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Synthesis and Structural Properties of (PS–PC/Co_2O_3–SiC) Nanocomposites for Antibacterial Applications

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The present work aims to fabricate the polystyrene (PS)–polycarbonate (PC)/cobalt (II) oxide nanoparticles (Co_2O_3 NPs)–silicon carbide nanoparticles (SiC NPs) nanocomposites' films to use in different antibacterial applications. The structural properties and antibacterial activity of (PS–PC/Co_2O_3–SiC) nanocomposites are studied. The structural properties include data of field emission scanning electron microscopy (FE–SEM) and optical microscopy (OM). The field emission scanning electron microscopy (FE–SEM) and optical microscopy (OM) confirm that the (Co_2O_3/SiC) NPs are distributed uniformly throughout the PS/PC blend. The results of antibacterial testing show that the diameter of inhibition zone increases with an increase in the (Co_2O_3/SiC) NPs' content. The diameters of inhibition zones for the gram-negative bacteria (*Salmonella*) are bigger than the diameters of the inhibition zones for the gram-positive bacteria (*Staphylococcus aureus*). The final results indicate that the (PS–PC/Co_2O_3–SiC) nanocomposites' films have good antibacterial activity.

Цю роботу спрямовано на виготовлення нанокомпозитних плівок з полістиролу (ПС)–полікарбонату (ПК)/наночастинок оксиду Кобальту (II) (Co_2O_3 НЧ)–наночастинок карбіду Силіцію (SiC НЧ) для використання в різних антибактеріяльних застосуваннях. Вивчено структурні властивості й антибактеріяльну активність нанокомпозитів (ПС–ПК/Co_2O_3–SiC). До структурних властивостей відносяться дані польової емісійної сканувальної електронної мікроскопії (ПЕ–СЕМ) і оптичної мікроскопії (ОМ). Польова емісійна сканувальна електронна мікроскопія (ПЕ–СЕМ) і оптична мікроскопія (ОМ) підтверджують, що НЧ (Co_2O_3/SiC) розподілені рівномірно по всій суміші ПС/ПК. Результати антибактеріяльного тестування показують, що діяметер зони інгібування збільшується зі збільшенням вмісту НЧ (Co_2O_3/SiC). Діяметри зон інгібування грамнеґативних бактерій (*сальмонели*) більші, ніж діяметри зон інгібування грампозитивних бактерій (золотистого стафілокока). Остаточні результати показують, що плівки нанокомпозитів (ПС–ПК/Co_2O_3–SiC) мають хорошу антибактеріяльну активність.

Key words: silicon carbide, cobalt oxide, polystyrene–polycarbonate nanocomposites, antibacterial agent.

Ключові слова: карбід Силіцію, оксид Кобальту, нанокомпозити полістирол–полікарбонат, антибактеріяльний засіб.

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1. INTRODUCTION

Nanotechnology is an important part of modern research, especially, when it comes to both making nanoparticles with different shapes, sizes, and chemical makeups and finding ways to use them to help people. The technology can be used in many different areas, especially in the medical, chemical, and physical industries. The catalytic activity and other properties of the nanocomposites, such as their ability to kill bacteria, are related to the nanocomposites. Nanocomposites are interesting because of their unique magnetic, electrical, optical, catalytic, and antimicrobial properties, as well as the way they are made and used. Nanocomposites can be made in many ways, including chemical, physical, biological, *etc.* Nanomaterials' unique and customizable features have fascinated researchers throughout the globe, and their potential is being studied in disciplines such as medical treatments and diagnostics, drug transport, antibacterial nanomedicine, photocatalysis, catalysis and energy generation [1–3].

