The Effects of SMR L Content on the Properties of ENR-25/RSC Compounds

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Abstract. Normally, direct introduction of recycled materials into polymer matrix could cause unwanted aggregations, which could effect on the properties of the final product. However, adding third material as a compatibilizer could enhance the properties of the product. This work studied the effects of different SMR L content (2, 4, 6, 8 and 10 PPhr) as a compatibilizer on the physical, tensile properties, and cure characteristics of ENR-25/rSC compounds. The results of cure characteristics showed decreasing on scorch time ($t_{2}$) and cure time ($t_{90}$) while increasing on minimum torque ($M_{L}$) and maximum torque ($M_{H}$) as SMR L increased in ENR-25/rSC/SMR L compounds. The values of modulus ($M_{100}$), tensile strength ($T_{s}$), hardness and crosslinking density increased gradually with increasing SMR L while elongation at break ($E_{b}$) decreased.

1. Introduction
The mixing of different polymer types together might be a valuable technique to improve the constituents with characteristics superior to those of individual components [1]. The main objective of polymer mixing is to improve the processing properties and also to enhance some properties such as (mechanical and physical properties). Furthermore, the blending of polymers could reduce the cost of the products. Nevertheless, one of the biggest flaws in polymer blending process is the phase
separation, which could be due to the poor interfacial adhesion between different polymer phases [2-5].

Adding third material as a compatibilizer into an immiscible binary system could be effective solution to improve the blending of polymers. The compatibilizer could interact chemically with both the phases or could make a certain interaction with one phase and a physical interaction with the other. Consequently, the adding of suitable compatibilizer improves the physical and mechanical properties of the composites [6-9].

Several researches have studied the compatibilizer effect on the properties of polymer blends, compounds or/composites. Teh et al. investigated the influences of epoxidized natural rubber (ENR) as a compatibilizer in melt compounded natural rubber with organ clay nanocomposites. They found that all properties such as cure characteristics, mechanical and morphological properties of the compatibilized composites are improved [10]. Other researchers, such as Angnanon et al. reported the compatibilization effect of acrylonitrile (ACN) and styrene copolymers on the natural rubber/ acrylonitrile butadiene rubber (NR/NBR) blends. The results indicated that the tensile properties and oil-swelling resistance of the blends increased as %graft copolymer increased and scanning electron microscopy (SEM) proved the improvement of interfacial adhesion between two rubber phases [11].

The effects of same compatibilizer, TOR on the physical properties, tensile properties, and cure characteristics of natural rubber / silicon catheter blends have been studied in another research [12]. Results showed that the increase in TOR content reduced the cure time and scorch time while torque improved. The physical and tensile properties of the blends improved in presence of TOR. Nevertheless, the compatibilized sample became less flexible as compared with uncompatibilized sample.

In the current research, standard malaysian rubber grade L (SMR L) was used as a compatibilizer into ENR-25/rSC blends to study the physical properties, tensile properties and cure characteristics of the compatibilized blends.

2. Experimental

2.1. Samples preparation and testing

The materials used in this study were: Natural rubber (25% mole epoxidation grade, ENR-25) as a raw material. Recycle Silicone Catheter (rSC) as filler. Standard Malaysian rubber grade L (SMR L) as a compatibilizer. N-cyclohexyl-2-benzothiazole sulfonamide (CBS) as an accelerator. Sulfur as a vulcanizing agent. Stearic acid and zinc oxide (ZnO) as organic and inorganic activators respectively.

The formulation of the rubber vulcanizates is listed in Table 1.

