# OPTIMIZING THE PROPERTIES OF VULCANIZED COMPOUNDS FOR FOODSTUFF CONVEYOR BELTS IN INDUSTRIAL MICROWAVE PER-HEATING

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**ABSTRACT:** This research finds a natural rubber-based material with good dielectric properties and low cost for a foodstuff conveyor belt (FCB) that can be heated with microwaves. For this purpose, epoxidized natural rubber-50 (ENR50) and standard Thai rubber 5L (STR5L) were mixed with a filler mixture of silica and magnesium carbonate. The FCB compound with filler (FCBcF) yielding the best vulcanization time, and the best mechanical, dielectric and dynamic properties, was selected for further study. The optimal FCBcF, ENR50:$SiO_2$:$MgCO_3$ (100:40:40) with microwave pre-heating at 2.45 GHz and 340 W for one minute before vulcanization, was well cross-linked and strongly converted the microwaves to heat. FCBcF also showed satisfactory mechanical properties with reduced cost of raw materials and reduced the curing time by 50% per round. The results demonstrate that pre-heating of FCBcF prior to vulcanization reduces the time and cost of fabricating FCBs, providing long-term economic and environmental benefits.

## 1. INTRODUCTION

A foodstuff conveyor belt (FCB) is an engineered rubber product (typically white) with high flexibility but low distortion. Natural rubber is the main raw material because of its non-toxicity, a requirement of foodstuff conveyance. The main concern is that other raw materials and the chemical rubber must comply with the laws and regulations of the Food and Drug Administration (United States). The compound formulation needs to be appropriate while satisfying the cleanliness and safety requisites. The conveyor belt must also be brightly colored, easy to clean, and fabricated by an efficient material preparation process. A typical FCB compound (FCBc) is natural rubber mixed with fillers. Natural rubber is a non-polar double-cross-linked polymer with high flexibility and other beneficial mechanical properties but is non-resistant to oil and non-polar solvents [1]. Currently, in Thailand, natural rubber is commercially modified to epoxidized natural rubber (ENR), in which the oxygen in the cross-linked regions forms epoxide rings by epoxidation reactions. The epoxide contents of ENR range from 10 to 50%. The ENR is more polar than unmodified natural rubber and has better heat and oil resistance. The polarity of 50% - epoxidized ENR is similar to that of acrylonitrile butadiene rubber (NBR) with medium acrylonitrile contents [2].

The filler in the rubber compound significantly lowers the fabrication costs and changes the physical properties of the material, especially the mechanical properties. The filler increases the electric conductivity and improves the longevity of the rubber. Two white fillers, silica and magnesium carbonate, are popular for natural rubber products because they provide good quality and aesthetically pleasing color. In refined powder form, magnesium carbonate is an efficient semi-reinforcing agent that improves the tensile strength, tear resistance, and degradation resistance [3]. Although the hardness and tensile strength provided by comparatively small silica particles (nano silica) are similar to those of black carbon filler, the organic agents on silica interfere with the silica–rubber bonding [3], whereas nano silica reduces the creep and drying shrinkage [4]. Consequently, black carbon confers stronger resistance to degradation and modulus than silica. Grafting silane on silica improves the silica–rubber bonding and improves the mechanical properties (especially its tear resistance) of the compound. The silane can be mixed with the fillers before compounding with rubber or added while mixing the rubber and fillers [5].

When vulcanizing mixed reclaimed rubber and natural rubber with carbon black as the reinforcing agent, microwave heating was found to affect the type of cross-linking in the compound. Specifically, more mono and di-sulfidic cross-links were formed in microwave-heated vulcanization than in conventional vulcanization. This result was attributed to the quick heating from the center of the sample, which gains the highest temperature. In contrast, conventional heating delivers heat to the compound from an outside source [6].

Microwaving can also be combined with conventional heating in a two-step rubber hose vulcanization: (1) pre-vulcanization with microwave energy, and (2) conventional vulcanization with heat conduction. This approach consumes less energy than conventional vulcanization [7].

Previous research has demonstrated that microwave preheating of compounds conserves energy in processing. In most of these studies, the microwave energy preheated a black compound containing carbon black reinforcing filler, and synthetic rubber was the main raw material. Microwaves are suitable for the manufacture of very thick products such as solid tires for forklifts. The present study investigates the physical properties of a FCBc after pre- and post-heating by industrial 2.45 GHz microwaves at various powers (0–1,700 W). The raw materials are natural rubber, standard Thai rubber (STR5L) or epoxidized natural rubber-50 (ENR50), with fillers of silica, magnesium carbonate, or their mixture. Microwaving is an alternative technique that quickly heats the compound from the inside out, and which reduces the time and energy of vulcanization (by reducing the costs and increasing the rate of production), thereby improving the competitiveness of the manufacturing process.

