



Plagiarism Checker X Originality Report

Similarity Found: 11%

Date: Friday, April 28, 2023

Statistics: 312 words Plagiarized / 2730 Total words

Remarks: Low Plagiarism Detected - Your Document needs Optional Improvement.

Mechanical Properties of Cement Concrete Composites Containing Nano-Metakaolin
Steve Wilben Macquarie Supit^{1, a)}, Rilya Rumbayan^{1, b)} and Adriana Ticoalu^{2, c)} ¹Senior Lecturer, Manado State Polytechnic, Department of Civil Engineering, North Sulawesi, Manado, Indonesia. ² Senior Lecturer, Sam Ratulangi University, Department of Civil Engineering, North Sulawesi, Manado, Indonesia. a) Corresponding author: steviewmsupit@gmail.com <mailto:steviewmsupit@gmail.com> b) rilya.rumbayan@gmail.com <mailto:rilya.rumbayan@gmail.com> c) adriana.ticoalu@gmail.com <mailto:adriana.ticoalu@gmail.com> Abstract. The use of nano materials in building construction has been recognized because of its high specific surface area, very small particle sizes and more amorphous nature of particles.

These characteristics lead to increase the mechanical properties and durability of cement concrete composites. Metakaolin is one of the supplementary cementitious materials that has been used to replace cement in concrete. Therefore, it is interesting to investigate the effectiveness of metakaolin (in nano scale) in improving the mechanical properties including compressive strength, tensile strength and flexural strength of cement concretes. In this experiment, metakaolin was pulverized by using High Energy Milling before adding to the concrete mixes. The pozzolan Portland cement was replaced with 5% and 10% nano-metakaolin (by wt.).

The result shows that the optimum amount of nano-metakaolin in cement concrete mixes is 10% (by wt.). The improvement in compressive strength is approximately 123% at 3 days, 85% at 7 days and 53% at 28 days, respectively. The tensile and flexural strength results also showed the influence of adding 10% nano-metakaolin (NK-10) in improving the properties of cement concrete (NK-0). Furthermore, the Backscattered Electron images and X-Ray Diffraction analysis were evaluated to support the above

findings.

The results analysis confirm the pores modification due to nano-metakaolin addition, the consumption of calcium hydroxide (CH) and the formation of Calcium Silicate Hydrate (CSH) gel as one of the beneficial effects of amorphous nano-metakaolin in improving the mechanical properties and densification of microstructure of mortar and concrete. INTRODUCTION Development of nano technology has brought many ideas in construction industry to study the properties of cement-pozzolan concrete due to the addition of nanoparticles.

Nano materials refer to materials with nano scale dimension containing nano-sized particles. The dimension of materials ranged from 100 nm down to approximately 0.1nm. This characteristic can increase surface area (per unit mass) and result in a corresponding increase in chemical reactivity [1]. As the strength of mortar and concrete is based on its nanometer size crystal structure, the usage of nano materials as additives has provided a unique opportunity for the improvement of cement-based materials.

One of the advancements made is the discovery that addition of nano-metakaolin can improve the mechanical properties of mortar and concrete. Kaolin is white, soft, plastic clay and mainly composed of the fine-grained plate. It is a unique industrial mineral, which remains chemically inert over a relatively pH range and it offers excellent covering when used as a pigment and filling applications. Metakaolin is obtained by heating kaolin (an industrial mineral referred to as "China Clay") to between 600°C and 800°C.

In cement concrete matrix, metakaolin reacts with calcium hydroxide (CH) and produces Calcium Silicate Hydrate (CSH), Calcium Aluminate Hydrates (CAH13 and C3AH6) and hydrated gehlenite (CsASH8). Some works demonstrated that metakaolin (in micro size) is a very effective pozzolan in enhancing early strength [2], and some improvement in the long-term strength [3]. Moreover, metakaolin has been shown to provide benefits in improving the resistance of cement composites due to some durability properties such as sulfate attack and chloride penetration [4, 5].

