Mechanical Properties of Grout Materials for Concrete Structure Repairs

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Abstract. This research studies about the characteristics of grout material used for repairs to concrete structures. The purpose of this test is to produce materials with optimum composition for use as alternative materials for grouting or retrofitting. Fresh properties testing is carried out in the form of checking the flowability value as a benchmark to determine the proportion of the mixture, in addition to the hardened properties tested in the form of water content, absorption value, specific gravity, unit weight, and initial rate of suction. The results of the fresh properties show that overall the material can be worked or applied. While the hardened properties test results show that RCFA shows quite good results compared to other types of grout material, this is indicated by the results of absorption, moisture content and initial rate of suction which is worth 0. Besides that the type of grouting RCFA also produces the highest compressive strength value that exceeds 100 MPa at 28 days. Type of grouting SSCG produces a compressive strength that is small enough that is below 10 MPa so it is recommended not to use this type of grouting to be applied to the repair of concrete structures.

Keyword: mechanical properties, grout material, concrete structures, concrete material.

1. Introduction

Concrete is one of the most commonly used structural materials because it has many advantages including strong compressive strength, economic strength, good performance and durability values [1-3]. Concrete constituent materials generally consist of aggregate, cement, and water. Durabilitas concrete is one important component in maintaining the performance of a concrete structure. There are many factors that affect, in the elastic condition, if the elastic value of the strain exceeds the tensile strain capacity, cracking will occur in the concrete. This crack will reduce the performance of the concrete structure so that it can cause corrosion in the reinforcement [4]. The occurrence of these problems, of course, needs to be done monitoring and repairing cracks that occur in concrete. There are many types of repair methods in concrete one of which is to use grouting injection. This process is used because it is more practical and easy to apply in the field.

Grouting material generally consists of cement and water. The grouting or retrofitting process is an attempt to insert cement paste into the cracks contained in concrete using high pressure. Usually the quality of grouting must be better than the quality of concrete and must have a fairly good flowability value. The use of grouting or retrofitting is usually used for buildings that were damaged after the earthquake. The use of grouting methods for structural repairs has been done a lot before, including in precast concrete and prestressed connections [5,6], improvements to the structure of columns, beams, column beam joints, and slabs [7-11], improvement of pipe structure for drainage channels [12,13], wind turbine repairs to offshore structures [14,15], and various other types of structures. In addition,
The use of this grouting method has the advantage of being very fast in the repair process. The development of grouting is very fast developing nowadays. Many innovations have been made to replace grouting with conventional methods such as by using environmentally friendly materials. This research will use three different types of grouting, namely conventional grouting using cement grout, geopolymer grouting using sodium silicate and grouting using resyn catalyst with fly ash. In each of these types of grouting use different compositions in accordance with the results of the trial mix to obtain a pretty good flowability value. In several previous studies, many concepts have been developed such as using bottom ash added ingredients [16], Rice husk ash [17], and fly ash [18-20]. In addition, the use of resins in grouting and mortar materials has also been widely carried out such as using epoxy resins [21], polyester resin [22], and polymeric resin [23].

2. Experimental Program

In this study using experimental methods through testing in the laboratory, in this section will explain the material used and mix proportion, as well as the testing method used. The variation of material used in this study consisted of three types, namely water and cement grout (WCG), Sodium Silicate and Cement Grout (SSCG), and Resyn Catayst with Fly Ash (RCFA). In this test each type of material uses a different composition, the results of the composition are obtained through trial using the control of slump values. In Table 1 the results are mixed desin separately for WCG, in Table 2 the results of the mix proportion for SSCG and in Table 3 are the results of the mix proportion for RCFA. In each type of grouting there are three variations.

| Variation | Water (ml) | Cement Grout (ml) | Ratio (CG/W) |
|-----------|------------|------------------|--------------|
| A         | 210        | 900              | 1:0.23       |
| B         | 230        | 900              | 1:0.26       |
| C         | 250        | 900              | 1:0.28       |

| Variation | Sodium Silicate (ml) | Cement Grout (ml) | Ratio (SS/CG) |
|-----------|----------------------|------------------|--------------|
| A         | 600                  | 300              | 1:0.50       |
| B         | 600                  | 450              | 1:0.75       |
| C         | 600                  | 600              | 1:1.00       |

| Variation | Resin Catalyst (ml) | Fly Ash (ml) | Ratio (RC/FA) |
|-----------|---------------------|--------------|---------------|
| A         | 200                 | 50           | 1:0.25        |
| B         | 200                 | 70           | 1:0.35        |
| C         | 200                 | 85           | 1:0.43        |

Tests conducted in this study consisted of two parts, namely fresh and hardened properties. In the fresh properties test, it only checks the flow index to ensure that the paste in each series of grouting can flow properly covering the cracks in the concrete. In the hardened condition, testing is done in the form of
water content, absorption, mass density, unit weight and initial rate of suction [24], and compressive strength testing [25]. Compressive strength testing is carried out with a 5 x 5 x 5 cm cube shaped specimen. Testing is done at the age of 7, 14, and 28 days. While the curing done in this study uses water curing [26].