Therefore, fabrication of nanocomposites containing two or more different nanoscale materials for many potential applications such as electronics, photonics, catalysis and biomedicine has gained tremendous interest as advanced nanomaterials due to their unique multifunctional nanoassembled systems, which exhibit simultaneously novel and enhanced properties. Researchers are now focusing on multifunctional nanocomposite particles containing, at least, one magnetic component, which may be used to create fascinating semi-conducting, plasmon, and magnetooptical features, when they are combined with magnetic nanoparticles (NPs) and metal nanomaterials [4].

Polystyrene (PS) is a transparent glass-like substance, which does not dissolve in acids, bases, or alcohol, but dissolve in aromatic hydrocarbons, benzene, and esters. Its melting point is of 239°C, density is of 1.05 g/cm^3, the glass transition temperature is of 100°C, and it is randomly crystallized [5]. Polystyrene (PS) is a clear, colourless, and bright thermoplastic polymer that is both useful and inexpensive. It is also had a low dielectric loss, a strong heat resistance, and it has lightweight. Because of its unique qualities, it is frequently employed as a transparent food packaging material, an electric cover, an insulator, a lamp cover, a filter, and a breathable thermal comfort textile. Because of its brittleness and weak mechanical characteristics, polystyrene has a restricted range of uses. Because of this, a variety of enhancements have been made to PS materials, including the incorporation of additional polymers and the development of a new manufacturing technique for PS materials that generates ones with superior mechanical and chemical capabilities [6].

Polycarbonate (PC) is a major engineering plastic because of its exceptional chemical and physical qualities, including outstanding heat stability and ductility, superb transparency, and high mechanical strength. It has been widely used in electrical and electronic products and automobiles as a result of this fact. Therefore, there is an oversupply of polycarbonate wastes, which is need to be disposed due to their widespread use. More research into ecologically acceptable and cost-effective methods for properly discarding polycarbonate trash is, therefore, still required [7]. Cobalt oxide (Co_2O_3) is one of the transition metal oxides in the form of a black powder having antibacterial and magnetic characteristics. The magnetic nanoparticles are independent particles with a maximum diameter of 100 nm, which exhibit magnetic characteristics. Because of its three semi-stable phases, cobalt is one of the most significant magnetic metals. For example, sensors, magnetic materials, electrochemical systems, smart absorbers, catalysts, and medical devices are all examples of applications for cobalt (II) oxide nanoparticles based on their unique features. Considering the variety of applications for Co_2O_3 NPs, optimizing their manufacture is essential. Controlling the effective parameters in the synthesis process may enhance nanoparticle structure, size, morphology, and surface characteristics [8].

Silicon carbide (SiC) is very resistant to wear and has good mechanical properties as well. SiC particles in the reinforced particulate can act like a cutting edge during machining and as abrasion at the tool–workpiece interface. It also affects the mechanical properties of the composites, such as their tensile strength and hardness [9]. Silicon carbide may present a biosafe path to protect restorative surfaces from bacterial adhesion and degradation without compromising the bulk properties of traditional dental-materials technology [10]. In this point, antimicrobial susceptibility testing using agar disk-diffusion, which was first devised in 1940 [11], is standard procedure in many clinical microbiology labs. Disk-diffusion assay, on the other hand, has many benefits over other techniques, including simplicity, cheap cost, and the capacity to test a large variety of bacteria and antimicrobial drugs, and the ease, with which the data may be interpreted. Patients with bacterial infections benefit greatly from antibiotics depending on the causative agent antibiogram, as established in multiple studies [12]. They all kill bacteria through different mechanisms: (i) metal ion selectivity (replacing original metals, which causes cellular dysfunction); (ii) metal reduction potential (generating or catalysing the formation of reactive oxygen species (ROS), which damage cellular proteins, lipids, and DNA); and (iii) direct nanoparticle (NP) interaction with bacterial surfaces, which can block membrane transport channels and disrupt electrochemical gradients [13]. The aim of current work is fabrication of PS–PC/Co_2O_3–SiC nanocomposites and studying their structural and antibacterial properties to use as coating materials for antibacterial applications.

