Research article

Enhancing Latex Compounds and Vulcanized Rubber Properties with Silver Nanoparticles

Jutatip Artchomphoo[1], Suwat Rattanapan[1], Irfun Masaesa-i[2], Weerasak Taengphan[3] and Diew Saijun[1]*

[1]Department of Science, Faculty of Science and Technology, Rajamangala University of Technology Srivijaya, Nakhon Si Thammarat, Thailand
[2]Department of Science, Faculty of Science and Technology, Princess of Naradhiwas University, Naradhiwas, Thailand
[3]Expert Centre of Innovative Herbal Products, Thailand Institute of Scientific and Technological Research, Pathum Thani, Thailand

Curr. Appl. Sci. Technol. 2024, Vol. 24 (No. 4), e0259474; https://doi.org/10.55003/cast.2024.259474

Received: 21 June 2023, Revised: 24 July 2023, Accepted: 29 November 2023, Published: 20 March 2024

Abstract

Keywords

natural rubber;

silver nanoparticles;

zinc oxide;

antibacterial activity

The production process of latex products requires the preparation of latex compounds by mixing latex with chemicals in a dispersion state. This experiment investigated the influence of added zinc oxide and silver nanoparticles on the properties of latex compounds and vulcanized rubber. It was found that increasing the amount of zinc oxide in the rubber compound resulted in a rise in the viscosity of the latex over the storage period. Increasing the zinc oxide content also led to a higher degree of crosslink noticed by a faster chloroform number determination of the vulcanization level and the opposite effect on the swell value of the rubber film with reduced swelling. The amount of 2.0 phr of ZnO as an activator gave the highest value of the tensile strength. The increasing amount of silver nanoparticles caused a decrease in the viscosity and exhibited a slower chloroform number with a decrease in the swelling of the rubber film. The amount of silver nanoparticles in the study period (0.0010-0.0022 phr) had little effect on mechanical properties but a significant effect on antibacterial activity. The 0.0010 phr of silver nanoparticles showed sufficient potential in inhibiting *Staphylococcus aureus* and *Escherichia coli.*

*Corresponding author: Tel.: (+66) 966527424
E-mail: diew.s@rmutsv.ac.th

1. Introduction

Natural rubber latex (NRL) is the cytoplasm of laticiferous cells from a plant called *Hevea brasiliensis.* It contains rubber and non-rubber particles. The amount of these constituents depends on various factors including soil conditions, quality of fertilizers, tapping systems, seasons, and so on [1]. The rubber particles are colloids in the range of 30-45% by volume; the other 10-20% (by volume) makes up the luteoid part. The particle and serum phases contain biochemical constituents such as minerals, soluble carbohydrates, and proteins [2]. The rubber particles dispersed in the serum phase are encapsulated by phospholipids that perform a stabilizing function [3]. Although rubber particles contain phospholipids that serve to maintain their natural state, they tend to become clumpy when left to dry. Due to bacterial decomposition of carbohydrates and lipids, acidic substances are released, causing the field latex's pH to decrease from 6.5 to 5.2 within 24 h. The main bacteria in field latex are *Bacillus*, *Lactococcus*, *Enterobacter*, *Serratia*, *Streptomyce*s, and *Micrococcus* [4]. As a preservative of the latex, an ammonia solution is often added to the latex to inhibit the activity of bacteria, which occurs due to the higher pH of the latex and hydrolyzed fatty acids present to form soap, which stabilize the rubber particles [5]. However, using field latex to prepare products often has problems with the consistency of the product. Therefore, latex products are often made from concentrated latex which has a dry rubber concentration of 60%, and can be produced in four ways: evaporation, creaming, electrolysis, and centrifugation. Centrifugation is a popular industrial method [6]. Latex concentrates are mixed with chemicals to form latex compounds for immersion or casting products. The rubber compound has a chemical composition that causes the rubber molecules to be crosslinked. The resulting properties such as viscosity and degree of crosslinking changed over time [7]. These factors affected the latex processing system and product quality.

Zinc oxide (ZnO) is widely used in the rubber industry. ZnO and TMTD (tetramethylthiuram disulfide) have been used as stabilizers in low ammonia concentrated latex [8]. ZnO is often used as a secondary gelling agent in conjunction with diphenyl guanidine (DPG) to make rubber foam from natural latex [9]. ZnO is also an essential component in the crosslinking reaction, activating the crosslinking of rubber molecules via sulfur or sulfur-donor system [10], thus affecting the properties of latex, including the product's characteristics.

Silver is a naturally occurring element slightly harder than gold, which is tough and bendable. Pure silver can conduct electricity and heat well when compared to other metals. In nature, silver exists in compounds such as sulfide bicarbonate or sulfate compounds, or complexes of chlorides and sulfates [11]. Currently, silver nanoparticles have attracted much interest in antimicrobial applications. Products incorporating nanosilver include clothing, water filtration systems, medical equipment, cosmetics, electrical equipment, and home appliances [12, 13]. Materials such as metal nanoparticles, metal oxide nanoparticles, carbon nanomaterials, and their composites have been intensively used as new antibacterial agents due to their small particle sizes, unique chemical and physical properties, and high specific surface area. Additionally, silver nanoparticles stand out among other nanomaterials. Silver nanoparticles have demonstrated exceptional antibacterial properties, leading to their extensive utilization in biomedicine, pharmacy, and the cosmetic industry. They exhibit excellent antimicrobial properties, lower toxicity, and better biocompatibility than other metallic particles [14, 15]. Silver nanoparticles were reported to be used as an ingredient in latex to prepare a rubber product with antibacterial activity. It was found that rubber formulations with a small amount of nanosilver effectively inhibited *E. coli* and *S. aureus* bacteria [16, 17].

ZnO is used as a common chemical in the rubber industry. However, the effect of ZnO content on the properties of latex compounds over storage time was negligible. ZnO is similar to silver nanoparticles in that it also has antibacterial properties and thus is used as an antibacterial agent in rubber products. At the same time, the influence of silver nanoparticles on various latex

compound properties, especially the degree of crosslink during the storage time, has not been reported. In this research, we are interested in studying the influence of ZnO and silver nanoparticle content in rubber films on the level of crosslink properties, mechanical properties, and also the antibacterial properties.

2. Materials and Methods

2.1 Latex and chemicals

Natural rubber latex with high ammonia concentration (HANR) with 60% dry rubber content from the TT Latex and Product Co., Ltd. was used throughout this study. Chemicals for the preparation of latex compounds were: 20% potassium oleate, 50% sulfur, 50% zinc diethyldithiocarbamate (ZDEC), 50% Wing stay L, 50% zinc oxide (ZnO) were purchased from Thanodom Trade Co., Ltd. and Ding Co., Ltd. Potassium hydroxide (KOH) was from Carloerba Co., Ltd., toluene, dichloromethane and silver powder particle size <150 nm were purchased from Sigma-Aldrich Co., Ltd.

2.2 Preparation of latex compound

The latex compounds were prepared by mixing chemicals with 60% high ammonia concentrated latex to form a dispersion. First, 50% potassium oleate and 10% KOH were added into the latex tank and stirred at a constant speed at 120 rpm for 1 h. After that, 50% Wing stay L, 50% ZnO, 50% ZDEC, 50% sulfur, and 0.001% silver nanoparticles were added. Details on the chemical ingredients and preparation process for various prepared latex compounds are presented in Table 1 and Figure 1, respectively.