3. Result and Discussion

3.1 Fresh and Mechanical Properties

Fresh properties testing conducted in the form of slump flow can be seen the results in Figure 1. From the results show that the WCG and SSCG experienced an increase in the value of slump, because in this variation the addition of liquid so that the more additions made by all the pasta will become more liquid, whereas in RCFA has decreased workability due to the addition made by the amount of fly ash that is solid so that the material will absorb a lot of water.

![Figure 1. Flow Index](image1)

Mechanical properties testing conducted in this study is shown in Figure 2 to Figure 6. In Figure 2 is the result of the examination of water content. Of the three types of grouting materials, SSCG produces a fairly high water content that is between 20 to 25%, the more cement grout compositions are used, the more water content will be generated, this is because the pores produced are also higher. In the WCG series it produces 5-12% water content, the more the amount of cement grout increases the water content will increase, this is similar to the results of SSCG, while the RCFA series does not produce water content at all, this shows the results of the paste is quite dense and water proof.

![Figure 2. Water Content](image2)

The absorption test results can be seen in Figure 2 where the resulting curve pattern is similar to the results of the water content check, this shows that the absorption with water content has a fairly close relationship. In the RCFA series it does not produce any absorption value, this shows that this type of grouting cannot be absorbed by water. Figure 4 and Figure 5 are the results of mass density and unit weight in each series. The results of mass density and unit weight show the grouting specimen is in normal condition. In Figure 6 is the value of absorption rate that occurs in the paste that has hardened.
The results show that SSCG gets the highest value, this shows that this type of grouting will be very easy and quick to absorb water. Whereas the other two types of pasta are slower. In RCFA it produces an initial rate of suction of 0, thus proving that this type of grouting is truly water resistant so it is suitable for use in exposed structures. From the results of examination of this material it can be concluded that SSCG is not good enough to be applied to the structure, further research is needed to apply this type of grouting in construction.
3.2. Compressive Strength

Compressive strength testing is done at the age of 7, 14, and 28 days. In Figure 7 is the result of compressive strength testing for WCG, the results show that the compressive strength produced at 28 days is quite high at around 58.66 MPa at a composition of 1:0.28. Whereas at composition 1:0.26 produces compressive strength of 46.64 MPa and at composition of 1:0.23 produces compressive strength of 44.42 MPa. These results indicate that the more water used produces better compressive strength, but of course there is an optimum limit of water that can be used to avoid bleeding.
SSCG series compressive strength test results are shown in Figure 8. The results show that the compressive strength obtained is not higher than 7 MPa, the results obtained are quite low compared to other types of grouting. Whereas the type of grouting RCFA produces the highest compressive strength at 28 days compared to other types of grouting. With a composition ratio of 1: 0.25 produces a compressive strength of 115.92 MPa, at a composition ratio of 1: 0.35 produces a compressive strength of 102.27 MPa, and at a ratio of 1: 0.43 produces a compressive strength of 97.98 MPa.

![Figure 9. Compressive Strength for Resin Catalyst Fly Ash Series](image)

4. Conclusion
Based on the experimental results it can be concluded that the use of WCG and RCFA grouting materials is sufficient in terms of fresh and hardened properties including the compressive strength of this type of material can be used to repair cracks in concrete. In the SSCG grouting series, it cannot be used as a repair material for cracks in concrete, the test results show that this type of grouting has a high water absorption rate and low compressive strength, so it will be very possible that the use of this material is not effective enough to repair cracks in concrete. RCFA grouting type produces quite good property values, there is no absorption and compressive strength higher than 100MPa, this grouting type is suitable to be applied to structures exposed to outside weather.

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6. References
[1] S. Jang, J. Kim, S. Kim, W. Park, H. Yun, The Effect of Shrinkage-Compensating on the Performance of Strain Hardening Cement Composite (SHCC), *Sustainability*, Vol 11(1453), pp. 1-14, 2019.
[2] K. Huang, X. Shi, D. Zollinger, M. Mirsayar, A. Wang, L. Mo, Use of MgO Expansion Agent to Compensate Concrete Shrinkage in Jointed Reinforced Concrete Pavement under High-Altitude Environmental Conditions, *Construction and Building Materials*, Vol 202, pp. 528-536, 2019.
[3] N. D. Van, E. Kuroiwa, J. Kim, H. Choi, Y. Hama, Influence of Restrained Condition on Mechanical Properties, Frost Resistance and Carbonation Resistance of Expansive Concrete, *Materials*, Vol 12 (2136), pp. 1-16, 2020
[4] S. I. K. Djaha, H. Prayuda, F. Monika, M. D. Cahyati, F. Saleh, Mechanical Properties of Geopolimer Grout with Bagasse Ash and Resin Catalyst, *Proceedings of the 1st International Conference on Engineering Science and Commerce ICESC 2019*, European Union Digital Library, 2019.
[5] T. Jiang, Q Kong, W. Wang, L. Huo, G. Song, Monitoring of grouting compactness in a post-tensioning tendon duct using piezoceramic transducers. *Sensors*. Vol 16, 2016.

