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Effect of Latex Compound Dwell Time for the Production of Prototyped Biodegradable Natural Rubber Latex Gloves

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Abstract. The production of prototyped biodegradable natural rubber (NR) latex gloves with the addition of sago starch as a fillers in latex compounding using Lab Scale Batch Dipping Machine has been investigated. As biodegradable gloves, the progress of biodegradation of NR latex gloves is also being determined through weight loss measurement test. Results showed the optimum dwell time of latex dipping was achieved at 6 sec with optimum tensile properties and within normal examination glove thickness. The weight loss of biodegradable NR latex gloves after one month soil burial showed additional of sago starch into latex compounding can accelerate the biodegradation process.

1. Introduction

Rubber gloves are one of the highest productions of consumable and disposable commodity in the global market. The Malaysian Rubber Glove Manufacturers Association (MARGMA) has estimated the global demand for rubber gloves in 2018 is expected to grow at 15% [1]. The continuing increased in demands of rubber gloves will directly contribute to rubber waste solid disposal problem.

In order to solve the increasing of disposal gloves, production of biodegradable gloves might one of the options to overcome this global issue. Biodegradable matter is material capable of being decomposed by bacteria or other biological means. It has the ability to be broken down into smaller, harmless products by way of the action of living organisms [2]. Moreover, the biodegradable NR latex gloves are usually less harmful to the environment than the commercial gloves. It might able to provide soil nutrients necessary for the regeneration of live.

The biodegradable NR latex gloves were produced by introducing bio-material into the NR latex system. According to Afiq and Azura [3], addition of the carbohydrates polymer such as sago starch as the bio-material can acts as filler through void spaces between the rubber matrix particles. It is much feasible for the microbial activity to occur during the disposal of biodegradable NR latex gloves. The microorganisms will produce specific enzyme that able to decompose the rubber molecules. Hence, it accelerates the rate of decompose of the biodegradable NR latex gloves.

In order to commercialize it as mass production, the production of the biodegradable NR latex gloves with the addition of sago starch as a fillers in latex compounding in larger scale is highly needed. As latex compound dwell time is one of the important parameters in gloves production, the aim of this study is to investigate the effect of latex compound dwell time toward physical properties of biodegradable NR latex gloves. Dwell time is the time interval between former dipping and withdrawal of former from the latex compound. This study is important to assess the relationship between dwell time, thickness and physical properties of biodegradable NR latex gloves.



2. Materials and Methods

2.1. Materials

NR latex was purchased from Zarm Scientific and Supplies Sdn. Bhd. with the initial properties of dry rubber content (DRC) of 60.8%, total solid content (TSC) of 61.7%, mechanical stability time (MST) of 1020 sec, and volatile fatty acid number (VFA no.) not exceeding 0.2. Meanwhile, sago starch was obtained from Sago Link Sdn. Bhd. with amylose and amylopectin content ranging from 22 – 31.7% and 68.3 – 78%; respectively and other compounding ingredients such as zinc diethyldithiocarbamate, zinc oxide, potassium hydroxide, antioxidant [2,2'-Methylene-bis(4-methyl-6-tert-butylphenol)] and sulphur were obtained from Farben Technique (M) Sdn. Bhd. Whereas calcium nitrate $[\text{Ca}(\text{NO}_3)_2]$, acetic acid and sodium hydroxide were purchased from Merck Sdn. Bhd.

2.2. Preparation of NR latex compound and pre-vulcanization process

The preparation of NR latex compound was carried out in accordance with a previous study [3]. All the ingredients were mixed for 2 hours at 270 rpm. The compound was then pre-vulcanized at temperature of 70°C in a water bath and constantly stirred at speed of 270 rpm until chloroform number 2 (degree of vulcanization of pre-vulcanized NR latex) has achieved. The pre-vulcanized latex was left for maturation process at room temperature for 18 hours.

2.3. Production of gloves

The formers (examination gloves type) were cleaned in the acetic acid and sodium hydroxide with the aid of brushes to remove any dirt attached to the formers. Subsequently, the formers were rinsed with the tap water to remove the chemicals. The temperature of acetic acid solution, tap water and sodium hydroxide solution were maintained at 60°C.

