Effect of sago starch loadings on soil decomposition of Natural Rubber Latex (NRL) composite films mechanical properties

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A B S T R A C T

Natural Rubber Latex (NRL) was compounded with 0—25 phr sago starch filler loadings. Effects of soil decomposition/degradation process on the mechanical properties of NRL films were investigated. Results showed that incorporation of sago starch decreased the physical properties of NRL composite films. As sago starch loading was increased, the physical properties of sago starch filled NRL (SSNRL) composite films decreased compared to control NRL films. The results indicated that optimum physical properties were achieved by 10 phr SSNRL composite films. Decomposition of NRL films was assessed through films mass loss and water vapor transmission rates of films. SEM analysis confirmed decomposition progress and filler agglomeration formation of NRL films as sago starch loading was increased above optimum loading. Fourier Transform Infra-Red analysis indicated doubly bonded carbon breakage in control (0), 10, and 25 phr films and carbonyl groups intensification signifying aldehyde and ketones groups' formation at the last week of soil decomposition period.

1. Introduction

Natural Rubber Latex (NRL) is a colloidal dispersion of *cis*-1,4 Polyisoprene in a form of milky sap which is obtained from incised bark of *havea Brasiliensis* tree. This commodity is usually used to produce thin film products especially Natural Rubber Latex (NRL) gloves (Linos et al., 2000; Linos and Steinbütchel, 2005; Rose and Steinbuchel, 2005.). Due to recent increase in awareness on barrier protection, especially after several outbreaks of epidemic pathogens (e.g. influenza A, HIV-AIDS and etc), production of NRL gloves has been increased tremendously worldwide. As NRL gloves are considered as single use materials, it increased the production of NRL gloves/other NRL thin film products solid waste upon disposal.

The problems occur due to hardly degraded NRL solid waste upon disposal. This is due to the presence of inorganic materials such as antioxidants and sulfur crosslinks that make NRL films resistant to microbial infections. During degradation of polyisoprene backbone chain, oxidation process occurs without exception (Rose and Steinbuchel, 2005). Rose and Steinbuchel (2005) reported that, by incubating squalene (*Trans*-1,4 Polyisoprene) with several

degrading enzymes from various *genuses*, the mechanisms of poly-isoprene molecular degradation is proposed.

Under aerobic condition, three metabolic pathways may occur; (1) Oxidation of terminal methyl group leading to formation of carboxylic acid derivatives group, (2) Hydratation of double bond to tertiary alcohol (aldehyde and ketones), (3) oxygenase-catalyzed cleavage of the internal bond resulting in polymeric molecular chain breakage. These events were confirmed by Fourier Transform Infra-Red (FTIR) analysis (Rose and Steinbuchel, 2005; Siti Zaleha Isa et al., 2007; Demirbas, 2007; Karim et al., 2008).

Even though polyisoprene backbone chain degradation (oxidation) can occur in natural environment, the process is time consuming. Thus, combination of latex systems with other degradable materials has been studied to accelerate the process. This is used to make the latex based products being able to decompose by means of microorganisms (biodegradable). Starch is one of the practical options to be used as a biomaterial in NRL compounding. This is due to several characteristics of starch which are; cheap, naturally abundant, high susceptible to biodegrade and it is a renewable resources (Hermansson and Svegmark, 1996; Chandra and Rustgi, 1998; Biliaderis et al., 2009; Kiing Sie et al., 2010).

Starch is a polysaccharide material having random coiled amylose and a branched structure of amylopectin linked by glucosidic linkages. Amylopectin has stabilizing effects, while amylose in a form of free molecules act as a stabilizer which able to

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form hydrogen bonding with latex colloidal particles (Biliaderis et al., 2009). During decomposition of NRL films, microorganisms which consume these substances (amylose and amylopectin) produce amylases and glucosidases enzymes that are able to hydrolyze the glucosidic linkages of both amylose and amylopectin molecular chain further. The enzymatic reaction takes place in both α-1,4-link in both components and α-1,6-link in amylopectin (Bates et al., 1943).

As the degradation process of starch components is more feasible compared to polyisoprene backbone chain in NRL, incorporation of starch in natural rubber latex (NRL) compound hypothetically increases the decomposition process of NRL film via oxidation in polyisoprene backbone chain and enzymatic cleavage in starch. The effect of decomposition process on NRL films was assessed via water vapor transmission rates and mass loss of NRL films. Apart from that, formations of several significant functional groups such as aldehyde and ketones which represent cleavage of rubber chain and intensification of hydroxyl group representing starch hydrolysis process were observable by Fourier Transform Infra-Red (FTIR) spectograph. SEM images were taken to confirm the formation of clear zone upon biodegradation process.