## 2. MATERIALS AND METHODE

### 2.1 Materials and Methods

The chemical constituents of the FCBcs are shown in Table 1. STR5L was manufactured by Chalong Latex Industry Co., Ltd. (Songkhla, Thailand), and ENR50 was manufactured by Muang Mai Guthrie Public Co., Ltd. (Phuket, Thailand). The reinforcing filler was silica (Ultrasil 233:$SiO_2$) and the semi-reinforcing filler was magnesium carbonate ($MgCO_3$) obtained from GSP Products Co., Ltd. (Bangkok Thailand). Zinc oxide (ZnO) and stearic acid ($CH_3(CH_3)16COOH$) were purchased from Sunny World Chemical Co.,Ltd. (Bangkok Thailand). Mercaptobenzothiazole disulfide (MBTS) and N-tert-butyl-2-benzothiazole sulfenamide (TBBS) used as accelerators were manufactured by Flexsys (Turmoil, Italy). The filler activator (polyethylene glycol, PEG 4000) and Couplink 89 silane coupling agent were kindly supplied by Chemical Innovation Co., Ltd. (Bangkok, Thailand). The curing agent (sulfur) was manufactured by Ajax Chemical Co., Ltd. (Samutprakarn, Thailand).

### 2.2 Preparation of rubber compounds

The compounding formulations used for the composites, as shown in Taber 1 were prepared by semi-efficient vulcanization. Compounds were mixed on a conventional laboratory two-roll mill according to ASTM designation D3184-80. ENR50 was first masticated for 4 min in the $SiO_2$/ENR, $MgCO_3$/ENR, and $SiO_2$/$MgCO_3$/ENR formulas; STR 5L was masticated similarly for 2 min in the $SiO_2$/STR, $MgCO_3$/STR and $SiO_2$/$MgCO_3$/STR formulas. The masticated ENR50 or STR5L was then mixed with the required amount of filler ($SiO_2$, $MgCO_3$ or a mixture of $SiO_2$/$MgCO_3$). Next, Zinc oxide, Stearic acid, Couplink 89 and PEG 4000 were added to the ENR50–filler and STR5L–filler mixtures, respectively, on the two roll mill. The accelerators (MBTS and TBBS) were added to the mixtures on the two-roll mill for 1 min, then sulfur similarly with 2 min mixing. Finally, the rubber compound was sheeted out and left at room temperature for 24 hours before testing and vulcanizing.

### 2.3 Cure characterization

Moving die rheometer (MDR type, Monsanto/ Rheometer MDR 2000, Japan) was used to determine to cure characteristics of the rubber composites at 150°C with 0.5° amplitude and 30 min. The cure characteristics of the dielectric material compounds were tested according to ASTM D5289-07a. The cure rate index (CRI), which characterizes the vulcanization.

### 2.4 Mechanical properties

The stress-strain curves of dielectric material compounds were measured on a universal tensile testing machine (Instron, model-5565, USA). The tensile strength, elongation at break, and modulus were determined at room temperature at an extension speed of 500 mm/min, according to ASTM D412-06 ae2 (Die C). The dumb-bell shaped specimens were cut from the vulcanized rubber sheets using an ASTM die type C (Dumbbell, model SDAP-100N, Japan). The hardness was tested according to ASTM D2240-05 (2010) using a Shore A durometer (Shore Instrument, model-716, USA.).

### 2.5 Rubber Process Analyzer (RPA)

The dynamic storage modulus (G′) was investigated in an RPA 2000 (Alpha Technologies, Akron, USA). In the strain sweep test, the strain was ranged from 0.56 to 500% at 80°C and 1 Hz.