Because of its highly disorganized structure, Proceedings of the 3rd International Conference on Construction and Building Engineering (ICONBUILD) 2017 AIP Conf. Proc. 1903, 050001-1-050001-6; <https://doi.org/10.1063/1.5011540> Published by AIP Publishing. 978-0-7354-1591-1/\$30.00 metakaolin reacts very rapidly with the CH produced during the hydration of Portland cement, improves the microstructure and the formation of Calcium Silicate Hydrate (CSH) gel [6]. There are some studies that have been conducted to investigate the effect of incorporating metakaolin (in nano size) to mortar and concrete on enhancing its properties.

From some conducted experiments, Morsy [7], reported the increase of compressive and tensile strength of cement mortars was 49% and 8%, respectively, due to the addition of 8% nano-metakaolin. It was also reported that nano-metakaolin acts as a nano-fiber due to its morphology, and also an activator in promoting hydration process. In cement concrete, it was found that the 28th day compressive strength increased around 30% at 10% replacement of cement with nano-metakaolin [8]. Significant improvement was also observed in this study on the split tensile strength results.

However, care should be taken in proportioning the replacement ratio of cement with nano-metakaolin since higher replacement ratio promotes the agglomeration of nano-metakaolin around the cement grain that can hinder the hydration process and effects the improvement of strength [9]. Recently, the utilization of nano-metakaolin as an additive in ultra-high performance concrete is reported by Norhasri [10]. They found that the filling effect of nano-metakaolin particles contributed the strength development at 3-7 days and the pozzolanic reaction that started at 14 days of age.

It was also observed that the compressive strength of the nano-metakaolin specimen was increased and showed a better strength compared to the Ordinary Portland Cement and micro-metakaolin concrete samples. A Similar observation was also reported by Fadzil [11]. In another study, the effectiveness of nano-metakaolin was found more beneficial as mineral additives in improving the microstructure and flexural strength of fiber reinforced cementitious composites [12].

Moreover, it also influences the initial crack, ultimate load, maximum deflection and toughness of reinforced concrete beams [13]. The previous study also found that the CH content of cement paste with 10% nano-metakaolin decreased to 42% due to the pozzolanic activity of nano-metakaolin and relatively remained constant when the nano-metakaolin replacement ratio was higher than 10%. While some research works reported the advantages of metakaolin in improving the properties of cement mortar and concrete, very fewer reports are available on microstructural analysis of cement composites containing nano-metakaolin.

Therefore, it is important to validate and evaluate the mechanical properties and microstructural analysis of cement composites containing nano-metakaolin, with a particular focus on the nano-metakaolin sourced from Toraget Village, Minahasa Region, Indonesia. The outcome of the experimental results will also give better understanding on nano-metakaolin production using High Energy Milling for potential development on the future research. Furthermore, the objective of this research is to investigate the effect of nano-metakaolin from Toraget Village as partial substitution of

Portland composite cement to the mechanical properties of concrete including compressive strength, tensile strength, and flexural strength. The microstructural analysis and phase identification of cement paste containing nano-metakaolin such as Backscattered Electron images and X-Ray Diffraction was also conducted to support the findings.

EXPERIMENTAL DETAILS Materials Portland Composite Cement (PCC), manufactured by PT. Semen Tonasa and Nano Metakaolin, denoted by PC and NK, respectively, were used as main materials in all mixes. Kaolin was obtained from Toraget Village, Minahasa Region in North Sulawesi Province. It was sun/air dried for about 8 hours and then the sample was dried in the oven at 110°C for 24 hours. After drying, the lumped kaolin clay was milled and later it was sieved using stainless steel sieve with No.100 openings. Afterwards, it was calcined in an incinerator at 800°C with constant temperature for 6 hours.

