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Synergistic Effect of Natural Rubber Latex Film Filled with Corn Starch

Zainathul Akhmar Salim Abdul Salim[1]*, Nor Azlina Hassan[1], Radin Siti Fazlina Nazrah Hirzin[1], Nurul Aizan Mohd. Zaini[2] and Dalina Samsudin[2]
[1]School of Industrial Technology, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia
[2]School of Industrial Technology, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM) Cawangan Perlis, Kampus Arau, 02600 Arau, Perlis, Malaysia
*Corresponding author (e-mail: zainathul@uitm.edu.my)

The use of personal protective equipment, especially disposable gloves, as frontline protection against pathogens has rapidly increased since the COVID-19 pandemic. Although crucial for infection prevention, the growing use of these gloves brings up concerns about waste management and environmental sustainability. This is because many of the materials used in making disposable latex gloves are non-biodegradable, costly, and non-renewable. Consequently, researchers are now focusing on employing renewable biomaterials as fillers in the formulation of latex gloves. Fillers are essential compounding ingredients in natural rubber latex (NRL) film production as they enhance processing and improve the mechanical properties of the NRL matrix. In this study, corn starch (CS) was used as a bio-filler in NRL compounding formulation as it is renewable, abundantly available, and low in cost compared to other synthetic conventional fillers, such as carbon black, silica, graphene, and carbon nanotube. This research focused on the effect of CS on the tensile properties and swelling behaviour of the NRL film. Different ratios of CS dispersion (0, 5, 10, 15, and 20 phr) were used in this study. The unfilled NRL film, which was compounded without CS, was designated as the control to differentiate its properties from filled NRL. In this study, the highest tensile strength and elongation at break were observed at 10 phr of CS loading in the NRL film. As for the modulus at 100% and 300%, the highest value was obtained with the addition of 15 phr of CS, indicating a stiffening effect. In the swelling test, an increase in the ratio of CS resulted in a decrease in the swelling value due to the good rubber-filler interaction between CS and rubber molecules. The increase in crosslinks contributed to higher tensile strength and reduced swelling properties.

Keywords: Natural rubber latex film; corn starch; bio-filler; tensile strength; swelling behaviour

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Malaysia is one of the largest manufacturers of disposable latex gloves in the world, and the demand for such products has significantly increased due to the COVID-19 pandemic. An interesting development in the field of latex glove manufacturing is the use of green elastomers made from renewable and environmentally friendly materials. This innovation has garnered global attention as it aligns with the growing focus on sustainability and eco-friendly practices [1, 2].

One component of latex glove production is the use of fillers in the rubber compound. These fillers serve various purposes, including reinforcing the material, improving processing, and reducing costs. Traditionally, non-renewable fillers like carbon black (derived from petroleum) and silica have been used [3, 4].

However, there is a growing interest in replacing these non-renewable fillers with renewable and easily available natural sources. Plant-based starch, such as corn starch, is one such alternative filler. Corn starch (CS) is abundant and can be sourced sustainably, making it an attractive option for those looking to reduce the environmental impact of latex glove production [5]. This shift towards using renewable and eco-friendly ingredients in latex glove manufacturing reflects a broader trend in many industries to reduce their environmental footprint and contribute to a more sustainable future [5, 6].

Preliminary studies on the use of CS as a filler in natural rubber latex (NRL) film are crucial for the development of sustainable disposable latex gloves. These studies can serve several important purposes, such as in material characterisation, where researchers need to understand how CS interacts with NRL and its impact on the material's physical and mechanical properties. This includes aspects like tensile strength, elasticity, flexibility, and durability.

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Table 1. The formulation of 50% dispersion of CS.

Compounding ingredients	Parts Wet
Corn starch	50
Water	40.5
KOH (10%)	1
Vulcastab LW (20%)	0.5
Methyl Cellulose (1.25%)	8

This study investigated how CS influences the tensile and swelling characteristics of the NRL film. Various proportions of CS dispersion, specifically 0, 5, 10, 15, and 20 parts per hundred rubbers (phr), were employed in this research.