### 2.6 Dynamic Mechanical Analysis (DMA)

The dynamic mechanical properties were determined by a dynamic mechanical analyzer (DMA 8000, PerkinElmer Inc., Waltham, USA). The samples were rectangular with dimensions of $(30 \times 10 \times 2)$ mm$^3$. The dynamic storage modulus

Table 1 Chemical formulations of FCBc

| Raw materials | phr[a] | | | | | |
|---|---|---|---|---|---|---|
| | SiO$_2$/ENR[b] | SiO$_2$/STR[c] | MgCO$_3$/ENR | MgCO$_3$/STR | SiO$_2$/MgCO$_3$/ENR | SiO$_2$/MgCO$_3$/STR |
| ENR50 | 100 | - | 100 | - | 100 | - |
| STR5L | - | 100 | - | 100 | - | 100 |
| SiO$_2$ | 40 | 40 | - | - | 40 | 40 |
| MgCO$_3$ | - | - | 40 | 40 | 40 | 40 |
| Zinc oxide | 3 | 3 | 3 | 3 | 3 | 3 |
| Stearic acid | 1 | 1 | 1 | 1 | 1 | 1 |
| [d]Couplink89 | - | - | - | 2 | 2 | 2 |
| [e]PEG4000 | - | - | - | 2.2 | 2.2 | 2.2 |
| MBTS | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| TBBS | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Sulfur | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |

[a]parts per hundred parts by weight of rubber dry basis (phr), [b]ENR: Epoxidized natural rubber, 50:ENR50, [c]STR: Standard Thai rubber, 5L:STR5L, [d]silane coupling agent and [e]filler activators.

(G′) and loss tangent (*tan δ*) were measured in tension mode. The temperature was ranged from -100 to 25°C, and the test frequency was fixed at 1 Hz.

## 2.7 Dielectric property measurements

The analyzer consisted of a coaxial cavity, a microwave reflectometer, a 0.35-cm coaxial cable, a 0.35-cm female calibration, and short and open-matched loads and software. The coaxial cavity was characterized in the 1.5–2.6 GHz range at a precision of 2% for the dielectric constant and 5% for the dielectric loss factor. The measured specimen was assumed as an infinitely sized, non-magnetic material with isotropic and homogeneous properties. During the test, the coaxial cavity must be closely contacted with the specimen [8]. The measurements were made by a portable network analyzer. After averaging five values for each rubber compound, the loss tangent [9] and penetration depth [10] were calculated by Eqs. (1) and (2), respectively.

$$tan\,\delta = \frac{\varepsilon_r''}{\varepsilon_r'} \qquad (1)$$

Here $tan\delta$ is the loss tangent, $\varepsilon_r''$ is the relative dielectric loss factor, and $\varepsilon_r'$ is the relative dielectric constant.

$$D_P = \frac{1}{\frac{2\pi f}{U}\sqrt{\frac{\varepsilon_r'\left(\sqrt{1+(tan\delta)^2}-1\right)}{2}}} \qquad (2)$$

Here $Dp$ is the penetration depth, $f$ is the microwave frequency (2.45 GHz), and U is the microwave speed (3x10$^8$ m/s, the speed of light).

Assuming a lossless magnetic field, the volumetric internal heat generation (*Q*) [11] was estimated by Eq. (3).

$$Q = \omega\varepsilon_o\varepsilon_r''E^2 = 2\pi \cdot f \cdot \varepsilon_o\varepsilon_r'(tan\delta)E^2 \qquad (3)$$

where *Q* is the density of the absorbed microwave power (W/m$^3$), *E* is the electromagnetic field intensity, *f* is the microwave frequency (Hz), *ω* is the angular velocity of the microwaves (rad/s), and $\varepsilon_o$ is the permittivity of free space (8.8514x10$^{-12}$ F/m).

## 3. Results and Discussion

### 3.1 Properties of FCBc vulcanized without microwave pre-heating

#### 3.1.1 Cure properties

The curing curves of FCBcF vulcanized without heating are shown in Fig. 1 and their cure characteristics are summarized in Table 2. To mix the rubber, chemicals, and fillers, firstly, the silica, silane, PEG, and oil were mixed into a master batch of rubber. Next, the other substances were added to reduce the silica crystallization and improve the filler dispersion. During this procedure, the siloxane (-Si-O-Si) and silanol (-Si-OH) on the silica surfaces easily react with silane and PEG, reducing the surface polarity (by breaking the cross-linking agents, especially polysulfide), and hence increasing their hydrophobicity [12]. This chemical change improves the compatibility with rubber and reduces the silica absorption that otherwise prolongs vulcanization in the MgCO$_3$/ENR, MgCO$_3$/STR, SiO$_2$/MgCO$_3$/ENR and