Table 1. Formulation of latex compounds for study of the influence of ZnO and silver nanoparticle on various latex compound properties

Components	Contents (phr)								
	F 1	**F 2**	**F3**	**F 4**	**F 5**	**F 6**	**F 7**	**F 8**	**F 9**
60% HA Latex	100	100	100	100	100	100	100	100	100
20% K-Oleate	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
10% KOH	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
50% Wingstay L	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
50% ZDEC	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
50% Sulphur	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
50% ZnO	0.5	1.0	1.5	2.0	2.5	2.0	2.0	2.0	2.0
0.1% Silver nano	-	-	-	-	-	0.001	0.0014	0.0018	0.0022

phr = Parts per hundred rubber

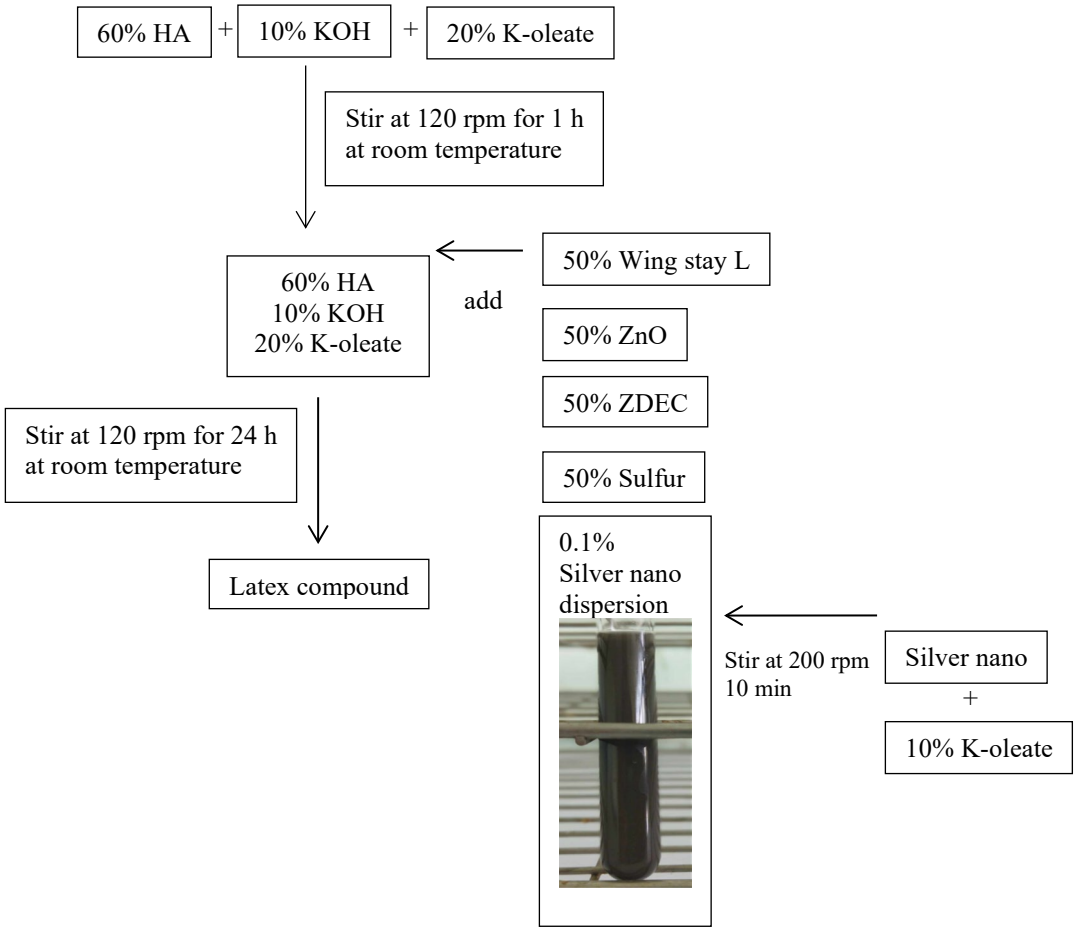

Figure 1. The preparation process for latex compounds
Remark: The concentration of all ingredients was calculated in percentage by weight

2.3 Preparation of vulcanized rubber sheet

The latex compounds were stirred for one day was cast in a glass mold, sized 25 x 25 x 0.2 cm. They were gradually poured into the mold to prevent air bubbles formation and left to dry at room temperature for 10 days.

2.4 Testing

2.4.1 Viscosity test

The viscosity of rubber compounds was measured with a Brookfield model DV-2T, rotor size LV-02 (62).

2.4.2 Chloroform number test

The chloroform number assay was conducted through the coagulation of a latex sample by mixing with an equivalent volume of chloroform. After 2-3 min, the coagulum was checked and classified by coagulum texture. The chloroform number was expressed as follows: (1) unvulcanized, (2) lightly vulcanized, (3) moderately vulcanized, and (4) fully vulcanized.

2.4.3 Swelling and crosslink density test

The objective of the swelling test is to find the weights of vulcanized rubber when exposed to organic solvents. The vulcanized rubber samples (1 cm x 3 cm) were weighed using an electrical balance and then swollen in toluene until equilibrium, which took 72 h at room temperature. The toluene was removed from the surfaces of the samples. The weight was determined, and the swelling property was calculated using equation (1). Then, the sample was dried in an oven at 60ºC until constant weight was achieved. The weight of the unswollen network at equilibrium was recorded. Equation (2) was used to determine the volume fraction of rubber films in their swollen state, Vr [18].

$$Swelling(\%) = \frac{W_2 - W_1}{W_1} \times 100 \quad (1)$$

Where W_1 is the initial weight of the rubber samples (g), and W_2 is the weight of the rubber samples (g) after immersion.

$$Vr = \frac{W_3/\rho 1}{\frac{W_3}{\rho 1} + (W_2 - W_3/\rho 2)} \times 100 \quad (2)$$

Where W_3 is the weight of unswollen rubber sample after drying; ρ 1 is density of the rubber samples; ρ 2 = density of toluene (0.867 g/cm^3)

The rubber films' crosslink density, x, was then determined using Flory-Rehner in equation (3).

$$x = \frac{-\{\ln(1 - Vr) + Vr + xVr^2}{Vs(Vr^{1/3} - Vr/2)} \quad (3)$$

Where χ is the interaction parameter for the rubber-toluene system (0.39); Vr is the volume fraction of the rubber films in a swollen state; and Vs is the molecular volume of toluene (106.2 cm^3/mol).

2.4.4 Tensile property test

The purpose of the tensile test is to determine the elastomeric behavior under an axial load at room temperature. Test data can be used to determine modulus of elasticity, tensile strength, and percentage elongation. Tensile testing with ASTMD 412 was performed by cutting dumbbell die C specimens with a tensometer, pulling the specimen at a speed of 500 mm/min, and measuring the tensile strength and elongation at break (300% and 500% modulus).

2.4.5 Morphology

The chemical dispersion in the rubber matrix with silver nanoparticles in the cross-sectional structures was examined using scanning electron microscopy (SEM) with a Zeiss Merlin compact instrument from Germany. The vulcanized rubber samples were frozen in liquid nitrogen, cryogenically fractured, and dried under vacuum. The samples were then coated with a thin layer of gold and imaged at 5 kV.

2.4.6 Thermal stability

A thermogravimetric analyzer (TGA) was utilized for the study. A TGA7, Perkin Elmer, USA, was employed to determine the decomposition temperature of the samples. A film sample weighing 9 to 10 mg was heated in a nitrogen (N_2) atmosphere, with temperature ranging from 35°C to 600°C, and with a gradual heating rate of 10°C/min.

2.4.7 Antibacterial test

The antibacterial activities of silver nanoparticles mixed in rubber film were characterized by the inhibition zone assay [16]. The antibacterial activity was examined by the Center of Measurement and Standard Accreditation, Faculty of Science, Prince of Songkla University. The rubber films were cut into 0.5 cm diameter spheres and placed on the inoculated agar surfaces. The test plates were incubated at 37°C for 24 h. After incubation, the agar plates were observed, and the mean values of the inhibition zone diameters were calculated. The tests were performed in triplicate.

