Effect of Alkaline Activator Addition on Grout Mortar Made from Cement and Silica Fume with Si/Al Ratios

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Abstract

The demand for improved material performance continues to increase as alternative materials technologies develop. Likewise with construction materials such as concrete, mortar, and the like. Grout mortar is a type of mortar that is commonly used to repair porous construction structures. As with filler materials in general, strength performance is also a demand in order to obtain a cohesive unity with the main structure. The addition of chemicals is allegedly an alternative that is worth studying to further increase the strength of materials, because changes in chemical properties will lead to changes in physical capabilities, in this context strong pressure. One example of a chemical composition that is widely used to improve the performance of a mixture is an alkaline activator due to its reactive properties. The addition of alkaline activators in certain proportions will change one of the chemical structures of the material, namely the ratio of silica and aluminum contents, or better known as the Si/Al ratio. With the benchmark in the previous study, the chemical content was analyzed by the XRF test, then a new mixture was made with a modified Si/Al ratio close to the target level, which are 4.5, 4.75, and 5. The research sample turned into a 5 x 5 x 5 cm mortar cube that was tested for compressive strength at the age of 7 and 28 days. After conducting research and analysis, it was found that none of the variations in the Si/Al ratio showed positive results in the development of compressive strength when compared to the performance of the previous sample. Only an average compressive strength of 15.8 MPa was obtained for the 7-day-old sample and 21.16 MPa at 28 days of age, while the sample was preceded at around 30 MPa and 40 MPa for the same age. This shows that the increase in the Si/Al ratio to the limit of 5 is inversely proportional to the improvement in the performance of the grout mortar.

Keywords: *Alkali Activator, Mortar, Practical Mixed Design, Silica Fume, Si/Al Ratio*

1. Introductions

Green materials instead of cement continue to be recommended of various types, such as fly ash, bottom ash, metakaolin, and even silica fume. Mostly, these substitute materials are a by-product of an industrial process that can still be used because they still have cement-like properties, both in terms of chemical composition and physical properties. Its use can also be used as a substitute or alternative material, which is to reduce a few percent of the cement portion until it is completely replaced. The author still uses silica fume which is also one of these alternative materials because it is quite easy to find in building material product providers. However, previous research has shown that alternative materials do not always have a positive impact on the development of their strength. The addition of silica fume up to a percentage of 15% will actually reduce the compressive strength of the mortar significantly. **[1]** Further analysis is needed to uncover why substitutes with different compositions do not have a positive impact on strength enhancement, one of which is the attempt at a chemical approach. Water as a catalyst for hydration reactions tends to contain no compounds that can be modified for the sake of increasing and decreasing levels of chemical composition. It is necessary to have a solution rich in certain substances so as to cause fundamental changes in the chemical composition of the mortar mixture, such as alkaline activators.

Research on silica fume as an alternative material to cement has been carried out a lot, so there are several references related to its physical properties. Some previous researchers stated that the SiO_2 content in silica fume ranges from 85-95%, while it is also called more specific levels such as 96% and 98%. Not only silica, which is the main constituent substance, there are also several minor compounds such as aluminum oxide, iron oxide, manganese oxide, potassium oxide, calcium oxide, and also sodium oxide, with percentages not reaching or around 1%. Other physical properties that are also identified are densities ranging from 0.55 – 0.7 kg/l, particle sizes between 300 – 400 nm, LOI ranging from 1 – 5, and even amber-like colors. **[2][3][4][5][6]** Morphologically, the form of silica fume is categorized into loose-looking raw silica fume (RSF) with a rough surface, and densified fume silica (DSF) is quite compact with relatively smooth surfaces. **[7]** For more detail, the micropellet shape of the silica fume crystal can be seen in **Figures 1a** to **1d** at various magnification conditions.