Table 2 Cure characteristics of the experimental formulations before pre-heating

| Sample | Min . Torque ($M_L$,dNm) | Max . torque ($M_H$,dNm) | Delta torque ($M_L$-$M_H$,dNm) | Scorch time ($ts_2$, min) | Cure time ($tc_{90}$,min) | Cure rate index (CRI,min$^{-1}$) |
|---|---|---|---|---|---|---|
| SiO$_2$/ENR | 0.7 | 9.4 | 8.6 | 2.6 | 7.6 | 20.0 |
| SiO$_2$/STR | 1.8 | 10.0 | 8.2 | 3.2 | 7.7 | 22.2 |
| MgCO$_3$/ENR | 0.4 | 6.7 | 6.3 | 2.7 | 3.6 | 111.1 |
| MgCO$_3$/STR | 1.3 | 7.9 | 6.6 | 1.9 | 2.7 | 125.0 |
| SiO$_2$/MgCO$_3$/ENR | 1.5 | 11.3 | 9.9 | 2.0 | 6.2 | 23.8 |
| SiO$_2$/MgCO$_3$/STR | 3.2 | 14.6 | 11.5 | 1.6 | 4.3 | 37.0 |

SiO$_2$/MgCO$_3$/STR cases. In addition, SiO$_2$/MgCO$_3$/STR was comparatively slowly vulcanized and its vulcanization ratio index (CRI) was higher than for SiO$_2$/MgCO$_3$/ENR. ENR50 is comparatively polar and can stimulate double cross-linking of the isoprene units, enabling more rapid vulcanization than STR5L [13]. The lower torque differences ($M_H$ −$M_L$) in SiO$_2$/STR, SiO$_2$/ENR and SiO$_2$/MgCO$_3$/ENR than in SiO$_2$/MgCO$_3$/STR also support lower crosslinking levels in the former group.
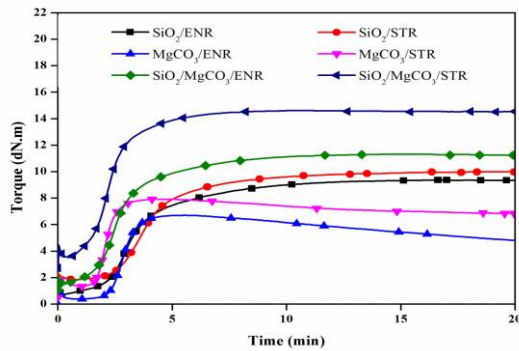


Fig. 1. Cure curves of the experimental formulations.

*3.1.2 Mechanical properties*

Fig.2 shows the stress-strain curves of the SiO$_2$, MgCO$_3$ and SiO$_2$+MgCO$_3$-filled vulcanizates (i.e., SiO$_2$/ENR, SiO$_2$/STR, SiO$_2$/MgCO$_3$/ENR and MgCO$_3$/ENR, MgCO$_3$/STR, SiO$_2$/MgCO$_3$/STR). The Young's modulus was higher in SiO$_2$/ENR, SiO$_2$/STR, and SiO$_2$/MgCO$_3$/ENR than in the MgCO$_3$/ENR, MgCO$_3$/STR and SiO$_2$/MgCO$_3$/STR vulcanizates. The Young's modulus (or modulus of elasticity) measures the stiffness of an elastic material and describes the elastic properties of objects such as wires, rods or columns during stretching or compression. Silica is a superior reinforcing agent for rubber because of its small primary particles and high specific surface; therefore, silica-filled vulcanized rubber possesses a comparatively high tensile strength. In addition, the properties of natural rubber reinforced by silica are similar to those of rubber reinforced with carbon black [3]. This finding agrees with the increased delta torque of these composites (see Table 2). As seen in Fig. 2 and Table 3, the SiO$_2$/ENR, SiO$_2$/STR, and SiO$_2$/MgCO$_3$/ENR

