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The Influence of Silica Nanoparticle-Based Modifying Agent on the Application of Hydrophobic Coatings

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HIGHLIGHTS

- The sol-gel-prepared silica incorporated into the RTV matrix demonstrated the optimal hydrophobic surface at contact angle 146°.
- Zeta potential analysis demonstrated the stability of nanoparticles at recorded average values of −41 to −50 mV.
- Some XRD peak intensities of hydrophobic coating (RTV silicone rubber/silica) coated glass differed from the neat component (RTV or silica).
- XRD differences between the neat materials and their corresponding composite demonstrate satisfactory incorporation and a cohesive layer that produced significant bonding between components.

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ABSTRACT

This works aims to investigate the influence of three different categories of silica, namely, precipitated silica, fumed silica and nanosilica prepared via sol-gel process, for hydrophobic application in this work. Nanosilica was characterised using scanning electron microscopy, Fourier transform infrared spectroscopy, particle size and zeta potential. Diluted silicone rubber (room-temperature vulcanising silicone) was also used as a matrix for these particles as (3/1) weight%; silicone rubber/silica. Cold spraying technique was applied to coat glass substrates. Fourier transform infrared analysis was applied to investigate the coating. SEM observation and particle size analysis established that the nanosize of silica is used with narrow-size distribution. Zeta potential analysis demonstrated the stability of nanoparticles at recorded average values of −41 to −50 mV. Wettability results showed that all types of silica incorporated into the silicone rubber present a hydrophobic surface. The maximum recorded value of contact angle was 146° for sol-gel-prepared silica/silicone rubber. The out findings indicated that these compounds are acceptable candidates for hydrophobic glass applications.

1. Introduction

Various industries, including biomedicine [1], filler [2], catalysis [3] and drug delivery systems [4], have shown increased interest and demand for silica nanoparticles in recent years. Particle size and uniformity exert a significant impact on the quality of nanosilica; hence, demand for silica nanoparticles with limited and monodisperse-size distribution is high. Microemulsion, flame synthesis and sol-gel processes are three traditional methods for synthesising silica [5].

Superhydrophobic (SH) film coating on substrates has been extensively investigated since the 1940s [6]. Wenzel, Cassie and Baxter [7] developed the basic idea of superhydrophobicity. Technology has advanced to the point that it can generate a wide range of useful applications, and determining optimal processes, methods and ideas is urgently necessary. Various experiments have been conducted in the last five years. The very rough leaf surface of many plants, such as lotus, spreads water as drops when observed with a microscope [8]. Water drops on a lotus leaf form beads on the surface and easily slide off [9] [10]. This phenomenon frequently occurs in a wide range of chemical substances and is often referred to as the lotus effect because of its association with the lotus leaf [11]. Choosing a low-cost manufacturing approach with optimum characteristics is an important issue in the field of superhydrophobic surfaces [6]. A significant feature in both theoretical research and commercial applications is the ability of solid surfaces to resist water [12]. Smart materials are usually used in the preparation of superhydrophobic surfaces [13].

T. Yeerken et al. produced a self-cleaning aramid fabric using a two-step coating method with a readily accessible material system consisting of polytetrafluoroethylene (PTFE) and silica and a chemical-resistant layer with contact angles ranging from totally penetrating to 130°. Others used SiO_2 nanoparticles to produce superhydrophobic coatings to minimise glass contamination. Glass substrates repel water with a contact angle of 150° with tunable adhesion after modifying it with silicone

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rubber [14]. B. N. Sahoo et al. developed a unique self-cleaning polymer composite with self-healing ability after chemical and mechanical damage utilising easily available components, such as polydimethylsiloxane (PDMS) and camphor soot particles. Self-cleaning properties have been created as a result of the optimum loading of camphor soot particles and composite coating on glass and stainless steel surfaces [15].