2. MATERIALS AND METHODS

The materials used in the present work are polystyrene and polycarbonate as matrix, while cobalt (II) oxide nanoparticles and silicon carbide nanoparticles are used as additives. The nanocomposites' films are prepared by mixing of 1 gm of 50% polystyrene (PS) and 50% polycarbonate (PC) in 50 ml of chloroform and, then, doped with various content of cobalt (II) oxide nanoparticles (Co_2O_3 NPs) (purity of 99.7% with diameter of 50 nm) and silicon carbide nanoparticles (SiC NPs) (purity of 99% with diameter of 80 nm) with concentrations of 1.3%, 2.6%, 3.9% and 5.2%. The casting method is used to fabricate the (PS–PC/Co_2O_3–SiC) nanocomposites. The structural characteristics of (PS–PC/Co_2O_3–SiC) nanocomposites' films were tested by the field emission scanning electron microscopy (FE–SEM) and optical microscopy (OM). The (PS–PC/Co_2O_3–SiC) nanocomposites were employed as antibacterial agents. The antibacterial agent was determined using a disc-diffusion method. The following equation was used to determine the overlapping respiratory inhibition ratios of bacteria, when the diameters of bacterial inhibition for the sample that killed the most bacteria were compared to the sample that did not kill the bacteria [14]:

$$R_D\ [\%] = \frac{D_{inhibition} - D_{non\text{-}inhibition}}{D_{inhibition}} \cdot 100\ [\%], \qquad (1)$$

where R_D [%] represents the percentage increase in the diameter of the inhibition zone of the bacterial respiratory overexpression inhibition zone after the addition of the nanocomposite; $D_{inhibition}$ represents the diameter of the inhibition zone of the sample, where bacteria were killed (the maximum inhibitory concentration), and the diameter of the inhibition zones of the sample, where no bacteria were killed (minimum inhibitory concentration), is represented by

$D_{non\text{-}inhibition}$.

3. RESULTS AND DISCUSSION

Figure 1 represents the geometric structures of the (PS/PC) blends (100 atoms), while the optimized structures of the (PS–C/Co_2O_3–SiC) nanocomposites (58 atoms) are shown in Fig. 2.

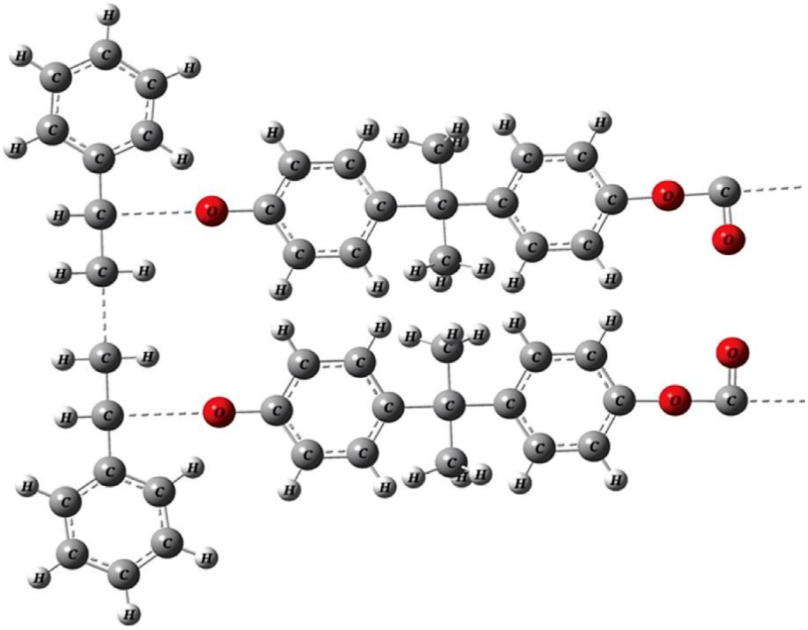

Fig. 1. Optimization of the geometries of (PS–PC) blends (100 atoms).

