



Compressive Behavior of Jacketed Specimens and Flexural Behavior of Concrete Beam Strengthened using Sodium Silicate Mortar

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Abstract: Damage in concrete structures depends on the load types. Flexural and axial loads are the most common load types that cause damages. The damage can be repaired by injecting materials such as sodium silicate. In this study, two methods are performed to repair concrete damages namely grouting in beam and jacketing on concrete cube samples with sodium silicate mortar. The grouting method was conducted in the first crack of beam, while the jacketing method was done by covering the concrete cube with sodium silicate mortar. The sample used was 15x15x15 cm³ of concrete cube and 15x15x60 cm³ of beam. The results showed that sodium silicate mortar improved 92% compared to the initial stage of compressive strength. However, the first crack at maximum load of the repaired beam occurred earlier than the controlled specimen. In general, the repairing method can be applied to reduce damage in concrete structures.

Keywords: Damage concrete, crack, grouting and jacketing, sodium silicate mortar

1. Introduction

Concrete is a non-ductile material that is formed by mixing cement, water, fine aggregate and coarse aggregate. Concrete is very often used to support compress load due to its hard nature. However, its brittle nature after the mixture hardens makes it vulnerable to damage and cracking. Concrete damages that usually occur are shear, flexural and axial failure. Shear and flexural failures commonly occur in beam structures, while axial failure occurs in column elements. Many researchers have studied concrete failures and the repairing methods.

Yang et.al. [1] studied a beam with flexural failure which was repaired by composite external reinforcement using carbon fiber reinforced polymer grid and cementitious matrix. The first stage of this research was to numerically estimate the target capacity of the beam. The ratio of targeted capacity to experimental test was determined about 1.05.

The other researcher also investigated the similar issue using different materials, i.e. ground rubber tire powder incorporated textile in RC [2]. This rubber was retrieved from wasted materials which used about 2.5% to 7.5%. Jayaprakash et.al. [3] used carbon fiber fabric to reinforce a beam under shear load. This fiber has tensile strength of 3.8 MPa with Young's modulus of 230,000 MPa. The study was done by numerical and experimental analyses. The finite element analysis was modelled by LUSAS. The results concluded that there is a similarity between numerical and experimental analyses. The use of fiber increases 50% from the initial shear strength.

Identical to flexural failure, axial failure on concrete structural members has been studied to be strengthened with many methods. One study has tested the strengthening of reinforced concrete columns using High-Performance Fiber Reinforced Cementitious Composite (HPFRC) with sprayed mortar strengthening bars [4]. This study specifically

applied the repair materials to concrete due to cyclic load which illustrates the earthquake. The result showed that this type of strengthening could improve the column performance after severely damaged. Another study on axial structural member improvement has also been developed using concrete jacket with reactive powder (RPC) and carbon fiber reinforced polymer (CFRP) wrapping [5]. This study had cylindrical specimens with reinforcing bar inside the concrete. The thickness of the material was about 25 mm from outside of the specimen. There were several parameters observed in this experiment, namely ductility, ultimate axial load, and energy absorption. The result showed that strengthening by CFRP for concentric axial load on repairment has shown to be significantly higher than the controlled specimen, and it has higher ductility compared to that strengthened with jacketing. The proposal of jacketing technique was also suggested to gain the yield load.

Several researches have investigated the repairing concrete element by jacketing ([6], [7], [8]). Alhadid and Youssef [6] did numerical analysis based on experimental test from another research to evaluate the strength of concrete beam after jacketing with concrete layer. The study recommended the modification factors to calculate deflections and capacity of repaired specimen. Concrete jacketing for structural member has also been studied for column under compressive load [7] and for standard reinforced concrete column [8]. The use of Steel-Reinforced Grout (SRG) was the main point of the repair for both studies. The samples made were cylindrical concrete layered with SRG. It is proved that adding SRG for repair could increase the compressive strength.