3. Results and Discussion

3.1. Effect of the zinc oxide contents

3.1.1 Viscosity

The viscosity properties of the latex compounds with different amounts of ZnO are shown in Figure 2. Over the first 4 days of storage, the viscosity of the latex compounds tended to decrease. After that, the viscosity of the latex compounds gradually increased until 16 days, and then it gradually stabilized. This was because stabilizing substances, such as K-Oleate and KOH, were added to the latex, making it more stable at the beginning of storage, resulting in a lower viscosity. After storage of the latex for 4 days, the degree of vulcanization increased, resulting in the latex viscosity gradually increasing. The viscosity of the latex compounds began to stabilize after storage for 16 days and remained stable due to no change in vulcanization level. The results showed that the viscosity of the latex compounds tended to increase with the amount of ZnO due to ZnO acting as a vulcanizing activator. Increasing ZnO content leads to faster vulcanization of rubber. As a result, the increase in viscosity of the latex compounds was in accordance with the experimental results of Anand *et al*. [19], who reported the effect of nanoparticles of ZnO on the viscosity of the latex compounds at 0.05, 0.1, and 0.5 phr. The viscosity of the latex compounds tended to increase with the amount of ZnO. From our experimental results, the latex compound at a storage time of 4 days that contained ZnO at 1.0 phr showed the highest viscosity. It is likely that the ZnO was well dispersed at this level and supported the vulcanization reaction, which resulted in high viscosity values. Using more ZnO may cause particle agglomeration, which reduces the effectiveness of the

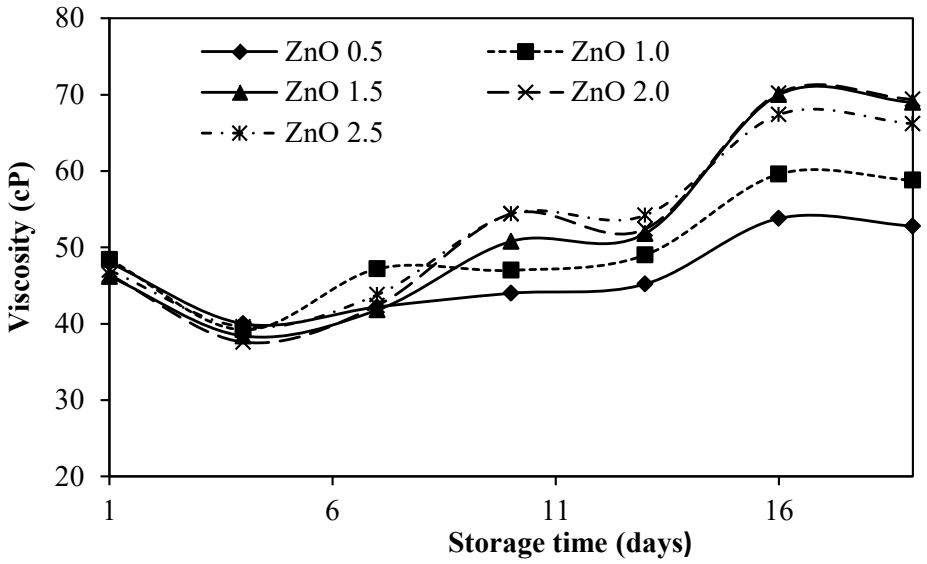

Figure 2. Viscosity of latex compounds at different levels of ZnO

ZnO. However, when the storage time of the latex compounds was increased to 10 days, the viscosity of the latex compounds tended to increase with the amount of ZnO. This extended storage period gives the chemicals dispersed in the latex enough time to vulcanize.

3.1.2 Chloroform number

A chloroform number test was used to determine the degree of pre-vulcanization of the latex compound. The chloroform number level of the latex compound increases with the storage period. The chloroform numbers of 0.5, 1.0, and 1.5 phr ZnO rubber compounds reached level 4 after storage for 25, 19, and 16 days, respectively. The latex compounds containing ZnO content of 2.0 and 2.5 phr had chloroform levels of 4 after being stored for 13 days. The experimental results are shown in Table 2. ZnO acts as an activator to activate the vulcanization reaction in the sulfur system. This makes the vulcanization reaction faster and increases crosslinking efficiency between rubber molecules [20]. Therefore, increasing the amount of ZnO in a latex compound promotes vulcanization. However, latex compounds vulcanized to chloroform level 4 are unsuitable because of the high vulcanization level. This experiment demonstrated that increasing the ZnO content in the rubber compounds resulted in a shorter retention time of the latex, especially in the case of latex with 2.0 ZnO and 2.5 phr added. It took 13 days to get to level 4.

3.1.3 Swelling and crosslink density

Swelling is caused by organic solvents diffusing into the rubber, weakening the bonds between the rubber molecules [21]. These organic solvents are typically inserted into the rubber. The crosslinking density between rubber molecules limits swelling. A high crosslink density is the reason for reduced swelling. The experimental results in Figure 3 show that swelling of the rubber decreases with increasing ZnO content due to the increased crosslink density. This finding is consistent with the experimental results of Chukwu *et al.* [20].

Table 2. Chloroform number level of latex compounds with various ZnO contents and storage times

ZnO contents (phr)	Storage Time (days)								
	1	**4**	**7**	**10**	**13**	**16**	**19**	**22**	**25**
0.5	1	1	1	2	3	3	3	3	4
1	1	2	2	2	3	3	4	4	4
1.5	1	2	2	2	3	4	4	4	4
2	1	2	3	3	4	4	4	4	4
2.5	1	2	2	3	4	4	4	4	4

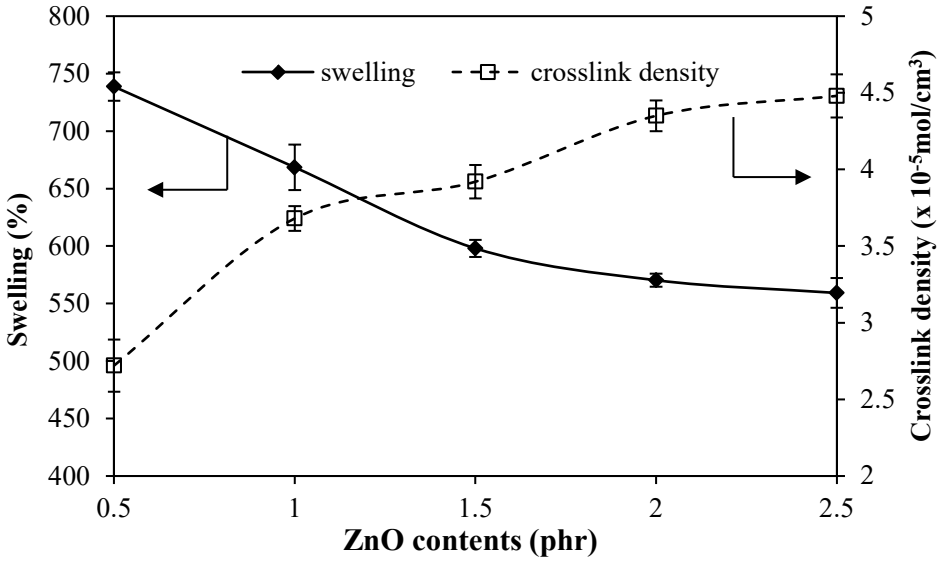

Figure 3. The swelling and crosslink density of vulcanized rubber with a variety of ZnO contents

3.1.4 Tensile properties

The tensile properties tested included 300% and 500% tensile modulus, tensile strength, and elongation at break of the rubber sheet with ZnO content of 0.5, 1.0, 1.5, 2.0, and 2.5 phr. As displayed in Figures 4 and 5, it was found that the modulus tended to rise slightly with an increase in ZnO content. The 300% modulus was in the range of 1.3-1.4 MPa, while the 500% modulus was in the range of 1.5.-1.7 MPa. The tensile strength was highest when using 2.0 phr ZnO because ZnO is an activator that acts as a support agent for the vulcanization reaction, resulting in better vulcanization of the rubber strength. However, using ZnO in amounts greater than 2.0 phr led to poor diffusion of ZnO particles, resulting in agglomeration and reduced efficiency. This finding is similar to the finding of Anand *et al*. [19], who reported the use of nanometer sized ZnO as an activator for rubber vulcanization with a sulfur system improved the tensile properties of the rubber