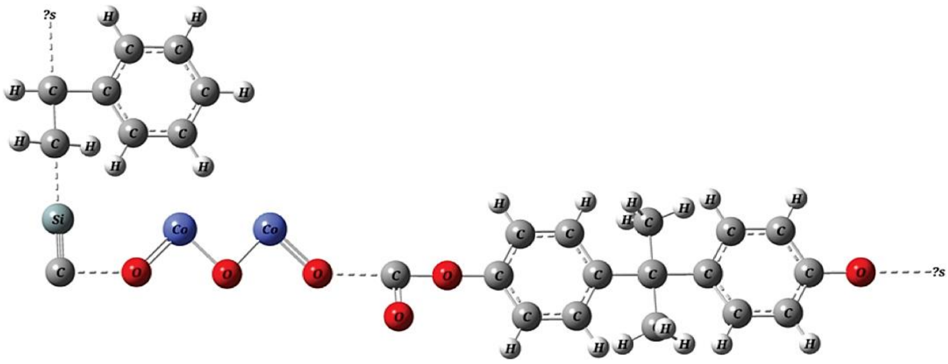

Fig. 2. The optimized structures of the (PS–PC/Co_2O_3–SiC) nanocomposites (58 atoms).

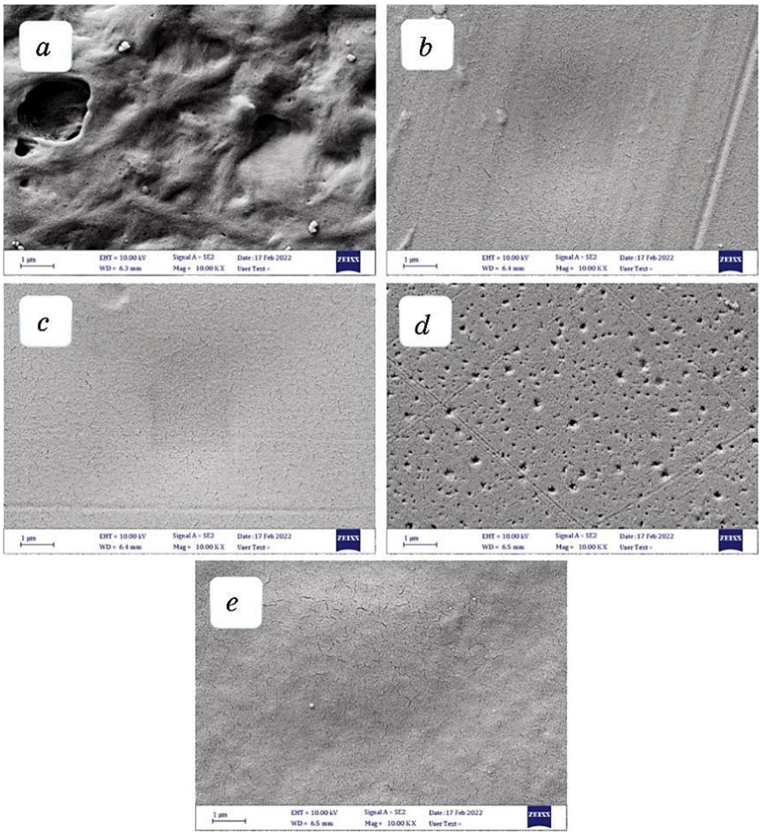

Fig. 3. FE–SEM micrographs of (PS–PC/Co_2O_3–SiC) nanocomposites: (*a*) for pure one; (*b*) with 1.3 wt.% (Co_2O_3/SiC) NPs; (*c*) with 2.6 wt.% (Co_2O_3/SiC) NPs; (*d*) with 3.9 wt.% (Co_2O_3/SiC) NPs; (*e*) with 5.2 wt.% (Co_2O_3/SiC) NPs.

