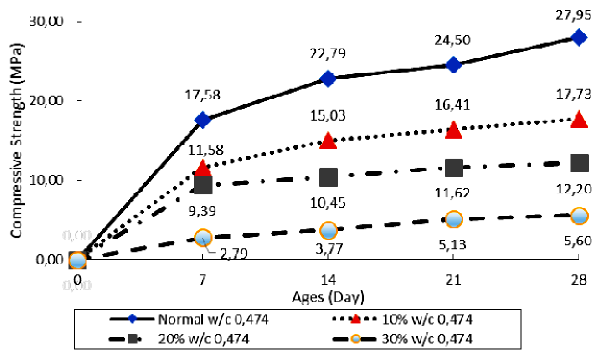

Fig. 12. Compressive strength and age of concrete with varied w/c.

Based on the results of measuring the compressive strength of concrete at ages 7, 14, 21, and 28 days (Table 8) and Fig. 8 to 11 demonstrate that the total compressive strength of concrete improves with increasing concrete age. The amount of aluminum waste ash and w/c ratio values had a substantial effect on the decline in concrete's compressive strength. This impact in every age (Fig. 12), where the larger the AWA content and value of the w/c ratio, the lower the concrete's compressive strength.

Table 8. Compressive strength of control and AWA concrete specimens with varied w/c ratio.

Specimens	Age (days)	Weight (kg)	P (kN)	A (mm^2)	Comp. strength $f'c$ (MPa)	Average $f'c$ (MPa)	Corrected $f'c$ (MPa)
Control specimen w/c=0.474	7	13.0	310	17671.46	17.54	17.58	26.19
		12.9	295		16.69		
		13.0	327		18.5		
	14	13.0	383		21.67	22.79	
		13.0	403		22.81		
		13.2	422		23.88		
	21	12.8	415		23.48	24.50	
		13.1	447		25.3		
		13.0	437		24.73		
	28	12.9	480		27.16	27.95	
		13.2	505		28.58		
		13.0	497		28.12		
10 % AWA & sand w/c=0.525	7	12.7	213	17671.46	12.05	11.85	17.25
		12.7	215		12.17		
		12.5	200		11.32		
	14	12.6	255		14.43	15.03	
		12.6	273		15.45		
		12.7	269		15.22		
	21	12.5	288		16.30	16.41	
		12.5	285		16.13		
		12.7	297		16.81		
	28	12.8	305		17.26	17.73	
		12.6	325		18.39		
		12.5	310		17.54		
20 % AWA & sand w/c=0.575	7	12.3	175	17671.46	9.90	9.39	12.43
		12.4	166		9.39		
		12.1	157		8.88		
	14	12.2	185		10.47	10.45	
		12.3	179		10.13		
		12.4	190		10.75		
	21	12.4	200		11.32	11.62	
		12.2	218		12.34		
		12.5	198		11.20		
	28	12.5	214		12.11	12.20	
		12.3	226		12.79		
		12.5	207		11.71		
30 % AWA & sand w/c=0.611	7	12.2	45	17671.46	2.55	2.79	4.82
		12.2	50		2.83		
		12.3	53		3.00		
	14	12.3	63		3.57	3.77	
		12.2	72		4.07		
		12.2	65		3.68		
	21	12.3	85		4.81	5.13	
		12.2	92		5.21		
		12.2	95		5.38		
	28	12.2	105		5.94	5.60	
		12.2	97		5.49		
		12.0	95		5.38		

Based on the average compressive strength (Table 8) of control concrete with w/c ratio of 0.474, 10% AWA concrete with w/c ratio of 0.525, 20% AWA concrete with w/c ratio of 0.575 and 30% AWA concrete with w/c ratio of 0.611 were 26.20 MPa, 17.25 MPa, 12.21 MPa, and 4.81 MPa respectively.

Also, this revealed that the average compressive strength of concrete containing 10% AWA, 20% AWA and 30% AWA decreased by 34.12%, 52.53% and 72.07% respectively compared to the those of the control concrete (Table 8).

On above discussion, it was determined that an increase in the value of the w/c ratio and the percentage of AWA led to a decrease in the compressive strength of concrete, necessitating a reexamination of the specimen production with a constant w/c ratio of 0.474, such normal concrete.

The evaluation of the organic and silt content of fine aggregate, it was determined that the utilized sand contained 2.17% mud. These results satisfy the mud content of SNI 03-2816:1992 code, which stipulates that the mud content must be less than 5%.

Because the water solution tends to be light brown in color, it may be claimed that the sand utilized has a little amount of organic matter. Based on the Standard Color Chart, the contaminants are visually represented by observation (Fig. 13).