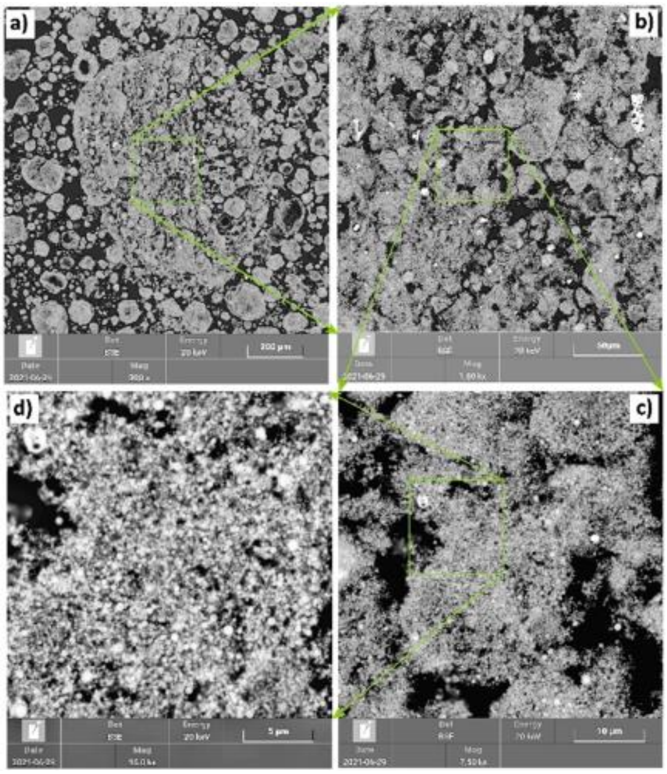


Figure 1 (a) Silica Smoking Micropellet, (b) Micropellet form at 1500x magnification, (c) Micropellet shape at 7500x, (d) magnification. Micropellet shape at 15000x magnification [8]

The correlation of using silica fume to increase compressive strength has been researched several times. The addition of nanosilica content of 3% - 5% has been proven to improve the strength performance of cement paste. **[9]** The small specific surface area of the fume silica also affects the strength of the cementitious-based material. **[10]** In other discussions, it has also been confirmed that the use of nanosilica by 8% can reduce the mirko pores of cement paste, which means that it increases the density so that the compressive strength increases. **[11]** The correlation with the porosity of the material was also evident in several other discussions, namely that with the addition of optimal levels of nanosilica and microsilica, porosity was reduced so that the compressive strength also improved. **[12]**

As mentioned earlier, the existence of chemical substances as catalysts needs to be a topic of discussion rather than conventional water use. Activators of the alkaline element group are often used because of their reactive ability to help better break down molecules. **[7]** The use of alkaline activators is also considered more environmentally friendly because the reaction that works differently from the hydrolysis reaction of carbon in concrete hardening in general increases CO_2 emissions into the atmosphere. **[13][14][15]** Previous research has used this solution extensively to alter the chemical properties of materials formulated in comparison of silica compounds and certain elements, such as sodium, potassium, and calcium. The ratios also vary, ranging from SiO_2/Na_2O of 1.8 and 1.6, 0.5 – 3 with a combination of KOH, Na_2SiO_3, and $Ca(OH)_2$, Na_2SiO_3/NaOH of 2.5, SiO_2/Na_2O of 1.4 which are all applied to test materials in the form of mortar. The precursor materials used are also diverse, ranging from *blast furnace, fly ash, metakaolin,* cement containing csalcium alumina, coconut oil residue, and *slag bottom ash* **[16][17][18][19][20]** In this study, sodium silicate or waterglass was used which has several phase forms depending on the composition level between SiO_2, Na_2O, and water or H_2O, as seen in **Figure 2**. Where area 1 is anhydrous, 2 are crystalline alkaline silicates, 3 are partial crystals, 4 are glass forms, 5 are hydrated glass forms, 6 are hydrated solutions, 7 are semi-solid, 8 are viscous solutions, 9 are semi-dilute solutions, 10 are thinner solutions, 11 are jelly forms. **[21]**