[6] B. J. Jaeger, M. J. Sansalone, R W. Poston, Detecting voids in grouted tendon ducts of post-tensioned concrete structures using the impact-echo method, *Structural Journal*, Vol 93, pp. 462-473, 1996.

[7] A. A. Mohammed, A. C Manalo, G. B Maranan, Y. Zhuge, P. V. Vijay, J. Pettigrew, Behavior of damaged concrete columns repaired with vovel FRP jacket, *Journal of Composites for Construction*, Vol 23, 2019.

[8] A. G. Tsnoos, Seismic repair of exteriors R/C beam to column joints using two-sided and threesided jackets, *Structural Engineering and Mechanics*, Vol 13, pp. 17-34, 2002.

[9] W. Hsu, C. Liu, Y. Shiau, W. Lin, Discussion on the reinforcement of reinforced concrete slab structures. *Sustainability*, Vol 11, 2019.

[10] W. A. Thanoon, M. S. Jaafar, M. R. A. Kadir, J. Noorzaei, Repair and Structural Performance of Initiality cracked reinforced concrete slabs, *Construction and Building Materials*, Vol 19, pp. 595-603, 2005.

[11] M. Z. Jumaat, M. H. Kabir, M. Obaydullah, A review of the repair of reinforced concrete beams. *Journal of Applied Science Research*, Vol. 2, pp. 317-326, 2006.

[12] F. Hngyuan, W. Fuming, W. Yuke, C. Can, The mechanical behaviour of drainage pipeline under traffic load before and after polymer grouting trenchless repairing, *Tunnelling and Underground Space Technology*, Vol 74, pp. 185-194, 2018.

[13] R. Wang, F. Wang, J. Xu, Y. Zhong, S. Li, Full-scale experimental study of the dynamic performance of buried drainage pipes under polymer grouting trenchless rehabilitation, *Ocean Engineering*, Vol 181, pp. 121-133, 2019.

[14] T. Chen, Z. Li, X Wang, G. Yang, J. Liu, Experimental study on the ultimate bending performance of grouted connections in offshore wind turbine support structures, *Thin-Walled Structures*, Vol 132, pp. 522-536, 2018.

[15] T. Chen, Z. Li, X. Wang, X. Gu, Q. Zhao, G. Yuan, J. Liu, Axial compression tests of grouted connections in jacket and monopile offshore wind turbine structures, *Engineering Structures*, Vol 196, pp. 1-19, 2019.

[16] V. Sata, A. Sathomsaowaphak, P. Chindaprasirt, Resistance of lignite bottom ash geopolymer mortar to sulfate and sulfuric acid attack, *Cement and Concrete Composites*, Vol. 34, pp. 700-708, 2012.

[17] F. Saleh, H. Prayuda, F. Monika, M. M. A. Pratama, Characteristics Comparison on Mechanical Properties of Mortars using Agriculture Waste as a Cement Replacement Materials, *IOP Conference Series: Materials Science and Engineering*, Vol. 650, 2019.

[18] T. Phoo-ngernkham, V. Sata, S. Hanjitsuwan, C. Ridturud, S. Hatanaka, P. Chindaprasirt, High calcium fly ash geopolymer mortar containing portland cement for use as a repair material, *Construction and Building Materials*, Vol 98, pp. 482-488, 2015.

[19] A. Naghizadeh, S. O. Ekolu, Method for comprehensive mix design of fly ash geopolymer mortars, *Construction and Building Materials*, Vol 202, pp. 704-717, 2019.

[20] D. Adak, M. Sarkar, S. Mandal, Effect of nano-silica on strength and durability of fly ash-based geopolymer mortar. *Construction and Building Materials*, Vol. 70, pp. 453-459, 2014.

[21] F. Colangelo, G. Roviello, L. Ricciotti, C. Ferone, R. Cioffi, Preparation and Characterization of New Geopolymer epoxy resin hybrid mortars, *Materials*. Vol 6, 2989-3006, 2013.

[22] P. Mani, A. K. Gupta, S. Krishnamoorthy, Comparative study of epoxy and polyester resin-based polymer concretes, *International Journal Adhesion and Adhesives*, Vol 7, pp. 157-163, 1987.

[23] J. M. M. Vidales, L. N. Hernandez, J. I. T. Lopes, E. E. M. Flores, L. S. Hernandez, Polymer mortars prepared using a polymeric resin and particles obtained from waste pet bottle, *Construction and Building Materials*, Vol 65, pp. 376-383, 2014.

[24] ASTM International, ASTM C642: *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*, West Conshohocken, PA, 1997.

[25] ASTM International. ASTM C109: *Standard Test Method for Compressive Strength of Hydraulic
[26] ACI Committee: *ACI 308R-01: Guide to curing concrete*, American Concrete Institute, Farmington Hills, 2008.

*Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)*, West Conshohocken, PA, 1999.