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RESEARCH ARTICLE

Durability of Alkali-Activated Concretes Under 5% Sulfuric Acid Environment

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ABSTRACT

The investigation focused on the resistance to 5% sulfuric acid degradation of the alkali-activated concretes (AAC). The AAC was manufactured using a blended binder of 50% slag and 50% F-type fly ash. The AAC was activated using a blend of 14 M sodium hydroxide and sodium silicate, with a hydroxide-to-silicate ratio of 1/2,5. Six AAC were produced against a 5% sulfuric acid environment, varying the binder amounts (400–500–600 kg/m³) and activator-binder (A/B) ratios (0,45–0,55). The chemical resistance of AAC was evaluated by visual appearance, variation in weight and compressive strengths. The findings pointed out that more gypsum and higher weight gain were obtained on the AAC specimens having 600 kg/m³ binder content. There is no or negligible influence of A/B ratio was found on the visual appearance and weight variation after acid attack. The results revealed that the highest durability was achieved with the maximum binder content of 600 kg/m³ combined with the 0,45 A/B ratio, while the lowest resistance was achieved with the minimum binder content of 400 kg/m³ and 0,55 A/B ratio. The additional water content of 7,5% by binder weight should be reduced to achieve higher mechanical strength for the AAC, especially for high-binder mixes (> 400 kg/m³).

Keywords: Alkali activated concrete (AAC), Sulfuric acid attack, Visual inspection, Weight change, Compressive strength

1. Introduction

The durability of construction materials is crucial for their performance and lifespan, particularly when exposed to severe chemical environments. The exposures of sulfuric, hydrochloric, and nitric acids are known to cause substantial damage to structures over their service life. Construction materials, particularly concrete, are often damaged by acid, which comes from sources like organic acid and acid rains available concrete sewage systems. Construction materials also face acid attacks from a variety of other industrial sources, including wastewater from chemical and mine processing plants. Acid penetration severely damages cementitious materials, which is not only an environmental problem but also reasons substantial financial burdens due to the great prices of restoration and maintenance. Therefore, high durability in construction materials is necessary for prolonging a

structure's service lifespan and decreasing maintenance requirements [1].

The use of cementitious constituents, i.e., slag or F-fly ash has been well-known in the cement manufacturing phases because these by-products materials decrease environmental hazards of the Portland cement (PC). Given that PC accounts for approximately 8% of global CO₂ emissions, researchers are actively exploring alternative cementitious materials to decrease its environmental impacts. Fly ash can be considered as an alumina-silicate basis [2–4], which is classified as low or high calcium fly ash, depending on its origin. Türkiye manufactures about 15 million tonnes of fly ash annually [5], and its utilization as a partial replacement for PC is gaining significance in efforts to decrease environmental pollution. Ground granulated blast furnace slag, a steel industry by-product, is also increasingly utilized to replace PC and promote more sustainable construction practices

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[6, 7]. Due to the higher CaO content, the contribution of slag to the mechanical strength is better than fly ash. However, both fly ash and ground granulated blast furnace slag are generally employed as partial replacements for PC in different cement manufacturing processes. The existing structural codes/regulations do not permit the utilization of direct usage of by-product materials as binder materials for structural utilization.

Driven by the need for environmentally friendly construction materials, researchers are progressively more focusing on incorporating industrial by-products and waste materials into green concrete formulations. As a central innovation in green concrete technology, alkali-activated materials (AAMs) are clinker-free and uses industrial waste as the main binder component, considerably decreasing environmental impact. The substantially lower CO₂ emission factors of both natural and industrial waste-based binder materials, relative to PC, play a crucial role in promoting environmental sustainability [8]. The substantial production of industrial by-products, coupled with disposal challenges and their potentially harmful nature, further supports their ecological viability as precursors in sustainable binder systems. Through the effective use of supplementary cementitious materials, alkali-activated concrete can achieve up to an 80% decrease in the carbon footprint compared to conventional PC-based concrete. In addition, the manufacture of PC results in extreme depletion of natural resources, with limestone quarries being particularly affected. These fundamental factors collectively drive scholars to discover and construct sustainable building materials aimed at lowering both costs and environmental impacts [9].

Alkali-activated concretes (AAC) are composed of aluminosilicate materials and alkali activators. F-type fly ash and ground granulated blast furnace slag are one of the most utilized by-product materials in the AAM manufacturing [10–12]. These aluminosilicate materials react with alkali activators for strength and durability. In general, sodium-based alkali activators, including sodium silicate and sodium hydroxide, are commonly chosen for geopolymerization instead of potassium-based alternatives because of their cost-effectiveness. The formed gel type during geopolymerization considerably impacts the mechanical performance and durability of the AAM. N-A-S-H (sodium aluminosilicate hydrate) gels, typically produced by low-calcium fly ash-based AAMs, provide a 3D network that contributes to good chemical resistance and thermal stability. On the other hand, slag-based AAMs form both C-S-H (calcium silicate hydrate) and N-A-S-H gels, which combine the strength characteristics of traditional PC hydration

products (C-S-H) with the chemical durability of N-A-S-H gels. This dual gel formation often results in enhanced early compressive strength improvement and superior performance, making this material particularly attractive for structural utilizations [13–16]. Fly-ash based AAMs requires elevated temperature curing of 65°C at 48 h, while slag-based AAMs can gain strength without elevated temperature curing due to high CaO content [16]. These studies [13–16] showed that AAM samples may have equal and even greater strength compared to PC samples if properly designed.