From those results (Fig. 14), it can be evaluated that the influence of the concrete age with w/c ratio 0.474 on the average of 10% aluminum waste ash (AWA) concrete compressive strength of 7, 14, 21 and 28 days are 12.51 MPa, 15.72 MPa, 16.97 MPa and 17.87 MPa respectively. On the other hand, the influence of aging on concrete containing 10% aluminum ash at w/c ratio as 0.525 is presented (Fig. 6). On the average of compressive strength of 7, 14, 21 and 28 days are 11.85 MPa, 15.03 MPa, 16.43 MPa and 17.73 MPa respectively.

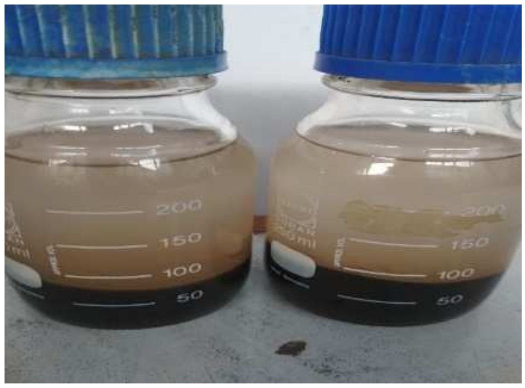

Fig. 13. Visual observation for organic content (mud) for fine aggregate.

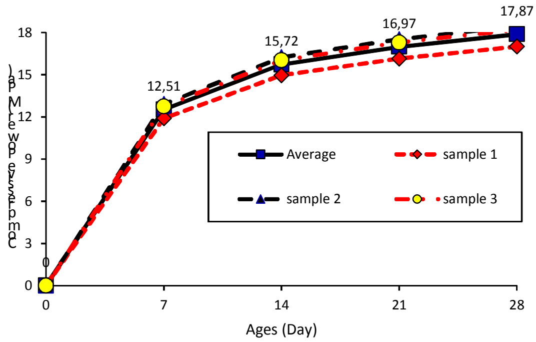

Fig. 14. Compressive strength at 10%AWA concrete (w/c = 0.474).

The influence of aging on concrete containing 20% AWA (Fig. 15) and 30% AWA (Fig. 16) at w/c ratio 0.474 are presented.

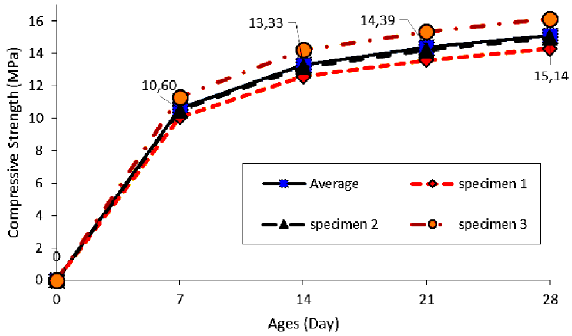

Fig. 15. Compressive strength at 20%AWA concrete (w/c = 0.474).

On the average compressive strength of 7, 14, 21 and 28 days of 20% AWA are 10.60 MPa, 13.33 MPa, 14.39 MPa and 15.14 MPa respectively. While for 30% AWA concrete at 7, 14, 21 and 28 days the compressive strength are 7.24 MPa, 9.11 MPa, 9.83 MPa and 10.35 MPa respectively. Hence at 28 days, the compressive strength of concrete containing AWA does not meet the specified value of 25 MPa.

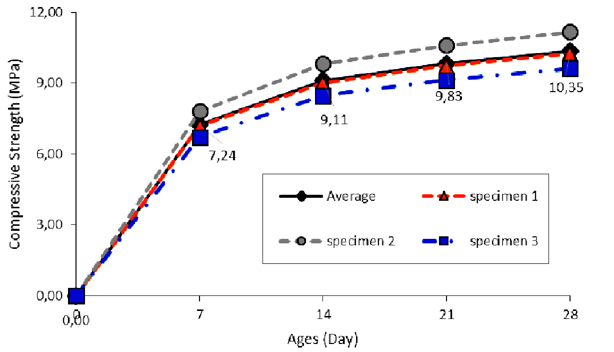

Fig. 16. Compressive strength at 30%AWA concrete (w/c = 0.474).

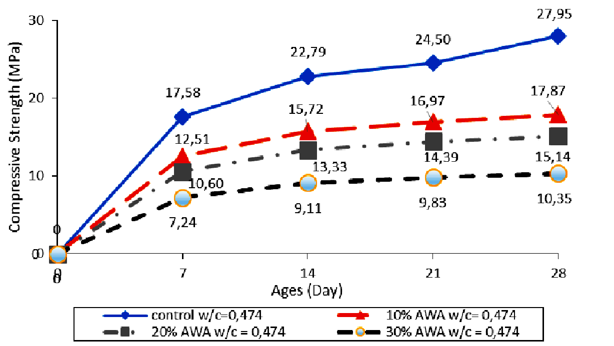

Fig. 17. Compressive strength and age of concrete specimen with constant w/c.