Y. Cheng et al.attempted to address the problem of dust accumulation on the fin surface of a mine air cooler, prepared a superhydrophobic polyurethane (SPU) emulsion from a polyurethane prepolymer made from raw-material waste cooking oil (WCO), modified the emulsion with polydimethylsiloxane and terminated amino polymer (ATP) and developed multiple nanocomposites by incorporating SPU emulsions with modified silicon carbide (APT-SiC) particles; contact and sliding angles, pull-off strength and thermal conductivity were considered with a modified filler ratio in nanocomposites; the researchers produced a superhydrophobic (polyurethane) coating with an APT-SiC particle concentration of 20% by weight; the obtained coating demonstrated high pull-off strength and excellent heat conductivity with a contact angle of 161° [16].

J. Zhu and K. Liao. reported that reducing glass surface contamination improves the performance of SiO_2 nanoparticles as a superhydrophobic coating; a glass substrate coated with a superhydrophobic surface presents adjustable adhesion after altering with PDMS and using a water contact angle of 155.1° [17].

Y. Peng et al. coated endothermic and superhydrophobic anti-icing compounds on ceramic and glass insulators and used analytically pure ingredients, such as cobalt nitrate, manganese nitrate 50% solution, copper nitrate, polyethylene glycol 200, citric acid, ammonia water and absolute ethyl alcohol, for the solar spectrum-selective endothermic coating, with CoCuMnOx as the light-absorbing pigment; three ceramic and two glass insulators demonstrated a respective increase of 13.68% and 22.96% in ice lightning voltage; glass insulators coated with anti-icing compounds provide greater protection than ceramic insulators [18]. H. T. Jaafar prepared highly water-resistant and water-resistant nano-coating by electrospinning of polymer solution (PS/DMF, PMMA/THF). It was also prepared with the addition of TiO_2 nanoparticles. They were subjected to an accelerated weathering test for 6 months. Higher contact angle to calculate the wettability of the surface was for (PS/DMF) coated specimen about (160º) [19].

Previous studies on hydrophobic surfaces showed that surface hydrophobicity typically improves and meets application conditions when the contact angle reaches 145°–165°. This work focused on common conditions in Iraq, namely, sandy and industrial environmental pollution, which cause failure of glass insulators in power transmission lines. PDMS and silicone rubber materials are widely used with different coating techniques, including cold spray, sputtering and spinning.

This work aims to prepare a hydrophobic coating that contains nanosilica and investigate the impact of silica type (fumed, precipitated and sol-gel-prepared silica) on the hydrophobicity of RTV coating on the glass substrate.

1. Materials and Methods

1.1 Materials

RTV silicone rubber type C-820 was supplied by Guo Chuang, China. Tetraethylorthosilicate (TEOS) was purchased from Sigma–Aldrich Company, USA. Silica fume type AEROSIL 200 was acquired from Evonik, Germany, whilst precipitated silica type Vulkasil C was obtained from Lanxess, Germany. Ethylene, methyl ethyl ketone and nitric acid were bought from Pronto Chemical Co., Turkey; EDUCEK, India; and Alpha Chemika, India, respectively.

1.2 Methods

Silica nanoparticles were prepared using a slightly modified sol-gel method. TEOS (2 ml) was mixed with ethanol (5 ml) in a conical flask container and magnetically stirred for 30 minutes at room temperature. Nitric acid (2.7 ml) was then added to this mixture as droplets whilst constantly stirring at 60 °C for 120 minutes until a gel is formed. The gel was then dried for 24 hours at 100 °C. Lastly, the sample was sintered in a muffle furnace for 4 hours at 600 °C [20].

SiO_2 nanoparticles (0.3 g) of fumed, precipitated, or sol-gel-prepared silica) and 99.5 ml of ethanol were ultrasonicated for 30 minutes to obtain mixture A and achieve the final coating containing a silica concentration of 33 wt. %. Meanwhile, 1 g of RTV and 50 ml of toluene are stirred for 30 min to obtain mixture B. Mixtures A and B were stirred together for 10 min to obtain a homogeneous mixture. The hardener was subsequently added and the mixture was blended for 10 minutes. The final mixture was placed in a spray pump, cold sprayed and dried at a temperature of 100 °C–120 °C.