Various factors are known to affect the mechanical strength and durability of AAM. Among these factors, alkali activator type, type, content and chemical composition of the alumina-silicate material, silicate/hydroxide ratio, sodium hydroxide molarity, and the curing temperature and time are significant elements influencing the residual mechanical strengths of AAC [17–21]. In addition, alkali activator/binder content (A/B) ratio may be another factor influencing the strength and durability of AAC. For the proper AAC design, a comprehensive understanding of how different factors influence the mechanical strength and durability of AAMs is essential. Key factors such as binder content and the A/B ratio may have a direct impact on the geopolymerization process. It is well-known that a binder content is a significant factor for the mechanical performance for the PC-based concretes, and most of the standards/guidelines suggest to use minimum 400 kg/m³ PC in concrete production against chemical attacks. In addition, water to cement ratio for PC-based concrete becomes generally in the range of 0.45–0.65; however, low water to cement ratio (0.45) is suggested to use for the harsh environments.

Chemical durability is a serious problem that reduces the service life of the reinforced concrete structural elements. Among the chemical environments, sulfuric acid, sodium and magnesium sulphates, and seawater attacks are the most pronounced chemical medium for the evaluation of the resistance of AAC [22–26]. The short-term and long-term chemical resistances of the AAC should be investigated under seawater, sulfate, and acid environments. In a similar manner to PC-based concretes, the chemical resistance of the AAC is also affected by volume change, permeability, crack occurrence, and spalling [27]. The previous study reported that AAC has greater corrosion and acid resistance than OPC concrete [23, 26, 28]. In another study, the effects of exposure to 5% sulfuric acid, 3.5% seawater and 5% magnesium sulfate environments on the chemical durability of various AAC and PC-based concretes were investigated. The study found that 5%

sulfuric acid posed the most severe chemical attack, and that AAC performed a better durability performance compared to PC-based concrete [22]. Moreover, the %3,5 seawater, %5 sulfuric acid and magnesium sulfate resistances of PC-based concretes, AAC, and ECC samples were investigated [26]. The findings pointed out that the decrease in the compressive strengths because of the sulfuric acid was about 2 times more than magnesium sulfate, and about 4 times higher than seawater attack. After 60 days of exposure to 5% sulfuric acid, compressive strength reductions of 52% and 40% were observed for PC-based and AAC specimens, respectively, indicating that AAC exhibits superior chemical durability resistance as compared to PC-based concretes [26].

In a comprehensive examination of the available literature, most existing studies only address individual parameters (e.g., NaOH molarity, binder content, curing conditions) on strength and durability performance; however, the combined influence of different binder contents and alkali activator/binder content (A/B) ratios has not been adequately highlighted. Thus, the originality of this study lies in examining the effects of different binder contents (400–500–600 kg/m³) and A/B ratios (0,45–0,55) together under a 5% sulfuric acid environment at both 120 days and 150 days. Due to the inadequate number of research examining chemical resistance of AAC, standards/guidelines for the AAC is not available. Additional studies are necessary to establish standardized guidelines for the structural use of AAC.

2. Material and method

2.1. Material

In this study, a binder composed of 50% Class F low-calcium fly ash and 50% ground granulated blast furnace slag was used. The alkali activator solution consisted of sodium silicate (Na₂SiO₃) and sodium hydroxide (NaOH), mixed at a silicate/hydroxide ratio of 2,5 by mass. Previous study has shown that a sodium silicate/ hydroxide ratio of 2,5 optimizes the compressive strength of AAC [29]. The NaOH molarity was selected as 14 M, since it was stated that the chemical resistance of AAC is the weakest molarity value when the sodium hydroxide molarity is 14 M [30]. Sodium silicate (SiO₂/Na₂O:2) with a density of 1,39 g/cm³ was supplied as a liquid and sodium hydroxide as a solid with 98% purity was supplied from a local chemical market. Sand and crushed stone (< 4 mm) were used as fine aggregates, and No I (4–8 mm) and No II (8–16 mm) aggregates were used as coarse aggregates. A polycarboxylic ether-based superplasticizer was used as a chemical admixture.

Table 1. XRF analysis of fly ash (FA) and slag (GGBFS).

