



The Effect of KOH and Fe₂O₃ on Natural Rubber Latex Film for Excretion Bag

Sonchai Intachai¹, Kantrakorn Suwanraksa², Tantika Charoenlap³, Nureeya Bintuan⁴, Weerawut Naebpetch⁵, and Panita Sumanatrakul^{6*}

¹ Innovative Materials Chemistry for Environment Center, Faculty of Science and Digital Innovation, Thaksin University, Phatthalung, 93210, Thailand

² Faculty of Science and Digital Innovation, Thaksin University, Phatthalung, 93210, Thailand

³ Faculty of Science and Digital Innovation, Thaksin University, Phatthalung, 93210, Thailand

⁴ Faculty of Science and Digital Innovation, Thaksin University, Phatthalung, 93210, Thailand

⁵ Faculty of Engineering, Thaksin University, Phatthalung, 93210, Thailand

⁶ Faculty of Engineering, Thaksin University, Phatthalung, 93210, Thailand

* Correspondence: spanita@tsu.ac.th

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Abstract: The excretion bag is an interesting innovation for elderly society, though a cost-effective, easy-to-use, and environmentally-friendly product remains challenging. To optimize mechanical features, the film bag was developed using Para rubber, a natural polymer as main composition by varying KOH stabilizer and Fe₂O₃ pigment. The formation of latex films was carried out using a CaCl₂ coagulant dipping process. Microscopy, SEM, and FT-IR were used to investigate the products obtained and their biodegradation. The biodegradation of the bag products spontaneously proceeded after 90-day soil burial. Adding KOH tailored the tensile strength, elongation at break, and tear strength for the mechanical properties of the as-formed films. Meanwhile, mixing Fe₂O₃ increased tensile strength but decreased elongation at break and tear strength. The obtained Para rubber bag may provide an optional innovation for facilitating the beloved elder on the excretion and other corresponding activities.

Keywords: Excretion bag; Natural rubber; Latex film; KOH; Fe₂O₃

1. Introduction

The population aged 65 and over is predicted to increase to 23 % by 2030, where one of the corresponding issues for elderly individuals is the high risk of falls due to aging-based physiological changes. Approximately 60-67 % of older adult falls occur inside the home or its immediate surroundings, often due to environmental hazards [1-2]. Toileting is a significant risk factor, with 34% of falls, especially at night, and nearly half at the bedside. Falls are hazardous for older people, with 28-35 % of those aged 65 and over at risk, rising to 32-42 % for those aged 70 and over, especially going to the bathroom. Additionally, at least 50 % of people aged over 65 face a fall each year, leading to increased hospitalization and medical costs [3-4].

Home environmental hazards, particularly standing and walking, result in high fall-induced injuries, where bathrooms and bedrooms are the most common places for these falls. Many studies have shown that the proximity between the bedroom and the bathroom and the installation of grab bars enhance safety. A bedside excretion device could reduce fall risks, supporting healthy aging [5-6]. Home hazard removal interventions have demonstrated a 38-39% reduction in fall rates among at-risk older individuals. The varied home

bathroom layouts require providers to tailor safety solutions for each case [7-9]. Almost all NR applications require high tear and wear resistance due to their strength and compressibility. Therefore, NR is used in many household products such as gloves, condoms, mattresses, pillows, laptop or phone casings, and so on [10-12]. Moreover, the benefits of NR-based innovation are renewability, biodegradability, and lower cost than synthetic rubber. Additionally, the rising price of crude oil and concerns about global warming are key factors driving the interest in NR's renewable material [13-14].

One effective solution for home health aides is a bedside excretion bag to mitigate the risk of nighttime falls. However, no current invention is made from 100% natural rubber. Natural rubber latex (NRL) or Para rubber is an excellent material for excretion bags due to its flexibility, high strength, tear resistance, and biodegradability [15-16]. Many natural rubber goods, including household and medical products, are molded using a simple dipping process. [17-19]. The structure of NRL, primarily composed of isoprene (C_5H_8) units, allows certain bacteria to degrade, making it environmentally friendly. Microbial degradation of rubber is advantageous as it does not produce harmful by-products and is energy-efficient [20-22].

Additive agents like KOH and pigments enhance the mechanical properties of NRL films. Besides, the optimal amount of dispersing agent can improve tensile strength and tear resistance [23-24]. In addition, various researchers have reported that iron oxide (Fe_2O_3) can act as an effective reinforcing filler by increasing the cross-linking density [25-26]. Therefore, this research created the excretion bag using natural rubber latex, focusing on suitable formulas and production methods by dipping. Furthermore, mechanical properties such as tensile strength, elongation at break and tear resistance, and biodegradability were also investigated. This work may provide a valuable procedure for developing innovation for facilitating an elder on excretion.

2. Materials and Methods

High ammonia-concentrated natural rubber latex (HA-NRL) was purchased from Geefin Rubbertech Co., LTD in Songkhla province, Thailand, where its dry rubber content was 60.0%. All of the used substances were obtained from Phatthana Chemical Co., LTD at Songkhla province, Thailand, which comprised of potassium hydroxide (KOH), sulfur (S_8), zinc diethyldithiocarbamate (ZDEC), zinc-2-mercaptobenzothiazole (ZMBT), zinc oxide (ZnO), Wingstay L, red iron oxide pigment (Fe_2O_3) and calcium chloride ($CaCl_2$). Before compounding, each chemical dispersion was prepared by grinding in a ball mill for 72 h, except for KOH and $CaCl_2$ aqueous solution.

