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Antibacterial nanocomposite preparation of polypropylene-Silver using Corona discharge

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ABSTRACT

Silver nanoparticles were coated on polypropylene film to study its antibacterial activity. For this purpose, the surface of polypropylene film was treated by the corona discharge and then the modified polymeric film was immersed in a stable and uniform colloidal solution of silver nanoparticles that was synthesized by chemical reduction of silver salt using hydrazine hydrate. A solution containing the silver nanoparticles were prepared using polyamide resin in three different concentrations of 0.01 M, 0.005 M and 0.001 M. The nanoparticles solution was exposed to ultrasound to prevent their agglomeration. Corona discharge was used to change the polarity of the nonpolar surface of polypropylene and prepare it for coating. The effects of corona treatment conditions on the surface modification and performance of the silver/polypropylene nanocomposite films were investigated. Characterisation of nanoparticles and the coated surface were carried out using UV–vis Spectroscopy, dynamic light scattering (DLS), X-ray diffraction (XRD) and scanning electron microscope (SEM). The images of SEM suggested that the coating of the film enhances with increasing the power and the time. The antibacterial activity of polypropylene-silver nanocomposite against two types of bacteria including gram-negative *Escherichia coli* and gram-positive *Staphylococcus aureus* was measured by disc-diffusion method. The current method of preparation significantly reduces the amount of required nanoparticles which ultimately offers lower production cost.

1. Introduction

Over the last a few decades, many researchers have studied synthesis and application of nanoparticles. They have manged to remarkably advance in utilization of nanotechnology in several application areas. Synthesis and application of nanoparticles usually are considered in range of 1–100 nm due to the higher surface area of smaller particles per unit volume [1,2]. Nanoparticles can incredibly change the physical, chemical and biological properties of materials. Metal nanoparticles can be synthesised by chemical, physical or even biological mechanisms. The chemical mechanisms such as chemical reduction, electrochemical techniques, photochemical reduction, thermal decomposition and physical methods such as electrical discharge and physical vapour condensation (PVC) are usually used in the synthesis of nanoparticles. Living organisms have a great potential in fabrication of nanoparticles/nanomachines, but these mechanisms are still unknown and they need further research and study [3,4]. The application of noble metals, in particular silver and gold, in catalysis and photonic provide very unique antibacterial properties. For example, silver is an effective antibacterial agent against 650 types of microorganisms [5,6].

Huang et al. [7] reported that antibacterial the properties of silver nanoparticles increases with decreasing size of particle. Lee et al. [8] have studied the antibacterial activity of silver nano-particles on *E. coli* bacteria. Kim et al. [9] studied antibacterial effect of silver nanoparticles against *E. coli*, yeast and *S. aureus* and they reported that the growing of yeast and *E. coli* was terminated at lower concentrations of silver nanoparticles, whereas for *S. aureus* bacterial growing rate slowed down the process but did not completely terminate it. In another work, antibacterial activity of silver nanoparticles was studied by Phu et al. [10] using various stabilizers. They found that silver-alginate nanoparticles have the highest antibacterial activity against the *E. coli* comparing to the other agents of AgNPs/PVP, AgNPs/PVA, AgNPs/sericin [10]. The reports on the inhibitory action of silver ions on microorganisms showed that upon silver ion treatment, DNA loses its replication ability and expression of ribosomal subunits proteins as well as some other cellular proteins, and enzymes essential to ATP production becomes inactivated [11].

Active packaging is an innovative area, which causes food products

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to have better sensorial features and extended shelf-life, thus ensuring enhanced food quality and safety There are several types of active packaging, including gas, moisture and UV absorbers, as well as flavor, antioxidant and antimicrobial releasers. One of the most modern active packaging systems is antibacterial packaging that is able to kill or inhibit the growth rate of microorganisms that contaminate foods. The antibacterial packaging films can be made by incorporation and immobilization of antibacterial substances in packaging materials. One of the most widely used polymers is polypropylene which is the best candidate for nano-composite production due to a number of advantages. Polypropylene cannot be coated with conventional methods because its surface is not polar [12]. Physical and chemical approaches can be used to modify polypropylene surface. Using chemical methods are not very appropriate approaches due to the limited lifetime of materials used in surface modification and also because of the possibility of undesirable changes in the material. In contrast, physical methods such as Corona discharge are more applicable with no drawbacks of chemical methods. In corona discharge method, the surface polymer turns polar due to applying of a very high potential difference. In corona discharge, the surrounding gases are transformed in to radicals, electrons and ions make the polymer influenced by chemical reactions and destroy the surface structure to facilitate coating [13].