samples were mechanically strong because ENR50 is polar [14] and facilitates the dispersion of silica and magnesium carbonate in the rubber matrix. The polarity of rubber enhances the rubber–filler interactions [15]; moreover, ENR50 is more viscous than STR5L [14]. The high viscosity of rubber also induces high shear forces that disperse the filler and prevent its agglomeration. The high specific surface of silica, with its many hydroxyl or silanol (-OH) groups, is conducive to chemical absorption. Especially, the polar surfaces enable rapid chemical reactions that absorb various chemical substances [3]. These properties justify the used mixing sequence, which improves the modulus at 300% elongation (MPa), the tensile strength (MPa), and the elongation at break (%) of the vulcanized rubber
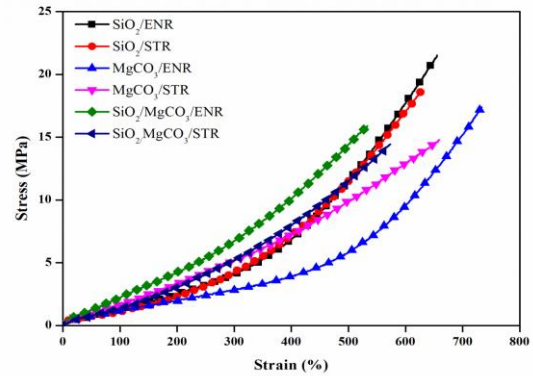


Fig. 2. Stress-strain curves of the experimental formulations.

*3.1.3 Dynamic mechanical properties*

Fig.3 plots the storage moduli as functions of strain amplitude for FCBcs filled with SiO$_2$, MgCO$_3$ or their mixture (i.e., SiO$_2$+MgCO$_3$) in the non-polar STR5L and polar ENR50 natural rubber matrixes. In each case, the storage modulus was comparatively high and nearly constant at strains below 1%. The modulus decreased at higher strains because the filler agglomerates were broken; this effect is known as the *Payne effect* [16]. Thus, by varying the type and quantity of filler, one can vary the modulus behavior and Payne effect of the filled rubber.

Table 3 Mechanical properties of the experimental formulations before pre-heating

| Mix symbol | Tensile strength (MPa) | Elongation at break (%) | 100 %modulus (MPa) | 300 %modulus (MPa) |
|---|---|---|---|---|
| $SiO_2$/ENR | $21.59 \pm 0.43$ | $657.09 \pm 7.64$ | $1.24 \pm 0.08$ | $4.11 \pm 0.37$ |
| $SiO_2$/STR | $18.57 \pm 2.33$ | $625.98 \pm 21.00$ | $1.11 \pm 0.04$ | $4.20 \pm 0.09$ |
| $MgCO_3$/ENR | $17.16 \pm 2.60$ | $729.23 \pm 13.53$ | $1.17 \pm 0.08$ | $2.81 \pm 0.25$ |
| $MgCO_3$/STR | $14.77 \pm 1.26$ | $657.09 \pm 6.56$ | $1.64 \pm 0.02$ | $5.18 \pm 0.10$ |
| $SiO_2$/$MgCO_3$/ENR | $15.85 \pm 3.17$ | $534.36 \pm 52.34$ | $1.36 \pm 0.11$ | $5.20 \pm 0.44$ |
| $SiO_2$/$MgCO_3$/STR | $14.40 \pm 1.23$ | $574.70 \pm 4.87$ | $1.64 \pm 0.10$ | $5.18 \pm 0.31$ |

The strain dependence of the storage modulus depends on the filler–filler interactions, which increase the elastic modulus [17]. $SiO_2$/$MgCO_3$/ENR has a higher storage modulus than $SiO_2$/$MgCO_3$/STR because a filler mixture agglomerates more readily than a single filler, consistent with the observed morphology. Moreover, adding fillers to non-polar STR5L rubber yields a lower storage modulus than adding fillers to the polar ENR50 matrix, because the filler dispersion is better in STR5L than in STR5L.

Fig.4 plots the storage moduli and *tan(δ)* values of the samples as functions of temperature. At some critical temperature, the storage modulus decreases rapidly and the sample changes from a glassy to a rubbery state (Fig.4(a)). The observed behaviors fall into two groups: (1) $SiO_2$/ENR, $SiO_2$/STR and $SiO_2$/$MgCO_3$/ENR, and (2) $MgCO_3$/ENR, $MgCO_3$/STR, and $SiO_2$/$MgCO_3$/STR. The storage modulus is higher in the first group because $SiO_2$ is a better reinforcing agent for STR5L and ENR50 than $MgCO_3$. The *tan(δ)* peaks in Fig.4(b) also indicate a critical temperature. This temperature called the glass transition temperature ($T_g$), was higher in $SiO_2$/ENR, $SiO_2$/STR, and $SiO_2$/$MgCO_3$/ENR than in $MgCO_3$/ENR, $MgCO_3$/STR and $SiO_2$/$MgCO_3$/STR. This difference is explained by the smaller size of the $SiO_2$ particles than of the $MgCO_3$ particles, enabling stronger rubber–filler interactions in both rubbers.[18] Moreover, comparing the rubber types with the mixed filler $SiO_2$+$MgCO_3$, the $T_g$ was higher in ENR50 than in STR5L because the polar ENR better interacts with the mixed filler [19].
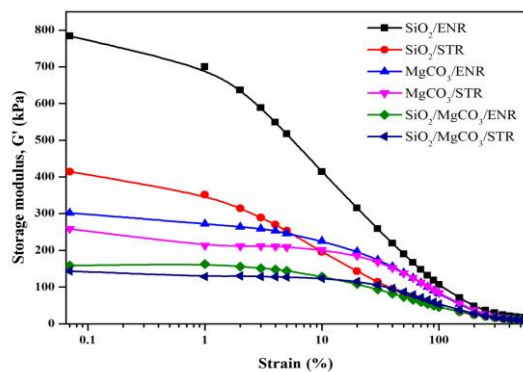