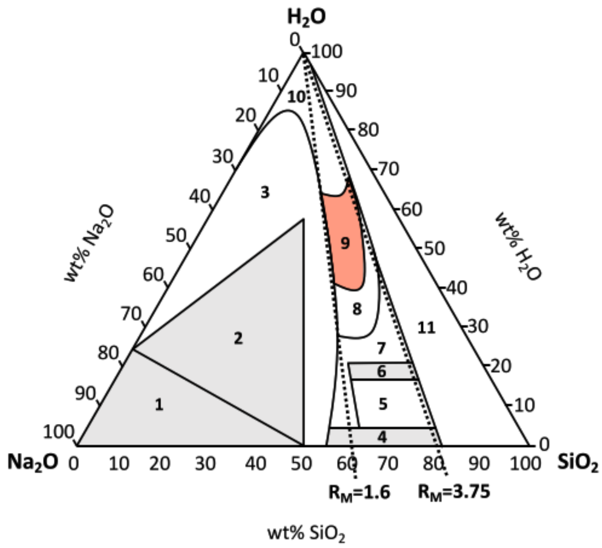


Figure 2. Various forms of sodium silicate activator alkaline solutions. [22]

Taking all of this into account, this study will be made based on the composition of the mortar obtained in the previous research, then reacted with an additional material in the form of an alkaline sodium silica activator, with a Si/Al ratio that is controlled in a manner so that the workability of the mixture is maintained.

2. Methods

Previous research recommended the following composition, listed in **Table 1**. After physical testing, the remaining mortar fragments are crushed, then XRF (X-Ray Diffraction) testing is carried out to reveal the oxide content. The results of the XRF test showed that the sample contained 11.1% SiO_2 and 2.3% Al_2O_3, as seen in **Figure 3**. By molarity analysis, it was found that this composition has a Si/Al ratio of 4.1. This ratio is next varied while maintaining the workability of the mortar by calculating the accumulated amount of water in the mixture which is close to 348.78 gr, so that the composition with the Si/Al ratio of 4.5, 4.75, and 5 as shown in **Table 2** is obtained.

Table 1. Composition of mortar in previous research

Sampel	Age (days)	Cement (gr)	Sand (gr)	Water (gr)	SF (gr)
5%	7	658.83	613.75	348.78	34.68
	28	658.83	613.75	348.78	34.68

Table 2. XRF test results of previous mortar samples

Application	<Standardless>
Sequence	1 of 1
Measurement time	18-jul-2025 07:55:36
Position	3

Compound	**Al2O3**	**SiO2**	**K2O**	**CaO**	**TiO2**	**V2O5**	**Cr2O3**	**MnO**	**Fe2O3**	**CuO**	**SrO**	**MoO3**
Conc	2,3	11,1	0,06	71,0	0,63	0,03	0,051	0,14	9,06	0,072	0,24	3,0
Unit	%	%	%	%	%	%	%	%	%	%	%	%

