JCE
Journal Of
Civil Engineering
ISSN 2086 - 1206 E-ISSN 2579 - 9029

Investigation of the effect of sandblasting waste treatment method as nano-silica on the compressive strength of concrete mortar

Muhammad Z. Abidin[a*], Wahyuniarsih Sutrisno[b], Rahmat D. Sutrisno[c]

Correspondence

[a]Master Student in the Civil Engineering Department, Institut Teknologi Sepuluh Nopember, ITS Campus, Sukolilo, Surabaya 60111, Indonesia.
[b]Lecturer in the Civil Engineering Department, Institut Teknologi Sepuluh Nopember, ITS Campus, Sukolilo, Surabaya 60111, Indonesia.
[c]Lecturer in Civil Engineering Department, Universitas Muhammadiyah Gresik, Gresik 61121, Indonesia.

Corresponding author email address: abizainal9466@gmail.com

Submitted : 01 July 2023
Revised : 01 July 2023
Accepted : 07 September 2023

Abstract

This study presents the effect of nano-silica (NS) from sandblasting waste as an additive on the mechanical properties of concrete mortar. Sandblasting process in shipping repair industry generate massive waste of silica sand. The silica sand produced from this process has quite fine particles and contains impurities such as residual rust, paint and other materials so it is dangerous for health if not used properly. In this research, the nano-silica was produced by using the sol-gel and mechanical grinding methods. In this research, nano silica material was added as an additive with a percentage varying from 0% to 5%. The results show that producing nano silica from sandblasting waste with a combination of sol-gel and mechanical grinding methods can produce an average size of 148.9 nm with 96.90% purities silica (SiO2). The compressive strength test also shows that adding NS can increase the compressive strength of the concrete. The highest compressive strength obtained from this research was. 29.76 MPa with the addition of 1% of nano-silica. This compressive strength is 37.5% higher than the control mixture.

Keywords

Waste, sandblasting, nano-silica, concrete, additives

INTRODUCTION

Concrete is a popular material with several benefits, such as easy handling, moldability, fire resistance, and low maintenance. Concrete is also one of the most widely used construction materials in the world due to its strength, durability, and low cost. It is a composite material that consists of several constituents, such as aggregates, water, and cement, which serve as an adhesive. However, concrete has some limitations, such as low tensile strength, low flexibility, and susceptibility to cracking, which can compromise its structural integrity and shorten its lifespan. As the demand for concrete increases every year, cement consumption also rises. Cement production is one of the industries that emit a lot of CO_2. Therefore, efforts have been made to reduce the use of cement, such as by using supplementary cementitious materials like fly ash and silica fume as cement replacements [1]. There are many ways to minimize the use of cement. For example, one approach is to develop the manufacture of geopolymer concrete using pozzolanic materials as a binder [2]. Another method involves using pozzolan in the form of fly ash and silica fume as a partial replacement for cement in SCC concrete, which can increase the compressive strength of concrete over a stable period from 3 days to 56 days [3].

In recent years, the application of nanotechnology in concrete has emerged as a promising solution to overcome these limitations and enhance the performance and durability of concrete structures. Nanotechnology is one of the technologies in the world of concrete. Nanotechnology utilizes characteristic chemistry and/or deep material physics based on materials engineering, resulting in concrete with unique mechanical and chemical properties compared to conventional concrete using micro-sized materials [4]. Nanotechnology involves the manipulation and engineering of materials at the nanoscale level. By incorporating nanomaterials, such as nanoparticles, nanofibers and nanotubes, into the concrete matrix, it is possible to enhance its mechanical, thermal and electrical properties. For example, the addition of carbon nanotubes can significantly increase the compressive and flexural strength of concrete, while the incorporation of nano-silica particles can improve its durability and resistance to cracking. The application of nanotechnology in concrete has the potential to revolutionize the construction industry, by enabling the development of high-performance and sustainable concrete structures. However, there are still many challenges to overcome, such as the cost and scalability of nanomaterial production, the compatibility of nanomaterials with concrete mixtures, and the potential toxicity and environmental impact of nanomaterials.