2. Characterisation

The surface morphology of silica nanoparticles was observed using a scanning electron microscope type Zeiss, Germany with a magnification of 30–70 km at an acceleration voltage of 5 kV. Surface tension stability and particle size distribution were determined using a zeta potential and particle size analyser HORIBA model SZ-100, Japan. The particle size was measured under the following conditions: scattering angle of 90°, temperature of 25 °C and pressure of 0.89 mPa.s. The zeta potential was measured at an electrode voltage of 3.9 V and conductivity of 0.054 ms/cm in medium viscosity.

The wettability of samples was evaluated by dropping deionised water at 25 °C on the coated surface using the contact angle measuring instrument CAM 120 Crating Nano Technologies, Taiwan. A digital screen was utilised in conducting further tests, including measurement of the contact angle with monitoring software.

3. Results and Discussion

Figure 1 shows the SEM image of the prepared silica via sol-gel method. Agglomerations and packing of silica particles exhibit spherical shapes with homogenous particle sizes of approximately 20–50 nm. J. Zhu and K. Liao.demonstrated similar results when surface scanning images of nanosilica agglomerates are presented in a dense manner, thereby indicating the formation of the hydrophobic surface state [17].

Figures 2 and 3 present the SEM images of precipitated and fumed silica, respectively. Precipitated and fumed silica particles demonstrated a larger average size of 50–100 nm and looser distribution than the prepared particles. Notably, fumed silica agglomerates are arranged in chains whilst precipitated silica agglomerates present bulky particle groups.

Figure 4 illustrates the particle size distribution of (a) prepared, (b) precipitated and (c) fumed silica. Approximately 80%, 85% and 80% of prepared, precipitated and fumed silica particles show a mean particle size of 285, 164 and 159 nm, respectively. These results are inconsistent with the SEM observation because these values refer to the agglomerate size instead of particles themselves.

Figure 5 can be used to predict the dispersion stability of colloidal silica in ethanol. The prepared silica via sol-gel method presents a zeta value of −41 mV, whilst precipitated and fumed silica particles show a zeta value of −50 and −47 mV, respectively. This finding clearly indicated that precipitated silica is more stable than the other types. The analysis of zeta potential of the three types of silica demonstrated (−40 to −50 mV) that the silica prepared via sol-gel method obtains a zeta potential within the acceptable stability range [21,22]. Hence, colloids with high negative or positive zeta potential are stabilised whereas those with low zeta potentials coagulate or flocculate [23,24].

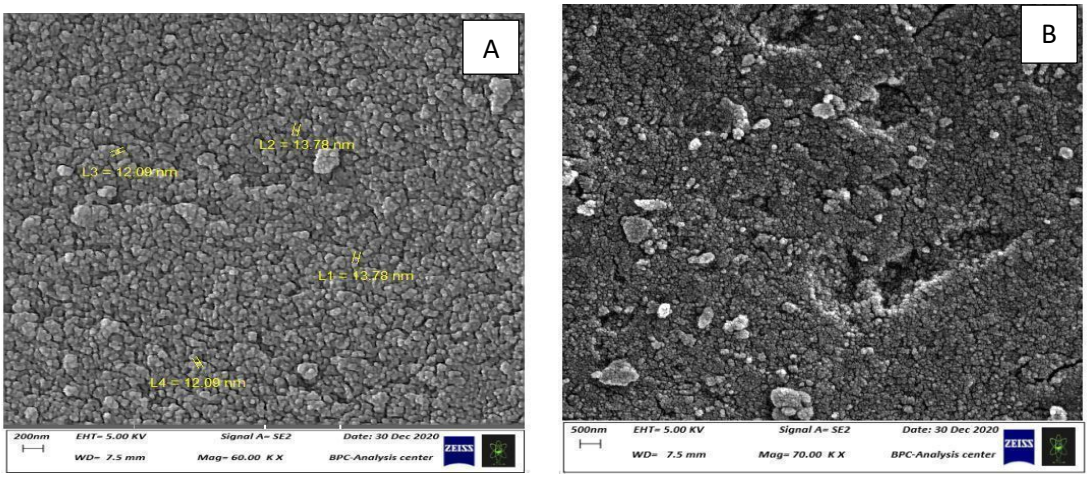

Figure 1: SEM image of silica prepared via sol-gel method at different magnifications of, a) 60 kx and b) 70 kx