Compound	**In2O3**	**BaO**	**Eu2O3**
Conc	2,0	0,2	0,2
Unit	%	%	%

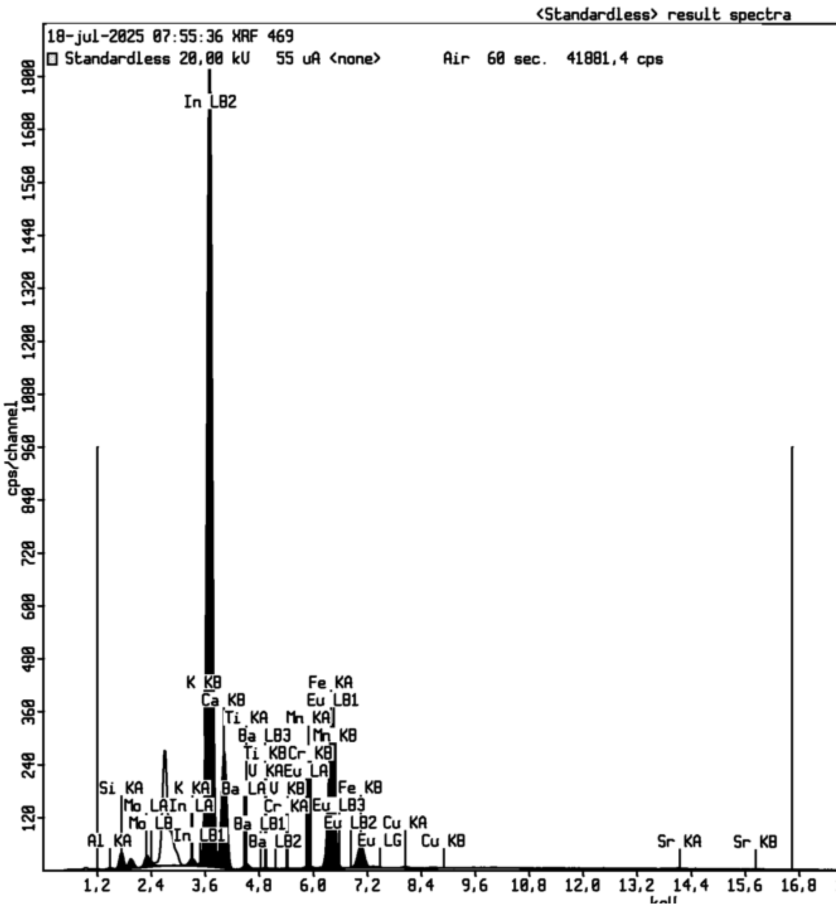


Figure 4. Results of previous mortar spectra tests

As for Si/Al contained in natrium silicate is not defined because the aluminum trioxide is not provided in the substance so that the solution only added some amount of silicate. For the solid compound, the ratio of Si/Al remained the same at 4,09 because the amount of silicate dioxide and aluminum trioxide are also not changed.

Table 3. Composition of the mortar mixture by adding sodium silicate

No	Natrium silicate solution				Solids			TOTAL		H_2O++	Si/Al Total
	Na_2SiO_3 (gr)	SiO_2 (mol)	Na_2O (mol)	H_2O (mol)	Solid (gr)	SiO_2 (mol)	Al_2O_3 (mol)	SiO_2 (mol)	H_2O (gr)	(gr)	
1	47	0,235	0,114	1,436	1307,26	2,418	0,295	2,653	25,85	322,93	4,501
2	77	0,385	0,186	2,353	1307,26	2,418	0,295	2,803	42,35	306,43	4,755

	Natrium silicate solution				Solids			TOTAL			
No	Na_2SiO_3 (gr)	SiO_2 (mol)	Na_2O (mol)	H_2O (mol)	Solid (gr)	SiO_2 (mol)	Al_2O_3 (mol)	SiO_2 (mol)	H_2O (gr)	H_2O++ (gr)	Si/Al Total
3	106	0,53	0,256	3,239	1307,26	2,418	0,295	2,948	58,3	290,48	5,001

3. Results and Discussions

After compressive strength testing was carried out at the sample age of 7 and 28 days using UTM (Universal Testing Machine) as shown in **Figure 5**, performance was obtained in the form of a graph in **Figure 6**. It was seen that the average compressive strengths of Si/Al composites of 4.5, 4.75, and 5 at 7 days of age were 15.8 MPa, 17.8 MPa, and 14.2 MPa. Meanwhile, at the age of 28 days, the average compressive strength increased to 22.67 MPa, 20 MPa, and 20.8 MPa for each variation. If these results are compared with the composition of mortar without the addition of alkaline solutions in previous studies, the tendency is to decrease. The average strength of a mortar without an alkaline solution is 30 MPa for 7 days, and 40 MPa for 28 days. As mentioned above, the Si/Al ratio before the addition of alkaline activators is 4.1, so by adding this ratio to 5, it actually results in a decrease in compressive strength performance.

