Effect of silica-palm shell carbon composite additive in enhancing the strength of the concrete in the oil-well cementing job

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Effect of silica-palm shell carbon composite additive in enhancing the strength of the concrete in the oil-well cementing job

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Abstract. This study provides an analysis of composite additive effect to concrete’s strength in the oil-well cementing job. The composite additive is originated from the nano-sized form of silica and charcoal from palm shell waste. The quality of the concrete will be determined from its porosity, compressive strength, and shear bond strength parameters. Those parameters must be reliable base on the most respectable standards in oil and gas industry, in this study we use the standard from American Petroleum Institute (API). Six concrete samples with different concentration will be tested to obtain these parameters. The result from the test shown a decrement trend of the porosity while the concentration is increased. In contrast, the highest values of compressive strength and shear bond strength are obtained from the sample with higher additive concentration. The optimum strength was obtained in sample with 0.02% The results become clearly proven through verification by scanning electron image where the additive has successfully fill the voids in the concrete’s sample, resulting in strength enhancement of the sample.

1. Introduction
Application of Nanotechnology transformed every industrial sector, particularly in energy industry. A precise engineering process and matters control at the scale of nanometer creates a new perspective in developing advanced material [1]. Through this innovative technology application, a product of nanotechnologies such as nanoparticles, nanostructure, nanosensor, and nanobots can be produced. These products can be utilized as an additive for improving the properties of the object material [2]

In the renewable energy sector, utilization of solar and fuel cell have been developed further by adopting nanotechnology [3]. An optimist signs also arose from the nonrenewable energy area where nanomaterial is successfully implemented in laboratory scale for enhancing the crude oil recovery and maintaining the lifetime of concrete, which is critical in supporting casing in the wellbore[4].

Quality of concrete in the wellbore is one of vital consideration to prolong the lifetime of oilwell structure. A longer lifetime of the well structure will reduce the cost of concrete quality improvement due to the bad bonding of cement concrete, causing micro annulus and fracture which is lead to casing corrosion and will affect to well performance in transporting liquid and gas phase of hydrocarbon from the reservoir to the surface. There are three parameters describes the quality of the concrete in an oil well construction. First is porosity, a parameter which define as a ratio of voids volume to the total volume of the concrete. The others are Compressive Strength (CS) and Shear Bond Strength (SBS), parameters which indicate the strength of the concrete in resisting load or pressure from the reservoir or mechanical load due to production job in the well. Moreover, the concrete must hold the tendency
of crack generation in the casing[5]. Based on API Standards article 10 A, the minimum values of the CS and SBS are 500 psi and 100 psi respectively [6]. Progressive development of Nanotechnology become eminent over a decade in the concrete industry. Works by Li et al.(2004) have successfully increased the mechanical strength of the cement mortar through nano SiO$_2$ and nano Fe$_2$O$_3$[7]. Another study by Campillo et. Al.(2007) have utilized nanoalumina for modifying the strength of belite cement, which friendly environmental and efficient[8]. In oil well construction, a study regarding the application of nanoparticle additive has been performed by Patil and Desphande (2012). Through laboratory scale experiment, they conclude that addition of nanosilica can increase strength and reduce fluid loss of the concrete [4]. Although application concrete strength has shown positive results by adding nanomaterial, an actual field-scale implementation still far away due to the cost of the nanomaterial additive. Therefore, another additive which is less-expensive should be needed to create a concrete not only strong enough but also economically friendly.

Through our experimental study, we introduced a nanocomposite additive, a combination of nanosilica and Palm-Shell Charcoal (PSC). The reason of using PSC is based on the fact that the source is abundant in Indonesia, where the palm oil plantation area grows up to 10.7 million hectares in 2014, increasing 21.5 % during 4 years since 2010. Moreover, the production reached 29.7 million tonnes in 2014 or increase 25 % since 2010[9], resulting in a huge source of palm-shell waste. Combination of these additives and cement slurry will be tested to observe the effectivity of the additives to porosity and strength of the concrete. A positive result from this study can be a big expectation for transforming an almost noneconomical waste product into a useful product with a better economic value and as an effort keep the environment clean.

2. Methodology

The experimental study divided into two distinct experiments. First is porosity determination where the objective is to investigate the effect of PSC nanocomposite in filling the voids in the concrete sample. The other experiment is biaxial loading test for determining CS and SBS parameter of the sample. From this results, the effect of the nanocomposite in enhancing the concrete can be observed.

2.1 Materials

API-Class G cement will be used to make concrete samples because of the oil-well condition where high-pressure and high-temperature environment tends to contact with the concrete. Class G cement can be utilized up to 8000 ft depth of cementation[10]. Nanosilica is synthesized by using the sol-gel method from Tetra Etil Organo Silicate (TEOS) material. The size of silica particle which is formed using this method is in the range of 10 to 20 nanometers (Table 1). Palm shell waste is acquired from the one of palm-oil factory in Indonesia. Palm shell will be burned at 500°C by using the electric oven. The charcoal Shells are ground and sieved to obtain a uniform sized of PSC. From its chemical composition in Table 2, PSC contains rich of silica or SiO$_2$ compound. Other material such as bentonite and calcium chloride will be added to the mixture to keep the slurry water content and to accelerate the time for the slurry to harden.