2. Experimental

2.1. Materials

NRL was purchased from Revertex (Malaysia) Sdn. Bhd. Initial properties of NRL were in accordance with ISO 2004:1979 standards where its dry rubber content was 60.0%, total solid content was 61.5%, mechanical stability time was 1100 s, and volatile fatty acid number did not exceed 0.2. Sago starch filler dispersion was prepared from sago powder by grinding in a ball milling for 24 h to induce gelatinization process. The powder was first mixed with the dispersing agents, Anchoid (5% wt/wt), potassium hydroxide, KOH (3% wt/wt), and distilled water (67% wt/wt). After the grinding process, the prepared sago starch was in the form of a highly viscous dispersion in brownish color.

2.2. Preparation of pre-vulcanized NRL films

Pre-vulcanized NRL films were prepared by the dry coagulant dipping process. Table 1 shows the formulation of NRL compound. Cleaned aluminum steel plates were dipped into a 10% calcium nitrate solution for 17 s and dried in an aired oven at 100 °C for 5 min. Then, the plates were dipped into pre-vulcanized NRL compound for 13 s followed by drying in the oven at 100 °C for 1 h. The dried NRL films were conditioned at room temperature for 24 h.

2.3. Preparation of soil degraded NRL films

Five series of control and Sago starch filled NRL (SSNRL) composite films were prepared. Each series are buried in a separate compost soil with pH around 4–6. The temperature of decomposition

environment was controlled at 29–30 °C with relative humidity of 80%. The soil moisture was maintained at 80%. Each series was taken out weekly for further testing.

2.4. Tensile properties

The tensile test was carried out according to ASTM D412. The NRL films were cut into dumbbell shapes before being subjected to the tensile test. The crosshead speed for the Instron tensile machine was set at 500 mm/min. Tensile strength of NRL films, elongation at break, and modulus at 100, 300, and 500% elongations were taken.

2.5. Tear strength

Tear strength test was carried out according to ASTM D624 by using Instron ™ machine. NRL films were cut into crescent shapes and thickness of the sample was measured before tear test. The crosshead speed was set at 500 mm/min. Results obtained were based on average of five samples.

2.6. Water Vapor Transmission (WVT) test

WVT analysis was done according to ASTM E96. NRL films were cut into 15 × 15 cm pieces. A cup was filled with silica gel and NRL films were used to cover the top of the cup. The cup was then inserted into a desiccator with a bowl of water at the bottom to ensure a high humidity environment. The desiccator was then sealed to prevent vapor loss except through the test sample. An initial weight of the apparatus was taken and then periodically weighed over time until results became linear. WVT of NRL films were calculated by using the formula given below.

$$WVT = \left[\frac{m, \text{ gradient of the best straight line obtained}}{\text{Week, days}} \right] \times \text{Size of films, cm}^{-2}$$

2.7. Analysis of mass loss

Soil burial films were taken out weekly and the weight of the films were taken after the films were leached and dried at room temperature for 18 h. The specific biodegradation rates based on the mass loss of films were calculated according to below formula.

$$\text{Mass loss} = \frac{\left(\text{Final mass, } m_f - \text{Initial mass, } m_0 \right)}{\text{Week}}$$

2.8. Scanning Electron Microscopy (SEM)

SEM analysis was conducted by using a Zeiss Supra 35 VP SEM machine with 100 and 1.0 K X magnifications depending on the needs of studies. The acceleration voltage was set at 10 KV. NRL

Table 1
NRL films compounding ingredients.

Chemical	Dry weight, (phr)
61.0% NR Latex	100
10.0% Potassium hydroxide	0.3
51.3% Sulfur	0.5
53.4% ZDEC	0.75
33.1% Zinc Oxide	0.25
52.2% Antioxidant 2246	0.5
25.0% Sago Starch.	5,10,15,20, and 25

Table 2
Mechanical properties for NRL films with respect to sago starch loading.

Sago starch loading, (phr)	Tensile strength, (MPa)	Elongation at break, (%)	M100, (MPa)	M300, (MPa)	M500, (MPa)	Tear strength, (N/mm)
0 (control)	22.79	1308.1	0.45	0.66	1.20	53.98
5	18.24	1192.1	0.47	0.69	1.35	57.80
10	20.73	1230.77	0.47	0.68	1.26	61.40
15	17.37	1037.36	0.48	0.70	1.30	61.99
20	16.77	1160.00	0.50	0.73	1.40	63.09
25	15.00	879.12	0.50	0.75	1.50	65.21