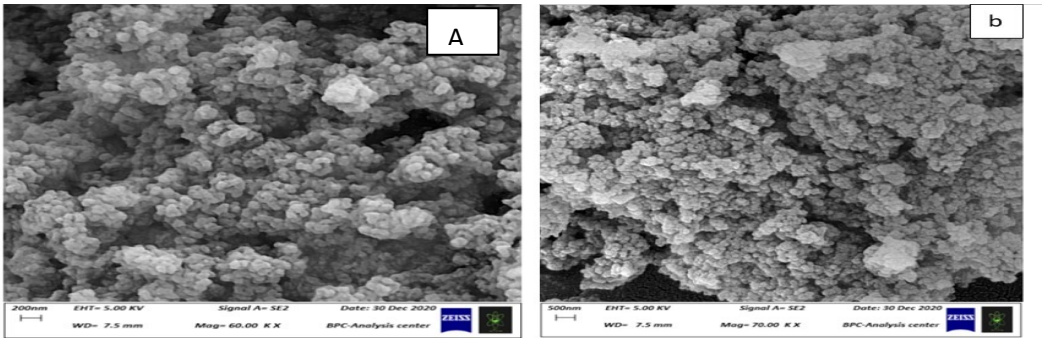

Figure 2: age of precipitated silica at different magnifications of, a) 60 kx and b) 70 kx

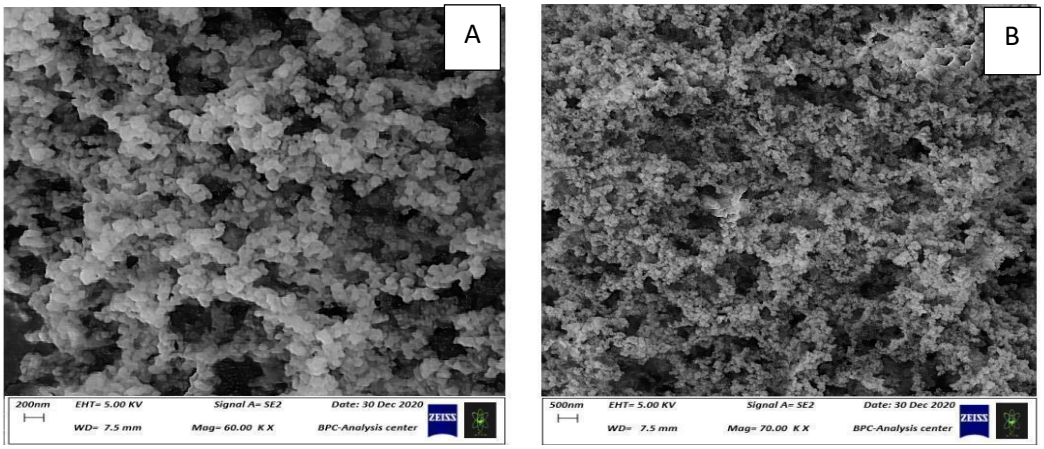

Figure 3: SEM image of fumed silica at different magnifications of , a) 60 kx and b) 70 kx