Nano-silica is a porous material that has a super small size and a large surface area [5]. The properties of the particles vary depending on changes in surface properties. If the material is composed of nanometer-sized particles, the overall properties of the material can be easily controlled [6]. Nano-silica is a material with a small size that has many benefits, particularly in the field of agriculture. Nano-silica can affect plant metabolic activity and morphology in several ways, such as adding structural color to plants and promoting plant growth and yield. It can also be used as a pesticide, fertilizer, and herbicide delivery agent [7].

The effect of nano-silica on concrete can also be seen in the research conducted by [8]. The use of nano-silica with a percentage of 0% to 1% can increase the compressive strength of concrete up to 152.45%. This is very beneficial because producing concrete with high strength requires using less volume of concrete as a constituent material in the form of cement, which also has an impact on the environment by reducing CO2 emissions resulting from the use of cement.

Sandblasting is a cleaning process that involves shooting particles in the form of silica sand against a surface, producing friction with a certain pressure. Sandblasting is very popular with shipping companies compared to conventional methods because of its higher efficiency and flexibility in following the shape of complicated surfaces. Solid blasting waste generated from coating removal during ship repair and maintenance poses environmental challenges [8], [9]. In the same study, it was stated that according to Indonesian Government Regulation No. 101 of 2014, sandblasting waste in the form of silica sand can be categorized as B3 waste (hazardous and toxic materials). If the silica dust contained in the waste is inhaled continuously, it can cause the spread of silicosis disease. Thus, the excess waste resulting from the sandblasting process in the form of silica sand with high silica content needs to be innovatively utilized.

Various studies and tests have been conducted in the field of concrete, utilizing nanomaterials and silica sand as raw materials for concrete. The use of nano-silica in the concrete mixture in the form of nano-silica colloid, at rates of 0%, 1.5%, 3%, and 4.5% of the cement mass, can increase compressive strength up to 62 MPa at 28 days old [10]. Nano-silica has been used in High-Performance Concrete (HPC) and Self-Compacting Concrete (SCC) as an anti-bleeding agent, to increase cohesiveness and reduce segregation. Using 2% nano-silica colloid can produce HPC concrete with a compressive strength of 85 MPa and high workability [11]. The use of silica sand from different locations or origins, as well as its various roles in concrete, can result in different reactions and effects. Silica sand originating from Tuban, with a silica (SiO2) content reaching 33.58%, can only be used as a filler and not as a substitute for cement [12].

The use of nano-silica in concrete can have various effects, especially on fresh and hardened concrete. Using nano-silica with a particle size of 9-200 nm can affect the workability, hydration heat, and compressive strength of concrete. A significant increase in compressive strength occurs with the addition of a small amount of nano-silica due to the increase in the pozzolanic reaction in concrete, which is influenced by nano-silica as an activator [13].

Based on these facts, this study aimed to modify silica sand from sandblasting waste into nanomaterials. The modification process was carried out in several steps to obtain the best quality nanomaterials. An investigation was also conducted to obtain the properties of nano-silica. The nano-silica was then incorporated into the mortar mixture at rates of 0% to 5%, with an increment of every 1%. Compressive strength tests of the mortar were performed to obtain information on the effect of the addition of nano-silica into the concrete mortar.

RESEARCH SIGNIFICANCE

This paper investigates the effect of processing sandblasting waste in the form of silica sand, which is then processed into nano-silica and mixed into concrete. Several treatments were carried out beforehand to clean the sand waste to obtain high silica purity. The nano-silica was prepared using the sol-gel method.

METHODOLOGY

A. PREPARATION OF NANO SILICA

The material used in this study is silica sand obtained from sandblasting waste at PT. Dok Pantai Lamongan. The company specializes in shipyard services and focuses on ship repairs. Silica sand is waste containing silicon dioxide (SiO_2) at 93.02%. This waste is later pre-treated by wash and subjected to several methods to further purify it.