The cleaned formers were first dipped into the coagulant tank for 10 sec and dried in the oven at 70°C for 5 minutes. The formers were then dipped into the pre-vulcanized latex tank with different dwell time (3, 6 and 9 sec) followed by drying in the oven at 100°C. After the first 3 minutes in the oven, the formers were taken out for beading followed by drying in oven again until the gloves were cured. The formers were taken out from the oven and the gloves were stripped with the aid of calcium carbonate powder after the formers were cooled.

2.4. Physical properties test

Tensile and tear tests were carried out according to ASTM D 412 and ASTM D 624 respectively by using Instron Machine (Model 3366) with the crosshead speed of 500 mm/min. Five specimen of each sample were used to obtain average values for tensile strength, elongation at break, modulus of elasticity (M100, M300 and M500) and tear strength.

2.5. Crosslink density

The swelling test was carried out according to ASTM D471 where a test piece weighing about 0.2 g was cut from NR latex films. The films were immersed in pure toluene in universal bottle before transferred into a water bath and heated at 40°C for 48 hours. The test piece was taken out, the loose liquid was rapidly removed by blotting with filter paper, and the swollen weight was

immediately measured. The volume fraction of latex (V_r) in the swollen network can be calculated by using equation (1).

$$v_r = \frac{W_B / \rho_r}{(W_B / \rho_r) + (W_A - W_B / \rho_s)} \quad (1)$$

where W_B and W_A are weights of NR latex samples before and after toluene immersion. ρ_r and ρ_s are the density of the NR latex (0.9203 g/cm³) and toluene (0.862 g/cm³); respectively. The crosslink density $[X]$ was determined by the Flory-Rehner theory in equation (2) [4].

$$[X] = \frac{-[\ln(1-V_r) + V_r + \chi V_r^2]}{V_s (V_r^{1/3} - \frac{V_r}{2})} \quad (2)$$

where V_s is the molecular volume of the toluene (105.91 cm³/mol) and χ is Flory-Huggins NR-toluene interaction parameter [4].

2.6. Biodegradation procedure and weight loss analysis

The gloves were buried in the soil for one month for biodegradation process. Upon collection, the gloves were rinsed and dried at room temperature to a constant weight and the weight was recorded. Weight loss of the samples with time was used to determine the degradation rate of the samples by following Equation 3:

$$\text{Weight loss (\%)} = [(W_i - W_d) / W_i] \times 100 \quad (3)$$

where W_i is the initial dry weight of the sample and W_d is the dry weight of the sample after biodegradation process.

2.7. Physical properties test

Tensile and tear tests were carried out according to ASTM D 412 and ASTM D 624 respectively by using Instron Machine (Model 3366) with the crosshead speed of 500 mm/min. Five specimen of each sample were used to obtain average values for tensile strength, elongation at break, modulus of elasticity (M100, M300 and M500) and tear strength.

3. Results and Discussion

3.1. Mechanical properties and crosslink density analysis

According to Fig. 1(a), it shows that the tensile strength of the NR latex gloves increased with dwelling time. This is attributed to the increased of films thickness due to increase of latex deposited on the former. This observation were augmented by the results of crosslink density shown in Fig. 1(b). The figure shows that 3 sec dwelling time produced the lowest crosslink

density and the highest was achieved at 9 sec. As the time for film formation is longer, more latex particles be able to settle to form continuous films and this phenomenon were manifested with the increased of crosslinking formed in cured NR latex films. It is in agreement with the work done by Zhao et al. which study the influence of crosslink density on mechanical properties of NR latex [5].

