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# NOVEL FOODSTUFF CONVEYOR BELTS COMPOUND FOR ENERGY SAVING: THE EFFECT OF MICROWAVE PRE-HEATING AND MIXED FILLERSON MECHANICAL PROPERTIES

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## ABSTRACT

This research presents an effect of microwave power being utilized in preheating of a foodstuff conveyor belts compound (FCBc), with or without mixed fillers, and sulfur at different volumes of 1.0, 1.5 and 2.0 phr respectively. Prior to hydraulic molding press at 150 °C, an FCBc is preheated for one minute through an industrial microwave system at a frequency of 2.45 GHz along with microwave power of 340, 850 and 1,700 watts whereas the cure timeis a time 50%. The result shows that the FCBc with mixed fillers and 1.0 phr sulfur with microwave power at 340 watts demonstrates an effective crosslink between the rubber and the fillers which subsequently produces the FCBc that contains better mechanical properties, not only at the lower cost on raw material but also the curing time reduces to 40.20 % per production round.

**Keywords:** foodstuff conveyor belt compound, microwave power, mixed fillers, raw material, mechanical properties, energy saving.

## INTRODUCTION

Many advantages of microwave power include its intensive heating capability and quality in a form of volumetric heating, its energy penetrating ability that leads to constant spreading of heat within an entire object whereas a heating duration is short, and more importantly, its energy is unmixed and nonpolluting to the environment. The device is small and maintenance is low as its component parts are lesser than others (Ratanadecho *et al*., 2006). Heating with microwave depends on a wave absorbing property of an object and the object used in this process must be a dielectric material which is the material of semi-insulator with a basic structure of dipoles, the property that contains microwave absorption competency that effectively transforms into thermal energy. Such heat occurs from the force of friction during a new arrangement of leading molecules while conducting the absorption which further leads to an act of heat spreading throughout an entire material (Metaxas *et al*., 1983). The new foodstuff conveyor belt compound of energy saving is a dielectric material consisting of epoxidized natural rubber-50 (ENR50) which is the rubber of higher dipoles than the normal one for being better heat and oil resistance (Yoksan., 2008). In addition, silica and magnesium carbonate, the white polar fillers of both reinforcing and semi reinforcing are popularly used with natural rubber as mixed fillers when better quality and colors of a product are required (Barlow., 1993, Sombatsompop *et al.*, 2004). Furthermore, there are some previous researches aimed to study various uses of microwave power to investigate different features of natural rubber, with or without carbon black (Laurence *et al*., 2000) and chemical bond breaking of crumb rubber being vulcanized by microwave (Wicks *et al*., 2000). The studies also include a method and tool used for heating a material with microwave power especially in a de-vulcanization process of crumb rubber through heating with microwave power which could be recycled into a new type of rubber (Anderson., 1978), using microwave to study a dielectric property of natural rubber at the pre and post vulcanization (Bovtun *et al*., 2001), cross-linking of rubber in microwave curing processes (Bogdal *et al*., 2003), relations between rubber molecules crosslink and microwave energy using a method of microwave tunnels (Khor *etal*., 2010). The conventional heating is additionally introduced by combining microwave power with hot air in order to vulcanize the rubber hose. Two steps of pre-vulcanization with microwave and conventional vulcanization are conducted enabling to rapidly mold the rubber while conducting energy saving when being compared with an original vulcanization process (Sejimo *et al*., 1987). Practically, a method of microwave heating the compounds is used in Avon Tyre Ltd., the company that produces solid tyres for forklift trucks in which the process can reduce the duration of 30 kg. compound compression molding from 120 minutes to 70 minutes through 10 minutes microwave heating prior to the compression molding (Sutton *et al*., 1988).

This research presents the use of microwave power at 340, 850 and 1,700 watts for one minute in preheating FCBc, with or without mixed fillers, and sulfur volumes of 1.0, 1.5, and 2.0 phr. FCBc specimens of both with and without microwave power are studied. The one with microwave power is further compressed with hydraulic molding press at 150 °C and the cure time ($T_{C90}$) is a time 50% in order to study the property of hardness in molecules crosslinking.