In this work, silver nanoparticles synthesis carried out using hydrazine hydrate as a reduction agent and polyvinylpyrrolidone (PVP) as a stabiliser. The advantages are a hydrophilic, non-toxic, environment friendly, suitable for mixing, antibacterial, soluble in water and also with many organic solvents is highly processible in many different applications. The objective of this work is fabrication of polypropylene/silver nanocomposites using corona discharge and investigate its antibacterial activity against two types of bacteria including *E. coli* and *S. aureus*. Characterisations of the nanoparticles and the fabricated silver nanocomposite films were analysed by UV–vis Spectroscopy, DSL, XRD and SEM. The antibacterial activity of the nanocomposite was tested by disc-diffusion method.

2. Materials and method

Polypropylene films with 20 μm of thickness and silver nitrate were purchased from Merck Co. Ltd. (Germany). Hydrazine hydrate as reducing agent, polyvinylpyrrolidone (PVP) and Tryptic Soy Broth (TSB) powder as a growth media, were all purchased from Sigma-Aldrich (Germany). PR548 resin was used due to its adaptability with polypropylene film during the process.

2.1. Preparation of the coating solution

Three silver nitrate solutions of 100 ml with concentrations of 0.01 M, 0.005 M and 0.001 M were prepared. The hydrazine hydrate reducing agent and PVP were added to these solutions and they were exposed to a direct sunlight. After a few minutes, the colour of solutions was absolutely changed to the brown which indicates that the solution contains nanoparticles. After the formation of nanoparticles, 100 ml of resin was added to each of the solutions. Each solution was placed in an ultrasonic machine for 15 min to prevent any agglomeration of nanoparticles.

2.2. Modifying of polymer surface using corona discharge

Corona discharge was used to polarise the surface of the polymer film. During the Corona discharge, direct current (DC) was generated by the transforming of alternative current (AC) of the household power. The apparatus had two electrodes which were very close together to create corona discharge. The high voltage difference between the electrodes ionizes the gases between the electrodes, which can be observed as sparks by the naked eye. The ionized gases generate free radical oxygen which can affect the surface of the polymer and create

Table 1
Taguchi method of experimental design. A: concentration (0.01 M, 0.005 M, and 0.001 M), B: Power (100 W, 5000 W, and 10000 W), C: times (1 min, 3 min, and 5 min).

Test Number	Factors		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

group functions on the surface. In this situation, the polymer readily reacts with the available group functions.

To prepare the surface of polypropylene, the polymer film was placed between the two electrodes. Corona discharge was applied for three different time periods of 1, 3 and 5 min and the experiments were repeated for each time slot with three different powers of 100, 5000 and 10,000 W. The films were coated using the prepared solutions with different concentrations and left to dry out in an atmospheric temperature. In the Taguchi design method which was used with L9 orthogonal array. Antibacterial tests were carried out on all 9 experiments and the optimum was determined.

2.3. Antibacterial tests

The disc-diffusion test was used to determine antibacterial property of the nanocomposite [14]. In this experiment, two different types of bacteria including *S. aureus* and *E. coli* were introduced to the nanocomposite surface and the results of the test were analysed. This experiment was repeated four times for each case study, by Table 1, and the average values were reported. In the disc-diffusion test, the fabricated nanocomposite film was placed on the bacteria growth medium to examine the antibacterial effect of the nanocomposite. The plate was then placed in an oven and left for 24 h at 37 °C and at the diameter as was measured by a precise ruler and the growing magnitude was reported. This test was carried out for all Taguchi arrangements and the best case was selected.

3. Results and discussions

3.1. UV–vis spectroscopy

Changing the colour of silver nitrate (AgNO3) suggests the formation of silver nanoparticles. The UV–vis absorption spectra was taken over the range of 350–600 nm. As mentioned earlier, one of the outstanding properties of metallic nanoparticles is their optical features where it varies by size and shape of nanoparticles. Surface plasmon resonance in metallic nanoparticles controls their unique optical properties and it changes by varying of some parameters such as size and shape of nanoparticles, their distance from each other and also reflecting index of surrounding environment [15].

Fig. 1 is the plot of spectrum at 0.01 M solution, it shows that the surface plasmon resonance of silver nanoparticles peaks at 420 nm, considering the fact that light absorption of silver nanoparticles happens in the range of 400–500 nm. For the two cases (with concentrations of 0.005 M and 0.001 M) which are not reported here, the peaks take place at very similar locations of 420 and 427 nm.

3.2. Dynamic light scattering

Dynamic light scattering (DLS) analysis is a nanoparticles