2.1 Preparation of rubber compound

The NRL film was prepared by compounding the ingredients, as shown in Table 1, in an EMS-51@Sharp electric mixer. High ammonia-concentrated NRL was slowly stirred at 1st speed for 4 min, and KOH solution was firstly added by varying in 0 and 2 phr. Then, the appropriated amounts of S_8 , ZDEC, ZMBT, Wing stay L, and ZnO dispersions were added to the latex matrix under stirring for 9 min. Next, Fe_2O_3 pigment dispersion was added by varying in 0 and 0.2 phr, where the total mixing time did not exceed 15 min. These film compounds were poured into $10 \times 10 \times 0.3$ cm³ of mirror mold and left to set at ambient temperature for 5 min before vulcanization at 80°C for 1 h and 30 min in a hot air oven. The vulcanized film was washed with water several times to remove non-reacted chemicals and then dried in the oven at 50°C for 12 h. The obtained rubber film sheet was collected in a desiccator overnight.

2.2 Preparation of excretion bag

Formula and process for excreta bags from Para rubber, including mold design, were claimed protection in the petty patent of invention. Thailand followed the request number of 2403000835. To prepare the latex compound, it was started by stirring concentrated latex to remove ammonia using the lowest paddle speed (level 1) for 4 min. Then KOH, S_8 , ZDEC, ZMBT, and Wingstay L were mixed, respectively, under continually spinning until 9 min. Next, ZnO and Fe_2O_3 were added and then continuously incubated in a 10-liter tank at level 1 paddle speed. The latex compound possessed a shelf life of approximately 24 hours. For the rubber waste collection bag production using the dipping method, the procedures were started by preparing a 10 % w/v $CaCl_2$ solution to act as a coagulant for the latex compound. Even a layer of $CaCl_2$ solution was applied to coat the mold with a thickness not exceeding 2 mm. The dried mold was dipped into the prepared latex compound, rotating slowly in alternating directions for about 2 min to ensure fine coating.

The latex compound was partially set on the mold, and the coated mold was cured in the hot air oven with a fan at 100°C for 1 h.

The cooled product was coated with talcum powder to remove the rubber waste collection bag from the mold. Finally, the rubber waste collection bag was placed on a three-legged commode, as shown in Figure 1.

Table 1. Various ingredients for para latex compounding formulation.

Ingredients	¹ TSC (%)	² phr	Roles
HA-NRL	60	100	Matrix
S ₈	50	1.0	Vulcanizing agent
ZDEC	50	1.0	Accelerator
ZMBT	50	1.0	Accelerator
ZnO	50	5.0	Activator
Wingstay L	50	0.2	Antioxidant
KOH	10	0, 2.0	Stabilizer
Fe ₂ O ₃	3	0, 0.2	Pigment

¹TSC is total solid content; ²phr is part per hundred rubber.

2.3 Characterizations

2.3.1. Morphologies

The surface morphologies of the NRL compounds were examined using an optical microscope (OM), specifically a stereo microscope with a digital camera instrument with an optical objective of 15X, model SZ2-ILST. SEM analysis was conducted using a Scanning Electron Microscope machine (FEI: Quanta 450 FEG), where the acceleration voltage was set at 10 KV. Before analysis, NRL film samples were mounted on aluminum specimen stubs and coated with a gold-palladium layer.

2.3.2 Fourier transform infrared (FT-IR) analysis

Fourier-transformed infrared (FT-IR) spectroscopy using a Perkin Elmer Spectrum One FT-IR spectrophotometer was applied to explore the functional group of the samples in the wavenumber range of 4000 - 600 cm⁻¹.

2.3.3 Tensile properties

The tensile test was carried out with an Instron Universal Testing Machine using a C-type dumbbell specimen according to ASTM D412. The crosshead speed for the Instron tensile machine was set at 500 mm/min. The tensile strength of NRL films and elongation at break were taken five times, and the average results were calculated.

2.3.4 Tear resistance

The tear strength test was carried out according to ASTM D624 by using an Instron Universal Testing Machine with a C-type specimen, and the thickness of the sample was measured before the tear test with a micrometer. The crosshead speed was set at 500 mm/min. The obtained results were based on the average of five samples.

2.3.5 Thermal aging

The hot-air aging test was carried out in a circulating oven at 70°C for 3 days before the dumbbell-shaped rubber sheets' mechanical properties were tested on a tensile tester with a 500 mm/min strain rate according to ASTM D412. Aging coefficient (k) was calculated using the following equation (1):

$$\text{Aging coefficient} = \frac{(TS_a \times EB_u)}{(TS_u \times EB_a)} \times 100\% \quad (1)$$

TS_a and TS_u are the tensile strengths of the aged and un-aged samples. EB_a and EB_u are the elongation at break of the aged and un-aged samples, respectively.

2.3.6 Soil burial testing

The soil was collected from 0–10 cm depth, and the samples were buried at a depth of 8–9 cm from the soil surface for 90 days under, allowing air diffusion. Each sample was buried in a separate compost soil with pH around 7. The temperature of decomposition environment was controlled around 30°C with relative humidity of 80 %. The soil moisture was maintained at 80 % by water control.