Researches on the application of Sodium silicate in concrete have been performed previously. One study has observed the utilization of Sodium silicate for mortar [9]. The results indicated that this kind of materials is better than conventional materials, not only in terms of the compressive strength, but also in terms of the resistance of water. Another researcher also sought for the tensile strength and microstructure of the Sodium silicate on geopolymer application], confirming that Sodium silicate enhanced the tensile strength resulted from the shrinkage and micro-cracks. Sodium silicate was also proved to be better than cement itself when reacting in mortar, in this case OPC mortar [11]. In binder structure, this material also increases the extent of crosslinking and has higher alkalinity which gives a more gel structure that is good for structural materials [12],[13]. In slag concrete, Sodium silicate has a good effect on increasing compressive strength [14]. Also, the workability of cementless mortars with sodium silicate is greater than that with OPC mortars [15].]. In any structural members, Sodium silicate has been applied in geopolymer concrete beam structure [16], double-walled self-healing concrete structural members [17], and even for coating to receive humidity resistance in heating condition [18]. The benefits of this material have been proved especially for concrete in construction materials.

However, a mix of sodium silicate with cement has not been tested to be applied for improving structural members. In this research, Sodium silicate was demonstrated to be used for improving damaged concrete samples due to compressive test by jacketing and for repairing the first crack on beam due to flexural testing by grouting. The purpose of this study was to know the effectiveness of using Sodium silicate mortars for repairing axial and flexural structure members. The compressive strength and interaction between load and displacement became the parameters to give the complete images of the mortar effectiveness. Furthermore, this study also contributed as a reference to researches on structural repair.

2. Materials and Samples

Local materials for the concrete were used in this study. The fine aggregate was from Mount Merapi area while the coarse aggregate was from Clereng, Yogyakarta. Material properties tests were performed to understand their characteristics for mix design purposes. There were two types of samples used in this study: one was the cubical concrete specimens and the other was reinforced concrete beams. The reinforcing bars used two diameters, namely 6 mm and 8 mm. The 6 mm was used for confinement reinforcement and the 8 mm was for the longitudinal bars.

2.1 Fine and Coarse Aggregates

Distribution size of the fine aggregate was checked to know whether it could be used or not as concrete mix. The Indonesian Standard (SNI) was referred to as guidance for the test, which in this case was based on SNI 8321:2016. The result of the distribution size is illustrated on Fig. 1. The fine aggregate passing cumulative used was slightly under the lower limit than the allowed especially on small sieve size, however this material was still acceptable for mix concrete.

Different with the fine aggregate, the distribution size test for coarse aggregate used in this study was not performed since the material particles had been maintained to be retained at the sieve with size of 20 mm and passed the size of 40 mm. Many types of tests were done to obtain the fine and coarse aggregate properties. These tests were directly related to the determination of ratios among all the materials for concrete mixing as well as the requirements needed from SNI. Below in Table 1, the properties test results are shown.

2.2 Concrete Mix Design

After the needed material properties were known, especially the fineness modulus of aggregates, the mix for concrete was designed. It was based on SNI 03-2834-2000 with the targeted compressive strength (f'_c) of 30 MPa.

Based on the design, it was suitable to use the water–cement ratio of 0.48. The proportion of water, cement, fine and coarse aggregates for the cube and beam concrete specimens can be seen in Table 2 below. For the record, these proportions are not for 1m³ but for making 1 sample with the designated size.

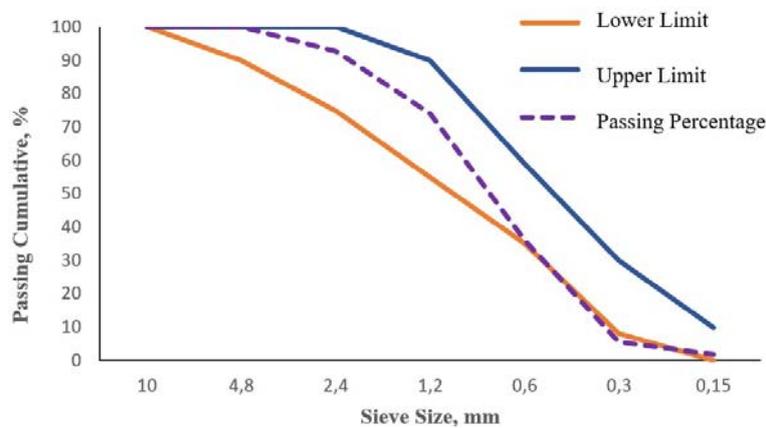


Fig. 1 - Fine aggregate distribution size

Table 1 - Material Properties test for fine and coarse aggregate

Test	Value for Fine Aggregate	Value for Coarse Aggregate	Unit
Fineness Modulus	3.5	-	-
Specific Gravity	2.68	2.6	-
Clay content	4.97	1.85	%
Water Absorption	9.95	2.14	%
Moisture content	14.39	1.17	%
Unit Volume	1.47	1.44	gr/cm ³
Abrasion (Los Angeles Test)	-	21	%

