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# Developing Self-Cleaning Photocatalytic $TiO_2$ Nanocomposite Coatings

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## ABSTRACT

Photocatalytic coatings with self-cleaning properties are becoming increasingly more popular due to the increased awareness of the importance of cleaning and the associated high cost of cleaning supplies and services. This research investigated self-cleaning photocatalytic polydimethylsiloxane (PDMS)/titanium dioxide ($TiO_2$) nanocomposite coatings and focused on selecting the optimal $TiO_2$ phase and concentration. To date, the comparison of the different $TiO_2$ phases as a nanocomposite coating has not been sufficiently considered. PDMS/$TiO_2$ nanocomposite coatings with three nanomaterial (NM) samples (an anatase, rutile, and mixed phase) and three concentrations of $TiO_2$ (0.6, 1 and 3 w/v%) were prepared, applied to glass slides by dip coating, and tested with respect to hydrophobicity, surface stability, antifogging, and photocatalytic properties. It was found that a stable hydrophobic coating with the optimal photocatalyitc performance was produced with 3 w/v% anatase $TiO_2$.

## KEYWORDS

Hydrophobic, Nanocomposite, Photocatalytic Coating, Polydimethylsiloxane, Self-Cleaning, Titanium Dioxide Nanomaterials

## INTRODUCTION

Surface coatings are often used to improve or introduce desired properties onto substrates of components in many industries such as the food (Aresta et al., 2013; Singh et al., 2017), cosmetic (Dréno et al., 2019), automotive (Ali et al., 2016; Coelho et al., 2012; Shafique & Luo, 2019), medical (Nasimi & Haidari, 2013; Rai et al., 2019), environmental (Pathakoti et al., 2018), electronics (Magdassi et al., 2010), and marine (Silva-Bermudez & Rodil, 2013; Tong et al., 2022) industries. Lately, advanced photocatalytic and hydrophobic surface coatings are being developed due to the desirable self-cleaning and antifogging properties which can be beneficial in many applications such as solar cells, windows (Adachi et al., 2018; Lan et al., 2013; Syafiq et al., 2018; Zhao & Lu, 2021), and optical lenses and in the automotive industry (Chemin et al., 2018).

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The self-cleaning ability of coatings can be a result of hydrophobicity (Banerjee et al., 2015; Benedix et al., 2000). Hydrophobic surfaces have low wettability, and contact angles of water droplets are around 100° or greater. When relying on hydrophobicity, self-cleaning coatings provide the benefit of reducing cleaning costs and conserving time and water due to the lotus leaf effect they create (Benedix et al., 2000; Rios et al., 2009). Presently, water scarcity is detrimentally affecting billions of people, and as such, water conservation is quickly becoming an international priority, with it being currently the 11th Sustainable Development Goal set out by the United Nations.

Hydrophobic surfaces can also contribute to high-performance antifogging properties. Antifogging coatings improve the optical performance of products since the substrate is always left optically clear (Chemin et al., 2018). Since the property of antifogging is achieved by having a coating with a surface tension that prevents the formation of stagnant water and water bubbles on a surface, the two properties of self-cleaning and antifogging can be achieved together with superhydrophobic coatings (Garlisi & Palmisano, 2017). Common drawbacks of current antifogging coatings include their limited lifetime, increased surface tension over time which leads to higher surface contamination, and a low surface stability (Chemin et al., 2018).

Besides hydrophobicity, photocatalysis can also result in the self-cleaning of surfaces (Fujishima et al., 2008; Nakata & Fujishima, 2012; Parkin & Palgrave, 2005; Ragesh et al., 2014). When photocatalytic semiconductors such as titanium dioxide ($TiO_2$), zinc oxide (ZnO), and nickel oxide (Moura & Picão, 2022) are irradiated with ultraviolet (UV) light, "electron-hole" pairs are formed and the holes cause oxidation whilst the electrons form the reduction system. From oxidation, hydroxyl radicals are created from oxidised hydroxide ($OH^-$) and water molecules. From the reduction system, peroxyl groups are generated from the dioxygen ($O_2$) found in the atmosphere (Bourikas et al., 2014; Jang et al., 2001; Lan et al., 2013). These hydroxyls and peroxyl groups, termed as reactive oxygen species (ROS), give rise to self-cleaning effects which degrade both organic and inorganic matter into safe compounds such as carbon dioxide and water (Bourikas et al., 2014; Jang et al., 2001; Lan et al., 2013; Tavares et al., 2014). Materials such as $TiO_2$ obtain photocatalytic effects in the nanometric range due to the high surface area to volume ratio (Strauss et al., 2014). These smaller sized nanomaterials (NMs) exhibit better photocatalytic effects (Moura & Picão, 2022; Wang et al., 2019) since the energy needed by the charge carriers is proportional to the NM size (Lan et al., 2013; Wang et al., 2019).

$TiO_2$ has the ability of heterogeneous photocatalysis, whereby $TiO_2$ in the solid state reacts with media which are in either the liquid or the gas state (Kumar et al., 2021; Yasmina et al., 2014) and therefore can have self-cleaning capabilities (Garlisi & Palmisano, 2017; Imran et al., 2015; Nam et al., 2019; Panutumrong et al., 2015; Syafiq et al., 2018; Yasmina et al., 2014). Jang et al. (2001) studied the photocatalytic properties of $TiO_2$ nanoparticles using methylene blue dye and found that the photocatalytic ability was inversely proportional to NM size and directly proportional to anatase fraction of a mixed phase sample. Furthermore, $TiO_2$ NMs provide benefits over other photocatalytic semiconductors including their low toxicity, high recyclability, and great chemical stability which makes them desirable for practical applications (Haider et al., 2019; Linden & Mohseni, 2014; Racovita, 2022; Shafaamri et al., 2020; Wang et al., 2019).

Research suggests that the phase composition of the $TiO_2$ can have an influence on the photocatalytic behaviour of the final coating and thus should be taken into consideration (Jang et al., 2001; Lan et al., 2013; Sakthivel et al., 2006). $TiO_2$ has three phases – anatase, rutile, and brookite – each of which has specific behaviour and properties (Racovita, 2022). The anatase and rutile phases are more commonly used in research due to the pair being the cheapest, more abundantly found, and most effective photocatalysts (Linden & Mohseni, 2014; Shafaamri et al., 2020; Wang et al., 2019). Furthermore, most research accepts that the anatase phase has the best photocatalytic performance (Augustynski, 1993; Jain & Vaya, 2017; Jang et al., 2001; Lan et al., 2013; Tayade et al., 2007). However, some research has found that a mixed phase of both anatase and rutile can lead to higher photocatalytic performance (Farbod & Khademalrasool, 2011). For example, while investigating the effect of particle size of synthesised $TiO_2$ NMs, it was found that a mixed phase $TiO_2$ NM with 71.5% of the phase being anatase and the rest rutile had the highest

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