Antimicrobial polymers: Antibacterial efficacy of silicone rubber–titanium dioxide composites

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Abstract
Control and reduction of microorganism infections in high-risk environments is up to date a challenge. Traditional techniques imply several limitations including development of antibiotics resistance and ecotoxicity. Then, polymers functionalized with photocatalysts arise as a promising solution against a broad spectrum of microorganisms found at, e.g. sanitary, food, and medical environments. Here, we present silicone rubber–TiO2 composites as novel antibacterial polymers. Four different types of composites with different TiO2 contents were produced and analyzed under UV irradiation and dark conditions in terms of particle distribution, chemical composition, photocatalytic activity, wettability, and antibacterial efficacy against Escherichia coli. Under UV irradiation, antibacterial sensitivity assay showed a 1000 times reduction of colony forming units after 2 h of light exposure so that the antibacterial ability of silicone–TiO2 composites was proved. Photocatalytic activity assessment suggested that reactive oxygen species induced by photocatalytic reaction at TiO2 particles are the main cause of the observed antibacterial effect. Scanning electron microscopy indicated no topographical damage after UV exposure. In addition, chemical analysis through Raman and X-Ray photoelectron spectroscopies demonstrated the stability of the silicone matrix under UV irradiation. Hence, the current work presents silicone–TiO2 composites as stable nonspecific antibacterial polymers for prevention of infections at multiple high-risk environments.

Keywords
Antibacterial polymers, silicone rubber, titanium dioxide (TiO2), composites, antibacterial activity

Introduction
Bacterial infections are up to date a primary human death cause. In consequence, multiple antibacterial solutions have been developed in order to prevent microorganism attachment and growth in environments with high risk of infection. So far disinfectants such as hypochlorite, hydrogen peroxide, or quaternary ammonium compounds are repeatedly applied, but their short-term effect and environmental safety limit their use.1-4 Then, antibacterial polymers arise as promising materials for long-term effective infection prevention at, e.g. sanitary facilities, food packaging, hospital environments, and water purification systems.5-9

Nowadays common antibacterial polymers are based on either biocidal polymers or silver compounds. The former are mostly polymers with uniform mechanical properties whose chains have intrinsic antibacterial activity through, e.g. the addition of quaternary ammonium compounds or halogenic components which in contact with the surface of microorganisms induce cell destruction.1,10 The latter primarily comprise polymers coated with silver-based compounds which in solution release silver ions already known for their fast antibacterial response, biocompatibility and high antibacterial effectiveness against a broad spectrum of microorganisms.11-14 Nevertheless, the slow response and no biocompatibility of most biocidal polymers as

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well as frequent allergic reactions and ecological problems caused by silver ions lead to photocatalytic compounds as a solution for safe antibacterial polymers.\textsuperscript{15–17} Among them, titanium dioxide (TiO\textsubscript{2}) emerges as a promising antibacterial agent for functionalization of polymers.

TiO\textsubscript{2} is a metal oxide semiconductor with a desirable photocatalytic efficiency, chemical stability, low toxicity, and acceptable cost.\textsuperscript{18,19} Antibacterial activity of TiO\textsubscript{2} is based on its intrinsic ability to induce the production of reactive oxygen species (ROS) in the presence of oxygen and water under UV irradiation. ROS cause oxidative degradation of biological structures followed by microorganism death.\textsuperscript{20} Therefore, TiO\textsubscript{2} is able to exert its antibacterial effect in close proximity to target microorganism without biocide release.\textsuperscript{20,21}