3. Results and Discussion

3.1 Physical feature morphologies before and after soil burial testing

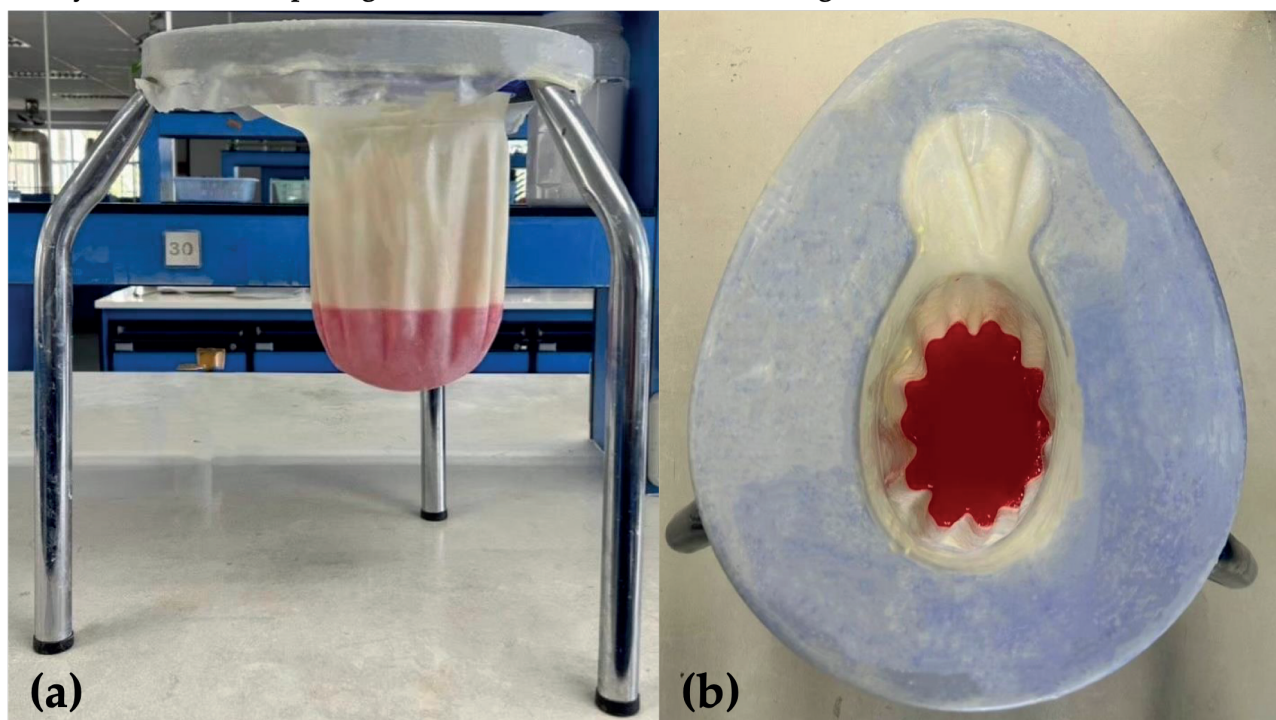


Figure 1. Excretion bag product at (a) side view and (b) top view.

Figure 1 shows the excretion bag product made from NRL compound mixed with KOH and Fe_2O_3 . It was noted that the utilization of this product was effortless, especially in facilitating the excretion of elders. Interestingly, it was a cost-effective product, just 3 \$ per piece relative to the others on the market, such as adult diapers (5 \$ per piece). Additionally, this excretion bag accommodated large amounts of water around 3 L. After use, the as-prepared bag could be easily washed with water and continually reused until the 4th cycle, keeping relatively high performance. It was thought that NRL material is resistant to chemicals, water, fatigue, wear, tear, and abrasion due to high tensile strength that can adhere easily to other materials [10-12].

To verify the morphology of products and their surface change after the biodegradation, the microscopic images were investigated, as displayed in Figure 2. Before testing, the surface of the waste collection bag mixed with KOH (Figure 2a) and Fe_2O_3 pigment (Figure 2b) was mainly smooth without any apparent change. As seen in the microscopic image in Figure 2b, the light red surface was observed, attributing to the presence of Fe_2O_3 pigment. For 45 days of soil burial, both of the films (Figures 2(c) and 2(d)) crumbled, and the surfaces became rougher and exhibited fractures, cracks, and holes, attributing to the biodegradation by soil microorganisms [27]. The degree of degradation was independent due to the uncontrolled biotic and abiotic factors. However, the thickness and form of materials played a crucial role in the biodegradation process under soil burial and composting conditions [28-30]. The microbial activities proposed the mechanism of biodegradation in light, heat, water, and air, as shown in Figure 3. Meanwhile, the biodegradation of the product containing Fe_2O_3 was further run through the reduction-oxidation process by Fe_2O_3 catalyst followed by Karimi-Avargani et al. (2024) [31]. As a result, the prepared films could be a preferable choice owing to biodegradability based on zero waste and environmentally friendly.