Chemical Composition	FA	GGBFS
CaO (%)	2,10	37,25
Al ₂ O ₃ (%)	25,26	11,89
SiO ₂ (%)	54,76	38,37
Fe ₂ O ₃ (%)	6,28	1,05
MgO (%)	2,08	8,13
SO ₃ (%)	0,20	0,38
Na ₂ O (%)	0,38	0,28
K ₂ O (%)	4,04	1,28
LOI (%)	3,30	0
SG (g/cm ³)	2,13	2,93
SS (cm ² /g)	3870	4320

The utilization of additional water to increase both alkalization and workability in AAC was also used in the previous work [31]. In this study, additional water was used in a similar manner, and the amount of additional water was selected to be 7,5 % of the binder weight. The physical and chemical characteristics of Class F fly ash and GGBFS used in this study are summarized in Table 1.

The specimens were named based on the percentage of binder materials. In the S50FA50 AAC sample, the first S50 term represents 50% GGBFS, and the second FA50 term represents 50% F-type ash material. The binder contents were selected as 400 kg/m³, 500 kg/m³ and 600 kg/m³, and the alkali activator/binder content (A/B) ratios were used as 0,45 and 0,55. This research also investigates the higher waste material usage in AAC so that waste materials reused in the construction sector, disposal of them may not be a problem for both environment and economy. Table 2 shows the material ingredients of AAC samples having A/B ratio of 0,45. In addition, the material ingredients of AAC specimens with an A/B ratio of 0,55 were given in Table 3. The first term S50FA50 presents %50 slag and %50 fly ash, the second term of 400 (200–200 kg/m³ FA + GGBFS), 500 (250–250 kg/m³ FA + GGBFS), and 600 (300–300 kg/m³ FA + GGBFS) indicate total binder content, kg/m³, and the last term of 0,45 and 0,55 illustrate the A/B ratio for the AAC specimens.

During concrete casting, the dry mixes (aggregates and FA + GGBFS) were first mixed for 2 minutes. Then, prepared alkali activator and half of the superplasticizer were included to the container within 1 minute and mixed for another minute to ensure homogeneity. Lastly, extra water and remained superplasticizer included to the container and mixed for 2 minutes. The superplasticizer content was adjusted individually for each mix to achieve S4 class consistency (160 ± 20 mm). After several trial mixes, target S4 class consistency was reached. Upon completion of the mixing procedure, the obtained mixtures were poured into 150 × 150 × 150 mm cubic moulds,

Table 2. Material ingredients for the AAC samples having 0.45 A/B ratio (kg/m³).

Materials		S50FA50-400-0,45	S50FA50-500-0,45	S50FA50-600-0,45
Coarse Aggregate	No I	487	413	335
	No II	487	413	335
Fine aggregate	Sand	314	266	217
	Crushed stone	314	266	217
F-type fly ash + slag		400	500	600
Superplasticizer		8	3	2
Sodium silicate		129	161	193
Sodium hydroxide		51	64	77
Additional water		30	37,5	45

Table 3. Material ingredients for the AAC samples having 0.55 A/B ratio (kg/m³).

Materials		S50FA50-400-0,55	S50FA50-500-0,55	S50FA50-600-0,55
Coarse Aggregate	No I	457	373	287
	No II	457	373	287
Fine aggregate	Sand	292	238	186
	Crushed stone	292	238	186
F-type fly ash + slag		400	500	600
Superplasticizer		8	3	2
Sodium silicate		157	196	236
Sodium hydroxide		63	79	94
Additional water		30	37,5	45

properly compacted, and stored at room temperature for 24 hours prior to demoulding. Following labelling, all specimens were maintained in a controlled laboratory environment until the scheduled compressive strength tests. It should be noted that no heat or water curing was applied to the AAC samples, since our aim is to use this AAC specimens in structural elements similar to OPC specimens without any cure applications. Otherwise, the heat-curing procedure hinders the utilization of AAC on-site applications.

2.2. Testing method

In this study, the chemical immersion method was employed to evaluate the performance of different AAC specimens under sulfuric acid exposure. Following the curing stage, the AAC specimens were placed in containers with adequate spacing to ensure full exposure and uniform absorption of the sulfuric acid solution from all surfaces. Separate 10-liter containers were used to prepare and store the 5% sulfuric acid solutions for the immersion tests. First, the AAC samples were positioned in the containers, and after that sulfuric acid solutions. The 5% sulfuric acid solution was slowly added to each container until it covered the specimens by a minimum of 3 cm. To prevent evaporation, the containers were subsequently sealed. In addition, unexposed AAC samples were kept under ambient laboratory conditions to serve as reference samples. The 150 × 150 × 150 mm specimens were utilized for the 5% sulfuric acid

exposure tests. Compressive strength tests were conducted at 120 days (28 days of curing + 92 days of acid exposure) and 150 days (28 days of curing + 122 days of acid exposure) to evaluate the effects of long-term chemical attack. A force-controlled loading rate of 0.6 MPa/s is applied to the specimens.

Currently, there is no standardized test method specifically established for evaluating the sulfuric acid resistance of AAC. Accordingly, the AAC samples were taken out of the 5% sulfuric acid solution and left to drying under laboratory conditions for 24 hours prior to testing. After the drying period, the surfaces of the specimens were photographed to visually evaluate the extent of surface damage caused by acid exposure. Afterward, the weights of the specimens were measured to calculate weight variations resulting from acid exposure. Lastly, the compressive strength of the specimens was tested following the procedures outlined in ASTM C39. Fig. 1 illustrates the AAC sample production, covering up the AAC samples to prevent alkali solution evaporation, chemical exposure, and compressive strength tests of the AAC specimens.