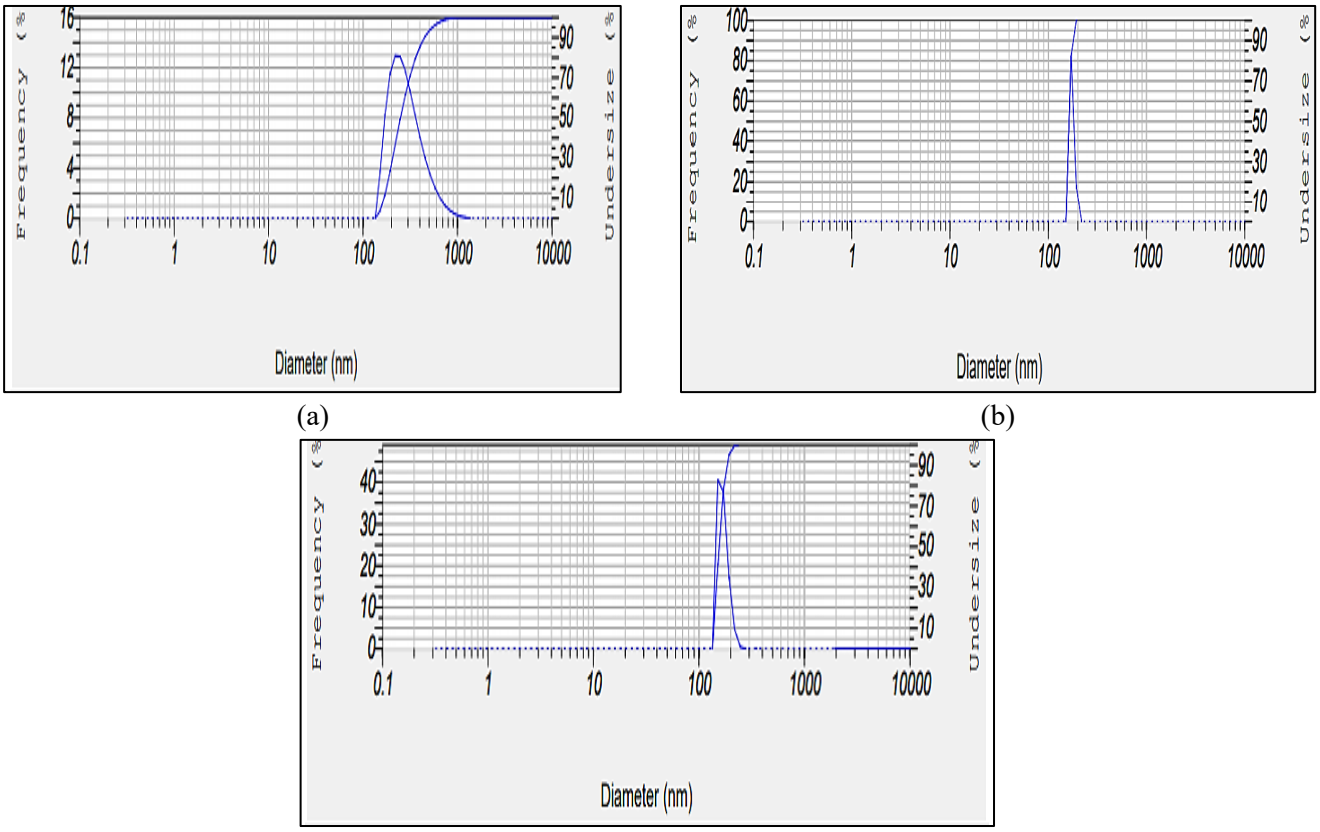

Figure 4: Particle size distribution of a) prepared, b) precipitated and c) fumed silica