Material preparation involves several pre-treatments that are carried out to produce clean and usable materials. The initial treatment is sieving, which separates the impurities contained in sandblasting waste. Silica sand, which is obtained from shipyard ships, is in a dirty condition and filled with stones, wood, and large iron flakes. Therefore, the initial cleaning process is essential to get better quality silica sand. The sieving process was performed using sieve number 16 to produce clean silica sand that is free from impurities. The next treatment involves washing the material with water until it is clean and finally rinsing it with distilled water to remove mud and oil from the sandblasting waste.

Figure 1 Cleaning using magnets

The last stage is cleaning with a magnet, which is crucial in removing small iron flakes found in the material, resulting in completely clean materials. The cleaning process, which utilizes a magnet, can remove dirt in the form of iron powder, as shown in Figure 1.

Visually, the results can be seen in Figure 1, in the form of dirt that resulted from the cleaning process using a magnet. In general, it can be observed that this process can remove iron flakes that pass through the sieve. The dirt lifted by the magnet is then tested using X-ray fluorescence (XRF) as shown in Table 1. From this process, 60.25% Fe_2O_3 was lifted, as well as SiO_2 that was lifted together with several grains of the silica sand. The last stage of the process involves preparing the material for use in the manufacturing process of nano-silica.

Table 1 Cleaning XRF test using magnets

No	Element Name	Percentage (%)
1	Fe_2O_3 (Iron Trioxide)	60,25
2	SiO_2 (Silicon Dioxide)	26.00
3	CaO (Calcium Oxide)	2,28
4	TiO_2 (Titanium Oxide)	1.65
5	CuO (Copper Oxide)	1.59
6	ZnO (Zinc Oxide)	1.24
7	PbO (Lead Oxide)	1.67

In general, nanoparticle synthesis can be carried out using two methods, namely the top-down and bottom-up methods. The top-down method involves the physical breakdown of particles into smaller ones, while the bottom-up method entails the creation of nanoparticles from smaller molecules [14].

The production of nano-silica involves two different methods, namely the sol-gel method and the mechanical grinding method. After both methods are used, the characteristics of the produced nano-silica are analyzed to determine which method produced the best quality.

The sol-gel method utilizes a chemical process for synthesizing various nanostructures, especially metal oxide nanoparticles such as titanium dioxide (TiO_2), silicon dioxide (SiO2), and zirconium dioxide (ZrO_2). In this method, a molecular precursor (usually a metal alkoxide) is dissolved in water or alcohol and converted into a gel through hydrolysis or alcoholysis by heating and stirring. The sol-gel method enables the preparation of very homogeneous composites with high purity. The gel obtained from a wet or moist hydrolysis or alcoholysis process must be dried first. The manufacturing process for nano-silica using the sol-gel method can be seen in Figure 2.

Mechanical grinding, or the grinding method, is a standard technique that has been used in various industrial application fields to reduce particle size. Several types of grinding are commonly used in mechanical grinding methods, including toothed rotor-stator mills, colloid mills, and media mills. The most used method is the media mill, which uses tools in the form of planetary ball mills and ball mill powder. The milling process is typically carried out for 20 hours to achieve the desired particle size, which can be as small as the nanoscale.

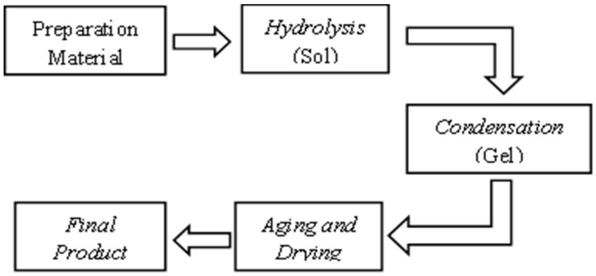


Figure 2 Making the nano-silica Sol-gel Method

B. MIXTURE COMPOSITION

The composition of mortar materials generally consists of sand and Portland cement. The Portland cement used has chemical content consist of 79.60% Calcium Oxide (CaO) and 9.30% Silicon Dioxide (SiO_2), as well as other compounds with varying percentages. Details of chemical composition of Portland cement shown in Table 2.