3. Result and discussion

3.1. Visual assessment

Fig. 2 shows the surface photos of the AAC after exposed to 5% sulfuric acid attack at 120 days. The AAC samples exhibited severe wear by forming white

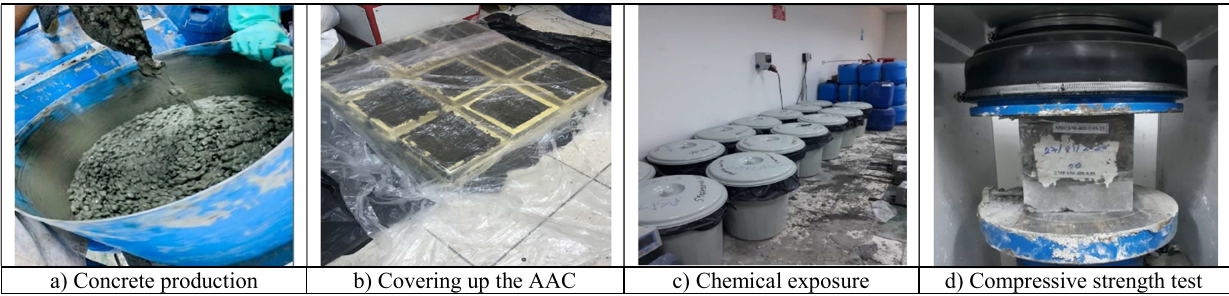


Fig. 1. Production of specimens and compressive strength testing after exposure to 5% sulfuric acid

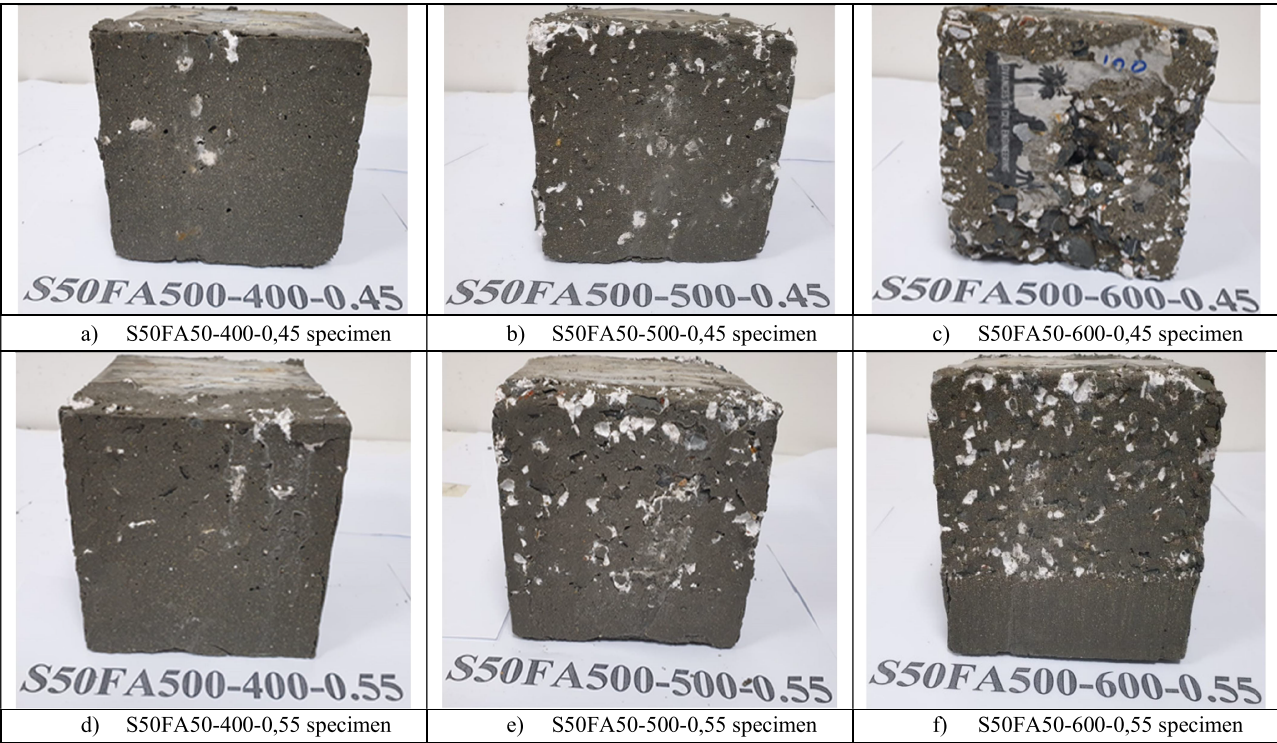


Fig. 2. Surface evaluation of AAC specimens following 120 days in 5% sulfuric acid.