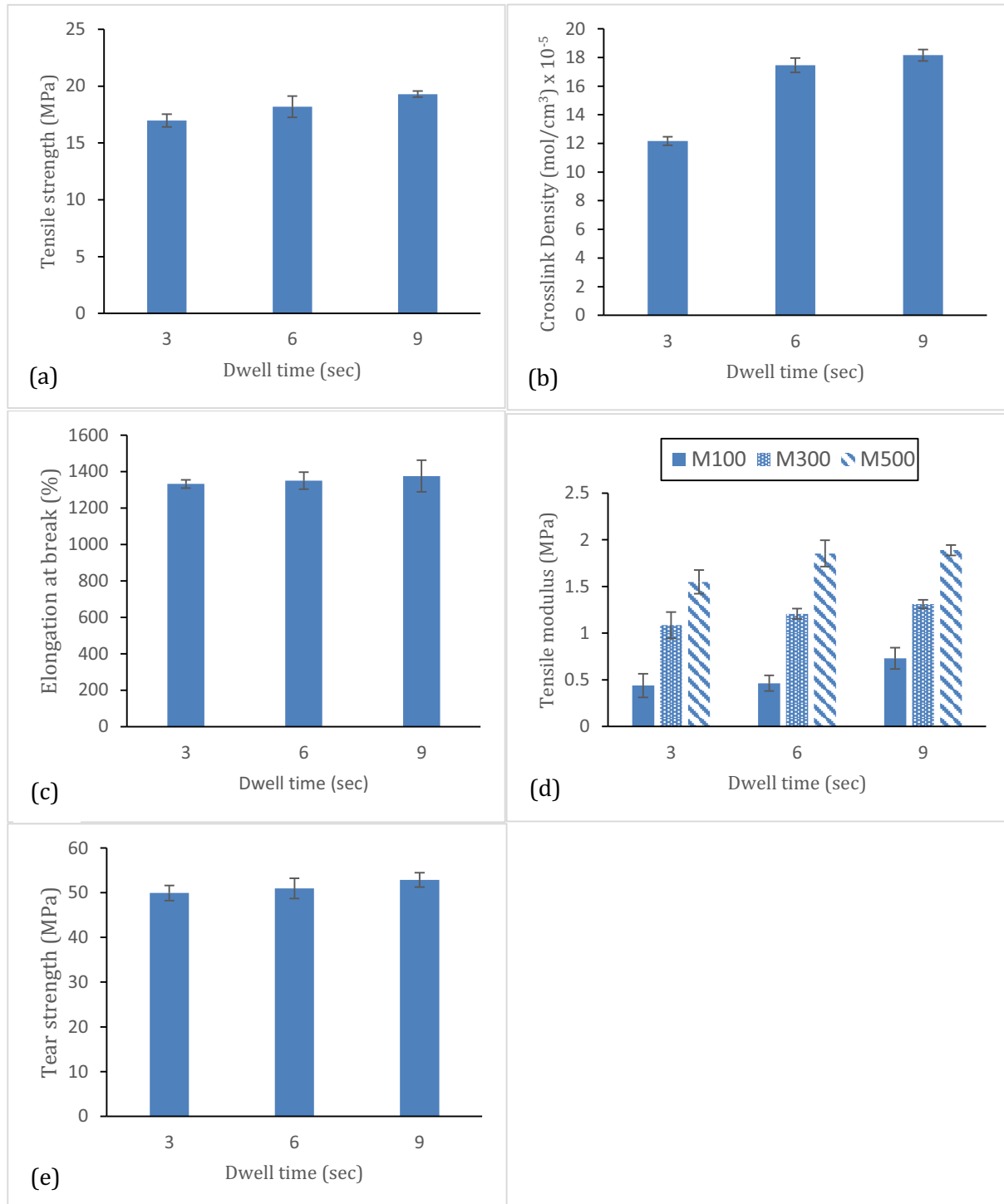


Fig. 1. (a) Tensile strength; (b) crosslink density; (c) elongation at break; (d) tensile modulus; and (e) tear strength of biodegradable NR latex gloves with different latex compound dwell time.

Fig. 1(c) shows the elongation at break of the biodegradable NR latex gloves with respond to different dwell time. It can be seen that the elongation at break slightly increased with increasing of dwell time. As discussed previously, the crosslink density of biodegradable NR latex gloves increased with increasing dwell time. The crosslink joint will provide restriction on the mobility of inter-crosslink chains. In other words, the higher crosslink density leads have to higher strain concentration as more forces needed to pull the specimen [7].

Fig. 1(d) shows the tensile modulus corresponding to different dwell time. It can be seen that the tensile modulus increase with increasing dwell time at 100, 300 and 500% of elongation. It shows similar trend to the tensile strength properties which indicates that the tensile modulus is affected by the crosslink density and the thickness of biodegradable NR latex gloves as discussed earlier. As the crosslink density increase and higher force is needed to deform the biodegradable NR latex gloves resulted in increase of tensile modulus.