Figure 5. Compressive strength testing and final results of mortar samples

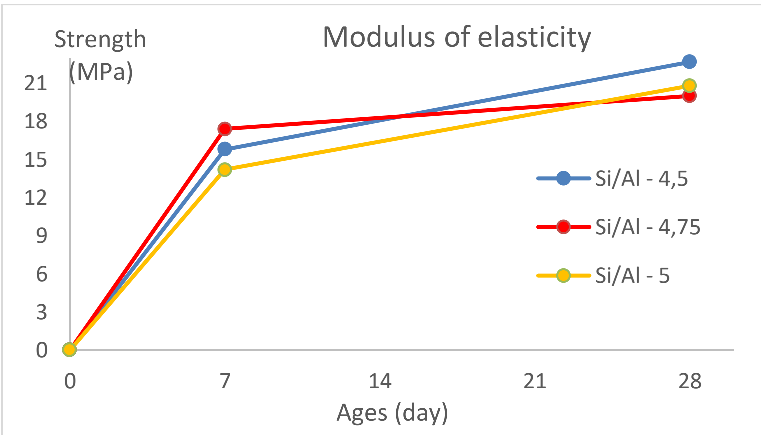


Figure 6. Compressive strength test results of all variations

Another research result obtained along with the compressive strength test is the modulus elasticity test. It can be seen from the results that at the age of 7 days, the modulus value is 732.77 MPa for the Si/Al variation of 4.5 and 871.61 MPa for the Si/Al variation of 4.75. Meanwhile, the results are quite significant in the Si/Al 5 sample with only 177.37 MPa. These modulus values decreased in all variations in the 28-day age test, namely 278.81 MPa for the Si/Al 4.5 variation and 220.19 MPa for the Si/Al 4.75 variation, both of which were quite identical. As was the case in the 7-day test, at 28 days of age the sample with the Si/Al 5 variation also produced the lowest modulus value, which was 158.75 MPa. All of these data are presented in the graph in **Figures 7 and 8**. It is used regression to determine the modulus because the data are not clearly recorded at the limit of conservative strain of 0,005.

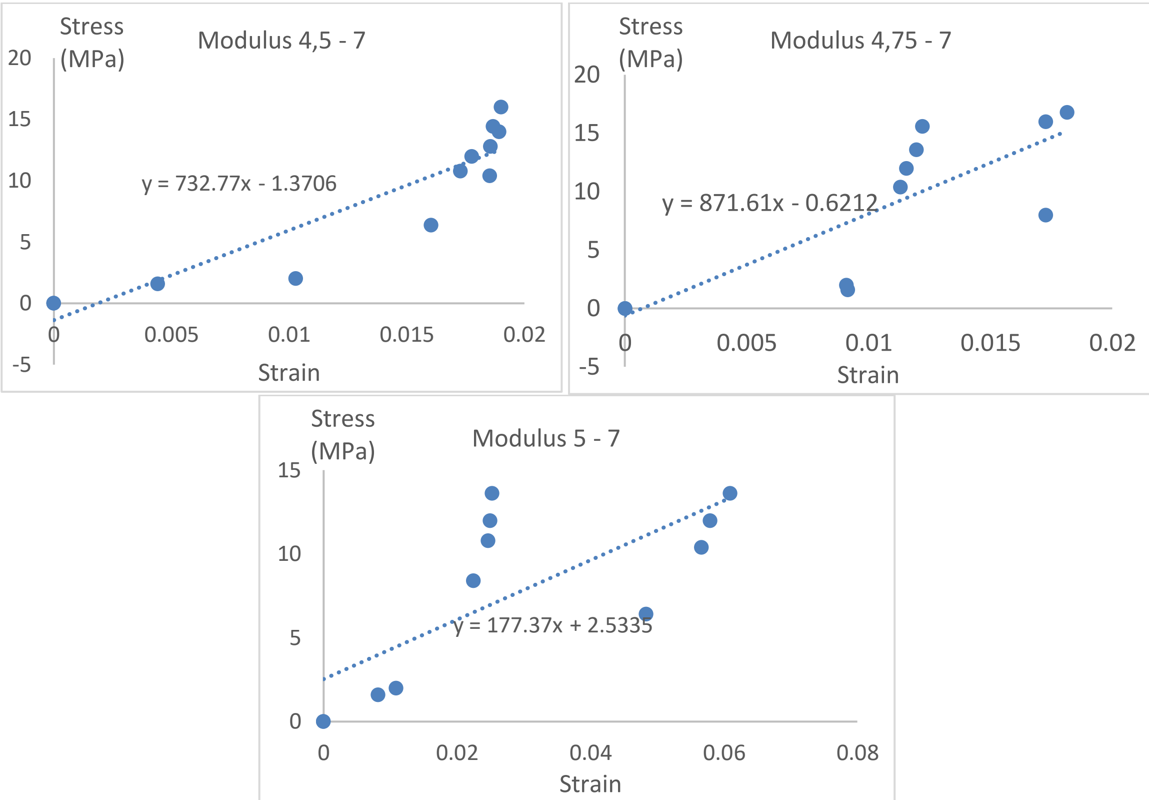
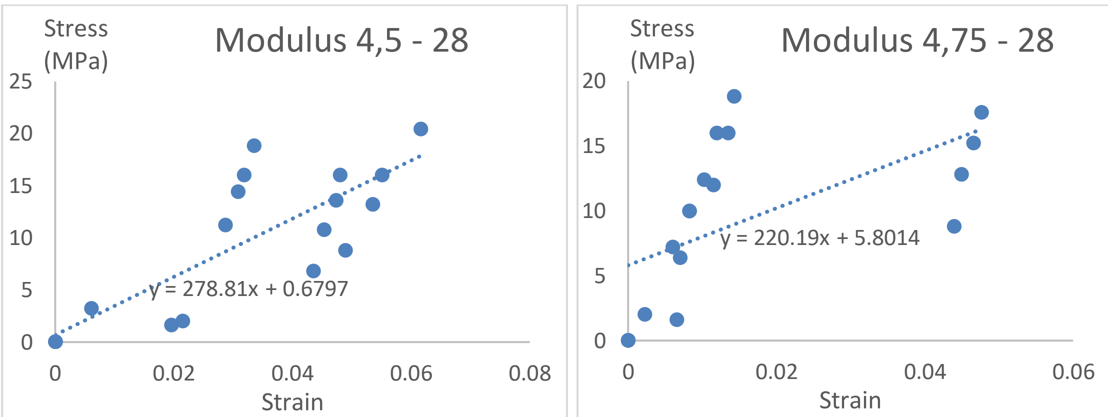


