THE EFFECT OF VOLUME VARIATION OF SILVER NANOPARTICLE SOLUTION TOWARDS THE POROSITY AND COMPRESSIVE STRENGTH OF MORTAR

H.S.A Tina, A. Andreyani and W.S.B. Dwandaru*

Jurusan Pendidikan Fisika, Fakultas MIPA, Universitas Negeri Yogyakarta

*email: wipsarian@gmail.com

Diterima 5 August 2016 disetujui 5 September 2016

Abstract

As the world is growing rapidly, people need better building materials such as mortar. The aim of this research is to determine the effect of adding silver nanoparticle solution towards the porosity and compressive strength of mortar. This research was started by making silver nanoparticle solution from nitrate silver ($AgNO_3$). The solution is then characterized using Uv-Vis spectrophotometer. 5 mM silver nanoparticle is added in the process of mortar production with volume variation of the silver nanoparticle solution. The porosity, compressive strength, and the content of mortar were determined by digital scale, universal testing machine, and X-ray diffraction, respectively. For silver nanoparticle solution volumes of (in mL) 0, 5, 10, 15, 20, and 25 the porosity obtained are (in %) 20.38, 19.48, 19.42, 18.9, 17.8, and 17.5, respectively. The best increase in compressive strength is obtained for (in MPa) 29,068, 29,308, and 31,385, with nanoparticle solution volumes of (in mL) 5, 10, and 15

Keywords: mortar, silver nanoparticle, compressive strength

Introduction

The growth and development of construction industry in Indonesia such as roads, buildings, and bridges are rapid. This development, certainly, demands a better quality of infrastructures. However, there are many buildings that are easily broken because of some problems such as natural disasters and low quality of the materials that are not strong enough to endure some pressure caused by environment interferences. The quality of a material can be determined from mixed-materials in which the building material is made from, treatments and the additive materials or additional materials that are added to the building material such as mortar. In addition, the amount of water also gives a big influence to the physical endurance such as the porosity and compressive strength.

Timuranto (2001) in Tjokrodimuljo examined the relation between mortar's strength and water reservation. The lower the water reservation means the less mortar's pores so that its strength is greater. The relation between mortar's strength, porosity, and density is influenced by the amount of cement (the ratio of cement and sand) and the factor of cement-water that are added to the mortar.

One of the ways to increase the strength of the mortar is by adding additional materials to the mortar in the mixing process. The functions of the additional material are to change some characters of the mortar to be more compatible for certain works and to lessen the expense so that the strength of the mortar can be increased and can be used for making a firm and strong building.

Mortar is a building material that is frequently used by people. The application of mortar is mostly in the building construction as an adhesive between the stones, walls, and concretes. Mortar is the mixing between cement, sand, and water with ratio of 1 : 2.75 : 0.5, respectively, in which the cement is the main adhesive. The correct portion or ratio of the materials is really important because it has a big influence toward the mortar's porosity and strength.

Porosity is a measure of empty space between materials. Moreover, it is also considered as the fraction of empty space (volume) that has a value between 0 and 1 or as the percentage between 0 and 100%. The aim of the porosity observation is to measure the empty space of the tested material. The bigger the porosity of the tested material means the less the strength and vice versa. Porosity examination is conducted to test the mortar's water absorbance by soaking the mortar for 7 days. The porosity can be determined using the following formula,

$$\% = \frac{m_b - m_k}{V_b} \times \frac{1}{\rho_{water}} \times 100\% \quad (1)$$

where m_b is the wet weight of the tested material (gram), m_k is the dry weight of the tested material (gram), V_b is the volume of the tested material (cm^3), and ρ_{water} is the density of the water (1 gr/cm^3).