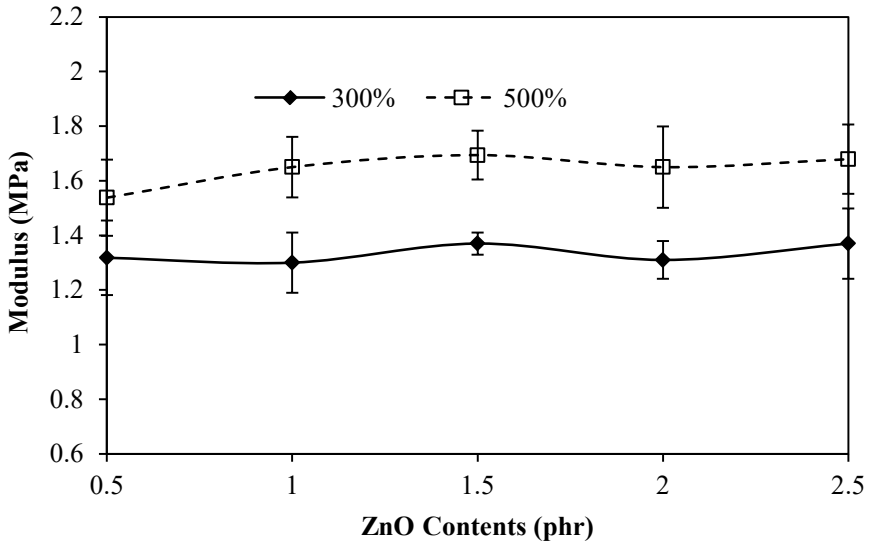

Figure 4. 300% and 500% modulus of vulcanized rubber sheets at various ZnO contents

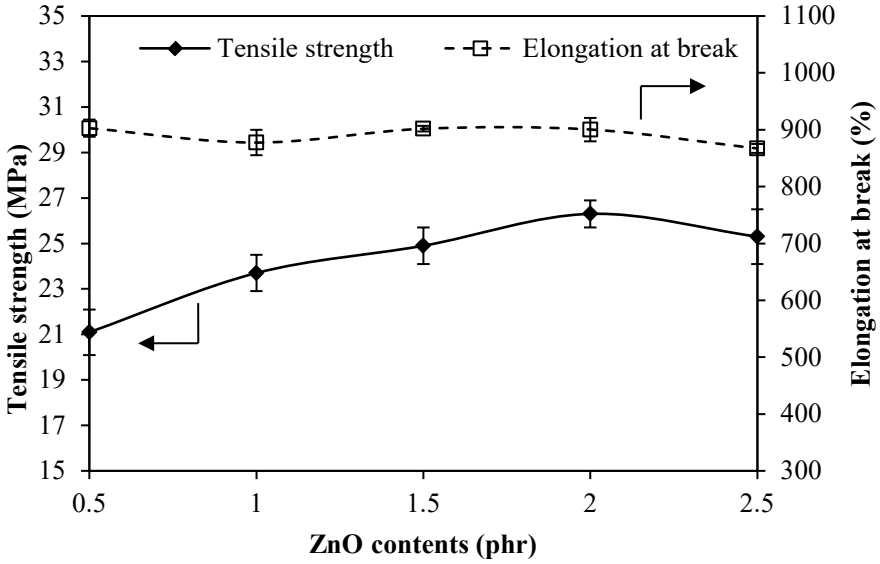

Figure 5. Tensile strength and elongation at break of vulcanized rubber sheets at various ZnO contents

when the amount of ZnO increased [19]. There are also reports of using ZnO mixed with natural rubber in the dry rubber state. Increasing ZnO activates the efficiency of crosslink reactions and provided higher mechanical properties and the best properties was at 5 phr of ZnO [20].

3.2 Effect of silver nanoparticle content

3.2.1 Viscosity

The viscosity of the latex compound with dosages of silver nanoparticles was in the range of 0.0010-0.0022 phr, as shown in Figure 6. The viscosity is plotted against the storage time of the latex compound. It can be seen that the viscosity of the latex compounds increased with a rise in storage time. Moreover, the latex compounds show a significant decrement with the increasing loading level of silver nanoparticles. Silver nanoparticles have been identified as having antibacterial properties [16, 17]. Natural rubber latex contains non-rubber components such as glucose, protein, and fat. These components are decomposed by bacteria in nature, releasing volatile fatty acids and causing latex particles to aggregate, making the latex gradually more viscous and eventually coagulating. The addition of silver nanoparticles, which effectively inhibit bacteria, leads to fewer volatile fatty acids forming. The latex becomes stable, and the viscosity decreases as silver nanoparticles increase.

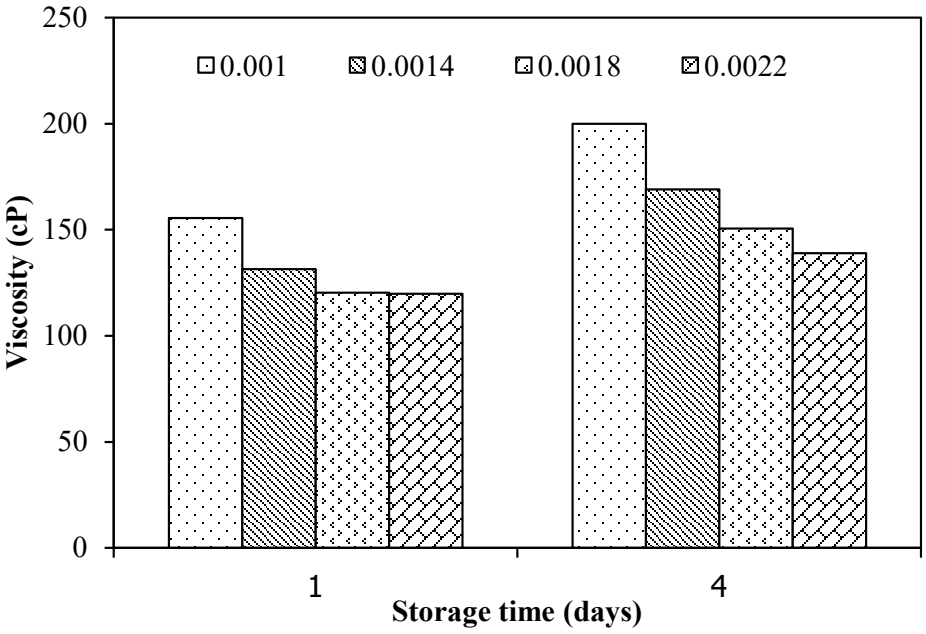

Figure 6. The viscosity of latex compounds with different silver nanoparticle contents

3.2.2 Chloroform number

Experimental results on the effect of silver nanoparticles in the latex compounds on the chloroform number are presented in Table 3. It was noted that the chloroform number tended to increase over the storage period. The findings indicated that adding silver nanoparticles produced a slow level of vulcanization as determined by the chloroform number method. This had benefits in terms of the longevity of the latex compound.

Table 3. Chloroform number level of latex compounds with various silver nanoparticle contents and storage time

Silver Nanoparticle Contents (phr)	Storage Time (days)							
	1	**4**	**7**	**10**	**13**	**16**	**19**	**22**
0.0000	1	2	3	3	4	4	4	4
0.0010	1	1	2	2	2	3	3	4
0.0014	1	1	2	2	2	3	4	4
0.0018	1	1	1	2	2	2	3	4
0.0022	1	1	1	2	2	2	3	4

3.2.3 Swelling and crosslink density

The swelling and crosslink density of rubber with various silver nanoparticles are indicated in Figure 7. Swelling of the vulcanized rubber sheets tends to decrease with the rising quantity of silver nanoparticles. This is probably because silver nanoparticles improve the vulcanization of rubber. Consequently, the crosslinking density between rubber molecules is higher, which limits the movement of molecular chains. Adding silver nanoparticles in natural rubber increases the crosslink density. The nanoparticles provide more reactive sites on the rubber molecules for the crosslinking reaction. The silver nanoparticles can also act as co-activators during the chemical vulcanization process, increasing the crosslink density between the rubber molecules. It has been reported that metal powder can increase the crosslink density between rubber molecules. Vinod *et al.* [22] reported that mixing natural rubber with 40 phr aluminum powder resulted in less swelling of vulcanized rubber than commercial fillers. This is because rubber mixed with aluminum powder has a higher crosslinking density than rubber mixed with other commercial fillers. Doma *et al.* [23] reported that lead metal powder could increase the crosslink density of lead/NR composite due to the decrease in volume fraction of the amorphous swollen phase (NR).