The metakaolin was then pulverized to nano size by using High Energy Milling instrument at CV. Nanotech Indonesia. The characteristics of nano-metakaolin from Toraget Village based on X-Ray Diffraction (XRD) analysis is shown in Fig. 1. It indicates that nano-metakaolin is amorphous material and is relatively less crystal with the SiO₂ content in nano-metakaolin is more than in micro-metakaolin hence makes a good synthetic pozzolan. **FIGURE 1.** X-Ray diffraction of nano-metakaolin Mixture proportions The mixture proportions were prepared as shown in Table 1. The water-cement ratio used was 0.4.

In concrete mixes, cement was replaced by nano-metakaolin at the percentage of 5% (NK-5) and 10% (NK-10), respectively. The compressive strength, tensile strength and flexural strength tests of concrete samples were conducted after water curing at 7 and 28 days. Superplasticizer was used to maintain the consistency and workability of concrete mixes where the dosage was calculated as a percentage by mass of total binders.

The mineralogical and microstructural characteristics of cement paste with nano-metakaolin were studied by means of Backscattered electron image (BSE) and X-Ray Diffraction (XRD). **TABLE 1.** Mixture proportions of cement concrete with different percentage of nano-metakaolin (kg/m³).
Materials PC NK-5 NK-10 PC 553 526 498
Nano-Metakaolin 0 27 55 Fine Aggregate 565 565 565 Coarse Aggregate 976 976 976
Water 223 223 223 Methods All concrete samples were mixed in a concrete mixer using water to binder ratio of 0.4.

The compressive strengths of concrete were determined according to ASTM C39 [14]

while tensile and flexural strengths were determined based on ASTM C496 [15] and ASTM C293 [16], respectively. The microstructure analysis and phases identification of cement pastes with nano-metakaolin were investigated through BSE Image and XRD analysis. EXPERIMENTAL RESULTS Effect of Nano-Metakaolin on Compressive Strength of Cement Concrete The compressive strength of cement concrete mixtures containing nano-metakaolin after 7 and 28 days is presented in Fig. 2.

It can be noticed from the results that adding nano-metakaolin to cement concrete mixtures enhances the resistance to the compression load. According to the results, the optimum dosage of NK in concrete mixes is 10% by weight of cement content, reaching the value of 29, 37 and 46 MPa at 3, 7, 28 days, respectively. The improvement in compressive strength in cement concrete with 10% NK is about 123% at 3 days, 85% at 7 days and 53% at 28 days, which indicates the positive influence of nano-metakaolin in enhancing the early-age compressive strengths of cement concrete.

The experimental result from Aiswarya [8] and Abo-El-Enein [17] also reported the beneficial effect of replacing cement with 10% nano-metakaolin in normal cement concrete. The beneficial effects of nano-metakaolin are suggested due to the physical filler characteristics of nano-metakaolin its self, and also the pozzolanic reaction between nano-metakaolin and the free calcium hydroxide liberated during cement hydration, which produces additional calcium silicate hydrate (CSH). FIGURE 2.

Compressive strength of cement concrete containing nano-metakaolin at 3, 7 and 28 days Effect of Nano-Metakaolin on Tensile and Flexural Strength of Cement Concrete Result in Table 2 shows the tensile strength and flexural strength of cement concrete with 10% nano-metakaolin at 7 days and 28 days. It can be seen that the addition of nano-metakaolin improves the tensile strength of cement concrete from 3.8 MPa to 4.6 MPa at 7 days and 4.2 to 4.7 MPa at 28 days, which are approximately 21% and 11% higher. A similar observation can also be seen in the flexural strength results were the addition of 10% nano- metakaolin shows a positive influence in increasing the modulus of rupture of cement concrete.

The improvement is about 15% at 7 days compared to the flexural strength of cement concrete without nano-metakaolin. However, there is no significant improvement was observed after 28 days. In a separate study, Sithara [18] also reported an increase of flexural strength (about 8%-28%) in the range of 5-10% nano-metakaolin. TABLE 2. Tensile and flexural strength results of concrete at 7 and 28 days. Materials Tensile strength (MPa) Flexural strength (MPa) Microstructure Analysis and Phase Identification Backscattered Electron Image The backscattered electron images are used to identify the constituent phases within cement paste based on their brightness.