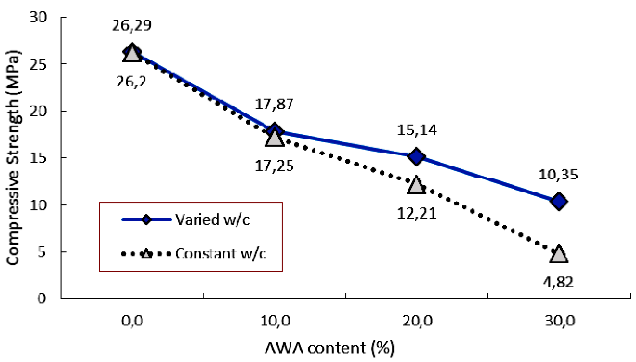

Fig. 18 Concrete compressive strength versus AWA content

According to Fig. 14 to 17 the decrease in average compressive strength of concrete containing 10% AWA (Fig. 14), 20% AWA (Fig. 15) and 30% AWA (Fig. 16) were respectively 31.78%, 42.17% and 60.49% less than the loss in average compressive strength of control concrete (Fig. 17).

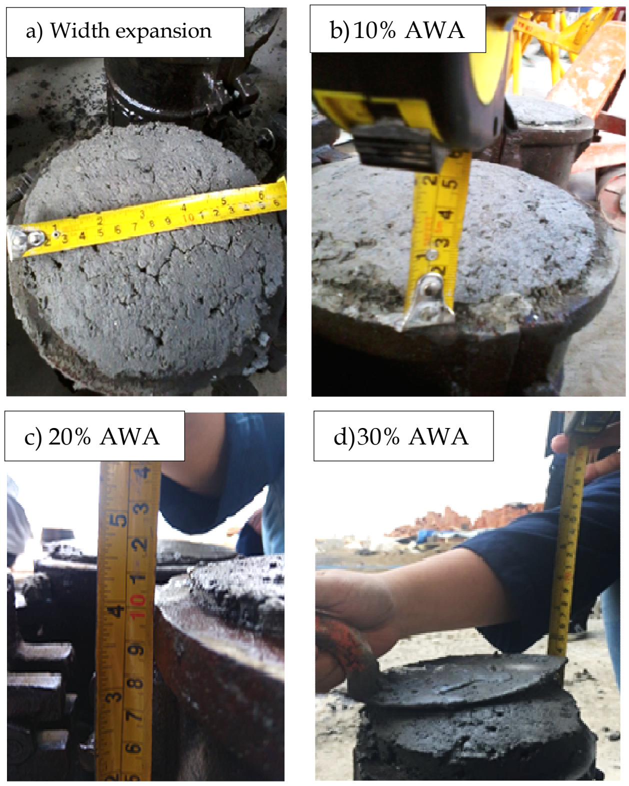

Fig. 19. Volume expansion in AWA concrete (w/c=0.474).

The proportion of aluminum waste ash has a significant effect on decreasing the compressive strength of concrete. This effect can be said where the larger the AWA proportion in concrete, the lower the value of the compressive strength of the resulting concrete (Fig. 18).

The compressive strength with the constant w/c ratio is larger than those with the varied w/c ratio due to the void presented by volume expansion of the concrete mixture caused by the addition of AWA as a substitute for sand.

Based on volume expansion, it was determined that the specimen had to be cut and reduced its weight due to the swelling over the mold (Fig. 19). The average volume expansion of 10% AWA, 20% AWA and 30% AWA concrete were 4.98%, 8.90%, and 13.89% expansion respectively (Table 9). On the basis of these data, it is possible to discern the influence of concrete volume growth on concrete strength.

Table 9. Volume expansion of AWA concrete.

Specimen	Height expansion (mm)	Volume expansion (1E-9 m³)	%	Avg. expansion (%)
10 % AWA & sand	5	3775.15	5.34	4.98
	5	3775.15	5.34	
	4	3020.12	4.27	
20 % AWA & sand	7	5285.21	7.48	8.90
	10	7550.29	10.68	
	8	6040.24	8.55	
30 % AWA & sand	13	9815.38	13.89	13.89
	15	11325.44	16.02	
	11	8305.32	11.75	

4. Conclusion

Based on the results and discussion, it was found that the compressive strength reduction in 10% AWA, 20% AWA and 30% AWA concrete were 31.78%, 42.17% and 60.49% of the control concrete compressive strength. Hence the replacement of sand with aluminum waste ash concrete hence can be directly utilized for making the lightweight concrete and can be further examined as treatment ingredient in the process of non-structural application.

5. Conflict of Interest

The authors wish to declare no competing conflict of interest.

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