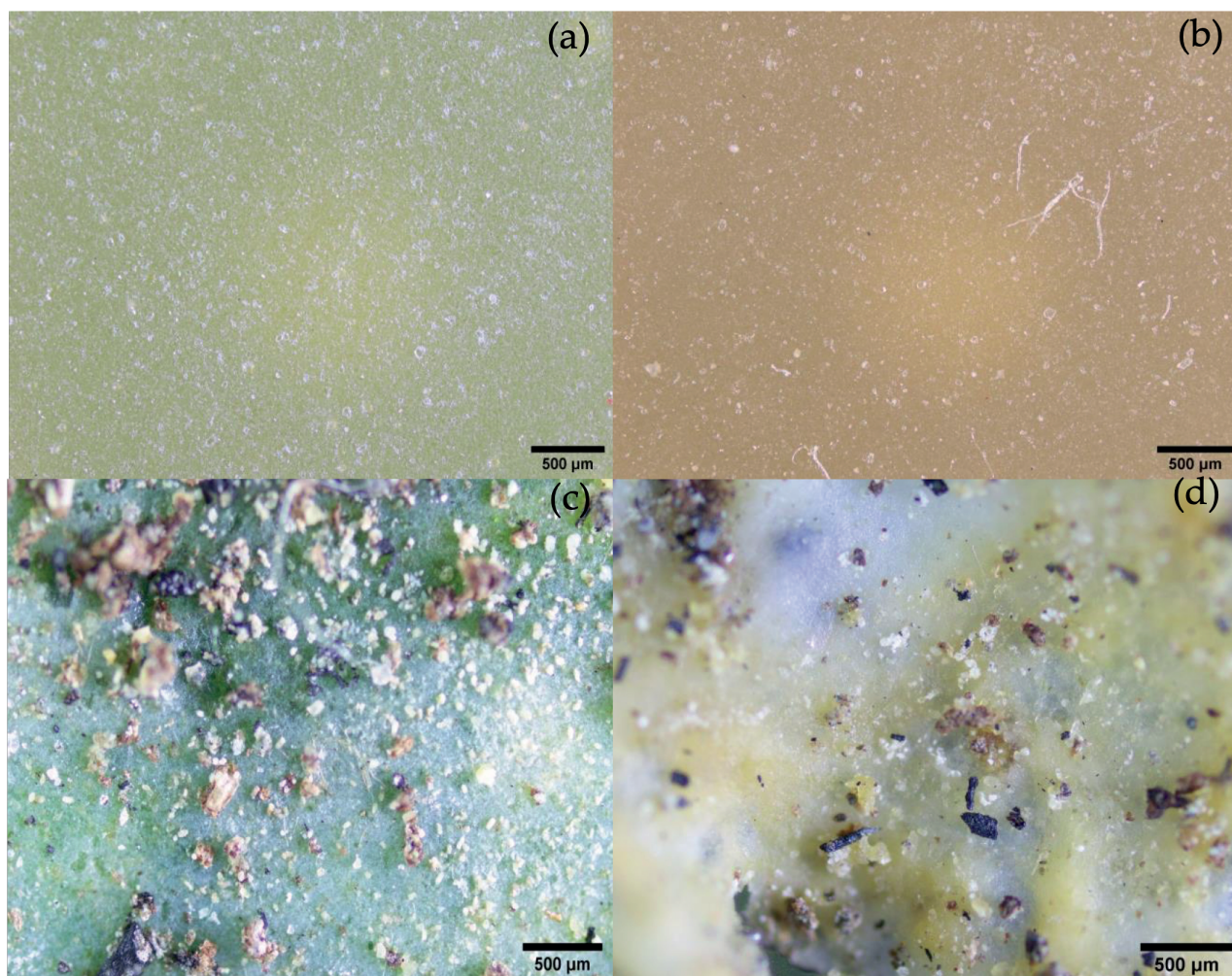


Figure 2. Microscopic images of the bag mixed with KOH (a, c) and Fe₂O₃ (b, d) before (a-b) and after (c-d) soil burial 45 days.

Various techniques were applied to confirm the biodegradation, and the bags' SEM images after being deposited for different long periods were investigated, as depicted in Figure 4. As seen in Figure 4a, the SEM image of the bag exhibited densely packed sheets corresponding to NRL's crosslink-framework structure [32-33]. By varying the biodegradation period, microbial colonies were observed after 12 weeks (Figure 4b). As the period elapsed, the microbial colonies and the hollow region on latex films' surface began to spread (Figures 4c and 4d). These gram-positive characteristics of microorganisms (mycelium type) consumed the polyisoprene chain (NRL film) as a sole energy source to generate an enzyme with further hydrolyzing glucosidic linkages in rubber compound [34-35]. The results could confirm the biodegradation mechanism through the soil system containing rich microorganisms [36].

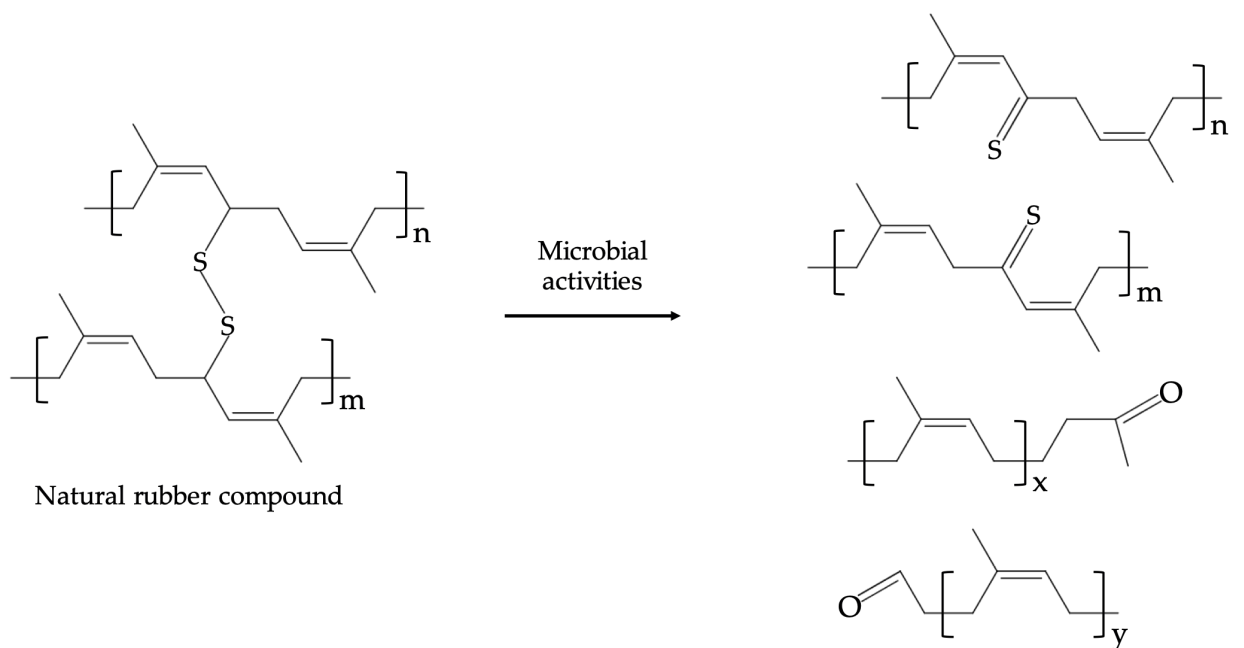


Figure 3. Proposed mechanism of natural rubber compound biodegradation.