The brightest (or white) parts can be classified as un-hydrated cement particles, the dark (or black) parts as voids and cracks and grey to dark grey parts can be classified in the order of CH, other hydration products, and C-S-H. Based on the image in Fig. 3, it can be seen that after 28 days of water curing almost all hydration products in cement paste containing 10% nano-metakaolin are mainly composed of amorphous and gel with low degrees of crystallinity which fill a major part of the total pore system while many white and black areas in cement paste sample indicating the un-hydrated cement particle and voids, respectively.

The results confirm that the microstructure of NK-10 paste is more uniform and denser than the microstructure of cement paste only. Additionally, the replacement of Portland composite cement with 10% nano-metakaolin was found to affect the hydration reaction and led to lesser capillary pores of the hardened pastes. (a) (b) FIGURE 3. Backscattered electron image of: (a) PC and (b) NK-10 specimens at 28 days X-Ray Diffraction The reactions during cement hydration at 7 and 28 days are studied through X-Ray Diffraction analysis.

On the XRD scale, the CH has a strong peak located at a 2-theta angle of 18.18° and 34.24° . The CH peak was considered to be the main indicator of performance in cement paste samples. The amount of CH that was analyzed through XRD patterns could be used to determine the CSH concentration indirectly. From Fig. 4, it can be seen that at 7 and 28 days the intensity of CH peaks in cement paste containing 10% NK was decreased compared to the intensity in cement paste without NK. The significant reduction can be seen in Fig. 4(a) at 2-theta angle of 18.18° and 34.24° where the intensity of CH in cement paste at 7 days decreased from approximately 225 to 60 counts and 320 to 100 counts, respectively.

The same trend was also shown in cement pastes at 28 days, where the addition of 10% NK decreased the intensity of CH at 2-theta angle of 18.18° and 34.24° from 260 to 80 and 250 to 90, respectively (see Fig. 4(b)). As a product of cement hydration, CH reacts with silica in the supplementary cementing system and forms CSH resulting in improved mechanical properties of mortar and concrete. These results also correspond to the compressive strength values measured at 7 and 28 days, where the addition of 10% NK in cement mortar and concrete obtained highest compressive strength. (a) (b) FIGURE 4.

X-Ray Diffraction analysis on cement paste with and without 10% nano-metakaolin.

CONCLUSIONS Based on the experimental study, the following conclusions are made: · The usage of nano-metakaolin in cement concrete composites was effective in increasing the compressive strength of samples tested at 3, 7 and 28 days. The highest

compressive strength was achieved by concrete containing 10% nano-metakaolin (by wt.). The results from tensile and flexural tests of samples containing nano-metakaolin at 7-day curing age demonstrate 21% and 15% improvement, respectively.

However, there is no significant improvement was observed after 28 days. The BSE and XRD analysis confirm denser microstructure and the formation of more CSH product during hydration reaction of cement paste containing 10% nano-metakaolin.

ACKNOWLEDGEMENTS The authors would like to acknowledge the financial support for this research from INSINAS 2016-2017 Fund, DIKTI, and CV. Nanotech Indonesia for nano-metakaolin production.

REFERENCES 1. J. Carmichael and P. Arulraj, ESTIJ, 2(1), 158-162 (2012). 2. C.S. Poon, L. Lam, S.C. Kou, Y.L. Wong, and Ron Wong, Cement and Concrete Research <[https://doi.org/10.1016/S0008-8846\(01\)00581-6](https://doi.org/10.1016/S0008-8846(01)00581-6)>, 31(9), 1301-1306 (2001). 3. P. Dinakar, O.K. Sahoo, and G. Sriram, Int. J. Conc.

Struc. Mat. <<https://doi.org/10.1007/s40069-013-0045-0>>, 7(3), 215-223 (2013). 4.

Al-Akhras, M.Nabil. Cement and Concrete Research

<<https://doi.org/10.1016/j.cemconres.2006.03.026>>, 36(9), 1727-1734 (2006). 5. E.