deposits on surfaces, and the loss of AAC mortar was observed. The result showed that the surface deterioration increased with the binder content, and the highest surface degradation was obtained on the AAC samples having 600 kg/m³ binder, while the lowest one was observed on the AAC specimens with 400 kg/m³ binder. The effect of alkali activator-to-binder content (A/B) ratio on the surface deterioration was found to be negligible. Similar gypsum amounts were obtained on the samples having A/B ratio of 0,45 and 0,55. The more gypsum occurrence of the AAC samples with 600 kg/m³ can be due to the more CaO content, causing to form calcium sulfate. As a result of chemical reactions in between SO₄ ions of sulfuric acid (H₂SO₄) and dissolved calcium ions of slag grains, gypsum (white deposits) is formed [23, 32]. The formed gypsum content may increase

with the increased binder content; therefore, AAC samples having 600 kg/m³ binder content showed higher gypsum amount on the specimen surfaces as a result of H₂SO₄ attack.

3.2. Weight change

The unit weights of the S50FA50-400-0,45, S50FA50-400-0,55, S50FA50-500-0,45, S50FA50-500-0,55, S50FA50-600-0,45, and S50FA50-600-0,55 specimens were found to be 2307 kg/m³, 2282 kg/m³, 2229 kg/m³, 2158 kg/m³, 2074 kg/m³, and 1998 kg/m³, respectively. The unit weights of the AAC specimens are lower than 2400 kg/m³ of the general plain concrete. The unit weights of the AAC specimens having 600 kg/m³ are almost found in the range of lightweight concrete limits (2000 kg/m³).

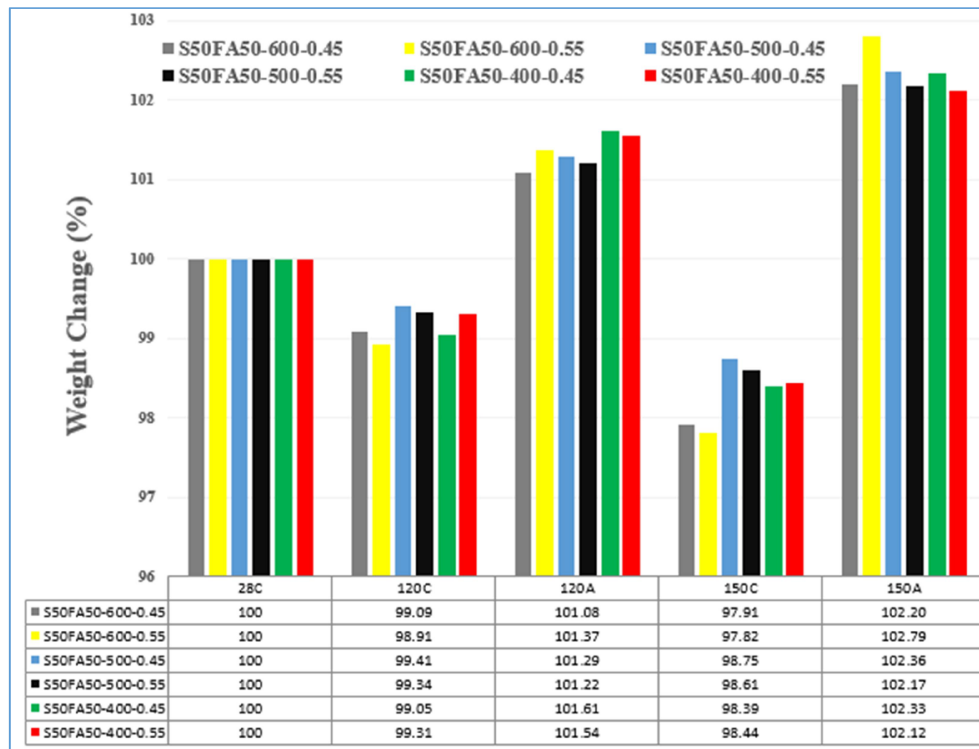


Fig. 3. Weight change of the AAC specimens before and after 5% sulfuric acid attack.

The increase in the binder content reduces the unit weights of the specimens. The weight change results of AAC samples subjected to 5% sulfuric acid attack are presented in Fig. 3. The results demonstrated a noticeable weight gain in the AAC samples following prolonged exposure to 5% sulfuric acid solutions. Specifically, this increase was recorded at 120 and 150 days, suggesting potential chemical interactions or surface alterations due to the acidic environment. The weight increase was found highest at 150 days after exposure to acid attack. The reason for this is that AAC samples absorb the sulfuric acid solution, leading to an increase in AAC sample weights as the samples absorb the acid solutions.

