

The Electrochemical Properties of SiC Nanoparticle Suspension

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This study places SiC nanoparticles into deionized water and uses NaOH and H₂SO₄ to produce alkaline and acid nanofluids, respectively. A Cu electrode was then inserted into the SiC nanofluid with different voltages activated to observe particle absorption at the electrode and to investigate the electrochemical properties of SiC nanofluid under the influence of voltage, as well as the aggregation and precipitation of particles. In addition, the three-polar method is used to produce anodic polarization curves of the acid and alkaline solutions with the SiC particles to determine the electric potentials of oxidation reduction of the acid and alkaline nanofluids, respectively. The overall purpose of this research was to investigate the electrical properties of SiC nanoparticles in SiC nanofluids of varying pH values.

Keywords electrochemical property, nanoparticle suspension, SiC

1. Introduction

Silicon carbide (SiC) possesses many good qualities such as high chemical stability, high temperature resistance, and strong heat impact resistance. Hence, its mechanical and physical properties have been investigated thoroughly for many years by many research institutions (Ref 1-3). Due to these advantages, SiC can be incorporated into high-stress elements such as rollers and other wear-resistant components. Also, SiC possesses superior electrical resistance and heat transfer properties, which make it a good choice for heating elements and substrate materials (Ref 4). As nanotechnology continues to advance, SiC nanoparticles will enjoy even wider applications in mechanical components. However, when a nanofluid is used as a form of application material, the electric field generated by environmental factors may affect the properties of SiC nanofluid. Furthermore, the change in the pH value of the SiC nanofluid may cause the electrical properties of the particles to change, making the nanoparticles more susceptible to aggregation. The main applicability of the SiC nanofluid is diminished as a result. It is, therefore, necessary to investigate the electrical properties of SiC nanoparticles to gain better insight into their electrochemical properties when used as a nanofluid, especially the behavior of the SiC nanoparticle suspension under the influence of an electric field and after the pH has been modified (Ref 5, 6).

This study placed SiC particles into deionized water and used NaOH and H₂SO₄ to produce alkaline and acid nanofluids, respectively. A copper (Cu) electrode was then inserted

into the SiC nanofluid to monitor any changes as the voltage was modified. In particular, particle absorption at the electrode and the precipitation of the SiC from the nanofluid was of interest. A field emission scanning electron microscope was used to observe the morphology of the agglomerated particles. The three-polar method was used to produce the anodic polarization curves to determine the electric potentials of the oxidation reduction reactions and to investigate the specific electrical properties of SiC particles in solution.

2. Experimental Method

The nanofluids were produced by incorporating 0.04 g of SiC particles with an average particle size of 50 nm into 100 cm³ of deionized water with a resistance of 17.9 MΩ to produce a saturated solution of SiC with a concentration of 0.04%. An ultrasonic vibrator operating at a frequency of 20 kHz was then placed into the solution for 20 min to make sure that the SiC particles were evenly dispersed and stabilized in the deionized water. The SiC nanofluid was then mixed with H₂SO₄ and NaOH to produce acid and alkaline suspensions at pH 2 and pH 10, respectively, to compare them with the neutral suspension. The experimental apparatus was composed of a direct current (dc) power supply and the electrochemical unit, as shown in Fig. 1. A Cu electrode was polished and placed into the dispersed SiC-saturated suspension with the positive and negative poles of the Cu plate connected to the power supply. Voltage was set at 10, 20, 30, 40, and 50 V. An electrical conductivity meter was used for measuring the change in resistance with an extra set of 100 Ω resistors attached during experimentation to detect minute changes in the current. Because temperature can greatly affect the chemical reaction rate, the experiment was conducted in an isothermal chamber to maintain a consistent temperature. The two most important variables in the experiment were the applied dc bias and the pH value of the nanofluid, because they can affect the intensity of the surface electron charge of SiC nanoparticles.