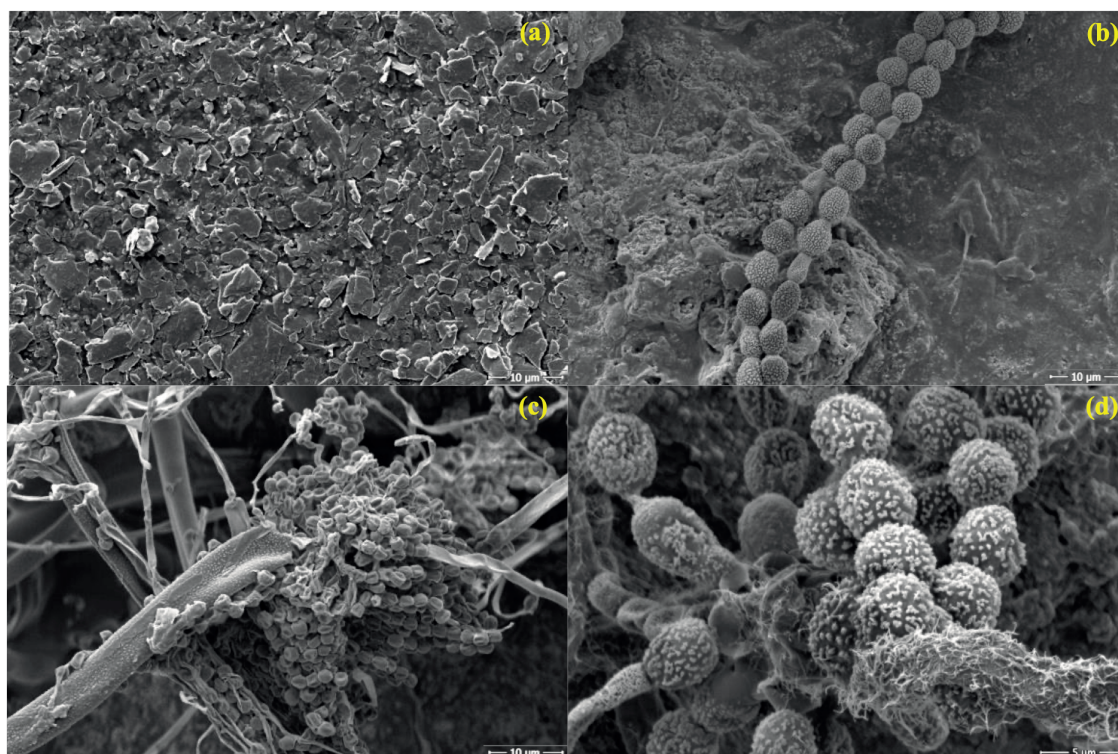


Figure 4. Morphologies of the bag (a) before and after soil burial for (b) 45 days, (c) 90 days at 5000x, and (d) 90 days at 12000x.

3.2 Functional groups from FTIR analysis

Besides, the characteristics of chemical species in the product mixed with KOH and Fe_2O_3 were investigated by using the FT-IR spectra based on functional groups, as shown in Figure 5. For the FT-IR spectrum of NRL film (before soil burial) showed the different infrared bands in the wavelength range $4000 - 650 \text{ cm}^{-1}$, where those located at 3676 cm^{-1} (hydroxyl groups at the mineral surface), $3286 - 3315 \text{ cm}^{-1}$ ($-\text{OH}$),

2918 – 2960 and 1437 – 1449 cm^{-1} ($-\text{CH}_3$), 2851 – 2853 and 1375 – 1378 cm^{-1} ($-\text{CH}_2$), 1637 cm^{-1} ($\text{C}=\text{C}$) and 834 – 839 cm^{-1} ($\text{C}-\text{H}$). The findings correspond to the FT-IR characteristics of cis-1,4-polyisoprene, that is, rubber monomer [37-38]. Relative to the infrared spectrum of fresh NRL film, most FT-IR bands for the NRL films after soil burial for 45 days and 90 days were similarly observed, indicating the presence of the same functional groups (cis-1,4-polyisoprene) [39-40]. However, the infrared intensities were lower, suggesting lower monomer units because of the shortening of the polymer chains by microbial [41-42]. Besides, the change in two FT-IR bands was observed. The band appeared at 1628 cm^{-1} because the $\text{C}=\text{O}$ bond of aryl ketone was stronger, whereas that appeared at 3676 cm^{-1} was weaker and disappeared for the sample deposited for 90 days, and the $\text{N}-\text{H}$ bond of the amide group at 1542 cm^{-1} also appeared [43]. These reasonable observations were consistent with polyisoprene chain scission's oxidation and hydrolysis processes [44-45].