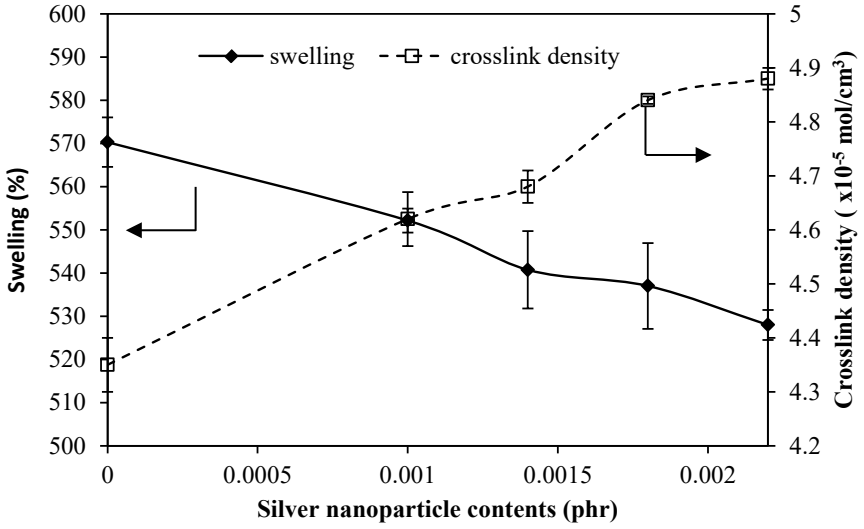

Figure 7. Swelling of vulcanized rubber with various silver nanoparticle contents

3.2.4 Tensile properties

The study of the tensile properties of vulcanized rubber at various silver nanoparticle levels indicated that 300% modulus, 500% modulus were in ranges of 1.1-1.8 MPa and 1.1-1.5 MPa, respectively (Figure 8). Figure 9 shows the tensile strength and elongation at break at 26.7-28.0 MPa and 883-900%, respectively. In general, fillers with small particle sizes have good reinforcement performance of polymers due to the high surface area between the polymer and filler [24]. In this experiment, small amounts of silver nanoparticles (0.001-0.022 phr) did not affect the reinforcement of vulcanized rubber. Naphon *et al.* [25] reported the effect of nanoparticles, namely titanium dioxide, on the tensile strength of natural rubber and the small amounts of titanium oxide nanoparticles did not affect the tensile strength of rubber. The tensile strength of natural rubber increases with titanium dioxide nanoparticles of 0.4 phr and above [25].

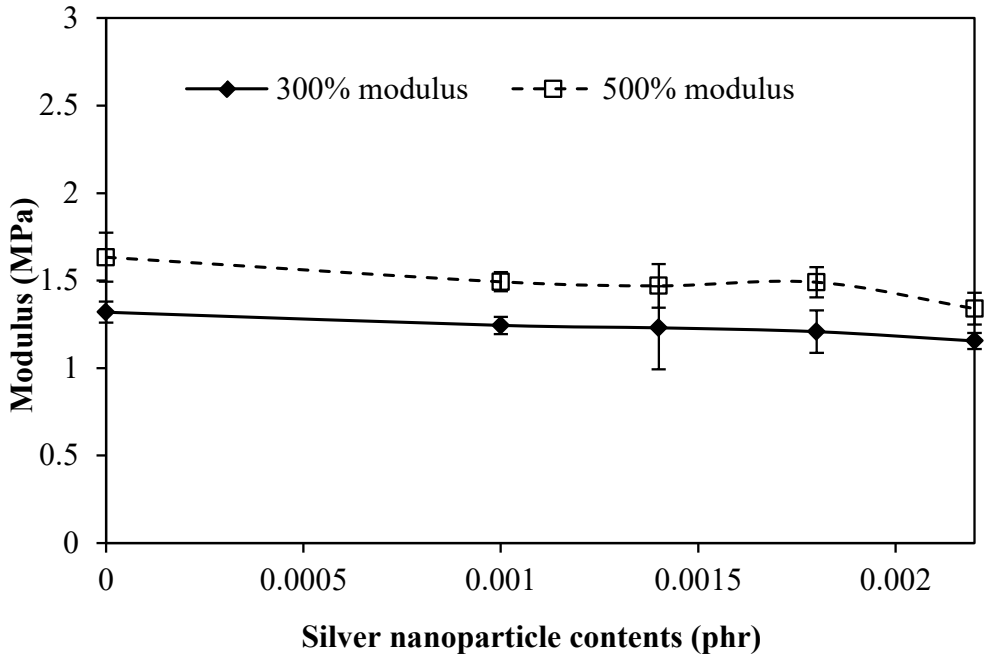

Figure 8. 300% Modulus and 500% Modulus of rubber film at various silver nanoparticle contents

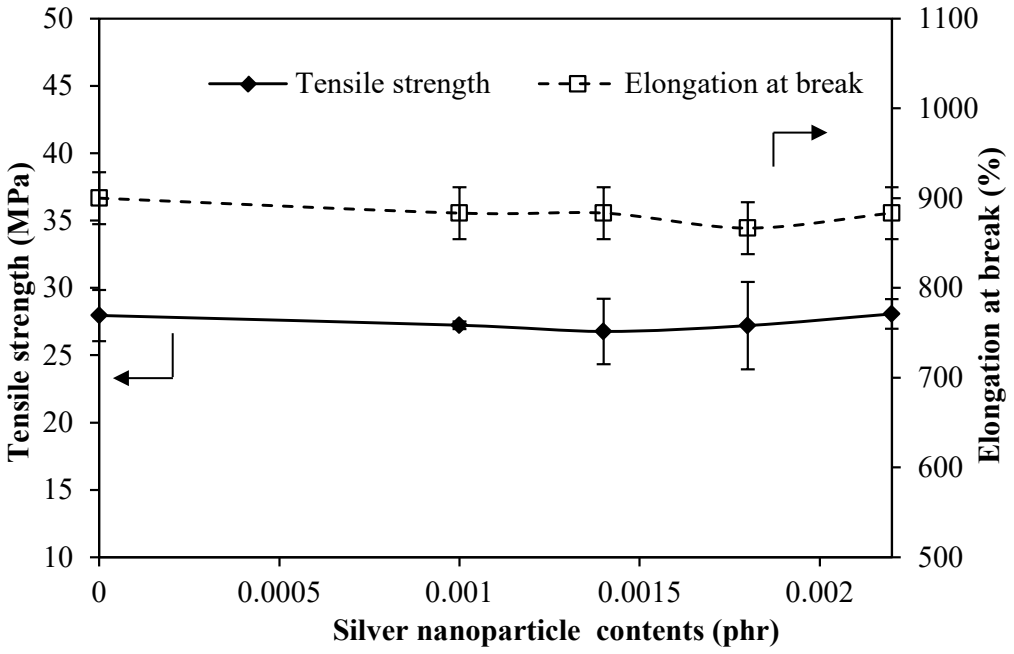

Figure 9. Tensile strength and elongation at break of rubber film with various silver nanoparticle contents

3.2.5 Thermal stability property

The thermogravimetric analysis (TGA) results in Table 4 and Figure 10 demonstrate that natural rubber with and without silver nanoparticles exhibited a weight reduction of 5% within the temperature range of 100 to 250°C. This reduction is ascribed to the liberation of water molecules and the occurrence of crosslinking and chain scission of non-rubber components within the rubber structure. Notably, upon closer inspection of the 250-330°C and 380-450°C temperature intervals, it becomes apparent that the inclusion of silver nanoparticles enhances the thermal stability of the rubber. The degradation sequence, occurring from approximately 250°C to around 400°C, indicates the breakdown of isoprene and its resultant byproducts, including amides, amines, proteins, carbohydrates, and other compounds [26].