Through the use of anodic polarization curves, the open circuit potentials of electrodes in the SiC nanofluid of different pH values could be compared, and the influence of the pH

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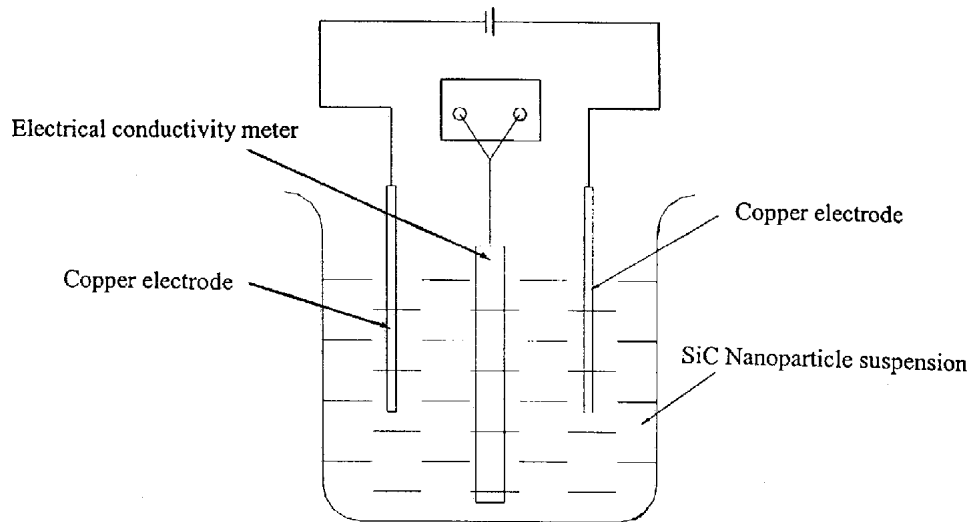


Fig. 1 Schematic diagram of the experimental setup

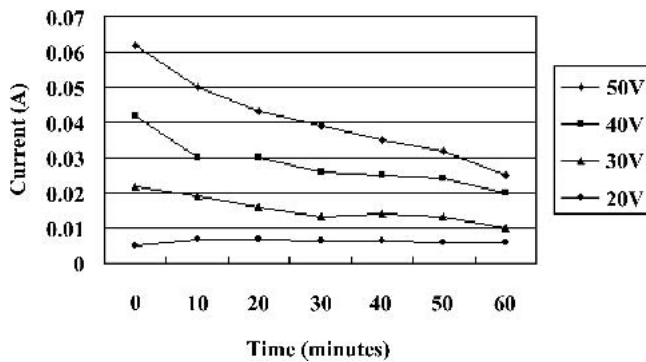


Fig. 2 Relationship between time and current under different voltages

value of the suspension on the surface electrical property of the SiC nanoparticles could be derived. This study used the three-polar method to produce the anodic polarization curve. A platinum counter-electrode was used. During the experiment, the voltages at the two electrodes were controlled, and the corresponding current was recorded. The scan rate of the potentiostat was set at 0.3 mV/s, from which the anodic polarization curve was derived.

3. Results and Discussion

The molecule in deionized water can be absorbed onto the surface of the particles via hydrogen and Van der Waals bonding, and dipole and coulombic attraction to cause SiC nanoparticles to carry an electric charge. As the experimental results show, after application of the voltage to SiC nanofluid, the SiC particles were absorbed onto the positive electrode and gradually precipitated due to mutual aggregation. The precipitation was accelerated if the applied voltage was increased. In addition, the SiC particles after precipitation will not be able to attain a stable state of suspension even after 20 min of agitation via ultrasonic vibration and will precipitate again within a very short time. The SiC particles were absorbed at the positive electrode due to the electric double layer (Ref 7, 8), which