EXPERIMENTAL

Pre-vulcanised NRL with 60 w/w% dry rubber content was purchased from Getahindus Sdn. Bhd., Tangkak, Johor, Malaysia. Food-grade CS was purchased from a bakery ingredients store in Shah Alam, Selangor, Malaysia. Corn starch was used as a filler to improve the physical and mechanical properties of NRL. Other compounding ingredients such as potassium hydroxide (KOH) and methyl cellulose were all purchased from Sigma-Aldrich. The formulation of 50% dispersion of CS is shown in Table 1.

Preparation of NRL/CS Film

The 50% dispersion of CS and pre-vulcanised NRL were mixed and blended in fractions varying from 0 to 20 phr, as shown in Table 2.

The mixture was stirred using a mechanical stirrer for 30 min. The compound was then cast into a glass mould with the dimensions of 20 cm × 20 cm. The NRL/CS film was then dried for 1 h at 100 °C. The thickness of the dry films was approximately 1.0–3.0 mm, depending on the amount of filler added. The samples were then ready for testing. The sample preparation and testing are summarised in Figure 1.

Table 2. The formulation of NRL/CS films.

Material (pphr)	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Pre-vulcanised NR latex (60 wt %)	100	100	100	100	100
Corn starch dispersion	0	5	10	15	20

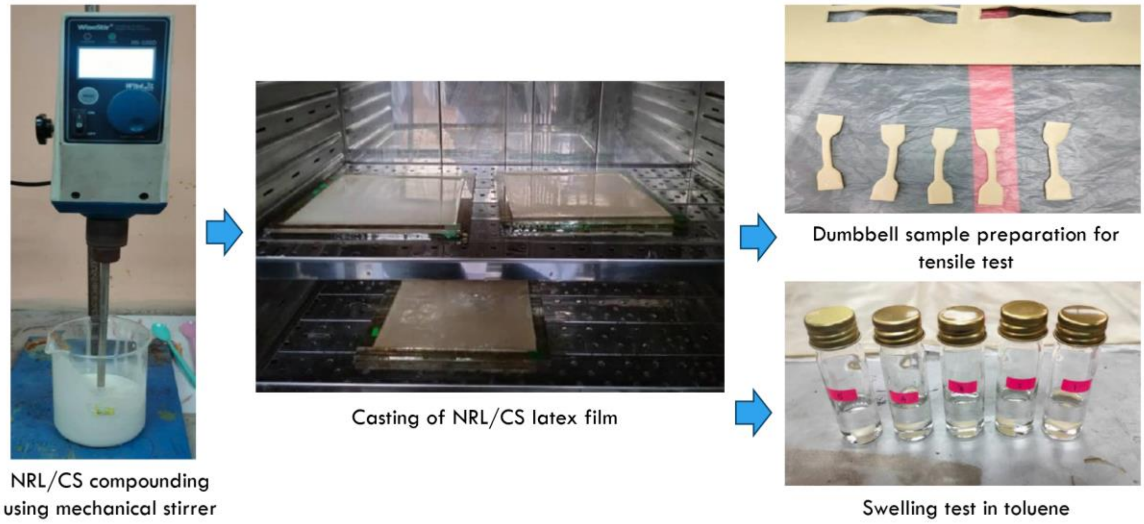

Figure 1. Sample preparation and testing of NRL/CS films.

Characterisation and Testing of NRL/CS Films

Fourier transform infrared (FTIR) spectroscopy was used to determine the functional groups and chemical characteristics of CS through molecular absorption and transmission. An FTIR spectrometer was operated at a frequency over a broad spectral range of 4000–450 cm^{-1}.