Table 2 - Details of concrete compositions

Materials	Value for cube specimens	Value for beam specimens	Unit
Water	0.76	3.04	Litre
Cement	1.58	6.33	kg
Fine Aggregate	2.14	8.56	kg
Coarse Aggregate	6.46	15.9	kg
Total	8.46	33.85	kg

2.3 Tensile Strength of Reinforcing Bars

Beam specimen cannot withstand itself without reinforcing bars. There are two possibilities of failure in the beam, namely flexural and shear failure. It is expected to fail from bending test, so that the shear strength must be stronger than its flexural. Two varieties of reinforcing bars were installed in the concrete, one had 6 mm of diameter and the other had 8 mm. These two bars were tested under the tensile test on universal testing machine (UTM). The 6 mm bar had yield stress (f_y) about 250MPa to 350 MPa and the 8 mm bar had about 350MPa to 420 MPa. Fig. 2 presents the complete result of the bar testing.

2.4 Cubical Concrete Specimens

The concrete sample jacketed with sodium silicate mortar was made cubical. This was chosen because the cube shape was easy to print and still relevant in accordance with the concrete specimen provision SNI 03-1974-1990. The concrete cube sample had a size of 15 cm x 15 cm x 15 cm with compressive test testing at an age of 28 days, requiring

calibration to normal compressive strength (f'_c) with a multiplier of 0.83. Below in Fig. 3 and Fig. 4 are displayed the concrete cube moulds and the implementation of curing of concrete samples.

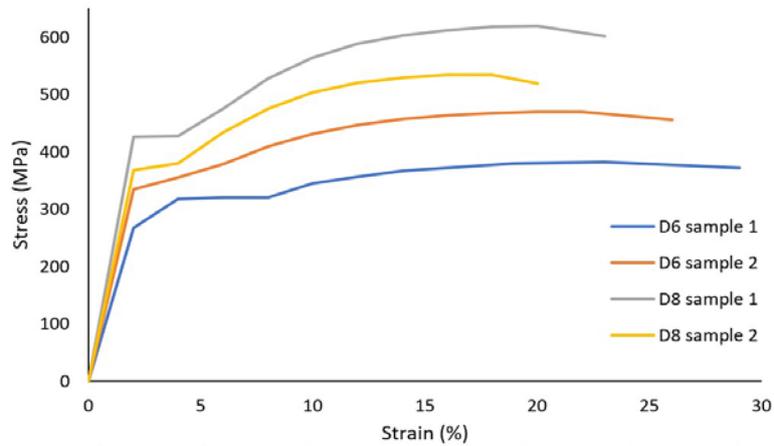


Fig. 2 - Stress-strain interaction of reinforcing bar used



Fig. 3 - Cubical concrete mould

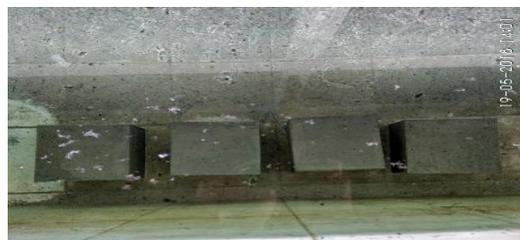


Fig. 4 - Cube specimens inside the water for curing

2.5 Reinforced Concrete Beams

Four reinforced concrete beam samples were used with 1 control beam which was not repaired. Three other samples were distinguished based on sodium silicate to cement ratio which was for grouting applied. The beam had a rectangular section of 15 cm x 15 cm with a total span of 62 cm. Moreover, the support was pinned-rolled support with a span length of 60 cm. The beam had the reinforcement configuration as depicted in Fig. 5 with the illustrated cast in Fig. 6. After cast, the concrete was cured by covering it using a wet gunny sack for 28 days, as pictured in Fig. 7.

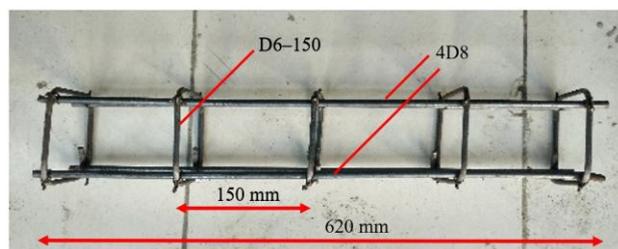


Fig. 5 - Reinforcing bars for beam specimens.