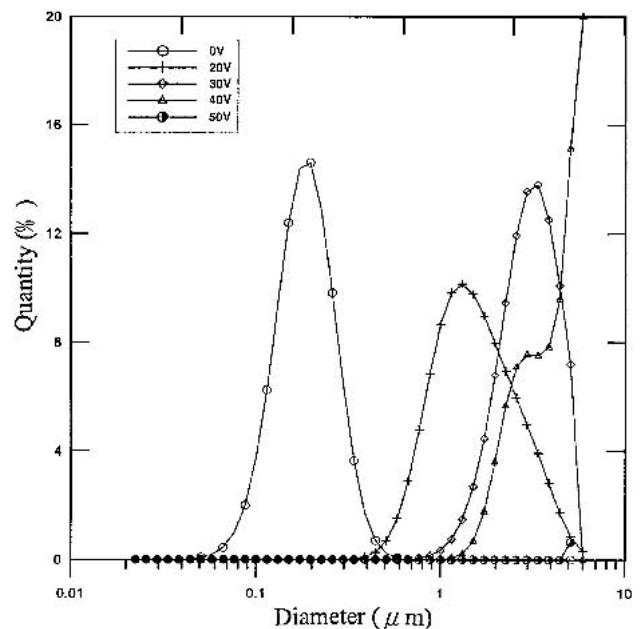


Fig. 3 Particle size distribution of nanofluid under different voltages

attracts the negatively charged SiC nanoparticles to the anode via electrophoresis. It appears that the SiC particles in deionized water carry a negative charge. To extremely minute nanoparticles, the mutual repulsive surface electric potential between particles disappears, and, hence, the Van der Waals force between particles can significantly affect particle behavior, causing nanoparticles to agglomerate (Ref 9). Figure 2 shows the changes of current with time of the SiC nanoparticles under the influence of varying voltages. The figure indicates a declining trend of current. This is mainly because some of the SiC particles in the suspension precipitated due to the electric field, and some of the particles were absorbed onto the surface of the electrode via electrophoresis. This caused the solution concentration to drop. As the voltage increased and the current density increased, the electrophoresis of particles increased in speed, causing the drop in the current of the nanofluid to be more evident.

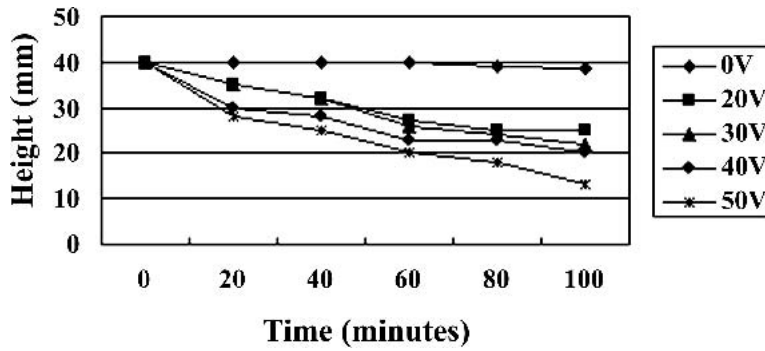


Fig. 4 Height change (original height 40 mm) of the SiC nanoparticle suspension under different voltages

The particle size distribution of the SiC nanoparticles after application of the voltage to the neutral (pH 7) SiC nanofluid was analyzed using the particle size analyzer shown in Fig. 3. As the figure indicates, the higher the applied voltage, the more intense the particle aggregation. In other words, the SiC nanoparticles in the deionized water will gradually agglomerate and precipitate as the duration of voltage application increases. Figure 4 shows the change of height of the suspension while SiC particles maintain the state of suspension after precipitation under different voltages. The figure indicates that as the voltage increases, particle precipitation accelerates, and the precipitation of SiC in the nanofluid without an applied voltage is not evident. Moreover, x-ray diffraction found that the pattern from the postprecipitated particles was consistent with that of the starting SiC particles. The aggregation and precipitation of particles were the result of changes in the electrical charge on the surface of particles after the voltage was applied.