Up to date, TiO\textsubscript{2} as antibacterial agent has been mainly applied as coating compound of, e.g. polyester fabrics, polyetheretherketone (PEEK), and polyurethane complexes.\textsuperscript{22–24} Although TiO\textsubscript{2} coatings demonstrated high bactericidal activity and efficiency, their high costs, inhomogeneous mechanical properties and demanding technology necessary for surface treatments lead to TiO\textsubscript{2}-based composites as an alternative.\textsuperscript{15} Previous works of this group assessed polypropylene, polyamide 6, and polyamide 12 as thermoplastic matrices for TiO\textsubscript{2}-based antibacterial composites.\textsuperscript{25,26} Despite the studies demonstrated an intense antibacterial activity under UV irradiation, all matrices showed strong degradation within the first 24 h of UV exposure, with clear evidence of chain scission and topographical damage. In order to avoid aforementioned drawbacks, the primary aim of this work was to develop and evaluate thermoset–TiO\textsubscript{2} composites against Escherichia coli under UV irradiation. Medical-grade silicone rubber was chosen as model polymer matrix given that its exceptional chemical and thermal stability in addition to its biocompatibility considering future applications at sanitary, medical, and food environments.\textsuperscript{27}

### Experimental section

#### Materials

Medical-grade silicone rubber tested according to USP Class VI (Silpuran 2430\textsuperscript{8}, room temperature vulcanization, two-components system) was supplied from Wacker Chemie AG (Germany) whereas nanostructured TiO\textsubscript{2} powder (Aeroxide\textsuperscript{8} P25 TiO\textsubscript{2}) with an average primary particle size of 21 nm was kindly provided by Evonik Degussa GmbH (Germany). Methylene blue (MB) for photocatalytic activity assessment and Tween 80\textsuperscript{8} used during microbiological assay were acquired from Merck (Germany). For antibacterial activity evaluation, samples were tested against \textit{E. coli} (Wildtype K12, DSM 498). Agar-agar, yeast extract, tryptone/peptone, and salts were supplied by Carl Roth GmbH + Co. KG (Germany).

#### Samples preparation

Composite samples were prepared by manual blending of silicone rubber with TiO\textsubscript{2} powder. In short, a specific amount of TiO\textsubscript{2} powder was blended with component A of the silicone rubber system until a homogeneous compound was obtained. Subsequently, component B was added and uniformly incorporated to the former compound. Finally, the obtained composite was degaussed for 5 min under vacuum and then poured onto an aluminum mold. Silicone rubber vulcanization was performed at 200°C for 45 min followed by a heat treatment at 100°C for 4 h, in line with silicone supplier instructions. Round platelets of 15 mm in diameter and 0, 2, 5, and 10 w/w% of TiO\textsubscript{2} were prepared.

Before every characterization assay, samples were thoroughly washed with 70% isopropanol, rinsed with distilled water, dried, and autoclaved at 121°C for 15 min.

#### Scanning electron microscopy

Surface topography as well as dispersion of TiO\textsubscript{2} particles in silicone rubber matrix was characterized using a scanning electron microscope (Hitachi S3500-N, Japan) operating at an accelerating voltage of 30 kV and fitted with an energy dispersive X-ray spectroscopy (EDX) accessory for further composition analysis. The samples were sputter coated with gold before SEM imaging. Micrographs were taken at low and high magnification in order to have a detailed overview of different batches of samples prepared during this study. Twenty-four-hour-UV irradiated and non-UV-irradiated samples of pure silicone and silicone–TiO\textsubscript{2} composites were analyzed.

#### Elemental and molecular analysis

Chemical analysis of 24 h-UV-irradiated and non-UV-irradiated samples of pure silicone (0% TiO\textsubscript{2}) and silicone–TiO\textsubscript{2} (10% TiO\textsubscript{2}) was performed through X-ray Photoelectron Spectroscopy (XPS) and Raman spectroscopy. XPS spectra were acquired with a Leybold-Heraeus LHS 10 XPS system in ultra-high vacuum at a pressure below 5 × 10\textsuperscript{−9} mbar hosting a nonmonochromatic MgK\textsubscript{α}-source (1253.6 eV). XPS samples were fixed on the specimen holder with a vacuum-compatible copper foil adhesive tape. The spectra were recorded at a constant pass energy mode set to 100 eV and a full width at half maximum of ~0.1 eV. The C 1s (284.38 eV) peak corresponding to adventitious carbon was used as energy reference to compensate
energy shifts due to charging. Shirley backgrounds were subtracted from all spectra and core level spectra were fitted by Gaussian/Lorentzian functions.