It should be noted that higher weight increments are also an indicator of a higher deterioration. Specimens with 400 kg/m³ binders showed highest weight gain at 120 days, while similar weight gains were observed at 150 days. The result also revealed that almost similar weight gains were obtained on the AAC specimens having 0,45 and 0,55 A/B ratios. Generally, deterioration caused by chemical attacks typically begins at the surfaces of specimens and gradually progresses inward toward their core. Thus, with extended exposure to acid attacks, such as up to 360 days, matrix loss, surface erosion, and particle disintegration are likely to occur, potentially resulting in weight loss following the chemical degradation

[32, 33]. On the other hand, weight loss was obtained on all control (unexposed) AAC samples at ambient condition due to the ongoing geopolymerization [22, 23].

3.3. Variation in compressive strength

The compressive strengths of the AAC samples before and after exposure to 5% sulfuric acid are shown in Fig. 4. The results pointed out that the compressive strengths of the AAC specimens increased over time, with the maximum values recorded at 150 days under ambient conditions. It should be noted that there is no heat curing or water curing applied on the AAC specimens. This increase is attributed to the ongoing geopolymerization reactions, which produce additional C-S-H and N-A-S-H type geopolymeric gels, thereby enhancing the compressive strength of the specimens. The peak strength was obtained on the S50FA50-400-0,45 specimens, while lowest one was observed on the S50FA50-600-0,55 specimens. The compressive strength of the S50FA50-400-0,45 specimen increased from 56,53 MPa (28 days) up to 60,62 MPa and 66,04 MPa at 120 days and 150 days, respectively. Meanwhile, the compressive strengths of the S50FA50-600-0,55 specimens enhanced from 31,64 MPa (28 days) up to 40,12 MPa and 43,14 MPa at 120 days and 150 days, respectively.

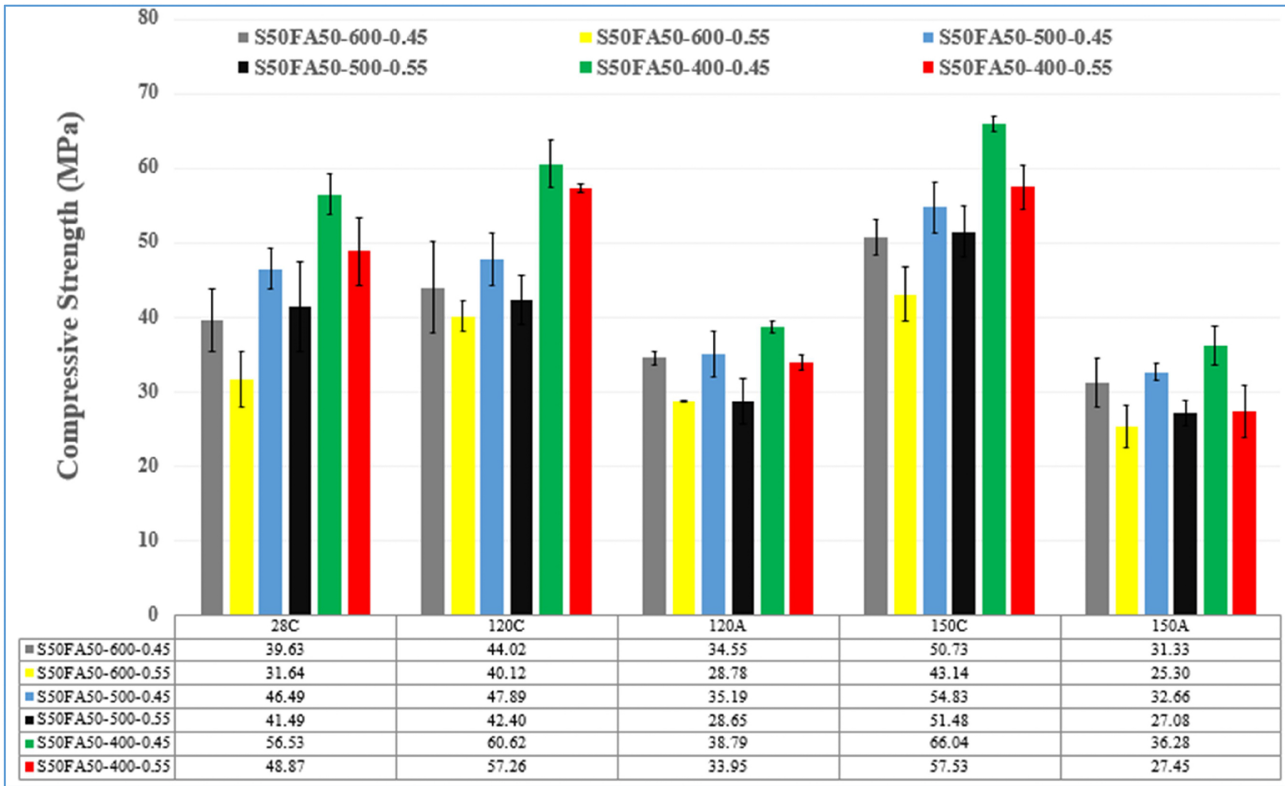


Fig. 4. Changes in compressive strength of AAC specimens due to 5% sulfuric acid attack.