The forces acting on the SiC nanoparticles in the nanofluid are illustrated in Fig. 5, where F_b denotes the buoyancy, F_v is the viscous force, and F_w is the downward force due to gravity. Because the particle surface carries an electric charge, the coulombic and Van der Waals forces acting on the particles will maintain a balance; hence, they can be ignored. Therefore:

$$F_w = D_s \times \frac{4}{3} \pi r^3 \times g \quad (\text{Eq 1})$$

$$F_b = D_w \times \frac{4}{3} \pi r^3 \times g \quad (\text{Eq 2})$$

$$F_v = 6 \pi \mu r v \text{ (Stokes' law)} \quad (\text{Eq 3})$$

where D_s is the density of the SiC, D_w is the density of deionized water, r is the average diameter of SiC particles, μ is the water viscosity, and v is the speed of precipitation of SiC particles in deionized water. Given that,

$$F_w = F_b + F_v \quad (\text{Eq 4})$$

Then,

$$\frac{4}{3} D_s \pi r^3 g = \frac{4}{3} D_w \pi r^3 g + 6 \pi \mu r v \quad (\text{Eq 5})$$

From Eq 5, the relationship between r and v can be derived as follows:

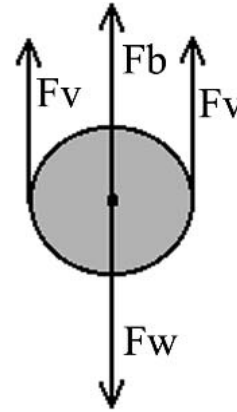


Fig. 5 Forces acting on the SiC nanoparticle

$$r = \sqrt[3]{\frac{\mu v}{2g(D_s - D_w)}} \quad (\text{Eq 6})$$

The speed of SiC particle precipitation can be determined after measuring the time required for the SiC particles in the nanofluid to completely precipitate due to agglomeration after the voltage treatment. Using Eq 6, the average diameter of the SiC particles can be determined. The experimental results show that after applying 20 to 50 V, the radius of the SiC particles ranged between 0.5 and 15 μm . The greater the voltage, the larger the SiC particle diameter becomes.

The particle size distribution in the SiC nanofluid at different pH values under varying voltages is shown in Fig. 6. As the figure indicates, lower pH leads to the increased agglomeration of SiC particles, making it easier to precipitate. The experiment also finds that when the same voltage is applied, the SiC nanoparticle suspension at pH 10 has a higher current than the SiC nanoparticle suspension at pH 2. In other words, when the pH becomes more acidic, the positive charge (H^+) surrounding the SiC particles increases, reducing the intensity of the negative charge on the surface of particles and causing the current in the fluid to diminish. As a result, the repulsive coulombic force between particles weakens, making it easier for the particles to agglomerate and precipitate. On the other hand, when the pH becomes more basic, the OH^- in the fluid will increase the negative charge on the surface of the SiC nanoparticles. As a result, the current intensifies making the particles easier to disperse rather than agglomerate and precipitate. The experiments revealed that the surface electric potential changes with