The tensile properties, including tensile strength and elongation at break, were determined in accordance with the ISO 37 standard. Five dumbbell-shaped specimens for each compound were tested with a cross-head speed of 500 mm/min. The tensile strength, modulus at 100% elongation (M100), modulus at 300% elongation (M300), and elongation at break were recorded. The average values of five samples were recorded and analysed.

The swelling test was performed in toluene according to the ISO 1817 standard. The NRL/CS samples were cut (1 mm × 1 mm) and weighed using an electronic balance and then swollen in toluene until equilibrium, which took 24 h at room temperature. After that, the samples were removed from toluene, and the final weight was recorded. The percentage of swelling was calculated according to the following equation:

$$\% \ swelling = \frac{W_2 - W_1}{W_1} \times 100\% \qquad (1)$$

Where W_1 and W_2 represent the weight of the specimens before and after immersion in toluene, respectively.

RESULTS AND DISCUSSION

FTIR Analysis

The FTIR spectra of CS are presented in Figure 2, whereas the interpretation of each peak is given in Table 3. As shown in Figure 2, the presence of absorption bands at around 3300–3600, ~2900, ~1150, and 1200–800 cm^{-1} in the spectra indicated the presence of OH, C–H, C–O–C, and C–O functional groups, respectively. In addition, the characteristic of C–O–C ring vibration on starch led to an absorbance peak at around 700–900 cm^{-1}. The C–O bending associated with the OH group resulted in an absorbance peak at around 1655 cm^{-1}. Furthermore, the absorbance peak at 1458.5 cm^{-1} implied the presence of CH_2 symmetric deformation. The outcomes matched the analysis conducted by Abdullah et al. [7].