For Raman spectroscopy, a Senterra Raman spectrometer (Bruker Corporation, USA) equipped with a 40 mW 488 nm laser and 50× magnification objective was used. Besides baseline correction through Rubber Band method, each Raman spectra was recorded with 1 s of integration time and 100 coadditions. Three specimens per sample were analyzed.

**Photocatalytic activity assessment**

Photocatalytic activity of pure silicone and silicone–TiO₂ samples was evaluated by means of MB discoloration assay according to DIN 52980. Briefly, specimens were arranged in 24-multiwell plates filled with 2 ml of 10 μmol aqueous MB solution. Subsequently, one group of samples was placed under a UV lamp (365 nm, 15 W, UV-A A15, Vilber, France) and continuously irradiated for 4 h whereas a second group was kept under dark conditions for the same amount of time. Then, MB changes were monitored through light absorbance variations at 620 nm, which were registered by an UV–Visible spectrometer (Multiscan FC, Thermo Scientific, Germany). The relative absorbance of MB was calculated with following equation

\[
\text{Methylene Blue Relative Absorbance (\%) = } \frac{\text{Ref}_{\text{abs}} - \text{S}_{\text{abs}}}{\text{Ref}_{\text{abs}}} \times 100
\]

where \( \text{Ref}_{\text{abs}} \) is the absorbance of MB solution not in contact with samples and \( \text{S}_{\text{abs}} \) is the absorbance of MB solution in contact with silicone and silicone–TiO₂ samples. Positive values of relative absorbance indicate prevalence of MB reduction whereas negative values indicate prevalence of MB oxidation. Therefore, as TiO₂ tends to reduce MB molecule, positive values of relative absorbance indicate predominance of TiO₂ photocatalytic activity.

Photocatalysts as TiO₂ normally undergo a deactivation process induced by UV irradiation. Thus, in order to assess such photocatalyst deactivation, samples were continuously preirradiated with UV light during specific periods of time under dry conditions. Subsequently, samples were subjected to above-mentioned MB protocol in order to measure remaining photocatalytic activity.

**Wettability**

The effect of TiO₂ particles on wettability was assessed through water contact angle analysis according to sessile droplet method under ambient conditions. One group of samples was irradiated with UV light for 24 h whereas a second group was kept under dark conditions for the same amount of time. Two microliter droplets of deionized water were pumped onto samples surfaces and contact angle was further obtained by analysis system OCA 20 (Dataphysics Instruments, Germany). Measurements were performed three times per sample and average values were reported.

**Antibacterial sensitivity assay**

Antibacterial effect of silicone and silicone–TiO₂ samples was evaluated against *E. coli* according to DIN 13697. Samples were inoculated with 10 μl of 3.5 × 10⁸ CFU/ml *E. coli* in PBS-0.1% Tween susp. Then, specimens were irradiated with UV light (365 nm) for 2 h at room temperature in order to induce photocatalytic response and subsequently thoroughly washed with 1 ml of PBS-0.1% Tween. Fifty microliters of former suspension was pipetted and dissolved in 450 μl of fresh PBS. These steps were repeated with inoculated specimens kept under dark conditions for 2 h. After that, 100 μl of each bacterial PBS suspension of each specimen was streaked and uniformly spread over LB-Bouillon agar in Petri dishes which were then incubated for 24 h at 37°C. Finally, colony forming units (CFU) were counted and evaluated.