Fig. 3. Storage modulus vs. strain amplitude curves of the experimental formulations, tested at 80°C and 1 Hz.
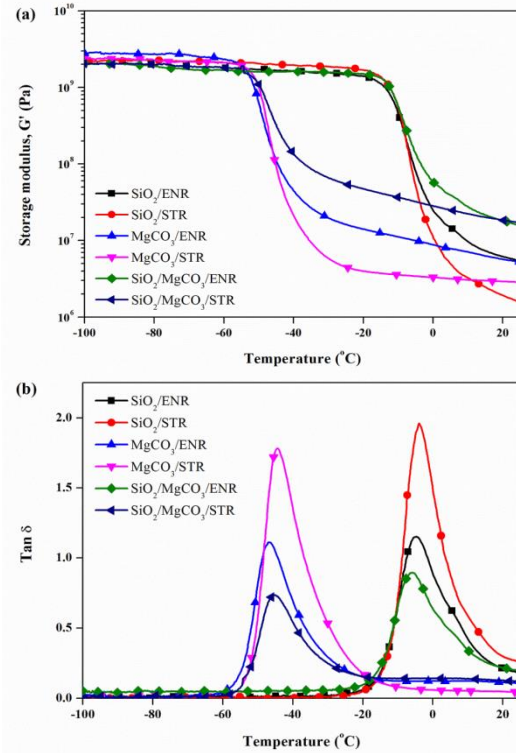


Fig. 4. (a) Storage modulus and (b) *tan(δ)* as functions of temperature for the experimental formulations

### 3.1.4 Dielectric properties

The dielectric properties of FCBcF before pre-heating are summarized in Table 4. The values of and (*tanδ*) were higher in $SiO_2$/$MgCO_3$/ENR, $SiO_2$/ENR, and $MgCO_3$/ENR than in $SiO_2$/$MgCO_3$/STR, $SiO_2$/STR and $MgCO_3$/STR, showing that although STR5L natural rubber forms cross-links with non-polar molecules [1], its microwave absorption capability is lower than that of ENR50. This can be explained by the larger molecules with poorer mobility in STR5L than in ENR50 under the alternating electric field. Therefore, the silica, magnesium carbonate and mixed fillers increase the energy absorption of rubber because they are electrically polar and can absorb microwaves. The silanol (Si-OH) groups on the silica surface confer an acidic, chemically reactive property and a high electric polarity at the surface [13]. Therefore, silica filler is more polar than magnesium carbonate.

Table 4 Dielectric properties of the experimental formulations before pre-heating

| Mix symbol | Relative dielectric constant $(\varepsilon_r')$ | Relative loss factor $(\varepsilon_r'')(\text{x } 10^{-3})$ | Loss tangent $(\tan \delta)(\text{x } 10^{-3})$ | Penetration depth $(D_p)$ (meter) |
|---|---|---|---|---|
| SiO$_2$/ENR | 2.400 | 0.0149 | 0.006194 | 0.406384 |
| SiO$_2$/STR | 2.321 | 0.0119 | 0.005137 | 0.498197 |
| MgCO$_3$/ENR | 2.490 | 0.0131 | 0.005276 | 0.468330 |
| MgCO$_3$/STR | 2.369 | 0.0097 | 0.004114 | 0.615673 |
| SiO$_2$/MgCO$_3$/ENR | 2.555 | 0.0169 | 0.006617 | 0.368711 |
| SiO$_2$/MgCO$_3$/STR | 2.427 | 0.0139 | 0.005717 | 0.437804 |