Badogiannis, E.Aggeli, V.G. Papadakis, S. Tsvivilis, **Cement and Concrete Composites**

<<https://doi.org/10.1016/j.cemconcomp.2015.07.012>>, 63, 1-7 (2015). 6. S. Supit, R.

Rumbayan, and A. Ticoalu, IJMAS, 3(5), 76-80 (2016). 7. M.S. Morsy, S.H. Alsayed, and M.

Aqel, IJCEE-IJENS, 10(1), 23-27 (2010). 8. S. Aiswarya, P. Arulraj and A. Narendran, ESTIJ,

3(1), 180-187 (2013). 9. M. S. Morsy, Y. A. Al-Salloum, H. Abbas and S. H. Alsayed,

Construction and Building Materials

<<https://doi.org/10.1016/j.conbuildmat.2012.04.099>>, 35, 900-905 (2012). 10. M. S. M.

Norhasri, M. S. Hamidah and A. M. Fadzil and O. Megawati, **Construction and Building**

Materials <<https://doi.org/10.1016/j.conbuildmat.2016.09.127>>, 127, 167-175 (2016). 11.

A. M. Fadzil, M. S. M. Norhasri, M. S.

Hamidah, M. R. Zaidi and J. M. Faizal, Proceedings of the International Civil &

Infrastructure Engineering Conference, Springer Science-Business Media, Singapore,

2013, pp. 887- 894. 12. H. Shoukry, M. F. Kotkata, S. A. Abo-el-Enein, and M. S. Morsy,

Construction and Building Materials

<<https://doi.org/10.1016/j.conbuildmat.2013.02.030>>, 43, 453- 460 (2013). 13. Lotfy, E.M

and Abdelshakor M, IJLTET, 8(2), 231-240 (2017). 14. ASTM C39, Standard Test Method

for Compressive Strength of Cylindrical Concrete Specimen. ASTM International, West

Conshohocken, PA, 2017. 15. ASTM C496, Standard Test Method for Splitting Tensile

Strength of Cylindrical Concrete Specimen.

ASTM International, West Conshohocken, PA, 2004. 16. ASTM C293. Standard Test

Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point

Loading). ASTM International, West Conshohocken, PA, 2016. 17. S. A. Abo-El-Enein, M. S. Amin, F. I. El-Hosiny, S. Hanafi, T. M. Elsokkary and M. M. Hazem, HBRC Journal <<https://doi.org/10.1016/j.hbrj.2013.09.006>>, 10(1), 64-72 (2014). A. Sithara and A. D. Sunitha, IJESIRD, 3(3), 156-163 (2016).

INTERNET SOURCES:

3% -

https://www.academia.edu/58502004/Mechanical_properties_of_cement_concrete_composites_containing_nano_metakaolin

1% - <https://aip.scitation.org/doi/10.1063/1.5011540>

<1% -

https://www.researchgate.net/figure/Backscattered-electron-images-and-corresponding-elemental-X-ray-maps-of-the-contact_fig3_320590745

1% -

https://www.researchgate.net/publication/281498432_Evaluation_of_chloride-penetration_resistance_of_metakaolin_concrete_by_means_of_a_diffusion_-_Binding_model_and_of_the_k-value_concept

5% - <https://aip.scitation.org/doi/pdf/10.1063/1.5011540>

<1% -

<http://download.garuda.kemdikbud.go.id/article.php?article=3008652&val=27192&title=Analysis%20of%20The%20Factors%20Affecting%20Tourist%20Visits%20in%20Minahas%20District>

<1% -

https://www.researchgate.net/figure/FTIR-spectra-of-the-phase-pure-C-S-H-and-the-C-S-H-ABA-systems_fig2_282999770

<1% - https://scholar.google.com/citations?user=iY_LBjAAAAAJ

<1% -

<https://www.sciencedirect.com/journal/construction-and-building-materials/vol/157>