Fig. 1(e) shows the effect of dwell time on the tear strength of the biodegradable NR latex gloves. It can be observed that the tear strength increased with increasing of dwell time. A thicker biodegradable NR latex gloves gives a higher strength value than a thin film with the same dosage of vulcanizing ingredients. It is reasonable to expect that a thin biodegradable NR latex gloves is easily ruptured due to incoherent formation of firm due to low amounts of material. It shows similar trend with the finding of Lim et al. who studies in mechanical properties of carboxylated nitrile latex film with varying thickness. They found that tear strength increasing with increased in thickness for carboxylated nitrile latex film [8].

Moreover, the crosslink density also affects the tear strength of the biodegradable NR latex gloves. As longer the dwell time, the higher the crosslink density. Hence higher force is needed to initial the crack and propagation in the specimen resulted in higher tear strength [9].

3.2. Gloves thickness analysis

Based on Table 1, the biodegradable NR latex gloves thickness increased with increasing longer dwell time. The thickness at 9 sec dwell time was the thickest, 0.191 mm, followed by 6 sec dwell time, 0.177 mm and 3 sec dwell time, 0.169 mm. It might be attributed to as the dwell time longer, there was longer time for the NR latex to colloiddally de-stabilize on the surface of the hot former. When more NR latex de-stabilized and deposits on the surface of the former, it leads to greater thickness.

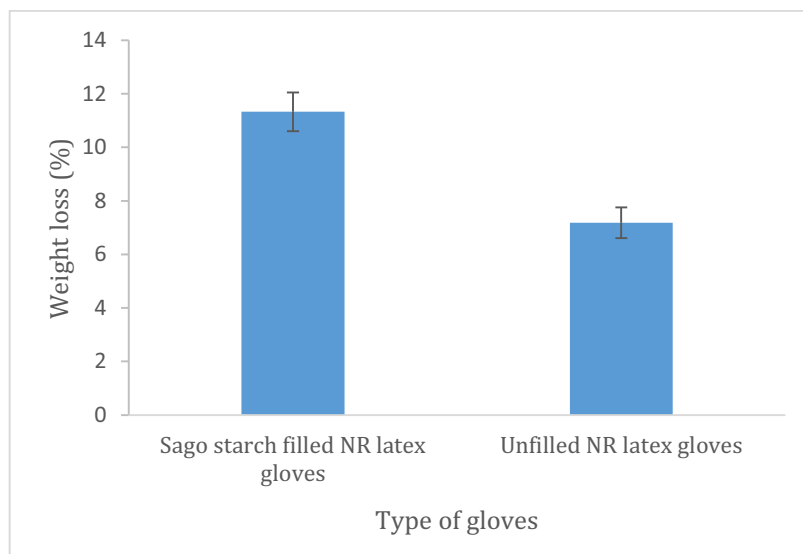
For this study, we have used the examination glove typed formers to produce the gloves; hence the right glove thickness need to consider. Normally, the examination gloves has made with thinner materials (0.1–0.18 mm) compared to surgical gloves (0.17–0.3 mm) [10]. Based on Table 1, it can be observed that 9 sec dwell time already exceed the maximum range for common examination glove's thickness. Besides, the aforementioned results between 6 and 9 sec dwell time also showed comparable physical strength and crosslink density. Thus, the dwell time at 6 sec was preferred to be the best dwell time for production of biodegradable NR latex gloves.

Table 1. Average gloves thickness at different dwell time.

Dwell time (sec)	Average gloves thickness (mm)
3	0.169
6	0.177
9	0.191

3.3. Mass loss analysis

Further study has been conducted to monitor the biodegradability of thin NR latex gloves. Fig. 2 shows the effect of biodegradation on biodegradable NR latex gloves on the mass loss assessment. For one month, the mass loss of biodegradable (sago starch filled) NR latex gloves was 11.33% whereas sago starch unfilled NR latex gloves was 7.19%. The mass loss might attribute to the consumption of sago starch by the microorganism in the soil. Due to microbial consumption of carbon in poly-isoprene chain in biodegradable NR latex gloves and the enzymatic cleavage of glucosidic links in sago starch, size and number of empty voids formed increased. This contributes to the increase of mass loss of biodegradable NR latex gloves as biodegradation process occurred [11].

**Fig. 2.** Biodegradation rate of the gloves after one month of biodegradation periods.

4. Conclusions

In conclusion, the dwell time at 6 sec was preferred as it showed high mechanical properties with a thinner NR latex gloves film. The incorporation of sago starch into latex compound has proven can accelerate the biodegradation of thin NR latex gloves.

Acknowledgments

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