| Physical Properties | Value |
|---------------------|-------|
| Density             | 2.17 – 2.66 gr/cm$^3$ |
| Melting Point       | $\pm$ 1700 °C |
| Boiling Point       | 2230 °C |
| Color               | White |
| Particle Size       | 10 – 20 Nanometer |
| Bulk Density        | 0.011 gr/ml |

| Chemical | wt% |
|----------|-----|
| MgO      | 4.9 |
| Al$_2$O$_3$ | 2.2 |
| SiO$_2$  | 30.1 |
| P$_2$O$_5$ | 19.6 |
| SO$_3$   | 3.28 |
| K$_2$O   | 17.5 |
| CaO      | 14.6 |
| Fe$_2$O$_3$ | 5.08 |
| CuO      | 0.388 |
| FeO      | 2.30 |

Table 1. Physical properties of nanosilica

Table 2. Chemical of composition of PSC
2.2 Procedure

Various concrete samples were prepared by mixing cement powder, de-ionized water, nano silica, palm shell charcoal and other additives. The material composition is based on Table 3. The mixture is mixed by using a high-speed propelled mixer. The velocity is constantly maintained at 4000 RPM for 5 minutes to achieve a homogeneous mixture of the slurry sample. 2 types of concrete mold, cubic and cylindrical are prepared for determining porosity, Cs, and SBS parameters. The cubic sample will be used CS test while the Cylindrical sample is needed for porosity and SBS test. Each slurry is then transferred into the concrete mold and dried at 180°F for 24 hours to ensure that all of the concrete samples are completely hardened.

| Sample Name | Composition             |
|-------------|-------------------------|
| A           | 0.02% Nanosilica        |
| B           | 0.02% Nanosilica + 1% PSC |
| C           | 0.02% Nanosilica + 2% PSC |
| D           | 0.02% Nanosilica + 2.5% PSC |
| E           | 0.02% Nanosilica + 3% PSC |
| F           | 0.02% Nanosilica + 3.5% PSC |

Each sample will be measured its porosity by implementing helium porosimeter apparatus. Samples are dried for 24 hours again in the oven at 180°F for re-ensuring no trapped liquid inside the sample. The bulk volume and mass of the Dried sampled will be calculated and weighted. Measured the dead volume of the apparatus by placing steel plug into the chamber and record the helium volume as dead volume data. Remove the steel plug from the chamber and placed the sample inside the chamber. Measured and recorded the volume of helium gas inside the chamber. The porosity can be determined by dividing the differential volume of helium gas when the sample inside the chamber minus dead volume with sample bulk volume.

The other experiment, CS parameter can be obtained from the biaxial loading test by using hydraulic test apparatus. The dried cubic sample is placed below the hydraulic piston before initiating the test. A Certain amount of pressure will be loaded to the piston, causing the piston moves downward and press the sample. The sample will withstand the vertical load from the piston, causing the increment of vertical pressure due to the loading will be continuously given. The pressure where the failure condition happened to the sample is recorded. CS is a ratio of recorded pressure to sample cross-sectional area. The test is then repeated for SBS determination by exchanging the cubic sample with the cylindrical sample. Scanning Electron Microscope (SEM) observation will be done to image the effect of nanocomposite on the concrete surface structure.

3. Result and discussion

The result from the porosity calculation on each sample shows an indication that PSC effectively fills the void of the concrete samples, causing a lower value of porosity. From Figure 1, the porosity of sample tends to reduce if the PSC concentration increase. Escalating the concentration up to 3 wt% resulting a decremental porosity to approximately 1%. Comparing the sample without PSC to another sample with 3 wt% of PSC, decremental value porosity reaches 93%. This porosity result is consistent with other experimental study by Chindaparist et. al (2005) where they utilized fly ashes material, which had larger particle size (6.4 micrometer), compare to nanosilica (20 nanometer)[11]. Image from the SEM observation also verifies the effectivity of PSC in filling the voids of the sample. Comparing Image sample A (Figure 2a) and sample E (Figure 2b) confirms that PSC has successfully sealed the pores, which is indicated by darker spot in the SEM image. Lower porosity will minimizes
the possibility of fluids trapped inside, resulting a compact bonding of the concrete and higher strength value [4].

![Figure 1. Porosity of each sample.](image)

Effect of Nanosilica-PSC nanocomposite to CS and SBS of each sample are plotted in Figure 3a and 3b respectively. All of CS and SBS values of each sample is satisfy the minimum requirement of CS and SBS value based on API standards. These plots prove that PSC effectively enhances the strength of the concrete. At low concentration of PSC (sample B and C), The CS and SBS values do not give a significant incremental value, compare sample without PSC (Sample A). however, for a sample with high concentration of PSC (Sample E), the CS and SBS rise up to 1000 and 150 psi respectively, 42% and 54% incremental compared to sample A. result from the sample F illustrates the more additional PSC is not always resulting in a concrete with better strength, concludes that sample E reveals an optimum condition where porosity is the lowest and highest for CS and SBS.

![Figure 2. SEM Image of Sample A (a) and sample E (b).](image)

![Figure 3. Compressive Strength (a) and Shear Bond Strength (b) of each sample.](image)

4. Conclusion
An experimental study has been performed to investigate the effect of PSC nanocomposite on porosity and strength of the concrete. Six samples are prepared and following a serial test for obtaining porosity, CS, and, SBS values. Results from test have shown that the porosity tend to decrease when the
concentration of PSC is increased. This is confirmed by results from SEM analysis where more darker spot can be found in the sample without PSC, means more voids in concrete sample is filled by an additive. another result from the loading test yields a higher value of CS and SBS for samples with higher concentration of PSC. In this test, optimum value is obtained for sample with 0.02% nanosilica and 3% PSC.

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