### Materials and chemicals

The formulations are designed as shown in Table-1.

**Table-1.**Compounding formulations.

| phr[a] | | | | | | |
|---|---|---|---|---|---|---|
| **Raw materials** | **[b]FCBc -[c]S1.0** | **FCBc -S1.5** | **FCBc -S2.0** | **[d]FCBcF -S1.0** | **FCBcF -S1.5** | **FCBcF -S2.0** |
| ENR50 | 100 | 100 | 100 | 100 | 100 | 100 |
| $SiO_2$ | - | - | - | 40 | 40 | 40 |
| $MgCO_3$ | - | - | - | 40 | 40 | 40 |
| $TiO_2$ | 8 | 8 | 8 | 8 | 8 | 8 |
| Stearic acid | 1 | 1 | 1 | 1 | 1 | 1 |
| ZnO | 3 | 3 | 3 | 3 | 3 | 3 |
| Neofow L90 | 5 | 5 | 5 | 5 | 5 | 5 |
| Paraffin wax | 1 | 1 | 1 | 1 | 1 | 1 |
| BHT | 2 | 2 | 2 | 2 | 2 | 2 |
| Couplink89 | - | - | - | 2 | 2 | 2 |
| PEG 4000 | - | - | - | 2.2 | 2.2 | 2.2 |
| MBTS | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| TBBS | 1 | 1 | 1 | 1 | 1 | 1 |
| Sulfur | 1 | 1.5 | 2 | 1 | 1.5 | 2 |
| Total | 122.6 | 123.1 | 123.6 | 206.80 | 207.3 | 207.8 |

[a] Part per hundred parts by weight of rubber dry basis (phr), [b] Foodstuff conveyor belts compound without mixed fillers, [c] Sulfur content (past per hundred parts by dry basis weight) and [d] Foodstuff conveyor belts compound with mixed fillers

## Preparation of rubber compounds

The raw material was prepared by mixing in an internal mixer (Brabender®GmbH&Co. KG, Duisburg, Germany), with a rotor speed of 60 rpm at a temperature of 70 °C. The compounding formulas are shown in Table-1. Before mixing, the rubber compounds were classified into two groups, namely (a) ENR50 without fillers: [FCBc] and (b) ENR50 with fillers (using a mixture of ($SiO_2$) and ($MgCO_3$) as fillers at 80 phr): [FCBcF]. A two-stage mixing procedure was employed to prepare all compounds. In the first step, ENR50 was first masticated for 3 min. The other ingredients including ZnO, stearic acid, Paraffin wax, BHT, Neoflow L-90 resins and $TiO_2$, were then sequentially added, each with a mixing step of 1 min, followed by the second step. The following order, ENR50 was first masticated for 3 min. Then, mix separately, $SiO_2$, $MgCO_3$, Couplink 89 and PEG 4000 with consecutive grinding times of 5, 3, 1 and 1 min, respectively. Similarly, the other ingredients, ZnO, Stearic acid, Paraffines waxes, BHT, Neoflow L-90 resins and $TiO_2$, were sequentially added, each with a mixing step of 1 min followed by the second step described below.

In the second step, after dumping the mixture from the mixing chamber, the accelerator (MBTS and TBBS) and sulfur were added into the mixture on a conventional laboratory two-roll mill size (8x20 inch) at a roller speed of 18:20 round per min (side roller : after the roller), according to ASTM designation D3184-80. The mixing temperature was 40-45 °C for 6 min. The rubber compounds were prepared using a conventional vulcanization (semi-EV). Significantly, the sulfur contents were varied from 1.0, 1.5 and 2.0 parts per hundred parts of dried rubber by weight basis, respectively. Then the mixtures were sheeted out and kept at the room temperature for 24 hours before testing. The rubber compounds were then vulcanized using a compression molding machine, under a pressure of 15 MPa at 150 °C, using the optimum cure time ($T_{C90}$) determined by a curing test with a moving die rheometer (Monsanto Rheometer, Model MDR 2000).

