Mechanical properties of nanogrout as advanced material for construction

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Abstract. Recent development in construction industry requires new materials with higher mechanical properties. Therefore, it is necessary to develop grout materials using materials at nano scale. The purpose of this study is to determine the optimal content of nanosilica in grout material. Initial mix was given code G0. Then the nanosilica was added with 1% content (code G1), 2% content (G2), 3% (G3), and finally 5% nanosilica content (G5). Compressive strength tests were carried out when the grout was aged 1, 3, 7, and 28 days. Whereas flexural strength test was carried out at 28 days. The result finding showed that the optimal nanosilica content was at 3% (G3), significantly improved compressive strength 24.6%, tensile strength 20.9% and flexural strength 25.6%. The contribution of this research is to introduce nanogrout as an advanced material, to overcome the challenges of increasingly complex construction work in the future.

1. Introduction
Grout material is used for structural repairs, honeycomb, spalling on columns, beams and precast concrete. In addition, grout material is widely used for bearing pads on bridge structures, machine foundations. The advantage of grout material is that it has high compressive strength, non-shrinkage, resistant to vibration and non-corrosive. Previous research has shown that grout material has resistance to acids, can be used to repair holes in underground buildings [1,2].

Grout material can be used as injection material for repair work on damaged buildings. In many cases concrete injection using grout will fill existing cavities [3]. Grout material can be produced by mixing 3% silica fume, 10-30% fly ash and 40% slag instead of cement [4]. Research on the effects of nanosilica use by comparing two types of nanosilica, which are in the form of powder and colloidal to the mechanical properties of concrete, the results show that nanosilica powder is more effective in improving the mechanical properties of cement mortar [5]. Then the addition of 5% colloidal nanosilica and 40% Fly ash, significantly improved the hardening process and increased the compressive strength of the cement paste [6]. The definition of nanogrout is a grout material added with nanosilica. This study carries out an analysis of the mechanical properties of nanogrount as advanced material for construction.

2. Methodology
The grout material used is a ready-mix material produced by John Hi-Tech Contrindo, and nanosilica HDKN 20, with grain sizes of 20-40 nm, produced by Bratachem.
Figure 1. (a) Nanosilica HDKN 20 (b) Results of XRD HDKN 20.

Specimens and testing in this study can be shown in Table 1, G0 is grout material without nanosilica as reference grout, G1 is grout material plus 1% nanosilica from grout weight, G2 is added 2%, G3 (3%) and G5 (5%).

| Code | Compressive strength and Tensile strength test | Flexural Strength |
|------|-----------------------------------------------|-------------------|
|      | 1 day | 3 day | 7 day | 28 day | 28 day |
| G0   | ✓     | ✓     | ✓     | ✓      | ✓      |
| G1   | ✓     | ✓     | ✓     | ✓      | ✓      |
| G2   | ✓     | ✓     | ✓     | ✓      | ✓      |
| G3   | ✓     | ✓     | ✓     | ✓      | ✓      |
| G5   | ✓     | ✓     | ✓     | ✓      | ✓      |

Then in the specimen the compressive strength, tensile strength and flexural test were carried out as shown in Figure 2. Compressive strength testing was carried out in accordance with ASTM C109/C109M and tensile strength is termed ASTM C496 / C496M [7,8]. The compressive strength testing of the specimen was carried out in a cube which has 50 mm x 50 mm x 50 mm. The compressive and tensile strength tests were performed at concrete ages 1, 3, 7 and 28 days. Flexural testing accordance with ASTM C78/C78-18, specimen of beam: 150 mm x 150 mm x 600 mm, tested at 28 days.

Figure 2. (a) Compressive strength (b) tensile strength (c) flexural strength.
3. Results and discussion

3.1. Compressive strength

Figure 3 reveals the value of concrete compressive strength at the ages of 1, 3, 7 and 28 days. At the age of 1 days, specimen G1, G2 and G3 there was an increase in compressive strength of 14%, 0%, 6% and 23%. While in the G3 there was a decrease of 29%. At the age of 3 and 7 days G1, G2 and G3 significantly, showed an increase in compressive strength, but at G5 there was a decrease in compressive strength.

Figure 3. Result of compressive strength.

At the age of 28 days the G1 specimen has an increase in compressive strength of 16.6%, in G2 by 1.5% and G3 by 24.6%. However, in G5 there was a decline of 22%. Addition of nanosilica with a percentage of 1%, 2% and 3% can increase the compressive strength of G1, G2 and G3. This is due to the pozzolanic activity of nanosilica was very high, which increased the amount of C-S-H and resulted in higher densification of matrix, improving the strength and make the interfacial transition zone become denser [9,10]. Whereas in G5 there was a decrease in compressive strength, because the addition of nanosilica with a percentage of 5% occurred the effect of agglomeration. As a result, nanosilica cannot be dispersed with a cement matrix so that pores and concrete are not homogeneous, this is in line with previous studies [11,12].

3.2. Tensile strength

The results of tensile strength tests are shown in Fig. 4. There are both increasing a decreasing trend in mechanical properties by changing the amounts of nanosilica the concrete tensile strengths of G1 and G3 in the age of 1 days there was an increase in tensile strength of 5.1% and 18.8%, while in G2 and G5 there was a decrease of 2.5% and 10.2%. At 3 days the tensile strength of the G1 and G3 increased by 4% and 8.4%, but at G2 and G5 there was a decline of 14.7% and 21.4%.

At 28 days the tensile strength in G3 has increased the tensile strength, an increase of 20.9%, in G1, G2 and G5 there has been a decrease of 10.3%, 19.55 and 15%. In general, based on the ACI formula for tensile strength of concrete was 0.5\(\sqrt{f_{c}}\), the G3 tensile strength is 3.65 MPa. While the tensile strength test results are 21.05 MPa. The increase in the dosage of nanosilica led to increasing the values of tensile strength at the age of 28 days [13]. Nanosilica provides a polarizing effect from this material, where the
material reacts with portlandite (calcium hydroxide) produced during the hydration process and converts it to C-S-H. In addition, nanosilica is tightly bound to the C-S-H gel by acting as a nucleus [14,15].

The results of the grout tensile strength test showed a higher increase than if using the ACI formula, thus the ACI formula for the concrete is not suitable for use in nanogrout.

3.3. Flexural test
The results of tensile strength tests are shown in Fig. 5. The flexural strengths of G1 and G3 in the age of 28 day an increase of 0.2% and 25.6 %. At G2 and G5 there was a decline of 23.8% and 61.8%. The improvements in flexural strength, because NS creates high numbers of nucleation sites through a seeding effect, precipitating cement hydration products thanks to extremely fine particle size [16]. NS acts as a reactive filler, reduces bleeding rates and increases packing of solid material particles by occupying space between OPC, sand and other materials, so as to increase flexural strength, this is in line with previous research [17].

Based on ACI-318M-05 [18], for concrete flexural strength of $0.62\sqrt{f'}c$ and other researchers [19], flexural strength is $0.75 \sqrt{f'}c$, then the value of flexural strength is 4.53 MPa and 5.5 MPa. While the test results on the G3 is 5.39, this result according to the existing formula thus flexural strength for concrete can be used in nanogrout.

![Tensile Strength (MPa)](image)

**Figure 4.** Result of tensile strength.
4. Conclusion
The percentage of optimal addition of nanosilica is 3% can increase the mechanical properties of 24.6% compressive strength, 20.9% tensile strength and 25.6% flexural strength. So that nanogrout can be a material for future construction.

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Figure 5. Result of flexural strength.
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