One of the ways to control the quality of mortar is by examining the sample or the tested material. The strength of the mortar can be defined as the comparison between the weight and the width of the mortar. One of the indicators of a good mortar is if it has high strength. Generally, the strength of a cement mortar is between 3 – 17 MPa. Wancik et. al. (2008) researched the cement mortar in a styrofoam with the proportion of the mixed-mortar volume of 1 : 15 and the number of cement-water factor of 0.4 which consists of 2.4 mm sifted sands and 1.5% viscocrete of the weight of the cement in order to make the production easier. The result finds that the 5 tested cube materials sized 5 cm x 5 cm x 5 cm produced an average strength of 79.01 MPa. Yulianingsih in Tjokrodimuljo (2004) examined the characteristics of cement mortar made from rough sand with different portion of the mixture volume. The result shows that the ratio of the mixture volume influences the pressing strength, pulling strength, water absorbance, and the density of the cement mortar. The mortar compressive strength can be found through the following formula,

$$f'_c = \frac{F}{A} \quad (2)$$

with f'_c is the compressive strength (MPa), F is the maximum weight (N), and A is the surface area (m^2).

Admixture is defined in standard deviation of terminology relating to concrete and concrete Aggregates (ASTM C.125-1999: 61) and in cement and concrete terminology (ACI SP-19) as a material beside water, aggregate, and hydraulic that are mixed with concrete and mortar. The additional materials are used to modify the characteristics of the concrete or mortar for example to make it more efficient to be used or for other purposes like energy saving (Mulyono, 2003: 117).

In order to increase the quality of the material, nanotechnology can be applied. Adding nanoparticle to mortar may decrease the porosity and increase the compressive strength of mortar. One application of nanotechnology in building material is specifically to strengthen mortar by using nanoparticle. According to Pacheco (2010), nanotechnology and nanomaterial can be used by construction industry. It covers nanoscale analysis of Portland cement hydration products, the use of nanoparticles to increase the strength and durability of cement composites, and the photocatalytic capacity of nanomaterials. Tanvir (2010) said that the development of nanotechnology for cement and concrete has particular importance. The cement hydration chemistry and the physical behavior of hydration products may be potentially manipulated through nanotechnology. The main objective of the development of cement-related nanotechnology is to produce stronger, tougher, lighter, and more durable products.

The definitions of nanotechnology, including nanoscience and nanoengineering in concrete, are provided by Florence (2010). Recent progress in nano-engineering and nanomodification of cement based materials is presented. The development in nanoscience can also have a great impact on the field of construction materials. Portland cement, one of the largest commodities consumed by the public, is obviously a good product, but the potential is not completely explored. Better understanding and engineering of complex structure of cement-based materials at nanolevel will definitely introduce a new generation of concrete, which is stronger and more durable, with desired stress strain behavior and, possibly, with the whole range of newly introduced ‘smart’ properties (Sobolev, 2008).

Mechanochemical activation was found to be an effective method to improve the strength of cement-based materials. It was proposed that this process is governed by the solid state interaction between the organic modifiers and cement. During this process, the surface of cement particles attaches the functional groups introduced from the modifiers; so the organo-mineral nano-layers are formed on the surface of the cement.

One of the products of nanotechnology is silver nanoparticle. This research is conducted to determine the influence of silver nanoparticle solution toward mortar’s porosity and compressive strength. Some benefits of using silver nanoparticle are the low cost and relatively easy to be made and to be applied. Nanoparticle is soluble with other materials and eco-friendly. Accroding to Kim (2010) Ag_2S crystal nanoparticles are in the size range of 5−20 nm with ellipsoidal shape, and they form very small, loosely packed aggregates. Some of the Ag_2S nanoparticles (NPs) have excess S on the surface of the sulfide minerals under S-rich environments. This study suggests that in a reduced, S-rich environment, such as the sedimentation processes during wastewater treatment, silver nanoparticle sulfides are being formed.

Research Method

Research materials. The materials that were used in this research are Portland cement type I, smooth aggregate (from Mount Merapi sand), water, and 5 mM silver nanoparticle solution.

Research instrumens. The research instruments used are given as follows: heater, 500 ml chemical glass, 250 ml measuring cup, pipette, solution stirrer, thermometer, test tube, test tube clamp, hand gloves, *laser pointer*, digital scale, scale, stirring shovel, tin plate, tin basin, cup for stirring cement, mortar solidifying iron, sand sifter 1.18 mm mesh on 16, mortar molding box 5 cm x 5 cm x 5 cm, pail, oven, ultimate testing machine.