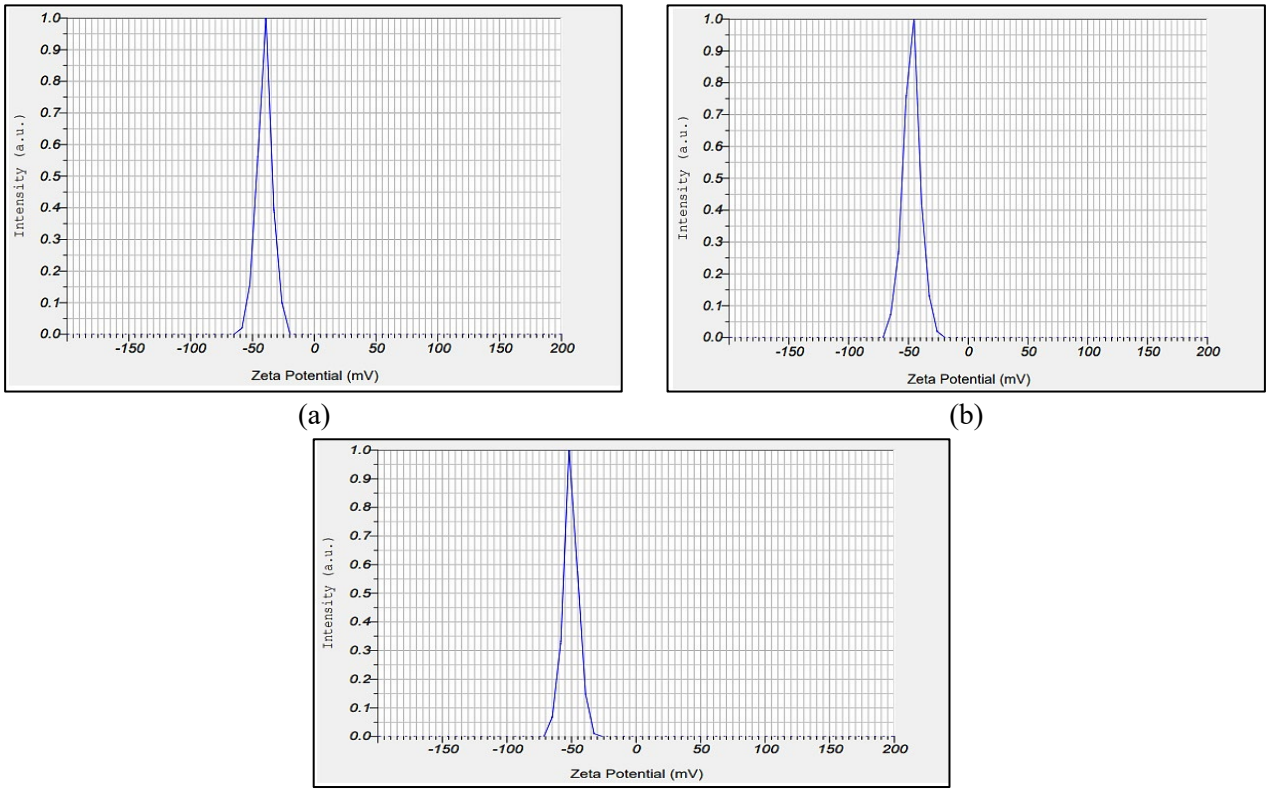

Figure 5: Zeta potential of a) prepared silica via sol-gel method, b) precipitated silica and c) fumed silica

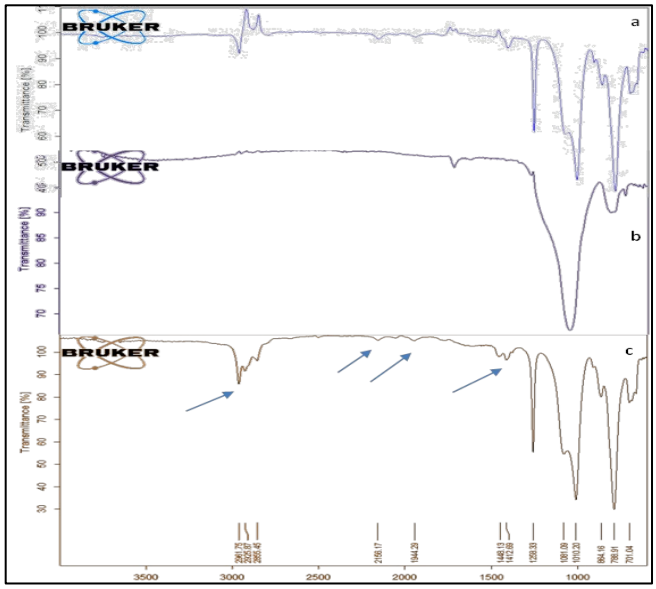

Figure 6: FTIR analysis of a) RTV silicone rubber, b) sol-gel-prepared silica and c) their composite