Table 2 Chemical composition of Portland Cement

No.	Element Name	Percent (%)
1	Silicon Dioxide (SiO_2)	9.30
2	Calcium Oxide (CaO)	79.60
3	Ferri Oxide (Fe_2O_3)	5.77
4	Sulfur Trioxide (SO_3)	1.50
5	Titanium Oxide (TiO_2)	0.42
6	Aluminum Trioxide (Al_2O_3)	1.90

The sand used is natural sand that has passed sieve number 8 to separate fine aggregate from stones. The additional material used in this experiment is nano-silica, which varies in specification and acts as an additive in the mortar. Nano silica was added into the mortar with different percentage from portland cement. The percentage is range from 0% to 5% with increase every 1% for each specimen. The specimen code was presented in Table 3.

Table 3 Percentage use of nano-silica

Specimen Code	Variation Of Nano-Silica	Size (cm)
V-0	0%	5x5x5
V-1	1%	5x5x5
V-2	2%	5x5x5
V-3	3%	5x5x5
V-4	4%	5x5x5
V-5	5%	5x5x5

The production of mortar must follow the method and proportion of the mixture specified in the standard as specified in ASTM C109. The standard provides guidance on the proper ratio of sand to cement, as well as the amount of water needed to achieve the desired consistency [15].The best results from two methods of Nano-silica testing will be used in the mortar mix for testing at 1 day, 7 days, and 28 days. The size of the sample form will be a cube with dimension 5cm x 5cm x 5cm, with the following variations. The detail Mixture of each sample show in the Table 4.

Table 4 Detail Mixture for Each Specimens

Specimen Code	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	w/c	Variation Of Nano-Silica (% of cement)
V-0	666.7	1833	0.5	0%
V-1				1%
V-2				2%
V-3				3%
V-4				4%
V-5				5%

RESULTS AND DISCUSSIONS

A. CHARACTERISTICS NANO-SILICA

A test was performed to gain information related to the particle size of the nano-silica produced from sandblasting waste can be seen in Figure 3. Figure 3 shows the results of the PSA test conducted using the sol-gel method with nano-silica.

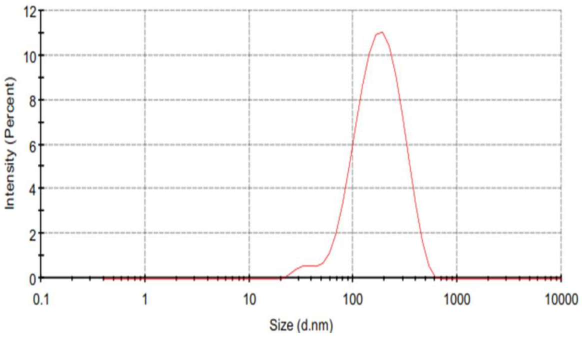


Figure 3 Results PSA nano-silica testing

The test result shows that the nano-silica produced using combination of the sol-gel and grinding method has an average size of 148.9 nm. The manufacturing process of nano-silica particles results in non-uniform particle sizes similar with the ones used by [13] for concrete mixtures with sizes ranging from 9-200 nm. The research perform by [13] shows that it effective for increasing the quality of concrete with only addition of 1% as additive.

The size of particle can affect the quality of concrete incorporating nano silica particle. Small particle sizes have a larger surface area than larger ones, which significantly affects the strength of concrete, as demonstrated by [16]. The use of nano-silica with a higher surface area result in an increase in the compressive strength of concrete. Therefore, this particle size might not the best size for a nano material because the average particle size still exceeds 100 nm. However, with a simple processing method, the particle size obtained is still quite good whereas indicated by the test results that 2.3% of the nano-silica material has a particle size in the range <35 nm. The result still can be improved by extending the duration of mechanical grinding.