Research procedures. Making 5 mM silver nanoparticle solution by 5 mM nanoparticle solution is produced by the following procedure. The solution of $AgNO_3$ is made by dissolving $AgNO_3$ powder in water. In order to get $AgNO_3$ solution with concentration of 5 mM, a formula is applied which gives the ratio between $AgNO_3$ and water, viz.:

$$M = \frac{m}{mr} \times \frac{1000}{V} \qquad (3)$$

where M is molarity, m is the weight, mr is the relative weight, and V is volume.

(a) **(b)**

Figure 1. (a) dissolving $AgNO_3$ crystal with the aquatic liquid; (b) smoothing the $AgNO_3$ solution in the measuring cup.

By applying the formula above, 0.85 gram of $AgNO_3$ powder is dissolved in 1000 mL of water. The process of dissolving $AgNO_3$ powder was done in some steps. Firstly, the $AgNO_3$ powder is gradually mixed into 100 mL of water and stirred. After they are mixed, $AgNO_3$ powder is continuously added into water and then stirred again.

Figure 2(a) shows the process of synthesizing silver nanoparticle $AgNO_3$ solution by adding 2 mL $AgNO_3$ solution of 5 mM concentration into the test tube and then heating it inside a tube filled with water of 100 ^{0}C for 10 minutes. Then the test tube was moved to the rack, and then added with 5 drips of sodium citrate ($Na_3C_6H_5O_7$) solution as much as 1%. Then, the solution is heated again until the solution is changed into yellowish color. The yellowish color is considered as one of the indicators that the size of the particles in $AgNO_3$ solution has been changed. Figure 2(b) shows the picture of silver nanoparticle solution.

(a) (b) (c)

Figure 2. (a) the synthesis of silver nanoparticle inside boiling water; (b) the result of 5 mM of silver nanoparticle solution; (c) a beam of laser passing through the silver nanoparticle solution (Tyndall effect).

The production of mortar.

In this research, we used the handout of laboratory practical research and building material as guidance. In addition, we were also guided by the standard of American Concrete Institute (ACI). Here, 599 gram of Portland cement, 1375 gram of sand, and 242 ml of water are mixed with silver nanoparticle solution of 0 mL, 5 mL, 10 mL, 15 mL, 20 mL, and 25 mL in volume. There are three samples for each volume variation of the nanoperticle solution. The silver nanoparticle solution was mixed with water but the volume of water was decreased with varying amount of 0 mL, 5 mL, 10 mL, 15 mL, 20 mL, and 25 mL, respectively, for each sample. The decrease of water volume that was substituted with silver nanoparticle solution is conducted in order to make the volume of the mixture constant.

After all the materials are ready, we poured sand and cement to the stirring cup, and then stirred until all the materials were blended homogenously. Subsequently, the materials were blended until it became smooth; then the mixture was moved to the 5 x 5 x 5 cm^3 mortar molding box.

24 hours later, the mortar was moved from the molding box and soaked in water. This soaking process is needed to hydrate the cement and water. This was conducted for 7 days.

Mortar porosity test

The procedure of testing the porosity of the mortar can be explained as follows:

1. the mortar sample was taken out from the soaking cup then dried with a fabric until there was no water dripping,
2. measuring the weight of the mortar to determine the wet weight of the mortar,
3. inserting the mortar to an oven for 24 hours,
4. measuring the weight of the mortar to obtain the dry weight of the mortar,
5. the above steps were repeated to all samples.

The value of the porosity can be determined by applying the formula for porosity as given in eq. (1).

Mortar compressive strength test

The steps of testing the compressive strength of the mortar may be given as follows:

1. taking out the mortar that has been soaked for a certain time (7 days), and then drying it with a dried fabric until there was no water dripping.
2. the mortar that would be tested was put in a pressing machine.
3. giving a pressure to the mortar slowly by using UTM to test the compressive strength of the mortar. The UTM is completed with a plotter to draw the graph of the tension of the mortar. The pressing machine that has been arranged was linked to a controlling computer.
4. after the mortar was broken as required, the computer automatically stopped counting and the value of the compressive strength counted by the computer is the value of the maximum compressive strength.
5. The above steps were repeated for other mortar samples.

The value of the compressive strength can be obtained using eq. (2).