Table 4. Comparison of thermal degradation temperatures obtained by analysis of TG technique for vulcanized natural rubber with and without silver nanoparticles

Silver Nanoparticles Content (phr)	Degradation Temperature (°C)		
	Being of Degradation	Temperature Maximum	End step of Degradation
0.0000	352.25	369.00	423.30
0.0018	353.69	369.66	423.61

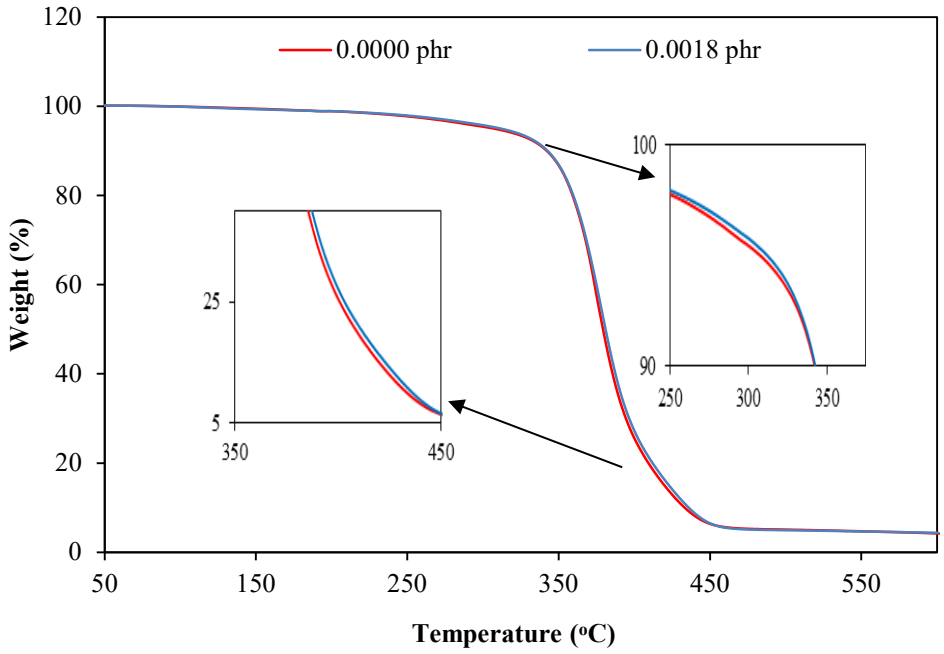

Figure 10. TG analysis of natural rubber with and without silver nanoparticles

3.2.6 Morphology

Figure 11(a) shows the morphology of silver nanoparticles of less than 150 nanometers. The distribution of chemical particles in the main phase is important, affecting the product's properties. This experiment examined the morphology with SEM to evaluate the dispersion of chemicals, especially the dispersion of silver nanoparticles. The silver nanoparticles were well dispersed without aggregation and embedded in the rubber phase, although silver nanoparticles were inorganic particles, as shown in Figure 11(b). ZnO is commonly used in the micrometer particle range as an activator in the rubber industry. The particle size of ZnO after the ball mill digestion process remains in the micrometer range. The particles of ZnO were dispersed with some aggregation, as shown in Figure 11(c) because their particle size was larger than silver nanoparticles. The characterization of chemical particles in vulcanized natural rubber consisted of ZnO, ZDEC, Wing stay-L, and sulfur, which are chemicals often used in the rubber industry; almost all chemicals exhibited particle dispersion in the range of micrometers, while silver nanoparticles presented with particle sizes in the nanometer range. According to the experimental results, micrometer-sized particles in Figure 11(d) may be particles of ZnO, ZDEC, and sulfur, which were in excess from vulcanization reactions, or Wing stay-L particles in the matrix, while nanometer particle sizes, possibly scattered silver nanoparticles, were also found.

3.2.7 Antibacterial properties

The inhibition zone diameters of *S. aureus* and *E. coli* of the rubber films (filled and unfilled silver nanoparticles) tested are shown in Table 5, Figures 12 and 13. The results showed that the rubber film filled with silver nanoparticles exhibited antibacterial activity against all bacteria tested.

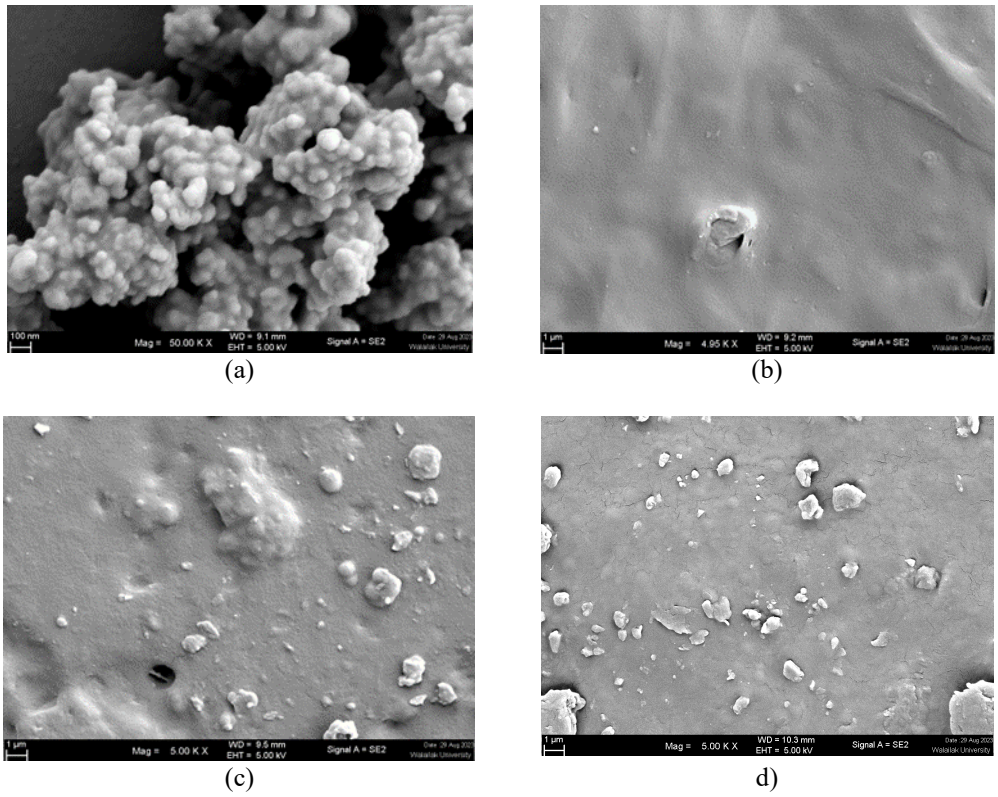

Figure 11. Morphology images (a) Silver nanoparticles, (b) Distribution of 0.0018 phr of silver nanoparticles in rubber matrix, (c) Distribution of 0.0020 phr of zinc oxide in rubber matrix, and (d) Distribution of all chemical ingredients in vulcanized rubber matrix

Table 5. The diameter of zones of inhibition (mm) of various concentrations of silver nanoparticles in rubber films against microorganisms

Silver Nanoparticle Contents (phr)	Clear Zone Diameter (mm)	
	S. aureus	***E. coli***
0.0000	0.00	0.00
0.0010	12.36±0.23	11.4±0.76
0.0014	12.38±0.33	11.96±0.54
0.0018	12.28±0.74	10.38±1.31
0.0022	12.25±0.56	12.46±0.84