Table 5 Nano-silica XRF testing sol-gel Method

No	Element Name	Percentage (%)
1	SiO_2 (Silicon *Dioxide)*	96.9
2	Fe_2O_3 (Iron *Trioxide)*	0.72
3	CaO *(Calcium Oxide)*	0.95
4	TiO2 *(Titanium Oxide)*	0.36
5	CuO *(Copper Oxide)*	0.09
6	K_2O (Potassium Oxide)	0.78
7	ZRO_2 *(Zirconium dioxide)*	0.04
8	SO3 (Sulfur trioxide)	0.08

To determine the purity of the synthesized silica, X-ray fluorescence (XRF) testing was conducted. The results indicated that the silica produced through the sol-gel method contained 96.9% silica, as shown in Table 5. Furthermore, the nano-silica particles produced through the ball milling process for 20 hours had a higher silica content compared to pure sand silica, which contained only 93.02% silica.

B. COMPRESSIVE STRENGTH TESTING

The compressive strength test of the mortar in this study was conducted using a Universal Testing Machine with capacity of 50 tons, with test ages of 1, 7, and 28 days. The test results for each variation of the mixture can be seen in Figure 4.

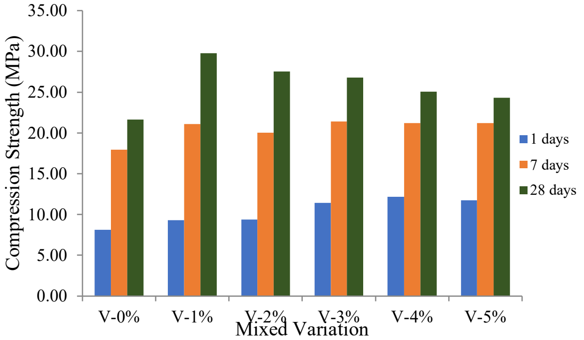


Figure 4 Compressive strength test results

Figure 4 shows the results of the compressive test for each variation. The test results indicate an increase in compressive strength. For mortar at the age of 1 day, 7 days, and 28 days. The test results also show that there was an increase in compressive strength of all sample with addition of nano silica compared to the control mixture. The highest compressive strength was observed at 28 days with an average of compressive strength reach 29.76 MPa at 1% variation. This compressive strength is 37.5% higher than the control mixture.

The increase in strength of mortar with age is due to the ongoing chemical reactions between cement and water, which lead to the formation of hydrated cementitious mixtures. During the initial hydration stage, the mixture shows lower compressive strength and have low binding strength. However, as hydration continues, the mixture become stronger and denser, leading to an increase in strength [17].

The addition of nano-silica can certainly affect the strength of the mortar. The addition of nano-silica, which has a high chemical silica content, can provide a different chemical reaction, as seen in Figure 4. With the addition of nano-silica, it can increase the strength of the mortar compared to normal mortar. The rate of increase in strength is influenced by several factors, including the type and amount of cement, the water-cement ratio, the curing conditions, and the fineness of the mortar constituent particles.

When using nano-silica as a additive in concrete, a large volume is not necessary, as demonstrated in Figure 4. The maximum strength is achieved at a 1% variation of nano-silica, and there is a decline in strength as the percentage of variation increases. [18] proved in their research that using nano-silica in concrete can increase the compressive strength, with the maximum effect observed at a 1% variation. The addition of 37.52% to the compressive strength is highly significant to the composition of the constituent materials in concrete, especially the amount of cement required. The addition of nano-silica can naturally reduce the volume of cement needed to produce concrete with the targeted strength. This is highly significant for the environment, as cement contributes to 6% of the world's CO_2 emissions [19].