Results and Discussion

The result of spectrophotometer Uv-Vis of silver nanoparticle solution

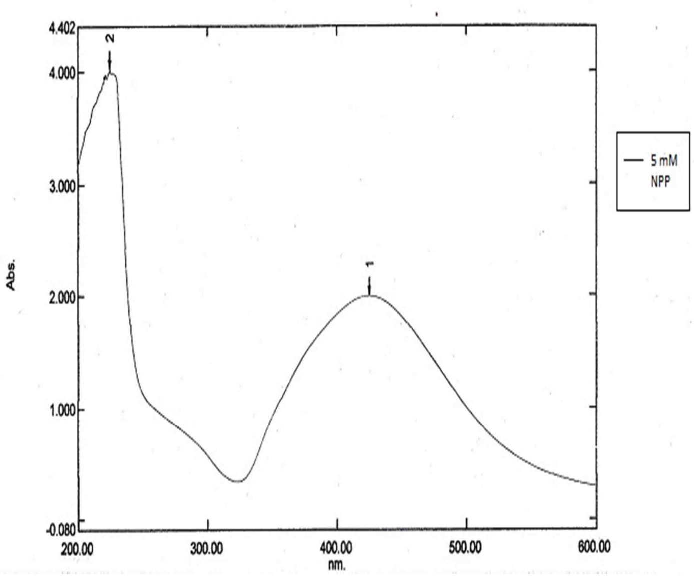

Figure 3. The result of 5 mM silver nanoparticle test using spectroscopy Uv-Vis.

Figure 3 above shows Uv-vis result of the silver nanoparticle solution sample. Silver nanoparticle has an absorbance of 1.997 with wavelength at maximum absorbance of 425 nm. The value of the wave length at maximum absorbance shows that silver nanoparticles are present in the solution.

Porosity test

Based on Table 1, we can obtain the results of wet mass and dry mass of the mortar, and then use the aforementioned results to find the porosity which is plotted in Figure 4.

From the data above, it can be seen that the value of the porosity without silver nanoparticle solution is 20.38%, while for the average porosity of the mortar with silver nanoparticle solution variation of 5 mL, 10 mL, 15 mL, 20 mL, and 25 mL, successively is 19.48%, 19.42%, 18.9%, 17.8%, and 17.5%. It can be seen that the more silver nanoparticle solution is added into the mixture, the less the mortar porosity becomes. This is caused by the increase of the number of the silver nanoparticles that occupy the pores inside the mortar such that it reduces the porosity of the mortar. The fitted model used in Figure 4 is the linear line. This means that the porosity decreases linearly as the volume of the nanoparticle solution is increased.

Table 1. The data result of porosity measurement.

No	Varieti of mix volume	Wet Mass (gr)	Dry Mass (gr)	Porosity (%)	Avarage Porosiy (%)
1	0	303.1	276.3	21.44	20.38
		287.8	269.3	14.80	
		291.4	261.0	24.32	
		291.1	264.9	20.96	
2	5	297.2	273.8	18.72	19.48
		275.7	250.2	20.40	
		287.4	264.2	18.56	
		286.0	260.7	20.24	
3	10	296.4	275.2	16.96	19.42
		290.3	264.7	20.48	
		291.6	266.9	19.76	
		283.8	258.2	20.48	
4	15	296.3	274.1	17.76	18.9
		286.8	262.3	19.60	
		291.8	267.8	19.20	
		291.1	267.3	19.04	
5	20	294.5	272.3	17.76	17.8
		287.6	265.3	17.84	
		287.6	265.2	17.92	
		288.0	265.9	17.68	
6	25	292.6	273.8	15.04	17.5
		293.5	270.8	18.16	
		295.7	273.3	17.92	
		289.4	265.8	18.88	