Fig. 6 - Concrete beam metal cast



Fig. 7 - Beam samples curing process

2.6 Sodium Silicate and Cement

Sodium silicate, or usually called as water glass, is the name for chemical compound of Na_2SiO_3 . This chemical was obtained from Bratachem, Indonesia. Its form is liquid so that it can directly be mixed with cement. This compound can be seen in Fig. 8. The cement used for this research was Portland Pozzolan Cement with “Semen Gresik” brand and the mixing between Sodium silicate with the cement to create Sodium silicate mortar is illustrated in Fig. 9.



Fig. 8 - Sodium silicate



Fig. 9 - Cement (left) and Sodium silicate mortar (right)

3. Experimental Tests

All the tests were performed at The Laboratory of Structure and Construction Materials, Department of Civil Engineering, Universitas Muhammadiyah Yogyakarta. The fresh properties done were only the slump test based on SNI 1972:2008 to make sure that the concrete had high workability. Compressive tests for the cubical samples and

bending tests for the beam specimens were performed by Universal Testing Machine (UTM) in this laboratory as seen in Fig. 10. For the bending test, the UTM was modified with some additional supporting steels to conduct three-point loading as suggested in ASTM C78. The configuration of the support system with modified steel can be seen in Fig. 11.

In this experiment, there were three main parameters observed during the test, namely compressive strength for the cubical specimens and load-displacement interaction for the beam samples for both condition, initial condition at an age of 28 days and after the strengthening using Sodium silicate.

The jacketing method for the cubical concrete samples was by using an additional casting from multiplex wood, which is presented in Fig. 12. This casting had a dimension of 16 x 16 cm² so that it left small gaps around the cube to be filled with sodium silicate cement. Different with the compressive test samples, the beam was repaired by making the first crack and the load for the first crack was predicted by manual calculation before the real test. After the first crack appeared, then the beam was prepared to be injected by sodium silicate mortar along its crack, then the bending test was continued on the next 28 days for its final age. This treatment is shown in Fig. 13.



Fig. 10 - Testing set up for concrete cube sample

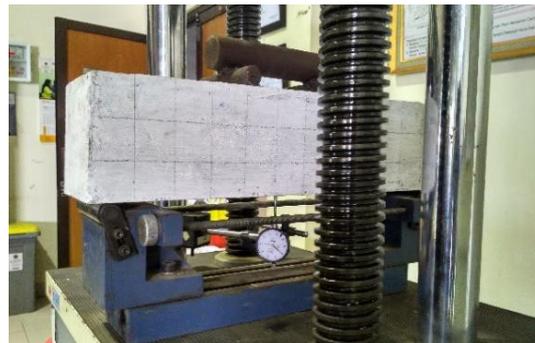


Fig. 11 - Testing set up for beam sample

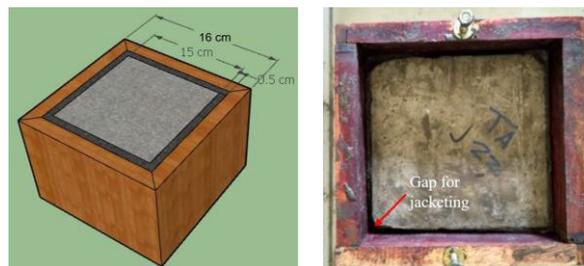


Fig. 12 - Concrete cube jacketing treatment



Fig. 13 - Concrete beam grouting treatment

4. Results and Discussion

The very first test in this experiment was Slump test. The average result obtained from this test was 13.7 cm, which was still acceptable since the requirement from SNI 1972:2008 was between 7.5 to 15 cm so the workability of the mixture was good. After that, the concrete was casted and tested with axial load to know the compressive strength. The result showed that the failure at the cubical concrete specimens was the same as predicted previously, which had compression failure. This failure is illustrated in Fig. 14. The specimen had a lot of spoiling especially on its body parts.



Fig. 14 - First attempt on concrete cube sample compressive test

Following this test, the same specimen went to multiplex wood cast and filled with sodium silicate mortar so that it covered all the surrounding of the cube. This represents the attempt to do a jacketing on structural member which has failed from axial test. The jacketed specimen is presented in Fig. 15.