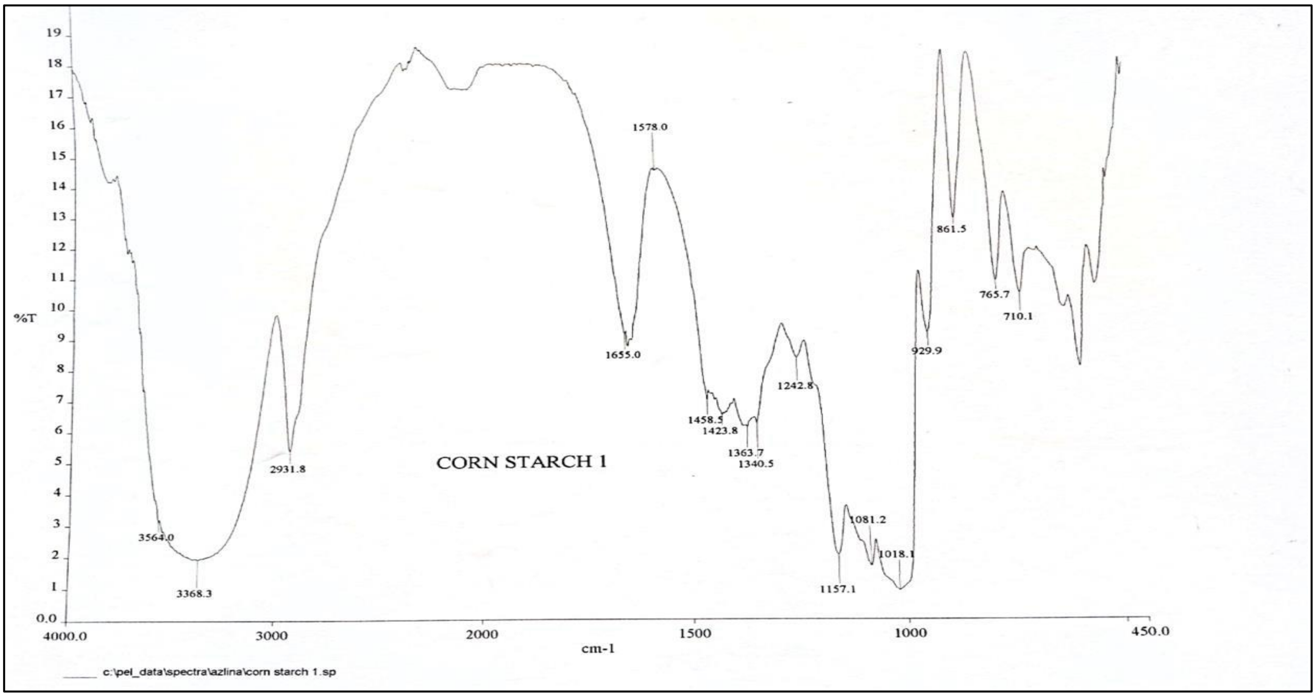

Figure 2. FTIR spectra of CS.

Table 3. Functional groups present in CS.

No	Functional groups	Wave number literature	CS
1	O-H stretching	3600 – 3300	3564, 3368.3
2	C-H stretching	2931	2931.8
3	C-O bending associated with OH group	1637	1655
4	CH_2 symmetric deformation	1458	1458.5
5	C-O-C asymmetric	1149	1157.1
6	C-O stretching	1200 – 800	1081.2, 1018.1
7	C-O-C ring vibration of carbohydrate	920, 856, 758	929.9, 861.5, 765.7

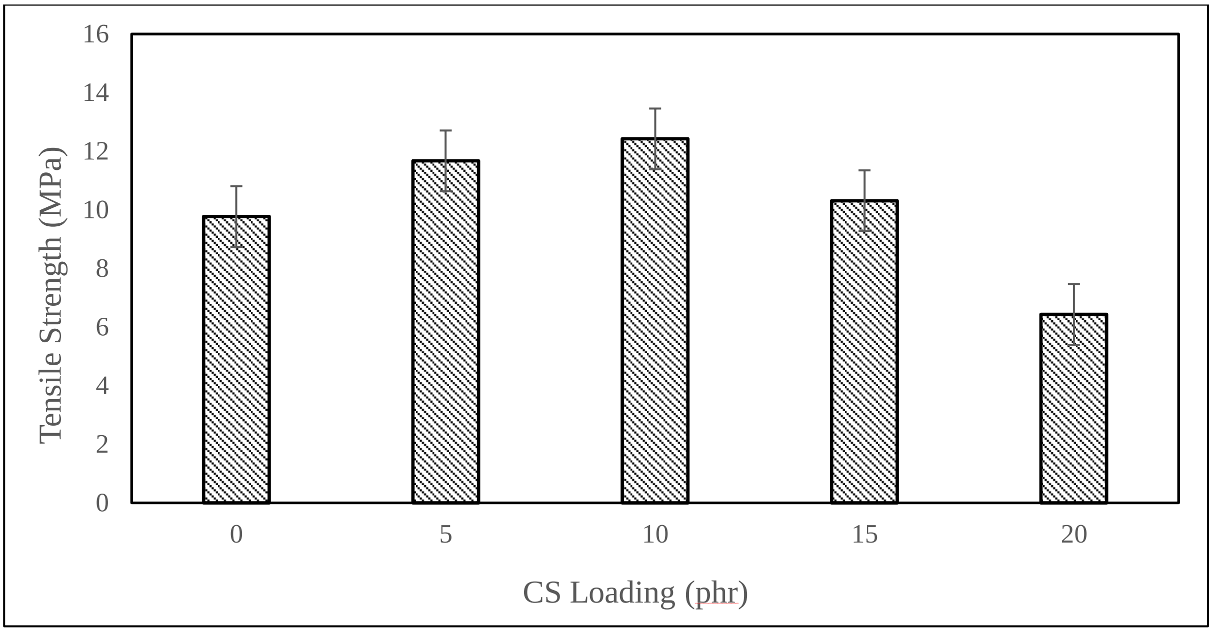

Figure 3. Tensile strength of NRL/CS films at different CS loadings.