Fig.5 shows the dielectric test results. SiO$_2$/MgCO$_3$/ENR exhibited the highest $\varepsilon_r'$ among the tested cases. When filled with silica and magnesium carbonate, the polar molecules of ENR50 absorb the microwave energy and convert it to heat. The fillers apparently increase the polarity of the already polar ENR50, enabling energy savings when pre-heating the FCBcs with microwaves. The thermal transformation was also affected. The volumetric internal heat generation ($Q$) in Eq. (3) depends on both the electric and magnetic fields in the dielectric medium [20].
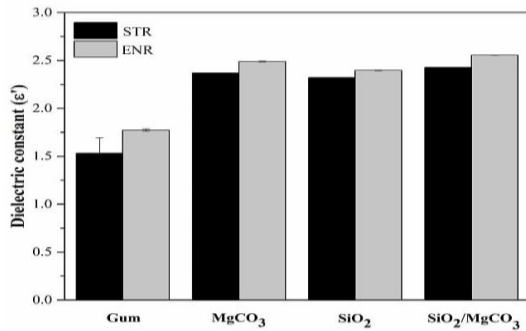


Fig. 5. Relative dielectric constants of the experimental formulations before pre-heating.

## 3.2 Properties of the selected vulcanized FCBc

According to the above test results, the best FCBc candidate was FCBcF (SiO$_2$/MgCO$_3$/ENR50). FCBcF is dielectric, appropriate for microwave pre-heating prior to vulcanization, and conserves the cost of raw materials. Therefore, this compound was evaluated in the further study. The microwave absorption of FCBcF was tested on samples of the area (150×150) cm$^2$ and thickness 4 mm. The specimens were subjected to 2.45 GHz industrial microwave radiation. The microwave power was varied as 340, 850 and 1,700 W, and the pre-heating duration was 1 minute prior to hydraulic molding at 150°C with a vulcanization duration of 50% $T_{C90}$. This test was aimed to assess effects of the microwave conditions on the mechanical properties of FCBcF (hardness, modulus at 300% elongation, tensile strength, and elongation at break), both with and without heat aging. The heat-

accelerated aging was performed in a hot air oven at 100°C for 22 hours.

### 3.2.1 Mechanical Properties

Panels (a) and (b) of Fig. 6 shows the hardness and modulus at 300% elongation, respectively, in the non-aged and heat-aged FCBcF samples. FCBcF is highly dielectric and well absorbed the microwave energy, thereby providing strong heating [6]. The silica and magnesium carbonate fillers are appropriate dielectric agents that tend to absorb rather than reflect the waves [21]. Thus, microwave-treated FCBcF should demonstrate superior mechanical properties. However, the fillers can obstruct the mobility of the rubber molecules and accordingly reduce the flexibility, thereby increasing the hardness after the heat-accelerated aging [3]. This effect of aging on the mechanical properties of FCBcF was preserved under all conditions of microwave preheating. However, increasing the microwave energy from 340 to 850 Watts tended to reduce the mechanical properties, because the stronger heating [6] increased the quantitative heat (Q) generated at the molecular level. Excessive heating reduces the cross-linking of vulcanized rubber [8]. When the microwave power was increased to 1700 Watts, the vulcanization degree was further degraded [22], with obvious loss of mechanical properties.

Panels (c) and (d) of Fig. 6 shows the tensile strength and elongation at break, respectively, in the non-aged and heat-aged FCBcF samples. Both properties declined with accelerated aging and with increasing microwave power, reflecting the stronger internal heating [6]. Both the non-aged and heat-aged FCBcF samples were highly dielectric and strongly absorbed the microwave energy. The cross-linking in FCBcF was reduced by the excessive heat [21], and the molecular chains can also be degraded by heat and oxidation during the aging process [23]. Increasing the microwave energy from 850 to 1,700 Watts worsened the mechanical properties of the heat-aged FCBcF. This can be explained by rapid moisture transfer under intense heating, called reversion. Reversion, which describes the loss of sulfur crosslinks in rubber under intense heat or