## Preparation of specimens

Two sets of specimens were prepared with a size of 150x150 $mm^2$ and a thickness of 4 mm. The first set was without microwave heating but molded with hydraulic molding press at 150 °C, according to cure time ($T_{C90}$). The aim for the second set was to use microwave power to heat the FCBc prior to the hydraulic molding press in order to reduce the cure time. So, FCBc with or without mixed fillers was preheated with microwave power (Panasonic NE-1756 microwave oven) at 340, 850, and 1,700 watts, a frequency of 2.45 GHz, for one minute before hydraulic molding pressing at 150 °C and cure time ($T_{C90}$) is a time 50%.

## Testing and characterization

### Curing characteristics

Curing characteristics of natural rubber/white fillers compounds were tested according to ASTM D5289-

07a using a Moving Die Rheometer (MDR Type, MONSANTO/ RHEOMETER MDR 2000, Japan.) with of Arc 0.5° at 150 °C. The optimum cure time (Tc$_{90}$(, scorch time (Ts$_2$(, minimum torque) ML), maximum torque (MH) and torque difference or delta torque (ΔH=MH - ML) were determined based on the curing curves. The cure rate index (CRI), a parameter which indicates the speed of curing reaction, was determined from rheometric data. CRI was calculated using the following relation as shown in equation (1) (Aprem *et al*., 2003).

$$\text{CRI} = \frac{100}{\text{Cure time} - \text{Scorch time}} \quad (1)$$

**Crosslink density characteristics**

The specimen was cut to a rectangular shape dimension of 1x1 cm$^2$and weighted both before and after soaking in 30 ml of toluene for 7 days. These weights were used to calculate cross-linked content as shown in equation (2) (Ratanadecho *et al*., 2002, Allen *et al*., 2003).

$$\eta_{swell} = \frac{-\text{In}(1-V_r) - V_r - \chi V_r^2}{V_m(V_r^{1/3} - V_r/2)} \quad (2)$$

$V_r$ is the volume fraction of rubber in swollen gel, $\chi$ is the rubber-solvent interaction parameter (0.406), $V_m$ is the molar volume of toluene (106.8 cm$^{-3}$ mol) and $\eta_{swell}$ is the swelling of rubber (%).

**Mechanical properties**

Mechanical properties in terms of tensile strength (MPa), elongation at break (%) and modulus at 300% elongation (MPa) were determined. Standard test procedures as prescribed by ASTM D412-06ae2 (Die C) were used for the determination of compound and vulcanization properties, using aInstron Model-5565,USA, and hardness (Shore A) was tested according to ASTM D2240-05(2010) using a Toyo-Seiki Model A-1/7301,Japan. For each testing parameter, an average value was calculated from at least three tests. Most standard deviations of all testing parameters were less than 10%.

## RESULTS AND DISCUSSIONS

**Curing characterization**

It is shown in Table-2 that a vulcanized property of FCBc with mixed fillers is higher than the one of non-mixed fillers which reveals that adding a proportion of mixed fillers enables to increase the viscosity in a form of filler-filler interaction due to an influence of a surface area or particle size as well as a polarity decreasing situation of the mixed fillers that causes such interaction and further forms a mass linking with effective spreading, resulting in a higher modulus value (Frohlich *et al*., 2005, Leblanc., 2002). Moreover, adding mixed fillers in FCBc can increase an acidic state that speeds up an accelerator and accordingly increases cure time (T$_{C90}$), when being compared with non mixed fillers FCBc. In addition, FCBc with or without mixed fillers shows a reducing value of scorch time (T$_{S2}$), cure time (T$_{C90}$) and cure rate index (CRI) when an amount of vulcanized substances are higher. Nevertheless, increasing a vulcanized substances proportion makes torque difference (M$_H$-M$_L$) higher which may mean that a linking level becomes high when a volume of the vulcanized substance increases.