Tensile Properties

Figure 3 shows the tensile strength of NRL/CS films at different CS loadings. The highest tensile strength was observed when the CS loading reached 10 phr. At this stage, the well-dispersed CS within the rubber matrix effectively enhanced the reinforcement of the film. However, as the filler content increased further, there was a notable and significant decrease in tensile strength. The decline in tensile strength at higher filler loadings was attributed to the formation of filler agglomerates, leading to a more pronounced interaction between fillers rather than between the rubber and fillers [8, 9].

Figure 4 shows the elongation at break of NRL/CS films at different CS loadings. The figure shows that there was an increase in elongation, and it reached the highest value upon the addition of 10 phr CS. However, the elongation at break of the films decreased gradually with an increase in CS loading. The incorporation of CS resulted in a reduction in the elasticity of the NRL films, rendering them more rigid [9]. This change was attributed to the limited interaction between the CS filler and the rubber matrix, mainly caused by the agglomeration of CS, which formed stress concentration points [10]. These points propagated cracks when stress was applied, contributing to the reduction in elongation at break [11].

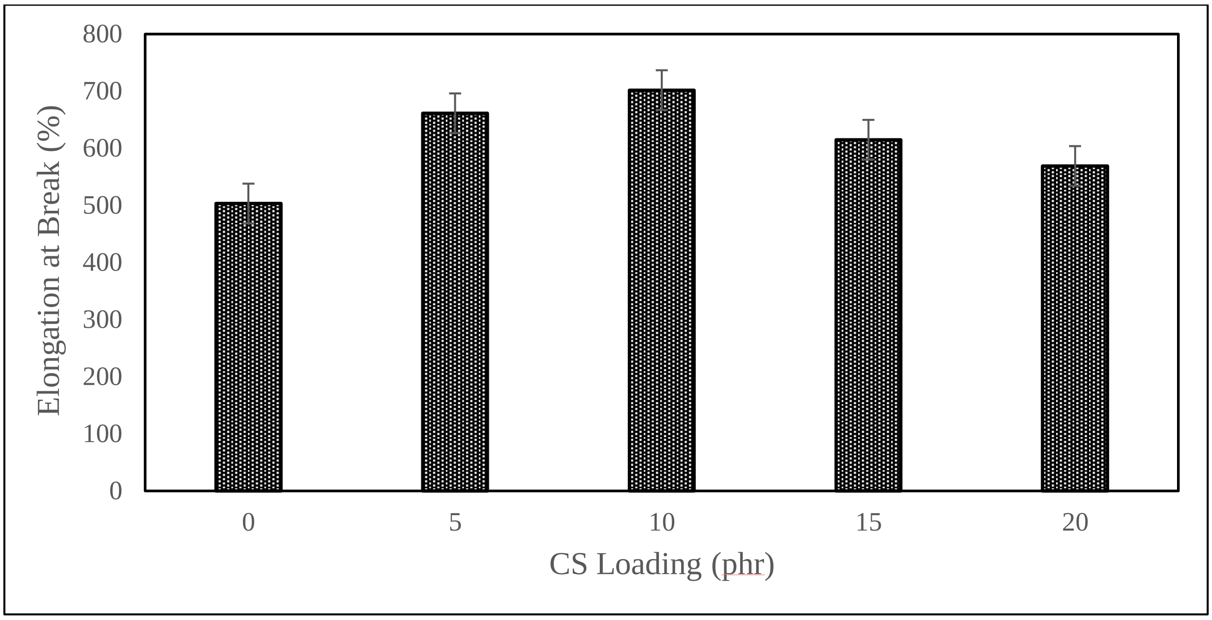

Figure 4. Elongation at break of NRL/CS films at different CS loadings

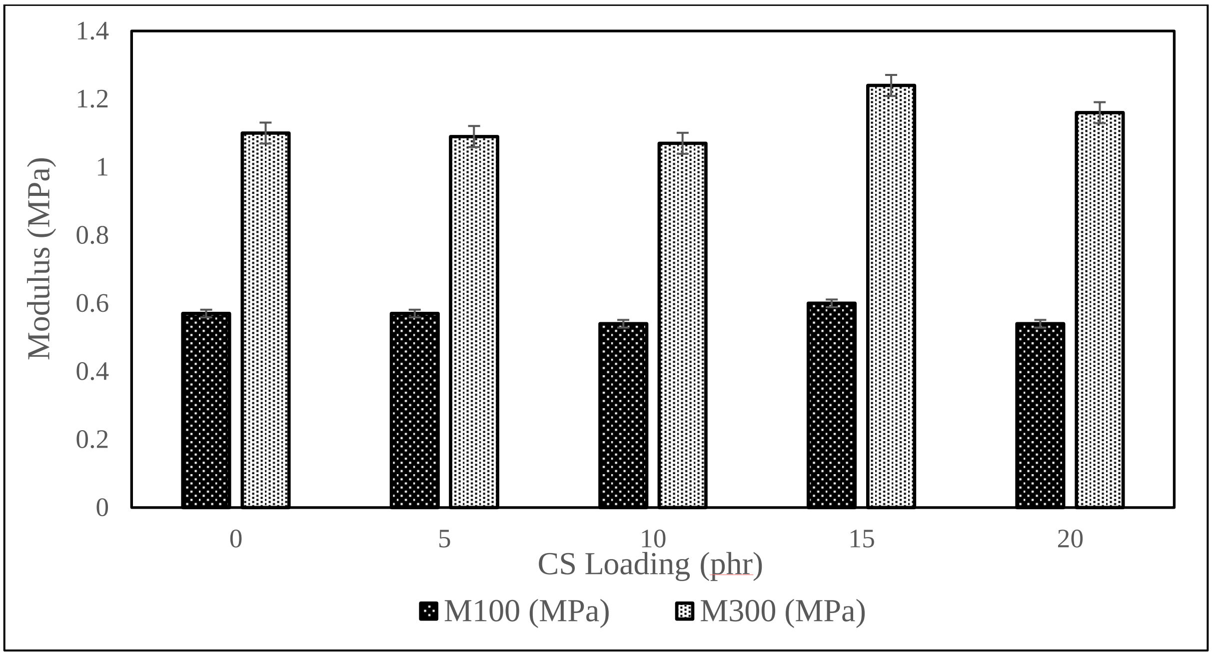

Figure 5. Modulus at 100% and 300% elongation of NRL/CS films at different CS loadings.

Figure 5 displays the modulus at 100% and 300% elongation, serving as indicators of the stiffness of the NRL films at various CS loadings. The highest modulus at both 100% and 300% elongation was achieved at 15 phr CS loading. This suggests that the stiffness of the NRL films increased with increasing filler loading [12]. The presence of a highly rigid filler like CS within the rubber matrix restricted the mobility of the rubber chains when subjected to stress, ultimately leading to the observed higher modulus values at 100% and 300% elongation.