C. SCANNING ELECTRON MICROSCOPY-ENERGY DISPERSIVE X-RAY (SEM-EDX)

SEM-EDX testing involves enlarging the concrete surface through electron projection and obtaining pictures from the reflected X-rays. XRD testing, on the other hand, analyzes the current of reflected X-rays to determine the mineral composition of the concrete. In SEM testing, coatings are applied to improve the quality of the pictures or results obtained. Coatings increase the intensity during the testing process. SEM-EDX testing was performed on concrete paste with a variation of 1% nano-silica mixture. This was based on the results of the compressive strength test conducted on 28-day-old concrete. The testing was carried out with multiple enlargements, and the results of the SEM-EDX testing can be seen in Figure 5.

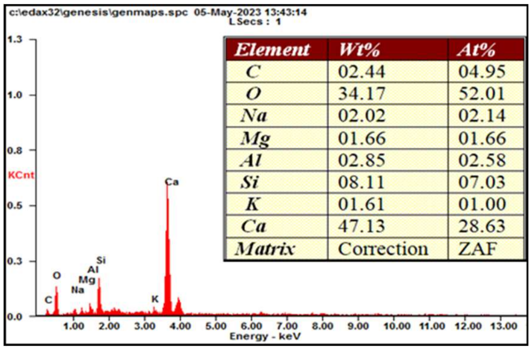
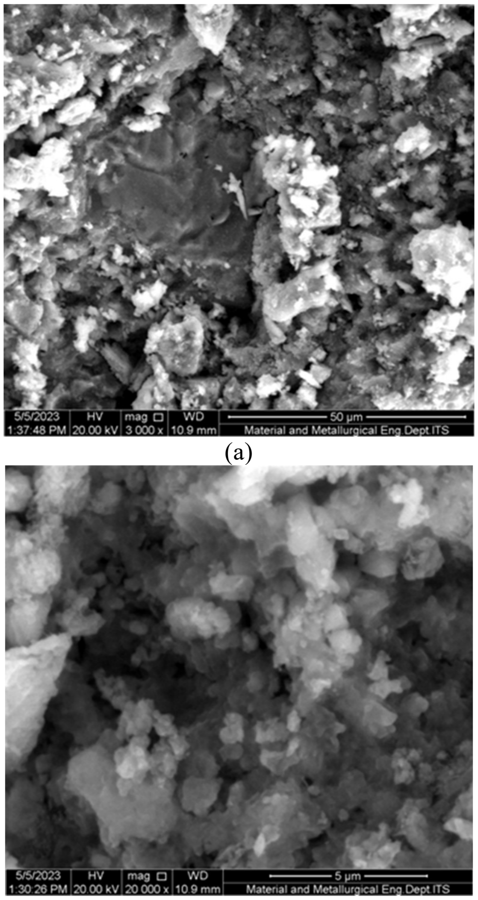


Figure 5 Graph results SEM-EDX testing



(a)

(b)

Figure 6 SEM test magnification (a) 3000 and (b) 20000

The test results presented in Figure 5 shows the presence of several chemical elements, namely Calcium (Ca), Oxygen (O), Carbon (C), and Silicon (Si), in the concrete samples with a variation of 1% nano-silica. Among these elements, Calcium (Ca) represents the dominant element with a percentage of 28.63%, followed by Oxygen (O) at 52.01%, Carbon (C) at 4.95%, and Silicon (Si) at 7.03%, respectively, at sequential order.

Results of magnification, which is shown in Figure 6, is performed to analyze the microstructures of the sample. From the results, no such large pore enlargement is observed. Based on Figure 4, the optimum strength of the concrete is achieved with a 1% variation of nano silica compared to other variations. This is because the dominant chemical element in cement is reacted with nano-silica to increase the properties and performance of the concrete, such as increasing strength and durability while reducing existing pores in the concrete.

D. X-RAY DIFFRACTION (XRD)

Observation of the microstructure using SEM (scanning electron microscopy) cannot provide a complete characterization of the microstructure [20]. Therefore, XRD (X-ray Diffraction) testing, as shown in Figure 7, was conducted. XRD testing is used to identify the minerals present in the concrete paste. XRD generates diffraction patterns from penetrating X-rays into the sample. These diffraction patterns can be used to identify the minerals present in the sample based on the position of the diffraction peaks.