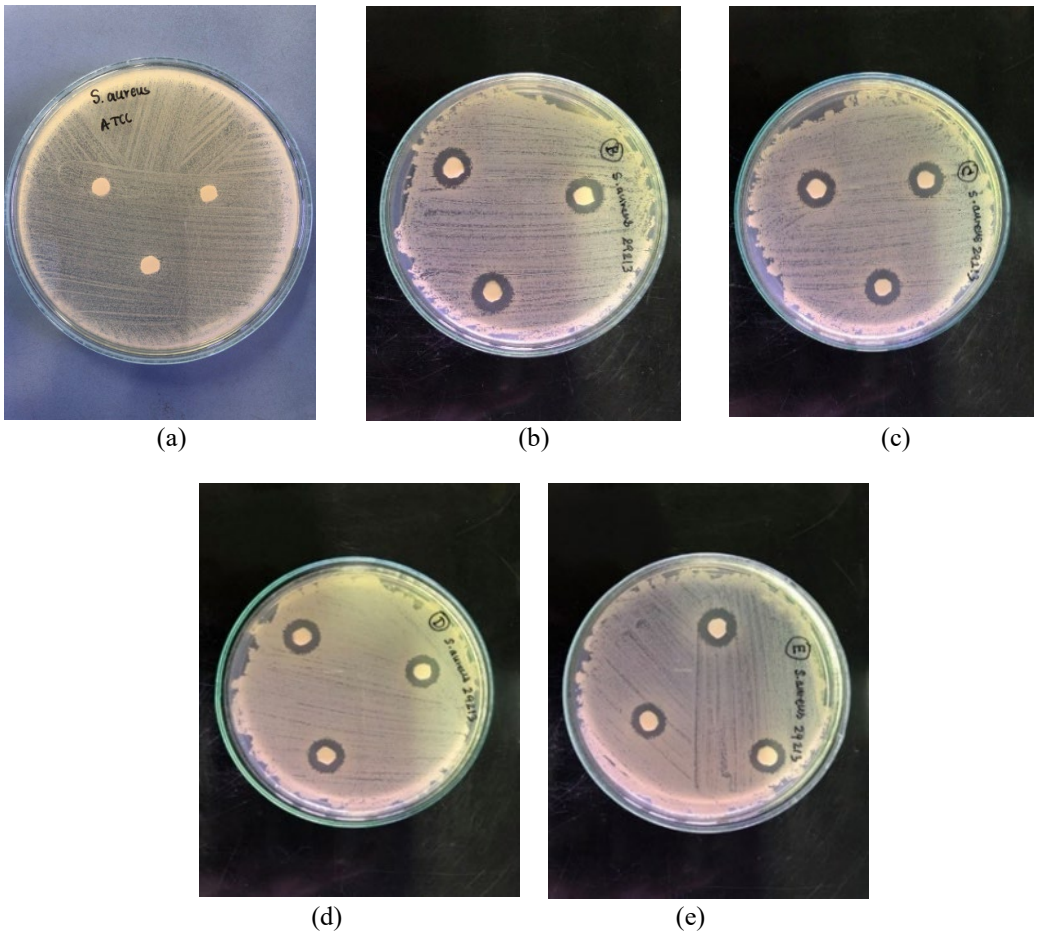

Figure 12. Growth inhibition of *S. aureus* bacteria in rubber films with filled and unfilled silver nanoparticles: (a) without silver nanoparticles (b) 0.0010 phr (c) 0.0014 phr (d) 0.0018 phr and (e) 0.0022 phr

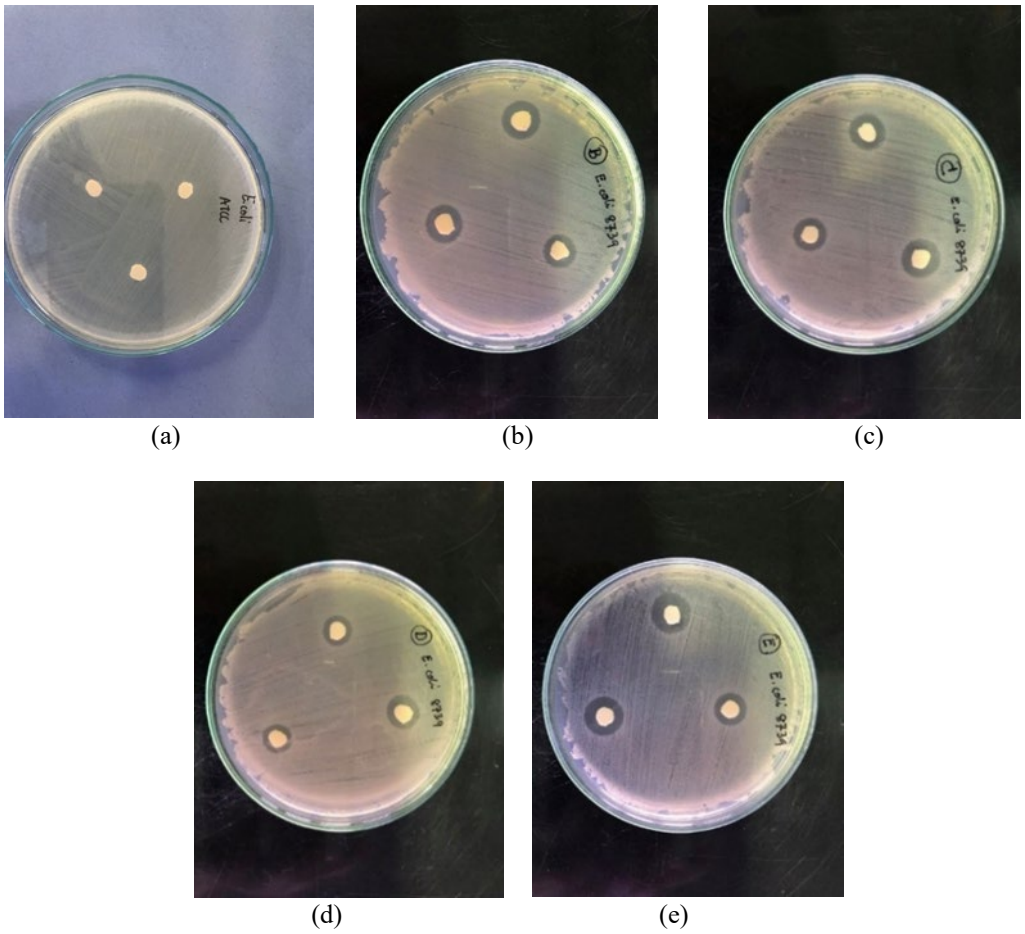

Figure 13. Growth inhibition of *E. coli* bacteria in rubber films with filled and unfilled silver nanoparticles: (a) without silver nanoparticles (b) 0.0010 phr (c) 0.0014 phr (d) 0.0018 phr and (e) 0.0022 phr

Moreover, silver nanoparticles present in the rubber films showed inhibition against *S. aureus* as well as *E. coli*. However, some scientific theories explain the possible mechanism as follow: 1) When coming in contact with the bacterial cell wall, the silver nanoparticles penetrate the cell wall into the interior, resulting in cell wall leakage and damage, leading to bacterial death: 2) The bacterial cell is damaged with free radicals formed by silver nanoparticles contacting bacteria; and 3) Silver ions released from silver nanoparticles are soft base, and can react with sulfur and phosphorus of the elements which obstruct bacterial DNA replication, resulting in bacterial death [12].

4. Conclusions

Zinc oxide affects latex compound properties. Increasing the amount of zinc oxide in the latex compound resulted in a higher viscosity of the compound latex and greater mechanical properties

of the rubber film. However, the swelling properties of the solvent in the rubber film tended to decrease. As for the mixing of silver nanoparticles with the latex compounds, viscosity decreased as the amount of silver nanoparticles increased. Moreover, the viscosity increased with the storage time. The chloroform number increased slowly when the amount of silver nanoparticles rose. The swelling of the rubber film in the solvent tended to decrease. Silver nanoparticles in the dosage range 0.0010-0.0022 phr did not cause much change in mechanical properties. However, the rubber films filled with silver nanoparticles can inhibit both bacteria (*S. aureus* and *E. coli*).

5. Acknowledgements

The research team appreciates the financial support provided by the Rajamangala University of Technology Srivijaya. Sincere thanks go out to Ms. Akanuch Bunsong and Ms. Patawadee Somboonmon for helping prepare chemicals for sample preparation. We would also like to thank other lecturers who helped us complete this work successfully.