Figure 7. Results of the 7-day-old sample elasticity modulus test



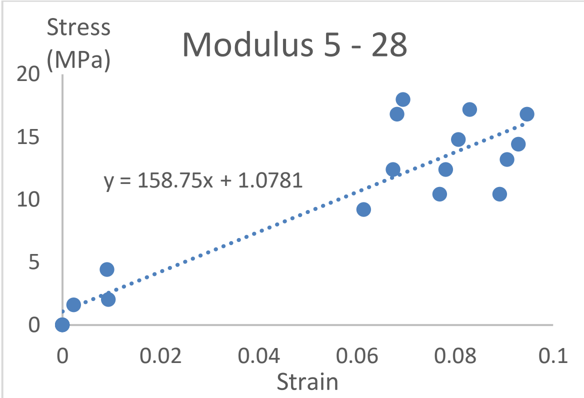


Figure 8. Results of the 28-day-old sample elasticity modulus test

4. Conclusions

The results of the XRF test stated that the previous sample had a SiO_2 content of 11.1% and Al_2O_3 of 2.3%. After the analysis of the Si/Al ratio, a score of 4.1 was obtained. The compressive strength results for this previous sample were about 30 MPa at 7 days of age and 40 MPa at 28 days of age. Then, several samples were made with Si/Al variations in the range of 4.5, 4.75, to 5 by changing the proportion of sodium silicate (Na_2SiO_3) and maintaining the workability of the mixture. After the pressure test was carried out, it was found that the variation sample experienced a decrease in compressive strength, namely 15.8 MPa, 17.8 MPa, and 14.2 MPa in samples with Si/Al content of 4.5, 4.75, and 5 respectively at 7 days of age. Meanwhile, at the age of 28 days, the values were 22.67 MPa, 20 MPa, and 20.8 MPa. This result indicates that the optimal Si/Al ratio value is not in the range above 4.5. Similar things were also seen in the modulus of elasticity test, where the values were 732.77 MPa, 871.61 MPa, 177.37 MPa in all three samples at 7 days of testing and 278.81 MPa, 220.19 MPa, 158.75 MPa at 28 days of testing. For further research, it is necessary to try the Si/Al variation below 4.7 to obtain the optimum value which is alleged to have an impact on improving compressive strength performance.

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