**Results and discussion**

**Surface topography**

Figures 1 and 2 show SEM micrographs of pure silicone and silicone–TiO₂ samples non-UV irradiated and UV irradiated, respectively. An overlap of Ti-EDX mapping with SEM pictures of non-UV-irradiated samples is displayed, which clearly suggests a uniform distribution of TiO₂ particles at all samples coexisting with agglomerates of around 20 μm possibly produced by defective manual stirring. EDX mapping also indicates that the higher the TiO₂ content, the higher the number of agglomerates detected. However, although such presence of multiple agglomerates, SEM micrographs reveal almost no exposed TiO₂ agglomerates at samples surface. Additionally, UV irradiation seems to have no noticeable effect on surface topography in accordance with Figures 1 and 2. Such composite response contrasts with previous results of this group, which demonstrated a strong observable degrading effect of UV light on most thermoplastics assessed as polymer matrices.

**Elemental and molecular analysis**

XPS survey spectra of 0% TiO₂ and 10% TiO₂ samples are shown in Figure 3. Strikingly, survey spectra as well as core level spectra of 10% TiO₂ specimens lack of
most intensive TiO$_2$ photoelectron lines which normally are found at 458.5 eV (Ti 2p$_{3/2}$) and 464 eV (Ti 2p$_{1/2}$). Hence, these results suggest the absence of TiO$_2$ particles at samples surface within the first 10 nm according to average analysis depth of XPS.\textsuperscript{31} Furthermore, even though SEM analysis did not prove any topographical change before and after UV irradiation, XPS core level spectra of Si 2p peak (Figure 4) contrastingly demonstrate silicone rubber oxidation, which is apparently caused by UV light and ROS induced by TiO$_2$-photocatalytic reaction. Figure 4 shows Si 2p peaks of 0% TiO$_2$ and 10% TiO$_2$ samples before and after 24 h of UV irradiation. As it can be seen in Figure 4, Si 2p peaks of pure silicone as well as 10% TiO$_2$ samples are shifted to higher binding energies after UV irradiation. Such peak shifting indicates that oxidation of silicone rubber takes place, a phenomena also observed after laser irradiation of silicone rubber samples during Armyanov et al. studies.\textsuperscript{32} However, while pure silicone Si 2p peak is shifted +0.05 eV, a +0.9 eV shift is recorded at 10% TiO$_2$ samples after irradiation suggesting a stronger oxidation. Deconvolution after curve fitting explains this effect. It is known that the energy of Si 2p peak is determined by Si position in the polymer chain as well as its oxidation degree. When Si atoms of silicone rubber are bound to two oxygen atoms (Si-(O)$_2$), Si 2p peak is at 101.8 eV; three oxygen atoms (Si-(O)$_3$), 102.6 eV; and four oxygen atoms (Si-(O)$_4$), 103.3 eV.$^{32,33}$ As in crosslinked silicone chains many Si-oxidation states could be found, Si 2p peak results in the convolution of Si-(O)$_x$-associated peaks. The analysis of deconvolved curves first indicates that Si 2p peak is resolved into two main components (Figure 4): Si-(O)$_2$ at 101.7 eV and Si-(O)$_3$ at 102.6 eV. Si-(O)$_4$ at 103.3 eV remains negligible for almost all samples except irradiated 10% TiO$_2$ specimens. After UV irradiation there is a clear increase of the area under Si-(O)$_3$ deconvoluted curves from 8 to 26% at 0% TiO$_2$ samples, and from 13 to 36% at 10% TiO$_2$ samples, indicating a clear oxidation of silicone rubber. Nevertheless, as after irradiation no intensity variation of Si-(O)$_2$ peak is recorded, it can be assumed that oxygen–silicon–oxygen bondings at the main chain were not broken so that exceptional stability of silicone rubber under UV irradiation was maintained. Hence, silicone rubber oxidation might be primarily attributed to split of methyl-side groups followed by oxygen bonding to remaining Si to produce an enrichment in nonstoichiometric oxygen deficient silicone chain.\textsuperscript{32} It must be noted that after irradiation Si-(O)$_3$ is significantly more intensive for 10% TiO$_2$ than for 0% TiO$_2$ samples, which suggests that ROS induced by

![Figure 1. SEM micrographs overlapped with EDX mapping of titanium (green dots) of (a) 0% TiO$_2$, (b) 2% TiO$_2$, (c) 5% TiO$_2$, and (d) 10% TiO$_2$ samples with no previous UV irradiation.](image-url)
photocatalytic reaction at TiO$_2$ intensify oxidation of silicone rubber.