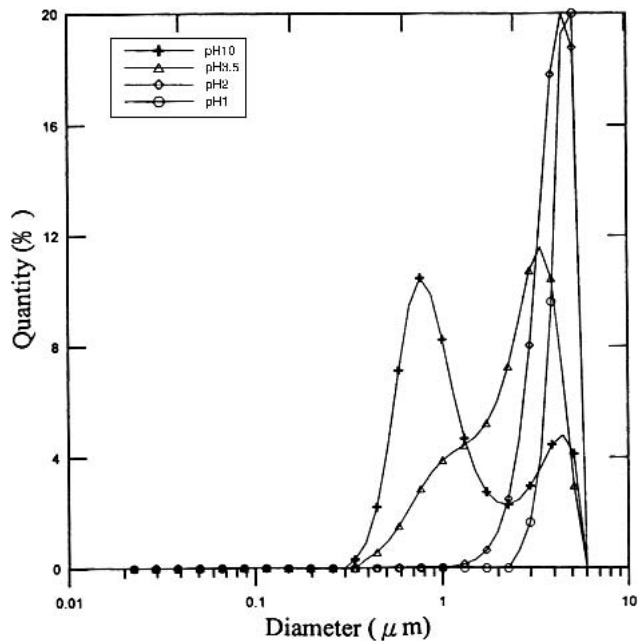


Fig. 6 Particle size distribution of the nanofluid at different pH values

the pH of the nanofluid. The transmission electron microscopy (TEM) images derived from the nanofluids with different pH values and voltages are shown in Fig. 7 to 9. As Fig. 7 and 8 indicate, the greater the applied voltage, the larger the SiC particles become. Given the same voltage conditions as shown in Fig. 7 to 9, SiC particles agglomerate more easily, and the size of the particles thus formed is larger in an acid fluid than in an alkaline fluid.

The three-polar method was used to produce anodic polarization curves to compare particle dispersion in SiC nanofluids of pH 2 and pH 10. As Fig. 10 shows, the erosion potential in nanofluid of pH 2 is approximately 620 mV, and 300 mV in the pH 10 suspension. Figure 10 also shows that SiC nanoparticles carry a stronger electric charge on their surface in the alkaline suspension (i.e., the surface electric potential is higher in alkaline suspensions than in acid suspensions). Therefore, it requires a lower open circuit potential to equalize the electric current at the cathode. In other words, the higher the pH of the SiC nanofluid, the greater the surface electric potential of the particles, and the more susceptible the particles are to agglomeration.

In applying a voltage to the pH 2 SiC nanofluid, the particles absorbed at the anode are removed, and a layer of transparent film, ~100 μm thick, was observed covering the Cu electrode. According to microhardness measurements, the transparent film has a hardness of 101 H_v, which is similar to that of the Cu electrode (97.5 H_v). Figure 11 shows that the transparent film does not contain any SiC. Hence, the film was the product obtained from the reaction of the Cu electrode with the nanofluid. In the meantime, the results from different voltage treatments showed that as the voltage is decreased, the density of the transparent film increased.

4. Conclusions

This study investigated the electrochemical properties of SiC nanofluids of different pH values under varying voltages.