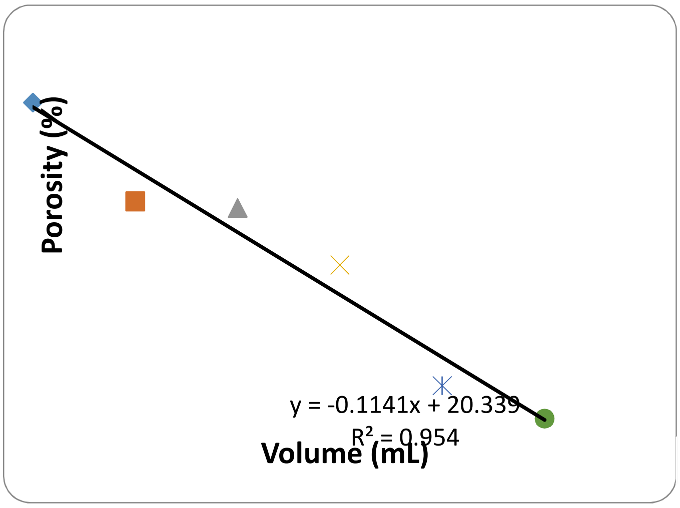

Figure 4. The graphic of the porosity vs silver nanoparticle volume of the mortar samples.

Compressive Strength

Based on Table 2 we can obtain the results for surface area and maximum force, and then use these components to find the compressive strength as an input in Figure 5.

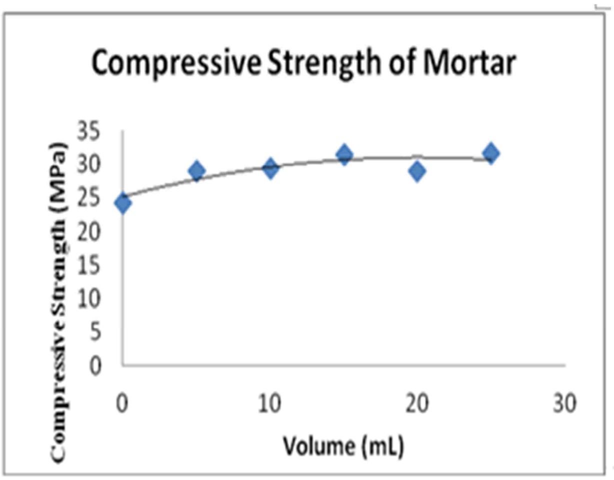

Figure 5. The graphic of the compressive strength vs the silver nanoparticle solution of the mortar.

The graphic of the compressive strength of the mortar may be observed in Fig. 5. From the graphic above, the compressive strength of the mortar without silver nanoparticle solution is 24.276 MPa, while for the average mortar compressive strength with variation of the silver nanoparticle volume of 5 ml, 10 ml, 15 ml, 20 ml, and 25 ml, successively, is 29.068 MPa, 29.308 MPa, 31.385 MPa, 28.926 MPa, and 31.370 MPa.

It is gained that the mortar compressive strength increases as the volume of the nanoparticle solution is increased from 5 ml to 15 ml that is 29.068 MPa, 29.308 MPa, and 31.385 MPa, while for 20 ml of nanoparticle solution the mortar compressive strength reduces to 28.926 MPa. However, for 25 ml nanoparticle solution the mortar compressive strength increases to 31.370 MPa.

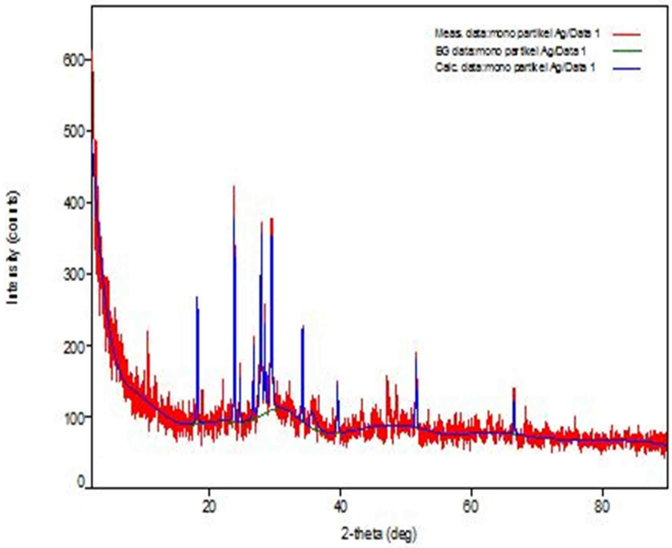

Figure 6. The graphic of the mortar's contents by XRD

Table 3. The data of mortar's contents.