**Crosslink density**

It is found as shown in Figure-1 that once a fraction volume of sulfur increases, a crosslinking percentage of non- microwave power FCBc also increases, especially the FCBc with mixed fillers. This is because high quantity sulfur causes high crosslink and an added proportion of sulfur enables to increase the density of the crosslink with mixed fillers (Makal *et al*., 2010). Moreover, it is also found that FCBc with mixed fillers while being through microwave power shows a density value of crosslinking higher than the one without mixed fillers at every level of microwave power. This means that FCBc without mixed fillers is able to conduct less energy alteration at the microwave power absorption. Hence, when fillers are added, the FCBc enables to absorb more microwave power as SiO$_2$, reinforcing filler, and MgCO$_3$, semi-reinforcing filler, are polar. Once polar fillers are mixed with FCBc, the mixed fillers enhance its polarity. This corresponds with a thermal occurrence by an effect of carbon black in natural rubber (Metaxas *et al*., 1983, Peter et al., 1999). It is further found when FCBc is heated by microwave power at 340, 850 and1700 watts that a sample with a sulfur quantity of 1.0 phr provides the highest crosslinking percentage and such percentage becomes slightly decreasing at 1.5 phr and 2.0 phr respectively. This is because when a sulfur proportion in the FCBc being heated with microwave power of the same watt and same duration, an FCBc temperature becomes higher leading to its additional energy absorbent capability and thermal condition that the FCBc subsequently absorbs microwave power and enables to change into better condition of thermal energy while heating ventilation within the FCBc remains the same. This causes a reduction in the crosslink density of the vulcanized rubber thermal degradation during a vulcanization process and further leads to some changes in a rubber intermolecular reaction as well as chain scission. Nevertheless, this degradation is in a physical property of the vulcanized rubber (Hoover, 1999).

Therefore, FCBc with or without mixed fillers and 1.0 phr sulfur, 340 watts microwave power at a wave frequency of 2.45 GHz for one minute of previous to the hydraulic molding press at 150 °C and the cure time 50%. They are quantity is optimized for study on mechanical properties.

**Table-2.**Curing Characterization of FCBc with and without fillers before pre-heating.

| Formulas | $M_L$ (Ib.in) | $M_H$ (Ib.in) | $M_H$-$M_L$ (Ib.in) | $T_{S2}$ (min) | $T_{C90}$ (min) | CRI (min$^{-1}$) |
|---|---|---|---|---|---|---|
| FCBc-S1.0 | 0.32 | 4.60 | 4.28 | 3.53 | 5.73 | 45.45 |
| FCBc-S1.5 | 0.35 | 5.61 | 5.26 | 3.02 | 5.42 | 41.67 |
| FCBc-S2.0 | 0.41 | 6.60 | 6.19 | 2.67 | 5.20 | 39.53 |
| FCBcF-S1.0 | 5.99 | 19.79 | 13.80 | 3.86 | 10.20 | 15.77 |
| FCBcF-S1.5 | 5.81 | 22.39 | 16.58 | 3.20 | 10.15 | 14.39 |
| FCBcF-S2.0 | 5.24 | 26.93 | 21.69 | 2.56 | 10.12 | 13.23 |