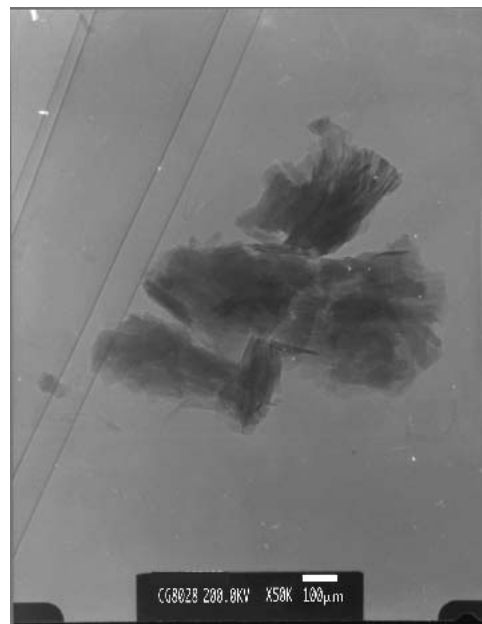


Fig. 7 A TEM image of the nanofluid at pH 2 and 20 V

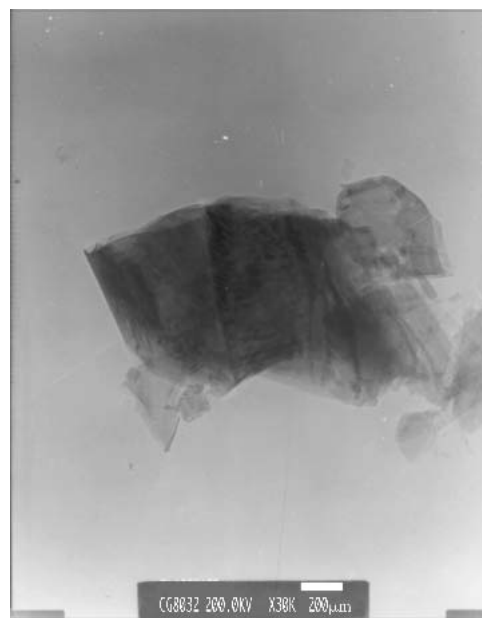


Fig. 8 A TEM image of the nanofluid at pH 2 and 30 V

From the experiment results and discussions the following conclusions can be drawn:

- After applying a voltage to the SiC nanofluid, the SiC nanoparticles will move to the positive pole due to electrophoresis. Hence, the surface of the SiC particles carries a negative charge.
- Under an applied voltage, the charge carrying the nanoparticles will be lost at the electrode, and the Van der Waals forces between particles will then cause the nanoparticles to agglomerate and precipitate.
- The surface electric potential of the SiC particles changes with the pH of the fluid. As the nanoparticle suspension becomes more alkaline, particle precipitation becomes

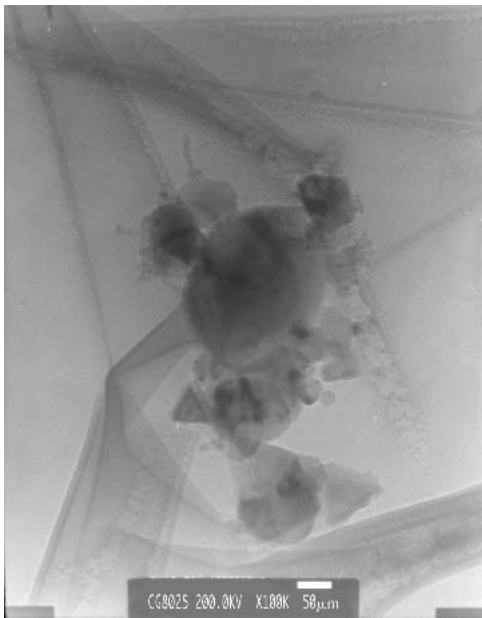


Fig. 9 A TEM image of the nanofluid at pH 10 and 20 V

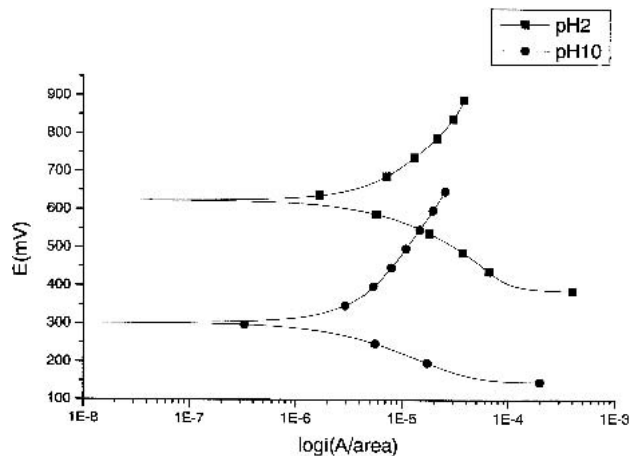


Fig. 10 Anodic polarization curves



Fig. 11 Energy dispersive x-ray spectrometer (EDS) pattern of transparent film

more difficult. On the other hand, as the nanoparticle suspension becomes more acidic, particle agglomeration becomes easier, leading to SiC precipitation.

- After application of the voltage, the SiC particles in the deionized water start to precipitate, and the process of precipitation accelerates as the applied voltage increases.
- Judging from the anodic polarization curves of the SiC nanofluid at different pH values, the increase in the pH of the fluid results in a higher surface electric potential of the SiC nanoparticle and in a lower open circuit potential.

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