Fig. 15 - Jacketed cubical concrete specimen with sodium silicate

There were three proportions of sodium silicate–cement ratio that were used in this study, namely 1:1, 3:4, and 1:2. The UTM machine can only read the maximum load so only the ultimate compressive strength can be known.

The first compressive test indicated that all the three ratios had the compressive strength more than 30 MPa as designed in the beginning. After the jacketing, these three ratios were tested again due to axial load and still had good average ultimate strength at least 72% from the initial strength for ratio 1:1 and 92% for ratio 3:4. This shows that the sodium silicate mortar really helped the cubical concrete to retain all the axial forces that occurred during the test, even though the repaired concrete could not go back to its full strength. The detail of the compressive test result for both conditions is presented in Table 3 while the damage during the test is depicted in Fig. 16.

Table 3 - Compressive test result for cubical concrete specimens

Samples	Sodium Silicate-Cement	Initial Test		Result after Jacketing			Residual Strength (100% - difference)
		Compressive Strength (MPa)	Average (MPa)	Compressive Strength (MPa)	Average (MPa)	(%)	
TA1		26.16		21.35			
TA2	1:1	39.75	32.65	24.14	23,48	28%	72
TA3		32.04		24.96			
TA4		39.53		33.27			
TA5	3:4	32.71	31.49	34.41	28,91	8%	92
TA6		22.25		19.05			
TA7		36.41		32.74			
TA8	1:2	40.38	37.93	41,13	33,34	12%	88
TA9		36.99		26,14			

After the test, these three ratios were observed closely to see the types of the damages. From Fig. 17, it can be known that ratio 1:1 and 1:2 were mostly damaged on the outer part, which is the sodium silicate mortar, while the ratio 3:4 had all the damages on its body.

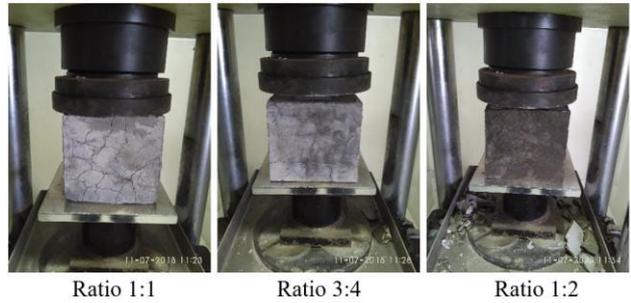


Fig. 16 - Failure at the compressive test for strengthened cubical specimens

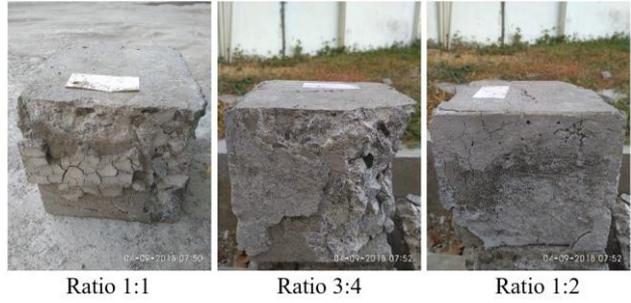


Fig. 17 - Detailed failure occurred in jacketed concrete cubes

The next experiment was bending test for beam specimens. The first crack that occurred in the beam was placed in the middle of the beam as illustrated in Fig. 18. This means that the beam had been damaged from the flexural failure. After retrieving the first crack, the injection of sodium silicate mortar grouting was done especially in the part of openings, then bending re-test was performed until the ultimate strength was obtained. The final failure on the three beams is depicted in Fig. 19.



Fig. 18 - Crack happens on beam samples for the first attempt



Fig. 19 - Bending failure for three grouted beams

The control beam was also tested as comparison especially on the first crack load and the ultimate load. The full result of the bending test is portrayed in Fig. 20 and Table 4.

There were three beam specimens involved in this test, with different Sodium silicate-cement ratios (SSCR). Beam 1 (B1), Beam 2 (B2) and Beam 3 (B3) had the SSCR of 1:1, 3:4, and 1:2 respectively. The load and displacement were observed to know the detail of P-delta curves. The first crack was also monitored, and all the first cracks were shown in Fig. 20 with different colors. After the crack, the beam was repaired then the loading was continued until all the specimens failed. The dashed lines illustrate the crack point and ultimate point of the control specimen results. These are drawn in Fig. 20 to compare all the results.