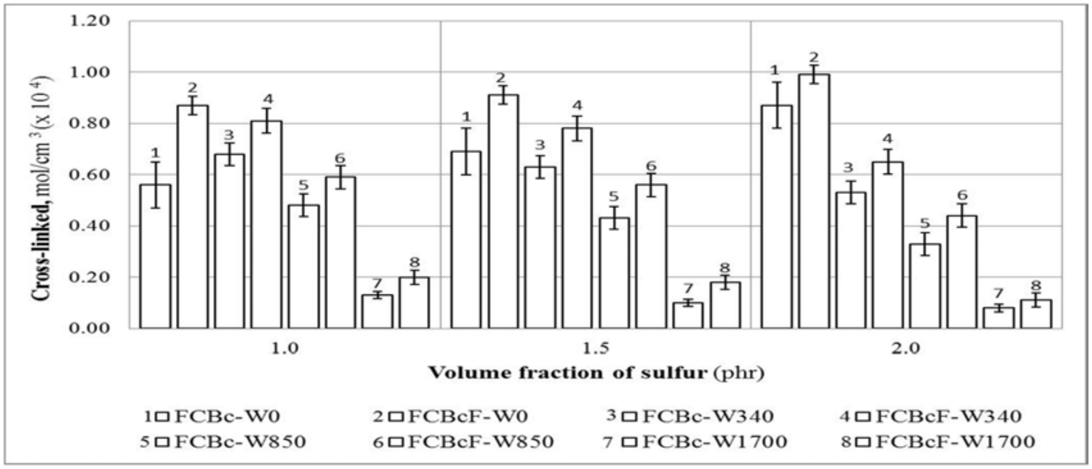

**Figure-1.**The relation between the cross-linking percentage and the sulfur content in FCBc, with and without mixed fillers; with and without microwave power.

**Mechanical properties**

It is described in Figures 2 (a) and (b), that FCBc with mixed fillers the with microwave power and non-microwave power possesses are hardness and modulus at 300% elongation at both property better than the one without mixed fillers of the same condition. The difference is clearly exposed since fillers of silica and magnesium carbonate are dielectric material that can reduce microwave reflections around a surface and help the wave to penetrate through the material better[2]. The dielectric material is able to absorb more waves and effectively transform into heating energy. Moreover, the mixed fillers can also obstruct a molecules chain movement making lesser flexibility in a compound that subsequently increases a hardness characteristic (Barlow, 1993). However, Figure-3(a), that FCBc with mixed fillers at increasing microwave power from 340 to 850 watts can invariable the hardness property which is due to the microwave power absorption within the material in a form of volumetric heat at a molecules level that once there is internal heat, it spreads to the external (Makal *et al*., 2010). The heat that follows is in a form of constant spreading while a double crosslink breaks and becomes a single crosslink with higher polarity. The bond with sulfur molecules is thoroughly occurred within an entire material making better crosslinking. It is also found that figure 3(b), that FCBc with mixed fillers at increasing microwave power from 340 to 850 watts can slightly decrease the property of modulus at 300% elongation which is because higher microwave power produces stronger electric field that further increases wave absorption (Doo-ngam *et al*., 2007) and subsequently, the heat within a molecules level becomes higher and causes a reduction of the molecules crosslink in the FCBc (Makal *et al*., 2010). On the contrary, Figure-2(a) and (b), that FCBc with mixed fillers once microwave power is increased to 1700 watts, the hardness and modulus at 300% elongation are property significantly reduced which are due to an oxidation reaction in natural rubber, especially at a high temperature, or it can be of sulfur bond releasing from linking among molecules (Varghese et al., 1994). In another word**,** this is a case of extensive microwave power that causes degradation because of heat bonding from sulfur crosslink, the effect of FCBc crosslink that reduces at a vulcanized level (Hoover, 1999).

As shown in Figure-2 (c) and (d), FCBc without mixed fillers a good property of tensile strength and elongation at break in all microwave levels. Since there is no mixed filler and it is a low dielectric material that when microwave penetrates into the material, the absorption and the transformation toward thermal energy are accordingly low (Doo-ngam *et al*., 2007). Similarly, FCBc with mixed fillers at becomes a high dielectric material or high polarity that when microwave goes through, the absorbed wave power transforms into thermal energy. An occurrence of the heating circulation is quick making both actions of absorption and transformations happen so fast that subsequently increase a heat level in the molecules**.** This causes some reductions of molecules bonding in the vulcanized rubber (Metaxas *et al.*, 1983). Furthermore, adding the fillers can also reduce the continuation of rubber phases that may cause an unpleasant or unstable distribution. A volume of mixed fillers can obstruct the rubber molecules movement that the rubber becomes more stiffness and brittleness. The result is a reduction of a property of tensile strength and elongation at break (Da costa *et al*., 2002, Ismail *et al*., 1999, Ismail *et al*., 2002). Increasing microwave power from 340 to 1,700 watts to FCBc with fillers can also reduce the property of tensile strength and elongation at break. This is because when there is a rapid circulation of moisture while watt power and heat are high, the crosslink density reduces and the degradation occurs. Therefore, because of heat, the crosslink bond releasing in FCBc with fillers can decrease the FCBc elongation (Nadkar *et al*., 2001).