Figures 3 and 4 show the field emission scanning electron microscopy (FE–SEM) and photomicrograph images (OM) of (PS/PC) blend with varying concentrations of (Co_2O_3/SiC) nanoparticles. From these figures, clusters of nanoparticles are formed at lower concentrations. With an increase in the nanoparticles' content in the matrix, a network is formed [15–20]. The surface morphology of the (PS–PC/Co_2O_3–SiC) nanocomposites has changed significantly as a result of the nanoparticles' addition. The images show that the grains grow as the nanoparticles' fraction rises. There are several randomly distributed aggregates or particles on the upper surface of films made of (PS–PC/Co_2O_3–SiC) nanocomposites. Grain distribution on the films' surfaces is uniformly dense. In (PS/PC) composite films, nanoparticles tend to form well-distributed aggregates.

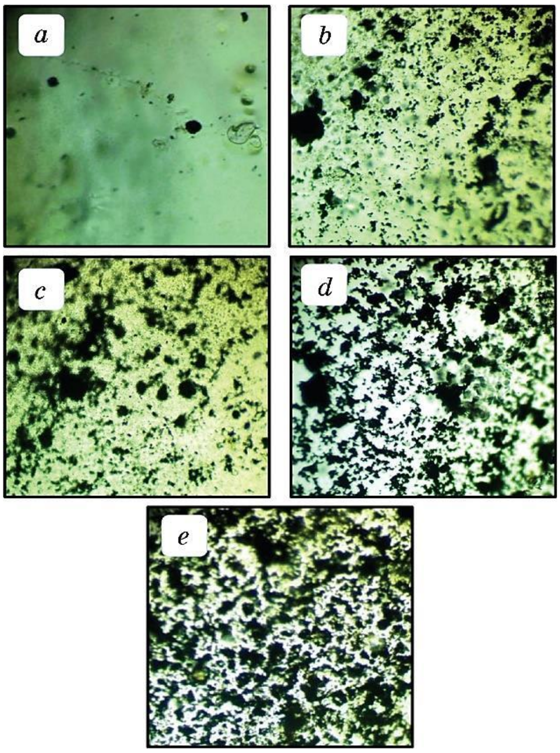

Fig. 4. Photomicrographs (×10) for (PS–PC/Co_2O_3–SiC) nanocomposites: (*a*) for pure one; (*b*) with 1.3 wt.% (Co_2O_3/SiC) NPs; (*c*) with 2.6 wt.% (Co_2O_3/SiC) NPs; (*d*) with 3.9 wt.% (Co_2O_3/SiC) NPs; (*e*) with 5.2 wt.% (Co_2O_3/SiC) NPs.

An antibacterial activity test is a very common and important microbiological test standard, by which we can determine the effectiveness of any antimicrobial substance.

This work represents the data of testing of (PS–PC/Co_2O_3–SiC nanocomposites for antibacterial activity with varying concentrations of nanoparticles (1.3, 2.6, 3.9 and 5.2 wt.%). For gram-positive bacteria (*Staphylococcus aureus*) and gram-negative bacteria (*Salmonella*), the antibacterial activity was measured by measuring the dimeters of inhibition around each sample using the agar diffusion method, and they are calculated by using relation (1) as of about 51.7% and 59.3%, respectively, when the Co_2O_3/SiC NPs content is of 5.2 wt.%.

Figure 5 shows that the gram-negative (*Salmonella*) inhibited NPs' films more effectively than the gram-positive (*Staphylococcus aureus*). Inhibition zone diameter increases with increasing Co_2O_3/SiC NPs' content. Nanocomposites' ability to inhibit microorganisms is seen in Table.