From the test outcome, it can be learned that the load to make the first crack of the repaired beam was not as high as the control beam which is possibly because the sodium silicate was not fully covered and did not have enough grip to maintain the beam concrete especially on the gap. Similar with the ultimate strength, the load to make the control beam reach the ultimate condition was still higher than the load for all the three beams.

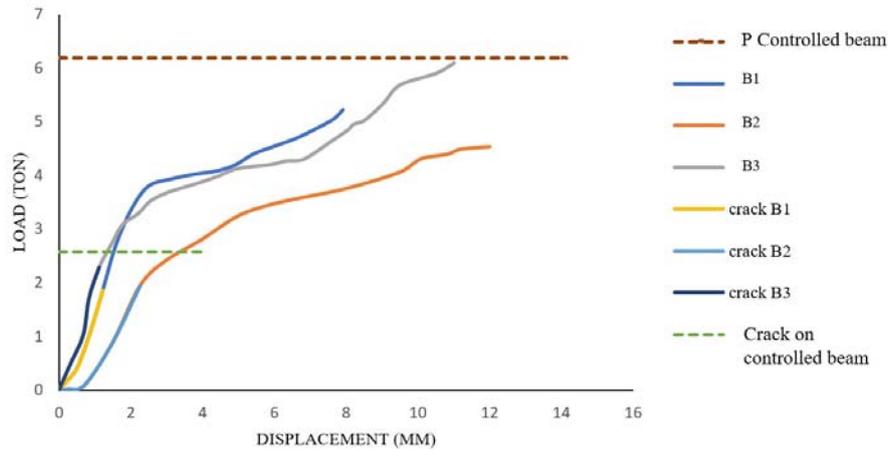


Fig. 20 - Bending test result of beam specimens.

Table 4 Detailed result of bending tests for beam specimens.

Condi	Code	P_u	Displacement
Initial First crack before repairment	B	2.57	1.
	B	2.66	0.
	B	2.65	0.
Crack after repairment	B	1.89	1.
	B	1.92	2.
	B	2.21	1.
Ultimate condition after repaired	B	5.32	7.
	B	4.63	12.
	B3	6.21	8,69
Crack on Controlled Beam	Dashed line	2.60	Not recorded
Ultimate Condition on Controlled Beam	Dashed line	6.31	Not recorded

In addition to the test result, it is noticed that the sodium silicate mortar had a short setting time, so the strengthening had to be done quickly before the mortar hardened. Fig. 21 shows the mixing condition of this mortar. In only 7 minutes, the mortar had already set so that it was hard to fill the crack gap. In 10 minutes, the mixture had partly hardened and created some clogs as illustrated in Fig. 22. This quick setting time might also be the reason of the lower bending test result for repaired specimen compared to controlled beam.

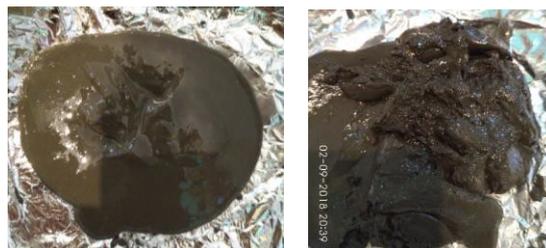


Fig. 21 - Setting time in 1 minute (left) and 7 minutes (right).

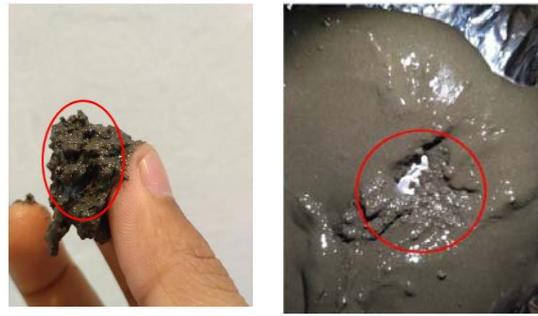


Fig. 22 - Clogging that happened in sodium silicate mortar after 10 minutes.

5. Summary

To sum up, sodium silicate can be mixed with cement and becomes a good material of mortar. This mortar is able to strengthen the cubical concrete specimens about 72% to 92% to its first strength due to compressive load. However, this shows different result on beam specimen, where the crack and the ultimate load are not higher than those of control beam. This might be caused by a short setting time, so it is hard for mortar to completely fill crack gaps and hold concrete surrounding it. Hence, this material and repairing method are introduced as a reference for future researches and for practical engineers' consideration to repair concrete with axial damages.

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