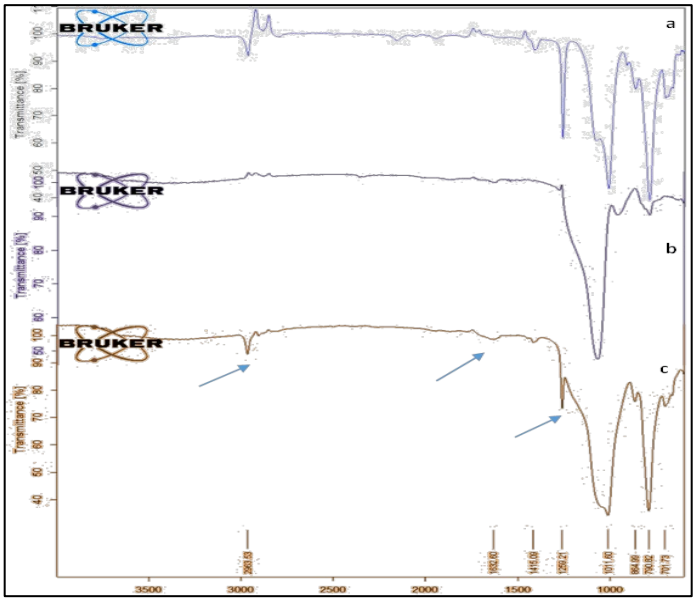

Figure 7: FTIR analysis of a) RTV silicone rubber, b) precipitated silica and c) their composite

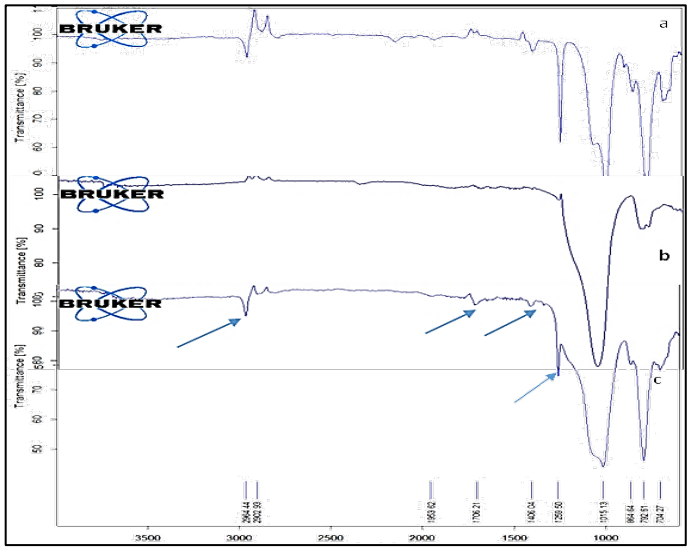

Figure 8: FTIR analysis of a) RTV silicone rubber, b) fumed silica and c) their composite