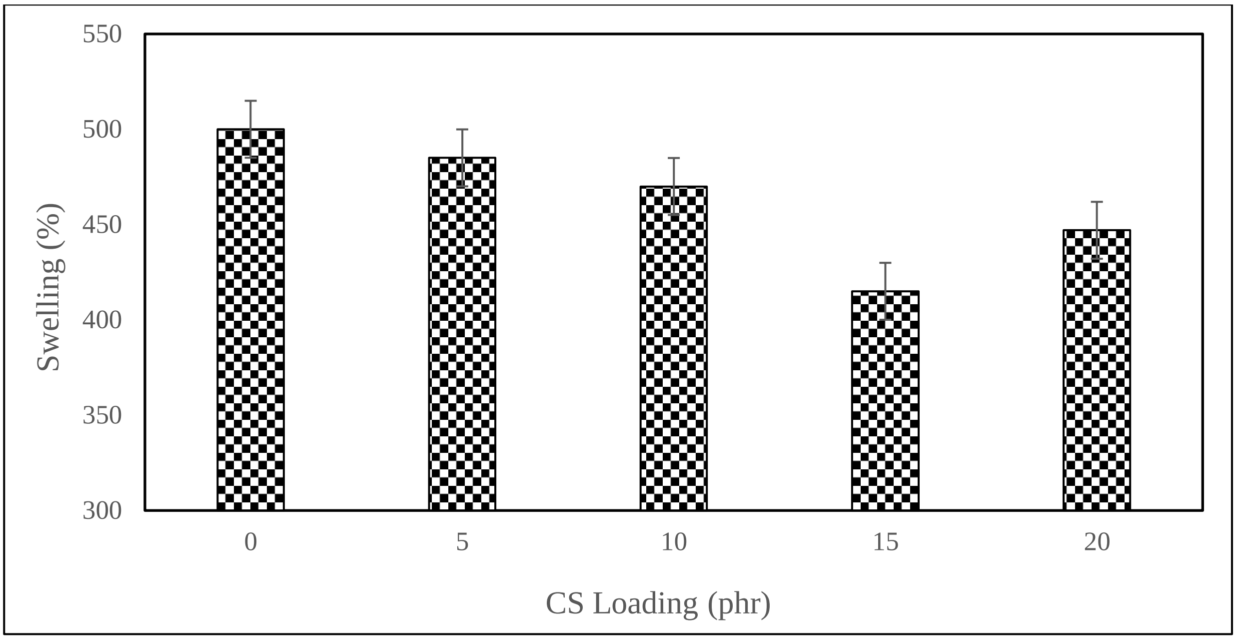

Figure 6. Percentage of swelling of NRL/CS films at different CS loadings.

Swelling Behaviour

Figure 6 illustrates the percentage of swelling of NRL/CS films at various levels of CS loading. The swelling test was employed to assess the interaction between the rubber and filler in the latex film. At first, the swelling decreased gradually with the increase of filler loading. This reduction in swelling was due to the good rubber-filler interaction between the CS and the rubber matrix. CS-filled NRL was effectively bonded in a way that reduced the rubber's affinity for absorbing solvent. The formation of more crosslinks results in higher tensile strength, which ultimately leads to reduced swelling properties [13]. This effect can be important in various industrial applications where rubber needs to resist swelling when exposed to different fluids. However, increasing the filler loading up to 20 phr caused filler particles to form larger aggregates, decreasing their interaction with the rubber matrix and weakening the strength properties. This resulted in an increase in swelling, as shown in Figure 6. These observations support the earlier discussion on tensile strength results.

CONCLUSIONS

The research findings suggest that the ideal loading of CS is 10 phr, as it recorded the highest tensile strength and elongation at break. However, the tensile strength decreased at 15 phr CS loading onwards. This decrease can be attributed to the weak interfacial adhesion between the hydrophobic natural rubber (NR) and the hydrophilic CS. Agglomeration occurred at high CS loading, leading to a reduction in the mechanical properties of the NRL films. These results emphasise the importance of finding the right balance between CS loading and the desired mechanical properties in the development of sustainable latex films.

It is advisable to perform surface morphology analysis using scanning electron microscopy to observe and assess the agglomeration of CS within the NRL film. Besides, the FTIR spectra of NRL/CS film can be obtained for comparison with raw CS spectra to confirm the interaction that occurred. This approach can provide valuable insights into the distribution and interaction of CS particles, helping to further understand their impact on NR film properties.

Conducting a soil burial test is also recommended to study the effect of incorporating CS on the degradation rate of the NRL/CS film. This test can provide critical information about the biodegradability of the film, which is essential for waste management and environmental considerations. Understanding how the film breaks down in soil can guide decisions on its disposal and sustainability.

These additional analyses and tests will contribute to a more comprehensive understanding of the behaviour of NRL/CS films, in terms of both their structural characteristics and environmental impact, helping to refine their formulations and applications.

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