Figure 5 shows Raman spectra of 0 and 10% TiO$_2$ samples before and after UV irradiation while Table 1 specifies main bands observed as well as their corresponding vibration mode. Typical silicone rubber bands are present at both spectra, whereas characteristic bands of TiO$_2$ P25 at 513 and 637 cm$^{-1}$ arise at after incorporation of TiO$_2$ particles. Both spectra lack of new bands or band shifting after UV irradiation, which demonstrates the absence of strong chemical modifications. Though, after UV irradiation, it must
be noted that the intensity of all silicone-related bands is diminished. Such effect is greater at 489 cm\(^{-1}\) (O–Si–O stretching) and 710 cm\(^{-1}\) (Si–C). These variations seem to be more pronounced for 10% TiO\(_2\) samples where, after UV irradiation, decreases of 24 and 22% at 489 and 710 cm\(^{-1}\) bands, respectively, are two times bigger than intensity decreases undergone by the same bands at pure silicone samples. Therefore, it can be further assumed that silicone rubber oxidation by UV light and ROS induces Raman intensity decrease of silicone-related bands.

**Photocatalytic activity**

Given that antibacterial effects of silicone–TiO\(_2\) composites might be principally due to oxidative degradation by ROS, photocatalytic activity was measured through MB discoloration assay at nonirradiated and irradiated samples. Many authors report that MB is mainly reduced by TiO\(_2\) under UV irradiation, which is observed as solution discoloration.\(^{36,37}\) Results are shown in Figure 6 where it can be clearly seen that, without UV light, samples lack of photocatalytic activity. Contrastingly, under UV irradiation, MB is discolored by composite samples where such effect linearly increases with higher contents of TiO\(_2\) particles, therefore suggesting ROS as primary cause of MB discoloration.

It must be particularly noted that even though ROS might be the main cause of MB discoloration, final relative absorbance is further influenced by strong absorption of MB on silicone rubber in addition to
oxidation of leuco-MB, the reduced form of MB molecule, by UV light. Latter phenomenon is likely to mask real photocatalytic activity which might be higher without such influence, as occurs with 2% TiO$_2$.\textsuperscript{38,39}

Photocatalysts as TiO$_2$ normally undergo a deactivation process over time under UV irradiation according to many works.\textsuperscript{40,41} To study this phenomena, samples were deactivated through preirradiation with UV light and subsequently subjected to ordinary MB assay in order to evaluate remaining photocatalytic activity of silicone–TiO$_2$ composites along the time and to determine optimal analysis time for further characterizations. Results shown in Figure 7 clearly demonstrate deactivation of the photocatalyst. Due to aforementioned oxidation of leuco-MB by UV light, a proper quantitative analysis cannot be performed.

Nevertheless, it can be observed that 5 and 10% TiO$_2$ samples lose $\approx$50% of apparent initial photocatalytic activity after 1 and 2 h of UV preirradiation, respectively, whereas after 24 h such decrease reaches values around 90%. Thus, to ensure photocatalytic activity at TiO$_2$ particles during characterization of samples, duration of assays was restricted to 24 h of UV irradiation.

It is worth to mention that UV light power applied in this work was around 50 times more intensive than UV light power at normal environments, so that longer photoactive times might be expected under ordinary lighting conditions.

### Wettability

Water contact angle in function of TiO$_2$ content of irradiated and nonirradiated samples is shown in Figure 5.