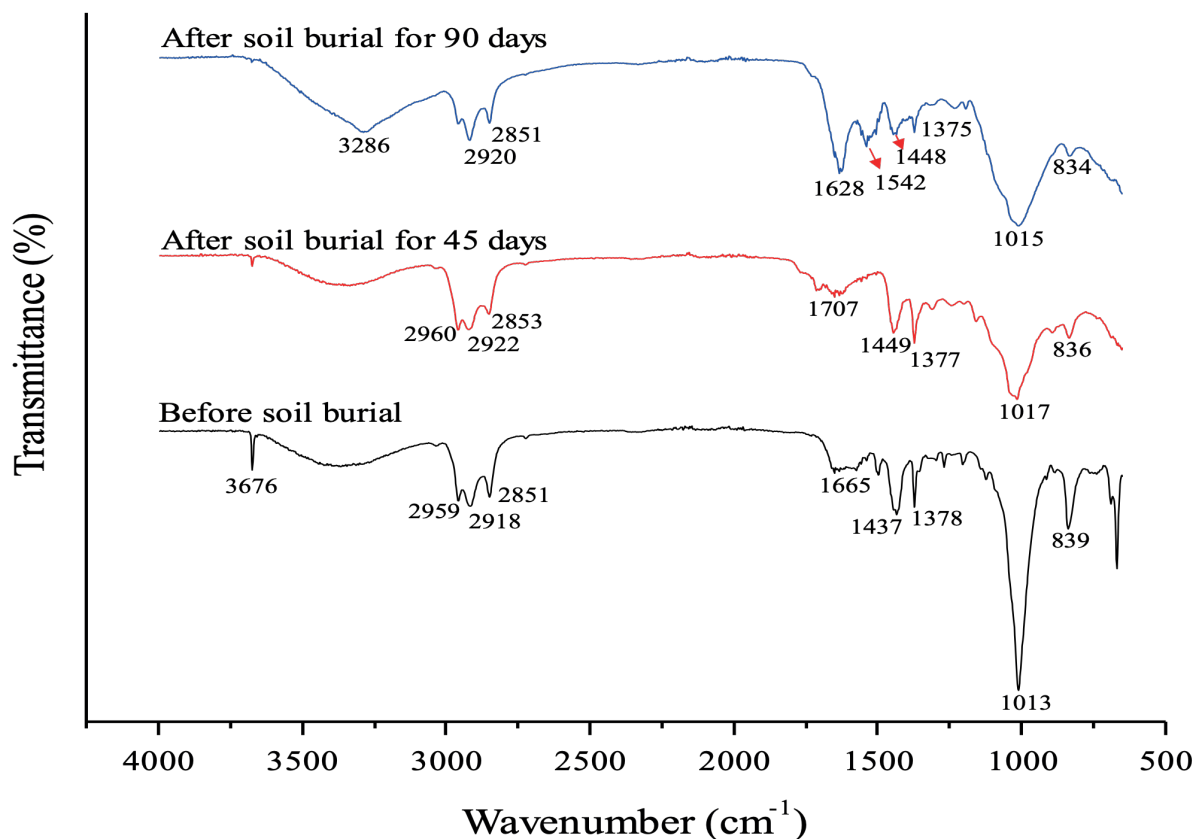


Figure 5. FT-IR spectra for the as-prepared film and after soil burial for 45 and 90 days.

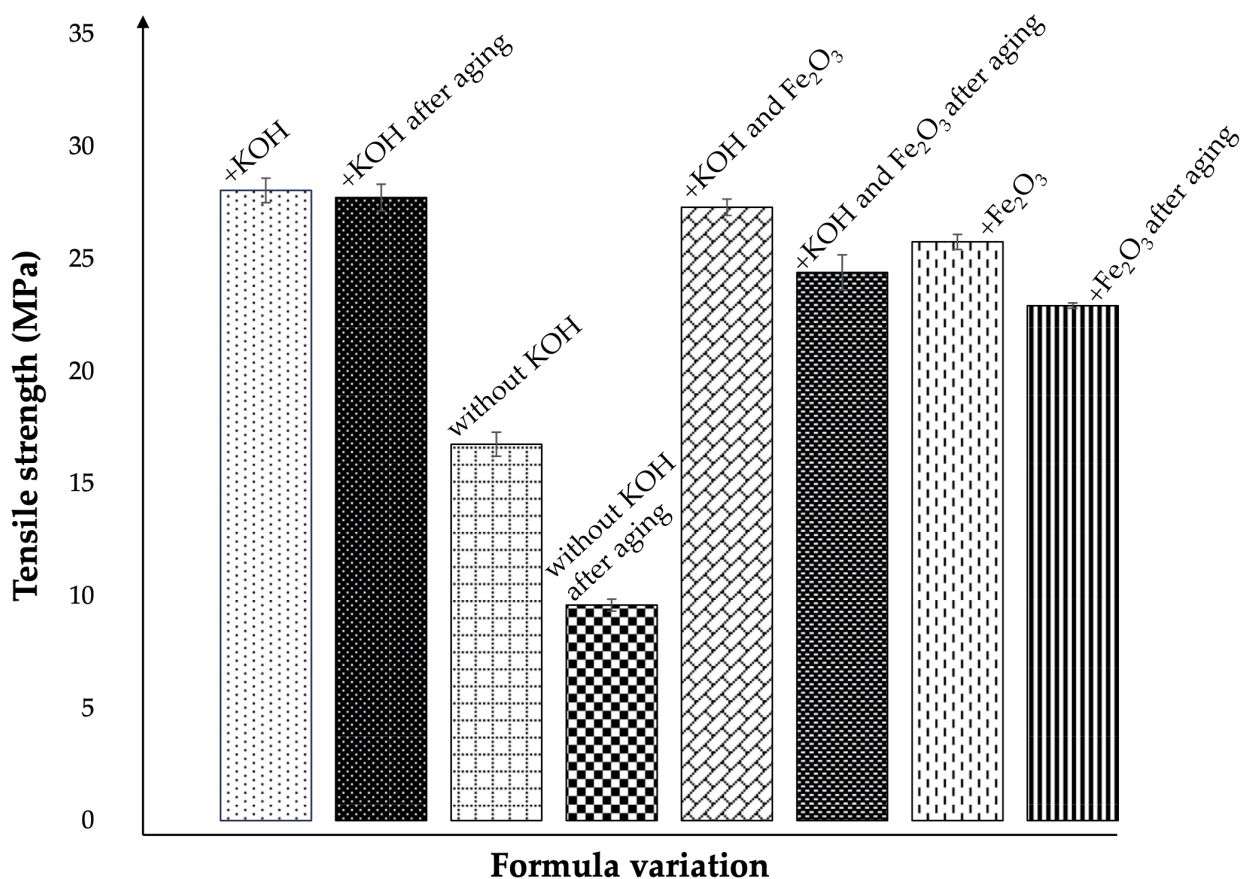
3.3 Mechanical properties

The mechanical properties of NRL products and those prepared by mixing KOH and/or Fe_2O_3 before and after aging were demonstrated by such features as tensile strength (Figure 6), elongation at break (Figure 7), and tear resistance (Figure 8), where all of the data are summarized in Table 2. Before aging, in Figure 6, the addition of KOH and/or Fe_2O_3 increasingly affected the tensile strength of rubber films. Relative to without the addition of KOH (16.75 ± 0.53 MPa), KOH could promote the highest strength of the rubber film (28.05 ± 0.55 MPa), suggesting an excellent stabilizer [38-39].

Table 2. Tensile strength, elongation at break, and tear resistance with different parameters for Para excretion bag.