Therefore, FCBc with mixed fillers at 340 watts microwave power at a wave frequency of 2.45 GHz for one minute of quantity is optimized.

## CONCLUSIONS

Prior to the hydraulic molding press at 150 ºC and the cure time 50%, preheating FCBc with mixed fillers, 1.0 phr. sulfur, and 340 watts microwave power at a wave frequency of 2.45 GHz for one minute making the internal heating within the compound at increase is the most suitable action. The outcome is foodstuff conveyor belts compound that contains better the density of molecule crosslinking and mechanical properties. Not only the cost of raw material becomes low but the curing time duration is also reduced to 40.20% per production round when being compared with a non-preheating situation. Hopefully, this knowledge can be beneficial for an industrial vulcanization process in the future.

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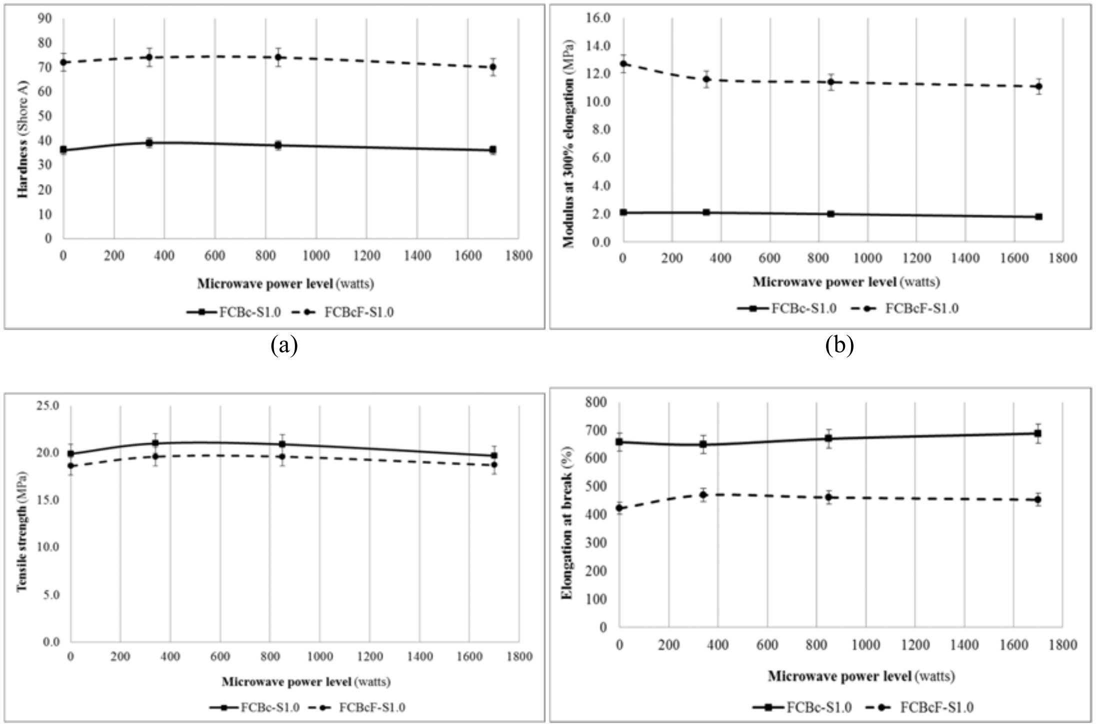

(a) (b)

(c) (d)

**Figure-2.**Mechanical propertiesof FCBc with and without mixed filler (a) hardness, (b) modulus at 300% elongation, (c) tensile strength and (d) elongation at break

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