On the other hand, compressive strengths of the AAC samples reduced significantly after being subjected to 5% sulfuric acid attack. The reduction in compressive strength became more pronounced with longer exposure to 5% sulfuric acid, with the AAC samples exhibiting their lowest strength after 150 days in the acidic environment. The compressive strength reductions were 21,52% and 38,24% for the S50FA50-600-0,45 specimens, and they were 28,27% and 41,36% for the S50FA50-600-0,55 specimens at 120 and 150 days, respectively. The compressive strength reductions were 26,52% and 32,42% at 120 days, and they were 40,44% and 47,41% at 150 days for the S50FA50-500-0,45 and S50FA50-500-0,55 samples, respectively. In addition, For the S50FA50-400-0,45 and S50FA50-400-0,55 samples, the compressive strength reductions were found to be 36,01% and 40,71% at 120 days, while they were 45,07% and 52,28% at 150 days under 5% sulfuric acid attack.

Moreover, results showed that the superplasticizer dosage decreases with increasing binder content (e.g., 8 kg/m³ for S50FA50-400-0,45 versus 2 kg/m³ for S50FA50-600-0,45). This suggests that despite the higher binder content, a lower amount of superplasticizer was sufficient to achieve the target S4 consistency, which may be due to both the increased

alkali activator content and additional water content (7.5% by binder weight) of the high-binder mixes. The additional water content of 7.5% by binder weight should be reduced to achieve higher mechanical strength for the AAC, especially for high-binder mixes (> 400 kg/m³).

Fig. 5 illustrates the residual compressive strengths of the AAC samples after being subjected to 5% sulfuric acid for 120 days and 150 days. The results revealed that AAC specimens having an A/B ratio of 0,55 deteriorated more than the 0,45 ones. In addition, higher binder contents increased the chemical resistance of the AAC samples against 5% sulfuric acid. Although compressive strength of the AAC samples having a 400 kg/m³ binder yielded higher compressive strength in both ambient and acid environments, compressive strength reductions due to the acid attack were found to be higher. This suggests a higher early strength and a low chemical resistance trend. For specimens with higher binder contents (500 and 600 kg/m³), the degradation was less pronounced, which can be attributed to the formation of more stable C-S-H and N-A-S-H gels, resulting in less volumetric change under acid exposure. After the evaluation of the AAC samples, the results yielded that higher binder content with a low A/B ratio exhibited the best chemical resistance, while lower binder

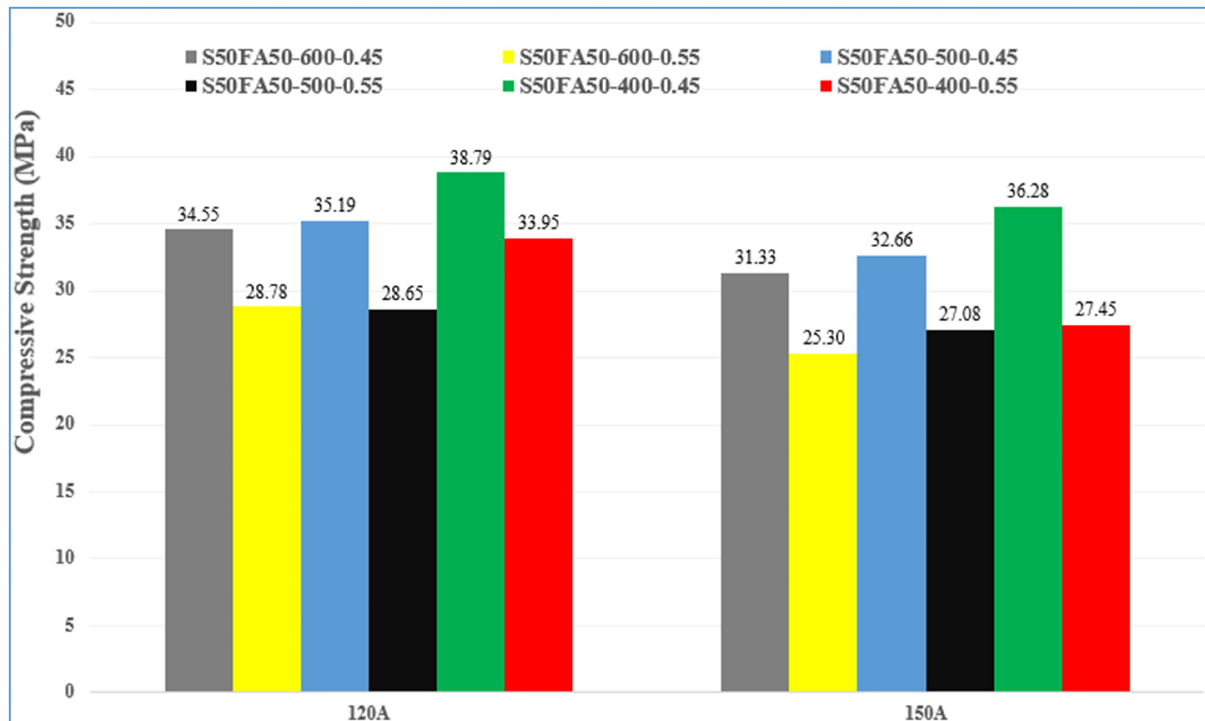


Fig. 5. Compressive strength retention of AAC specimens after 5% sulfuric acid attack for 120 and 150 days.

content having a high A/B ratio showed the lowest chemical resistance against 5% sulfuric acid attack.