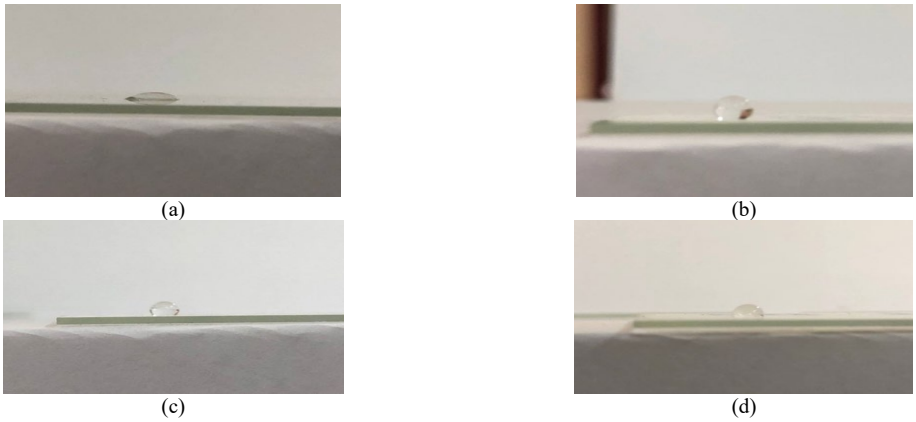

Figure 9: Wettability of a) uncoated surface and RTV with b) prepared, c) precipitated and d) fumed silica

Figures 6, 7 and 8 present the FTIR analysis of (a) neat RTV silicone rubber, (b) neat silica and (c) their composite as well as the effect of adding sol-gel-prepared, precipitated and fumed silica to the RTV, respectively.

Some peak intensities of silicone rubber/silica differentiated from that when it was neat (RTV or silica). As shown in Figure 6, new peaks appeared at wave numbers 2957, 2156, 1944 and 1448 cm−1. Figure 7 also shows that different peaks appear at 2963, 1632, 1415 and 1011 cm−1. Meanwhile, new peaks were observed at 2964, 1953, 1706 and 1406 cm−1 in Figure 8. Differences between neat materials and their corresponding composite demonstrate satisfactory incorporation and a cohesive layer that produced significant bonding between components [25, 26].

Figure 9 shows the water drops on (a) uncoated glass and glass coated with RTV silicone rubber with 33%wt of (b) sol-gel-prepared, (c) precipitated and (d) fumed silica. It was noticed the different wettability of coated surface against uncoated, the first seems like hydrophobic surface. Due to this naked eye observation, the contact angle was determined as shown in Figure 10. It was 146.9º, 128º, and 119º for RTV coating with 33 wt. % of prepared silica precipitated silica and fumed silica. Hence, the sol-gel-prepared silica exhibited the optimal hydrophobic surface with RTV rubber. SEM images revealed optimal hydrophobic properties despite the agglomeration and particle size of the prepared silica. These findings are similar to the results of J. Zhu and K. Liao [17].

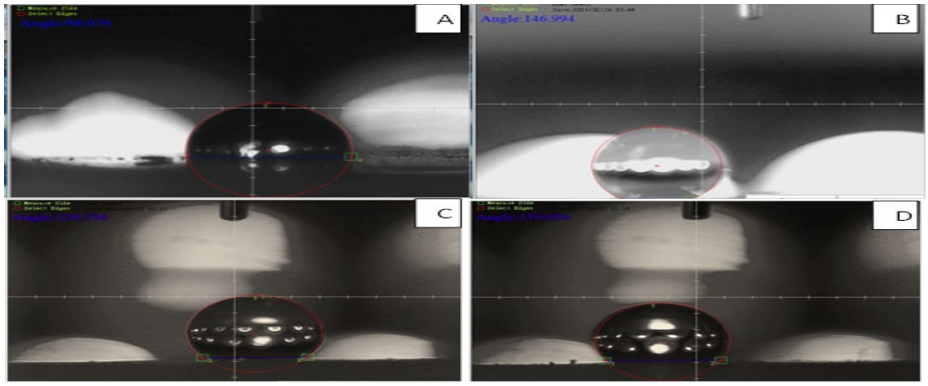

Figure 10: Contact angle of a) uncoated surface RTV with b) sol-gel-prepared, c) precipitated and d) fumed silica

4. Conclusions

The following conclusions can be drawn from this study:

- Different types of silica incorporated in the RTV matrix were successfully used as a hydrophobic coating on glass substrates and exhibited different contact angles in the range of 90°–46°.
- The sol-gel-prepared silica incorporated into the RTV matrix demonstrated the optimal hydrophobic surface at 146°.
- The increase in silica content led to the increase of contact angles in some concentrations.
- The stability of silica through diluted RTV for coating application was electrically stable.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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