Parameters	Tensile strength (MPa)	Elongation at break (%)	Tear resistance (N/mm)
KOH	28.05±0.55	1134.60±17.09	46.53±0.05
KOH after aging	27.73±0.59	1038.82±17.32	38.37±0.26
without KOH	16.75±0.53	1066.73±16.97	35.71±0.01
without KOH after aging	9.59±0.27	925.62±9.08	30.82±0.31
KOH and Fe ₂ O ₃	27.30±0.37	1105.57±17.39	41.84±0.40
KOH and Fe ₂ O ₃ after aging	24.40±0.78	888.23±6.44	36.63±0.52
Fe ₂ O ₃	25.76±0.34	1056.20±18.70	24.59±0.32
Fe ₂ O ₃ after aging	22.92±0.12	821.13±6.29	21.33±0.43

Meanwhile, Fe₂O₃ could also tailor the tensile strength (25.76±0.34 MPa), which could be a good second stabilizer to reinforce the films. These phenomena arose from the perfect vulcanization process because KOH and Fe₂O₃ could drive the complete vulcanization reaction between polyisoprene with S8 [44-45], supporting the good distribution on the rubber film surface (Figure 4a). Interestingly, after aging, the tensile strength of all modified products was significantly higher than that of the film without adding KOH after aging. In addition, the strength of the modified films with KOH and/or Fe₂O₃ after aging was slightly reduced compared to those before aging. These results indicated that KOH and Fe₂O₃ could protect the heat treatment of the rubber film.

**Figure 6.** Tensile strength of NRL compounds with the effect of KOH and/or Fe₂O₃.

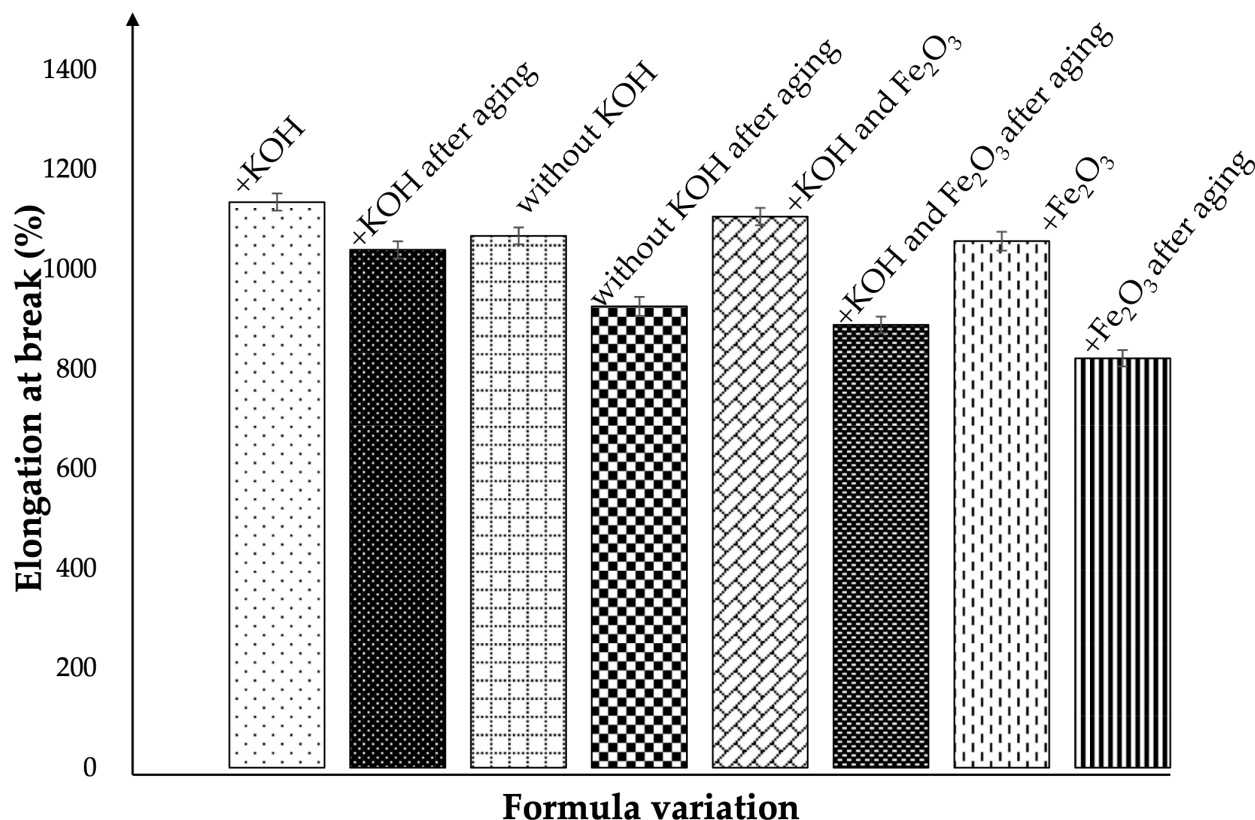


Figure 7. Elongation at break of NRL compounds with the effect of KOH and/or Fe₂O₃.

The effect of KOH and/or Fe₂O₃ was further investigated, demonstrated by elongation at NRL compound break, as shown in Figure 7. Without the addition of KOH (1066.73±16.97 %), the presence of KOH in the film could tailor the elongation at break (1134.60±17.09 %) because the vulcanization process reached the optimal condition of 2.0 phr KOH. On the other hand, the elongation at the break of the films was slightly increased by adding KOH and Fe₂O₃ (1105.57±17.39 %) due to the reduction in the rigidity of the films [25-26]. The value was slightly reduced by adding Fe₂O₃ (1056.20±18.70 %), which might slightly lengthen the rubber compound's hard segment. To compare the film after aging, the elongation at break for the product mixed with KOH showed a higher value than that without KOH, indicating high thermal stability. However, the presence of both KOH and Fe₂O₃ and only Fe₂O₃ in the films made the elongation at break slightly lower, indicative of the stricter component produced by adding excess Fe₂O₃ amounts.