Weight ratio		
		mono partikel Ag
	Phase name	Content(%)
-	Quartz	2.1(7)
-	Anorthite, sodian, syn	97(6)
-	Silver	0.80(3)

From the XRD test of the mortar which is already three months old, we can conclude that the content of the mortar consists of quartz (2.1%), anorthite, sodion, syn 97%, dan silver (0.8%). From the XRD test there is still a trace of silver content although the age of the mortar has been three months old, in solid condition, and drainage process.

Table 2. The data result of compressive strength.

No	Varieti of mix volume	Surface Area A (m^2)	The max force (F) (N)	Compressive strength f**c'** (MPa)	Average Compressive strength (MPa)
1	0	0.0025	61220	276.3 24.488	24.276
			61240	269.3 24.496	
			59840	261.0 23.936	
			60460	264.9 24.184	
2	5	0.0025	56747	22.699	29.068
			72980	29.192	
			69330	27.732	
			91620	36.648	
3	10	0.0025	76850	30.740	29.308
			73410	29.364	
			59050	23.620	
			83770	33.508	
4	15	0.0025	66474	26.589	31.385
			83580	33.432	
			85440	34.176	
			78360	31.344	
5	20	0.0025	64390	25.756	28.926
			83740	33.496	
			46870	18.748	
			94260	37.704	
6	25	0.0025	61316	24.526	31.730
			82130	32.852	
			86510	34.604	
			87340	34.936	

Conclusion

From the discussion above we conclude as follows: The compressive strengths of the mortar with the silver nanoparticle solution volume variation (in ml) of 5, 10, 15, 20, and 25 are obtained as 29,068 MPa, 29,308 MPa, 31,385 MPa, 28,926 MPa, and 31,730 MPa, respectively.

Based on the porosity test of the mortar, the more the silver nanoparticle solution is added into the mixture, the less the porosity becomes. The addition of 25 ml silver nanoparticle solution gives the lowest porosity of the mortar. From XRD, it is obtained that the silver content in the mortar is around 0.8% although the mortar is already three months old.

References

[1] ASTM, 2003, *Concrete and Aggregates: Annual Book of ASTM, Vo1.04.02*, Philadelphia.

[2] Florence, S. & Konstantin, S. 2010. Nanotechnology in Concrete-A Review. *Construction and Building Material* 24: 2060-2071.

[3] Jain, P.K. & Jain, V. 2006. Impact of Nanotechnology on Healthcare-Application in Cell Therapy and Tissue Engineering. *Nanotechnology Law & Bussines* 3(4): 411-418.

[4] Kim, B.J. Park, C.S. Murayama, M. & Hochella, M.F. 2010. Discovery and Characterization of Silver Sulfide Nanoparticles in Final Sewage Sludge Product, *Environonmental Science & Technology* 44(19): 7509-7514.

[5] Mulyono, T. 2003. *Concrete Technology*. Yogyakarta: Andi Offset.

[6] Pacheco-Torgal, F. & Jalali, S. 2010. Nanotechnology: Advantages and drawbacks in the field of construction and building materials. *Construction and Building Material, Elsevier. Elsevier*. 25(2): 582-590.

[7] Ramsden, J.J. 2009. *Applied Nanotechnology*. Oxford: Elsevier.

[8] Sobolev, K. Flores, I. Hermosillo, R. & Torres-Mertinez, L.M. 2008. Nanomaterials and Nanotechnology for High-Performance Cement Composites. *International Concrete Abstracts Portal*, 254: 93-120.

[9] Tanvir, M. & Nur, Y. 2010. Strength Enhancement of Cement Mortar with Carbon Nanotubes. *Transportation Research Board of the National Academies* 2142: 102-108.

[10] Tjokrodimuljo, K. 2004. *Concrete Technology*. Yogyakarta: UGM Press.

[11] Wancik, A. Satyarno, I. & Tjokrodimuljo, K. 2008. Cement Mortar Composite Styrofoam Bricks. *Forum Teknik Sipil* XVIII(2): 780-787.