excessive vulcanization duration, degrades the properties of vulcanized rubber [24]. Meanwhile, the heat-aging process reduced the flexibility of the vulcanized rubber [23]. The filler can bond poorly with the rubber phase and be poorly distributed. It can also obstruct the movements of the rubber molecules, increasing the hardness and brittleness. These phenomena also degrade the mechanical properties [25].
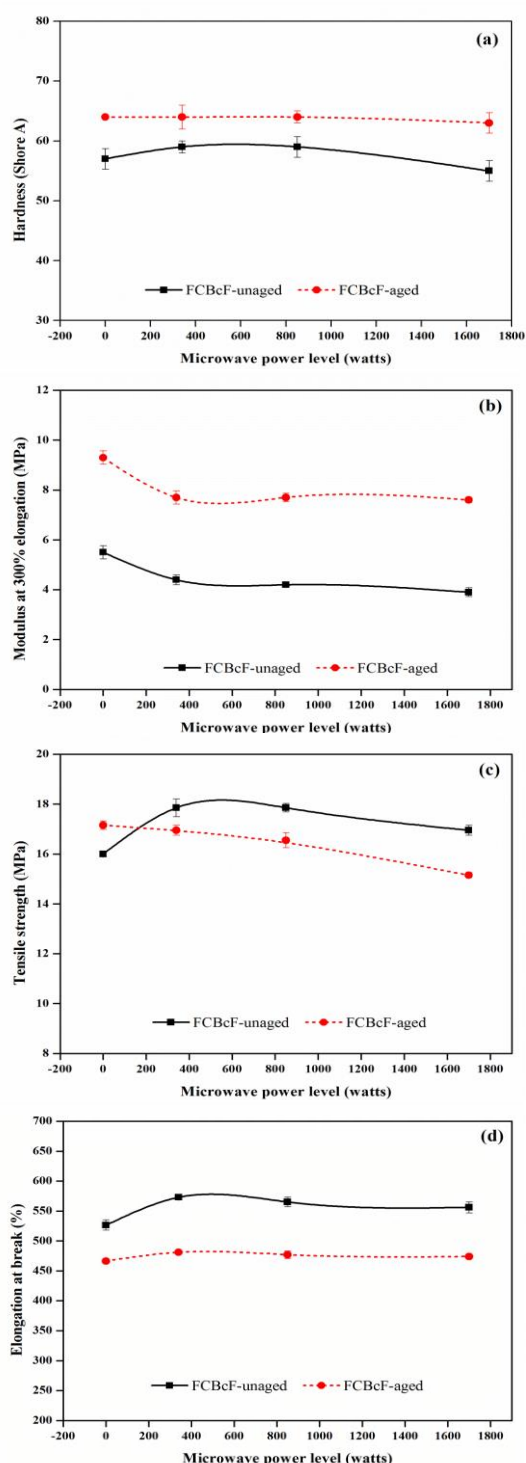


Fig. 6. (a) Hardness of the selected food conveyor

belt compound with filler (FCBcF) in the non-aged (black) and age-accelerated (red) cases. (b) Modulus at 300% elongation of non-aged (black) and age-accelerated (red) FCBcF. (c) Tensile strength of non-aged (black) and age-accelerated (red) FCBcF and (d) Elongation at break of non-aged (black) and age-accelerated (red) FCBcF.

## 4. CONCLUSION

FCBcF was prepared by mixing ENR50 with silica and magnesium carbonate fillers at a mass ratio of 100:40:40. Among the tested candidates, this formulation exhibited the highest dielectric, and dynamic mechanical properties, while also lowering the production cost. To mix the rubber, chemicals, and fillers, began by mixing the silica, silane, PEG, and oil to a master batch of rubber, then added the magnesium carbonate to reduce the effective adhesion between the rubber and fine chemicals. The main raw material of FCBcF was ENR50, which conferred stronger material properties than STRL. The ENR50, silica, and magnesium carbonate components are polar and tend to absorb microwaves, converting the energy to heat. The fillers can intensify the polarity of the already polar ENR50, but tend to reduce the mobility of the rubber molecules. The vulcanized compound was strongly resistant to oil (a non-polar solvent). The FCBcF was pre-heated for 1 minute with 2.45-GHz microwaves of varying power (340, 850, or 1,700 W), then vulcanized by hydraulic molding at 150°C for a duration of 50% $T_{C90}$. The mechanical properties were tested without aging and after accelerated aging at 100°C for 22 hours. Microwave pre-heating at 340 W for 1 minute achieved the best hardness and modulus at 300% elongation after aging and the best tensile strength and elongation at break in the non-aged specimen. Heating at higher microwave powers degraded the mechanical properties of the FCBcF.

These proof-of-concept results indicate the feasibility of pre-heating FCBcF by microwaves prior to vulcanization in the industrial manufacture of FCB.

## 5. Acknowledgments

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