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**Table 1.** Raman analysis. Raman bands at 0% TiO$_2$ and 10% TiO$_2$ samples nonirradiated and irradiated with UV light.\textsuperscript{34,35}

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**Figure 5.** Raman spectra of (a) 0% TiO$_2$ and (b) 10% TiO$_2$ samples irradiated and nonirradiated with UV light. Spectra were obtained with a laser operating at $\lambda$ 488 nm. For color interpretation, the reader is referred to the web version of this article.
As it can be seen, nonirradiated samples undergo a contact angle decrease from 111° to 103° with higher contents of TiO₂, whereas samples UV irradiated demonstrate an increase of contact angle with respect to nonirradiated ones. Both phenomena must be explained separately.

As it was previously proved through XPS, silicone rubber is oxidized by UV light and ROS. Such oxidation usually induces contact angle decrease at silicone rubber, according to what many authors report. 42–44 However, it must be noted that decreases recorded up to date imply the use of extreme conditions in order to produce contact angle reductions, which are primarily due to significative increments of Si-(O)₄. For instance, Youn et al. reported a 10° water contact angle decrease after 5000 h of exposure to UV light λ 313 nm, whereas Olah et al. observed a reduction by 4° after 36 h under UV light λ 185 nm and 55 ppm ozone atmosphere. 42,44 Both studies also showed XPS spectra with Si-(O)₄ peaks at ~103.3 eV with intensities and areas of the same order of magnitude as Si-(O)₂ peak which indicated a marked oxidation of silicone. Then, as in this work no extreme conditions were applied in addition to the lack of Si-(O)₄ peaks at 103.3 eV after UV irradiation, it can be assumed that any variation of contact angle was not caused by oxidation of silicone rubber.

In order to obtain droplet images, contact angle measurement necessarily implies the use of a light source which, besides visible light wavelengths, emits a portion of UV-A spectra. Given that the relatively high quantum efficiency of TiO₂, few photons with enough energy emitted by the light source of the device are suitable to excite electrons at TiO₂ particles. 45 Therefore, ROS are subsequently produced during the contact angle measurement and, therefore, induce the observed temporal hydrophilic effect at nonirradiated samples. Then, when considering contact angle dependency on TiO₂ content at nonirradiated samples as shown in Figure 8, in addition to the absence of such response after 24 h of UV irradiation, it can be concluded that contact angle variations are primarily caused by ROS which after 24 hours of UV irradiation are not anymore detected due to aforementioned intrinsic photocatalyst deactivation process.

Antibacterial sensitivity assay

Figure 9 shows the results of antibacterial sensitivity assay, which clearly demonstrates that silicone–TiO₂ composites have antibacterial activity under UV light
and that increased amounts of TiO$_2$ particles lead to a lower surviving rate of bacteria. As it can be seen, with 10% of TiO$_2$ content 1000 times reduction of CFUs per milliliter was obtained after 2 h of incubation under UV irradiation. Contrastingly, results under dark conditions indicate less than 10 times reduction of CFUs per milliliter at all samples proving the absence of photo-induced antibacterial activity in addition to a slight intrinsic antibacterial activity of silicone rubber. Hence, it can be assumed that silicone–TiO$_2$ composites exert antibacterial effect under UV irradiation and that such effect is primarily due to ROS produced by photocatalytic reaction at TiO$_2$ particles.

**Conclusion**

Antibacterial polymers are nowadays an effective solution against recurrent infections. Silicone–TiO$_2$ composites arise as a promising and technologically not demanding approach against a broad spectrum of microorganisms. In this work it was shown that ROS released from material bulk under UV light exerted an antibacterial effect against *E. coli* for specific periods of time. This effect was shown to be more intensive with higher contents of TiO$_2$. Furthermore, silicone rubber matrix demonstrated to be resistant against UV light and ROS. Therefore, our study clearly suggests silicone– TiO$_2$ composites as exceptionally stable antibacterial polymers.

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**References**

42. Youn B-H and Huh C-S. Surface characterization of silicone polymer used as an outdoor insulator by the measurement of surface voltage decay. Surf Interface Anal 2002; 33: 954–959.