3.4 Tear resistance

As seen in Figure 8, the tear resistance of NRL samples (before and after aging) was enhanced when KOH (46.53±0.05 and 38.37±0.26 N/mm) and both KOH and Fe₂O₃ (41.84±0.40 and 36.63±0.52 N/mm) were mixed, which could be indicated that the use of KOH and Fe₂O₃ caused the rubber films more tear resistant relative to without the addition of KOH (35.71±0.01 and 30.82±0.31 N/mm). It has arisen from the effect of stabilizers and inorganic components [44-45]. Whereas both values (before and after aging) were decreased for adding only Fe₂O₃ (24.59±0.32 and 21.33±0.43 N/mm), supporting the more rigid rubber compound with the enhanced stiffness.

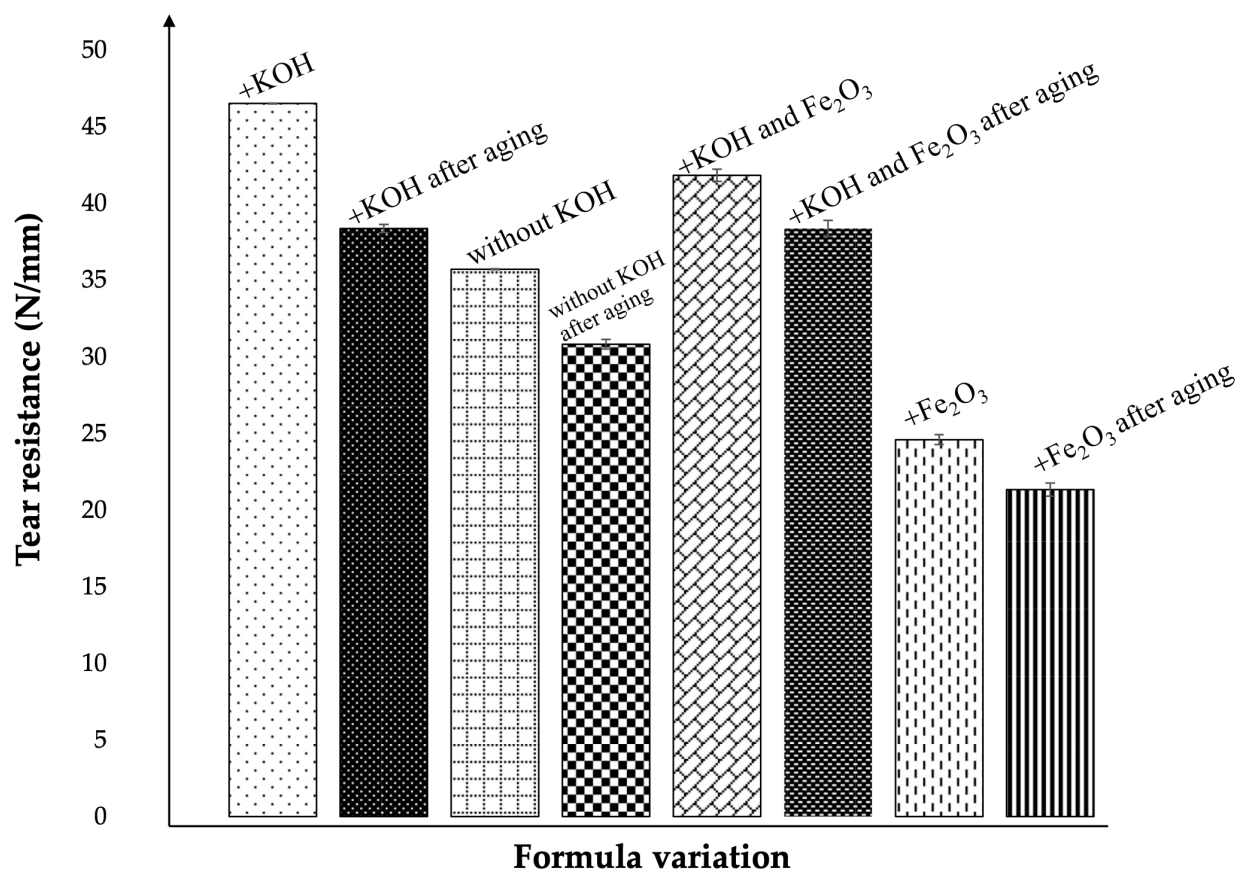


Figure 8. Tear resistance of NRL compounds with the effect of KOH and/or Fe₂O₃.

3.5 Thermal aging

Table 3. Aging coefficient with different parameters for Para excretion bag.

Parameters	Aging coefficient (%)
KOH	90.51
without KOH	49.63
KOH and Fe ₂ O ₃	71.81
Fe ₂ O ₃	69.17

From Table 3, The aging coefficients were calculated based on the deformation energy before and after aging, which were analyzed to assess the effect of stabilizer and pigment on the stability of the compounds. These thermo-oxidative aging coefficients of compounds containing KOH (90.51 %), both KOH and Fe₂O₃ (71.81 %), and Fe₂O₃ (69.17 %) were higher than that without the addition of KOH (49.63 %), confirming that the presence of stabilizer and pigment increased the aging resistance. Therefore, the stabilizer proved to be the most effective anti-aging substance. Additionally, the addition of pigment also significantly improved the stability of the compound [46].

4. Conclusions

This study was achieved by fabricating an excretion bag made from Para rubber compound with the addition of KOH and/or Fe₂O₃. The physical characteristics of the products were satisfactory, showing high reusable performance due to the chemical and mechanical features of natural rubber latex and biodegradation after the burial for 90 days through bio-activities by microorganisms. The effect of KOH could increase the tensile strength (11.30 MPa), elongation at break (67.87 %), and tear strength (10.82 N/mm), and these values were slightly lower after aging, indicating an efficient stabilizer. Additionally, the blending of Fe₂O₃ tailored

the tensile strength (9.01 MPa) as the role of the second stabilizer. As the optimal conditions, the presence of both KOH and Fe₂O₃ could enhance all three mechanical characteristics, attributed to the stabilizers' synergistic effect. This study may provide a valuable process and optional innovation to produce a Para rubber bag for older adults to use at the bedside or other corresponding activities to protect them from falling risk.

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