The study concludes that samples with a higher binder content (600 kg/m^3) exhibited greater surface gypsum formation and higher weight gain, suggesting a higher tendency for deterioration. However, compressive strength results showed that mixes with 600 kg/m^3 binder content showed better chemical resistance. It should be noted that visual deterioration, weight gain, and compressive strength loss represent different stages of durability degradation. The visual deterioration exhibits the surface degradation of the specimens. The weight change results are affected by the various stages. In the first stage, the weight gain was observed in the samples due to the acid penetration from the surface to the interior regions. Then, volume expansion occurred in the samples due to gypsum formation, and hence, cracking, matrix wear, and particle disintegration occurred on the samples, leading to the loss of weight of the specimens. This degradation starts from the surface and progresses to the interior regions. In the study, a higher binder content led to more CaO and gypsum formation (visual damage) while also resulting in a lower ultimate strength loss (greater chemical resistance). This could be attributed to slower acid penetration from the surfaces of the samples into the interior regions due to lower permeability.

4. Conclusion

In this study, the influences of different binder contents and alkali activator/binder content (A/B) ratio were investigated under 5% sulfuric acid attack on the fly ash-slag based alkali activated concrete (AAC) specimens. The results obtained are as follows:

- Surface appearance outcomes revealed that a higher amount of gypsum formed on the AAC specimens having a higher binder content due to the acid attack. The specimens having a 600 kg/m^3 binder content showed higher gypsum content than the specimens with 500 and 400 kg/m^3 binder contents, respectively. Also, there is no or negligible effect of A/B ratio found on the gypsum formation, similar gypsum contents were observed on the specimen surfaces with A/B ratios of 0.45 and 0.55.
- Weight measurements results showed that the AAC samples experienced weight gain due to absorption of the 5% sulfuric acid solution. This initial increase in mass is likely caused by the penetration of acid into the pore structure and possible formation of secondary reaction products. The highest weight gain was obtained on the samples having a 600 kg/m^3 binder, while lowest weight gain was obtained on the AAC specimens

with a 400 kg/m³ binder at 150 days. Similar weight gains were obtained on the AAC specimens having 0,45 and 0,55 A/B ratios.

- Compressive strength results revealed that although higher compressive strengths were obtained on the AAC specimens having a 400 kg/m³ binder, the deterioration due to acid attack was found more on the AAC samples having a 400 kg/m³ binder. The chemical resistance increased with an increasing binder content, and the AAC specimens with a 600 kg/m³ binder exhibited the greater sulfuric acid resistance. In addition, AAC samples with an 0,45 A/B ratio performed better chemical resistance than the AAC samples having an 0,55 A/B ratio. The best chemical resistance was observed in AAC specimens with a binder content of 600 kg/m³ and an A/B ratio of 0,45, whereas the poorest chemical resistance was found in samples with a binder content of 400 kg/m³ and an A/B ratio of 0,55.
- The findings yielded that the chemical durability resistance of the AAC samples was similar to the performance of OPC specimens. Therefore, AAC can be utilized as a construction material in the structural design of RC structures. However, the standardization process of the AAC is still difficult due to the various factors of AAC, influencing the mechanical strength and durability of AAC, i.e., alkali activator type, NaOH molarity, Na₂SiO₃ chemical composition, Na₂SiO₃/NaOH ratio, additional water, the binder type and its composition, curing regime, type of superplasticizer and content, and their multiple interactions.
- Lowering the 7,5% additional water content (by binder weight) may improve both mechanical strength and durability in high-binder AAC binder (> 400 kg/m³).

5. Future study

In the research, additional water is added (7,5% binder weight) to the AAC to decrease superplasticizer content and to obtain similar S4 slump consistency values for all AAC. This extra water may reduce further the compressive strength values of the AAC having a 600 kg/m³ binder, leading to the reduced durability. In the future study, the AAC samples may be produced without additional water and they should be exposed to the different chemical attacks (i.e., magnesium sulfate, seawater). In addition to this, different sodium hydroxide molarities (8 M and 12 M) and sodium silicate/hydroxide ratios (1, 1,5, and 2) may be used in the upcoming study to influence effect of alkali activators on the resulting

mechanical strength and durability performance of the AAC specimens. Further study is needed to use these novel cement-free materials in the structural applications. Also, microstructural analyses (e.g., SEM, EDS, XRD, TGA) should be conducted to provide a deeper understanding of the degradation mechanisms.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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None.

Author contribution

All of the authors have contributed equally to the article. Further, all of the authors have validated and approved the final manuscript.

Data availability

All graphs and data obtained or generated during the investigation appear in the published article.

Dataset

Data will be available based on request.

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