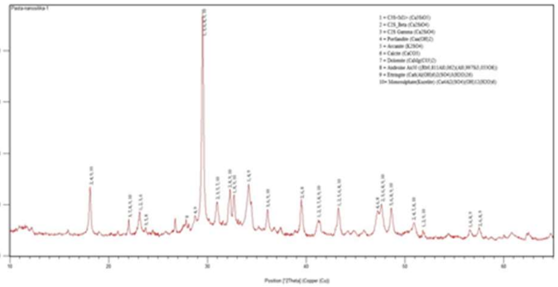


Figure 7 Results XRD testing

Table 6 Results XRD testing

Crystal name	Chemical Formulas	Amount (%)
C3S<M1>	Ca3SiO5	1.73
C3S <M3> HKL 8-120	Ca3SiO5	1.92
C2S_beta	Ca2SiO4	4,33
C2S gamma	Ca2SiO4	1.50
Portlandite	Ca(OH)2	5.05
Calcite	CaCO3	17.56
Dolomites	CaMg (CO3)2	3,62
Andesine An50	(Rb0.811Al0.062)(Al0.997Si3.003O8)	2.79
Etringite	Ca6(Al(OH)6)2(SO4) 3(H2O)26	1.84
Tobermorite	Ca5(OH)2Si6O16(HO)4	1.45

Based on Figure 7, there is a pattern chart showing the position and intensity of diffraction peaks in the crystal structure of a concrete paste sample. The height of the diffraction peaks on the chart reflects the phase of the crystal along with its size. Some dominating crystals can be seen in Table 5.

The results of the XRD test presented in Table 6 show the presence of several dominant crystal forms, including Andesine An50, Dolomite, C2S_beta, Portlandite, and Calcite. These crystals have respective percentages of 2.79%, 3.62%, 4.33%, 5.05%, and 17.56%, with intensities above 8000.

Good microstructural observations were conducted using XRD and SEM-EDX. The test results showed a connection between the two techniques. The XRD testing revealed that calcite crystals had the highest percentage among the crystal types formed. Calcite is formed because of chemical reactions in cement during the hydration process, with the chemical formula CaCO3. On the other hand, the SEM-EDX results showed that the elements with the highest percentage were Calcium (Ca), Oxygen (O), and Carbon (C). By combining the results of the XRD and SEM-EDX tests, a more detailed analysis can be conducted. During the hydration process in concrete or paste, $Ca(OH)_2$ acts as a calcium source for the formation of calcite ($CaCO_3$) crystals when it comes into contact with carbon dioxide in the air. Therefore, based on the descriptions, it can be confirmed that the chemical elements resulting from the SEM-EDX testing are connected to the formation of Calcite crystals, as observed in the XRD testing.

CONCLUSIONS

This study experimentally investigates the compressive strength of mortar produced with nano-silica which obtained from processing sand blasting material. Based on the experimental test and analysis, the following conclusion was drawn.

1. Nano-silica produced with combination of the sol-gel and mechanical grinding method using sand blasting waste materials has average particle size of 148.9 nm.
2. Compressive strength results shows all the samples with addition of nano-silica from 1% to 5% has higher compressive strength compared to the control variation.
3. Among the different variations, the highest increase in compressive strength occurred with the addition of 1% nano-silica. At 28 days of testing, the compressive strength reached 29.76 MPa which is 37.5% higher than control mixture.

Considering the test results, the addition of nano silica gives benefits to increase quality of the concrete. It also can promote the utilization of byproducts materials, which is in this case is silica sand from sand blasting, into a more useful product. However, the process of converting sandblasting into nano materials by using sol-gel and mechanical grinding method still produce nano silica with particle size higher than typical commercial nano silica. Therefore, these shortcomings should be examined in future research.

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