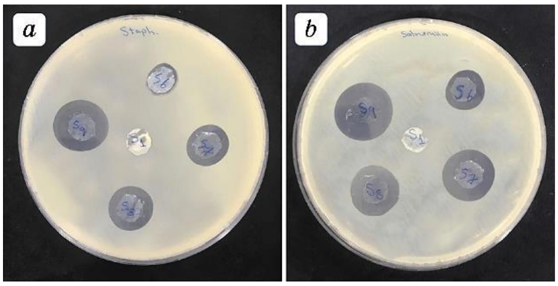

Fig. 5. Antibacterial activity of (PS–PC/Co_2O_3–SiC) nanocomposites: (*a*) images for inhibition zone of gram-positive bacteria; (*b*) images for inhibition zone of gram-negative bacteria against *Staphylococcus aureus* and *Salmonella*.

TABLE. The values of inhibition zone diameters of (PS–PC/Co_2O_3–SiC) nanocomposites.

Content of (Co_2O_3, SiC) NPs, wt.%	Inhibitions zone diameter	
	Gram-positive (*Staphylococcus aureus*)	Gram-negative (*Salmonella*)
0	0	0
1.3	15	21
2.6	22	28
3.9	25	29
5.2	30	33

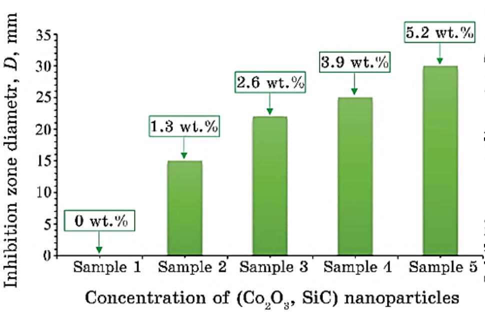

Fig. 6. Inhibition zone diameter of (PS–PC/Co_2O_3–SiC) nanocomposites for gram-positive bacteria (*Staphylococcus aureus*) with concentrations of 1.3 wt.%, 2.6 wt.%, 3.9 wt.%, 5.2 wt.%.

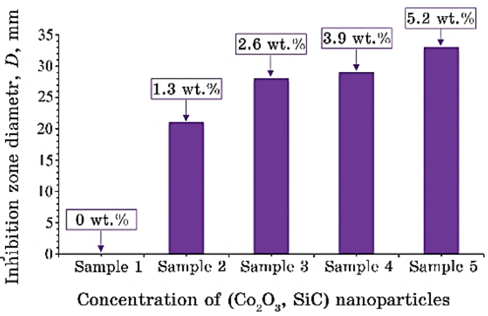

Fig. 7. Inhibition zone diameter of (PS–PC/Co_2O_3–SiC) nanocomposites for gram-negative bacteria (*Salmonella*) with concentrations of 1.3 wt.%, 2.6 wt.%, 3.9 wt.%, 5.2 wt.%).

As demonstrated in Figures 6 and 7, increasing the concentration of nanoparticles resulted in an increase in inhibition. Antibacterial effect has been connected with the suppression of reactive oxygen species (ROS) because of their capacity to destroy bacterial cell membranes, as well as their impact on ROS levels and which cells and proteins may be harmed by activating death receptors [21–25].

4. CONCLUSIONS

This study includes enhancing the structural properties and antibacterial activity of the (PS–PC/Co_2O_3–SiC) nanocomposites' films. The (PS–PC/Co_2O_3–SiC) nanocomposites were analysed using field emission scanning electron microscopy and optical microscopy. The antibacterial activity of the nanocomposites' films was tested by the disc-diffusion method. It was found that the (PS–PC/Co_2O_3–SiC) nanocomposites exhibit excellent antibacterial activity against both *Staphylococcus aureus* and *Salmonella*. The results of antibacterial activity showed that the diameter of inhibition for gram-negative bacteria (*Salmonella*) was larger than the diameter of inhibition for gram-positive bacteria (*Staphylococcus aureus*). Finally, the (PS–PC/Co_2O_3–SiC) nanocomposites may be useful in biotechnology and medical engineering fields.

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