References

[1] Suksup, R., Imkaew, C. and Smitthipong, W., 2017. Cream concentrated latex for foam rubber products. *IOP Conference Series: Material Science and Engineering*, 272, https://doi.org/10.1088/1757-899X/272/1/012025.

[2] Reis, G.O., Menut, P., Bonfils, F., Vaysse, L., Hemer, Y. and Sanchez, C. 2015. Acid-induced aggregation and gelation of natural rubber latex particles. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 482, 9-17, http://doi.org/10.1016/j.colsurfa.2015.04.015.

[3] Yu, H., Wang, Q., Li, J., Liu, Y., He, D. and Gao, X., 2017. Effect of lipids on the stability of natural rubber latex and tensile properties of its films. *Journal of Rubber Research*, 20(4), 213-222.

[4] Salomez, M., Subileau, M., Intapun, J., Bonfils, F., Sainte- Beuve, J., Vaysse, L. and Dubreucq, E., 2014. Micro-organisms in latex and natural rubber coagula of Hevea brasiliensis and their impact on rubber composition, structure and properties. *Journal of Applied Microbiology*, 117, 921-929.

[5] Santipanusopon, S. and Riyajan, S.-A., 2009. Effect of field natural rubber latex with different ammonia contents and storage period on physical properties of latex concentrate, stability of skim latex and dipped film. *Physics Procedia*, 2, 127-134, https://doi.org/10.1016/j.phpro.2009.06.020.

[6] Khamput, P. and Suweero, K., 2011. Properties of mortar mixing with medium ammonia concentrated Latex. *Energy Procedia*, 9, 559-567.

[7] Sasidharan, K.K., Josept, R., Palaty, S., Gopalakrishnan, K.S., Rajammal, G. and Pillai, P.V., 2005. Effect of the vulcanization time and storage on the stability and physical properties of sulfur-prevulcanized natural rubber latex. *Journal of Applied Polymer Science*, 97, 1804-1811, https://doi.org/10.1002/app.21918.

[8] Sirisomboon, P. and Lim, C.H., 2019. Rapid evaluation of the properties of natural rubber latex and its products using near-Infrared spectroscopy. In: A. Sand and E.G. Zaki, eds. *Organic Polymers*. London: IntechOpen, https://doi.org/10.5772/intechopen.8549.

[9] Phomrak, S., Nimpaiboon, A., Newby, B.Z. and Phisalaphong, M., 2020. Natural rubber latex foam reinforced with micro and nanofibrillated cellulose via Dunlop method. *Polymers*, 12, https://doi.org/10.3390/polym12091959.

[10] Pornprasit, P., Pechurai, W., Chiangraeng, N., Randorn, C., Chandet, N., Mungkornasawakul, P. and Nimmanpipug, P., 2018. Nanomodified ZnO in natural rubber and its effects on curing characteristics and mechanical properties. *Chiang Mai Journal of Science*, 45(5), 2195-2200.
[11] Wijnhoven, S.W.P., Peijnenburg, W.J.G.M., Herberts, C.A., Hagens, W.I., Oomen, A.G., Heugens, E.H.W., Roszek, B., Bisschops, J., Gosens, I., De Meent, D.V., Dekkers, S., De Jong, W.H., van Zijverden, M., Sips, A.J.A.M. and Geertsma., R.E., 2009. Nano- silver – a review of available data and knowledge gaps in human and environmental risk assessment, *Nanotoxicology*, 3(2), 109-138, https://doi.org/10.1080/1743539090 2725914.
[12] Kornkai, K. and Phatharamanon, R., 2017. Plant extract synthesized silver nanoparticles and their antimicrobial activity. *KKU Science Journal*, 45(1), 34-52. (in Thai)
[13] Keawkong, N., Sripanom, L., Jea-U-bong, J. and Thiphoo, S., 2014. Synthesis and characterization of physical and antimicrobial properties of silver nanoparticles synthesis based on chemical reduction method. *Science and Technology RMUTT Journal*, 4(2), 1-10. (in Thai)
[14] Crisan, C.M., Mocan, T., Manolea, M., Lasca, L.L., Tăbăran, F.-A. and Mocan, L., 2021. Review on silver nanoparticles as a novel class of antibacterial solutions. *Applied Science*, 11(3), https://doi.org/10.3390/app11031120.
[15] Thanasuwannakul, N., Buntum, T. and Suwantong, O., 2023. Preparation and characterization of porous natural rubber loaded with silver nanoparticles. *Current Applied Science and Technology*, 23(3), https://doi.org/10.55003/cast.2022.03.23.008.
[16] Rathnayake, W.G.I.U., Ismail, H., Baharin, A., Darsanasiri, A.G.N.D. and Rajapakse, S., 2012. Synthesis and characterization of nano silver based natural rubber latex foam for imparting antibacterial and anti-fungal properties. *Polymer Testing*, 31, 586-592, https://doi.org/10.1016/j.polymertesting.2012.01.010.
[17] Zhang, Y., Xue, X., Zhang, Z., Liu,Y. and Li, G., 2014. Morphology and antibacterial properties of natural rubber composites based on biosynthesized nanosilver. *Journal of Applied Polymer Science*, 131(18), https://doi.org/0.1002/app.40746.
[18] Sarih, N.M., Gwee, K., Maher, S. and Rashid, A.A., 2002. Natural rubber (NR) latex films with antimicrobial properties for stethoscope diaphragm covers. *Materials*, 15, https://doi.org/10.3390/ma15103433.
[19] Krishnamoothy, A., Varghese, S. and Kurian, T., 2015. Effect of micro and nano zinc oxide on the properties of pre-vulcanized natural rubber latex films. *Progress in Rubber, Plastics and Recycling Technology*, 31(3), 145-156, http://doi:10.1177/147776061503100301.
[20] Chukwu, M.N., Ekhator, I. and Ekebafe, L.O., 2019. Effect of zinc oxide level as activator on the mechanical properties of natural rubber composite. *Nigerian Journal of Technology*, 38(3), 675-679, https://doi.org/10.4314/njt.v38i3.19.
[21] Ruslimie, C.A., Norhanifah M.Y., Fatimah Rubaizah, M.R., Asrul M. and Rubaizah, M.R.F., 2015. Effect of prevulcanisation time on the latex particles, surface morphology and strength of epoxidized natural rubber films. *3rd International Conference on Chemical, Agricultural and Medical Sciences (CAMS-2015),* Singapore, December 10-11, 2015, pp. 64-69.
[22] Vinod, V.S., Varghese, S., Alex, R. and Kuriakose, B. 2001. Effect of aluminum powder on filled natural rubber composites. *Rubber Chemistry and Technology*, 74(2), 236-248. https://doi.org/10.5254/1.3544947.
[23] Doma, A.S., El-Khatib, A.E., Abu-Rayan, A.E., Wazeer, W. and Abbas, M.I., 2021. A study on some physical properties of conductive Pb/NR composites. *Journal of Rubber Research*, 24, 807-817, https://doi.org/10.1007/s42464-021-00137-0.
[24] Barrera, C.S. and Cornish, K., 2017. Processing and mechanical properties of natural rubber/waste-derived nano filler composites compared to macro and micro filler composites. *Industrial Crops and Products*, 107, 217-231, https://doi.org/10.1016/j.indcrop.2017.05.045.

[25] Naphon, P., Wiriyasart, S. and Naphon, N., 2020. Thermal, mechanical, and electrical properties of rubber latex with TiO_2 nanoparticles. *Composites Communications*, 22, https://doi.org/10.1016/j.coco.2020.100449.
[26] Cabrera, F.C., Agostini, D.L.S., dos Santos, R.J., Teixeira, S.R., Rodríguez-Pérez, M.A. and Job, A.E., 2013. Characterization of natural rubber/gold nanoparticles SERS-active substrate. *Journal of Applied Polymer Science*, 130(1), 186-192, https://doi.org/10.1002/app.39153.