Rubber with the additives and chemicals were mixed using Two roll mill model X-S-K/160-X-320 according to ASTM D-3184/89. Cure characteristics were studied using Rheometer (MDR 2000) according to ASTM D-2240/93. Hot-press machine was used to mold rubber compounds based on curing time at 160 °C temperature and 30000 kg pressure. To form tensile test species, Dumbbell-shaped mold was utilized. Instron machine model 5582 was utilized for tensile test based on ASTM-D/412. Durometer device model Shore A was utilized for hardness test. The vulcanized species were immersed in Toluene solvent for swelling test based on ASTM-D/3616. Crosslinking density was calculated using Flory-Rehner equation based on swelling test data [13].
Table 1. The ingredients of ENR25/rSC/SMR L compounds.

| Ingredients       | Phr |
|-------------------|-----|
| ENR-25            | 100 |
| ZnO               | 5   |
| Stearic Acid      | 2   |
| CBS               | 1   |
| Sulfur            | 2   |
| rSC               | 10  |
| SMR L             | 0   |

3. Results and discussion

3.1. Curing characteristics

The curing characteristics results (curing time $t_{90}$, scorch time $t_2$, maximum torque $M_H$ and minimum torque $M_L$) of ENR25/rSC/SMR L compounds were summarized in Table 2. It can be seen clearly that $t_{90}$ and $t_2$ became shorter as compatibilizer loading increased in the compounds. This was attributed to the unsaturated SMR L rubber, which led to increase the incorporation between ENR25 and SMR L in short time. Thus $t_{90}$ and $t_2$ decreased.

$M_L$ exhibited declining as SMR L content increased. This indicates better processability of the vulcanizates after compatibilization. This led to decrease in the viscosity of the compounds. Whereas $M_H$ exhibited an opposite tendency, which increased as SMR L loading increased in ENR25/rSC/SMR L compounds. This could be due to the unsaturated structure of SMR L, which bonded with the ENR25 and enhanced the crosslinking density of the compounds [14-16]. This observation is also refers to the improvement of ENR25/rSC compounds incompatibility with the presence of SMR L as a compatibilizer.

Table 2 The curing characteristic of ENR25/rSC/SMR L compounds.

| SMR L | $t_2$ (min) | $t_{90}$ (min) | $M_L$ (dNm) | $M_H$ (dNm) |
|-------|-------------|----------------|-------------|-------------|
| R0    | 1.12        | 7.1            | 6.9         | 23.9        |
| R02   | 0.65        | 6.8            | 4.0         | 26.0        |
| R04   | 0.55        | 6.1            | 3.7         | 27.3        |
| R06   | 0.50        | 5.2            | 3.2         | 28.2        |
| R08   | 0.45        | 4.5            | 2.5         | 31.5        |
| R10   | 0.30        | 3.8            | 1.8         | 34.6        |

3.2. Tensile and physical properties

The effects of SMR L content as a compatibilizer on the tensile properties such as tensile strength (Ts), elongation at break (Eb) and modulus (M100) of the ENR25/rSC/SMR L compounds are shown in Figure 1 a, b, and c respectively.

It’s easily observed that the Ts values increased steadily as compatibilizer loading increased (Figure 1 a). The Ts increasing was because of the high dispersion of rSC in ENR25 as SMR L added. This was led to improvement in the interfacial adhesion of the compounds by reducing the interfacial energy between phases, Thus Ts increased.

Eb percentages decreased with the existence of SMR L in ENR25/rSC/SMR L compounds (Figure 1 b). The adding of SMR L as a compatibilizer restricted the mobility and flow of rubber compounds, which in turn led to decrease in the flexibility of the compounds too [16].
M100 value improved as SMR L added in ENR25/rSC/SMR L compounds (Figure 1 c). This was due to the presence of unsaturated SMR L that made a good incorporation with ENR-25 matrix and also increased the distribution of rSC in the vulcaniziateas, which in turn developed the crosslinking density of the compounds [16-18] (Figure 1a).

Hardness values (Figure 2 b) exhibited same trend of crosslinking density (Figure 2 a). Furthermore, the hardness of the composites improved as SMR L content increased (Figure 2 b). Nah et al. reported that the improvement on hardness with existence of compatibilizer could be due to the fact that the crosslinking relative degree was higher than other compounds, which made the compatibilized rubber compounds more rigid and stiff [19].

**Figure 1 a**

**Figure 1 b**

**Figure 2 a**

**Figure 2 b**

![Graph a](image)

![Graph b](image)
Figure 1. The variation of (a) tensile strength, (b) elongation at break, and (c) Modulus of ENR25/rSC/SMR L compounds.

(a)

(c)
4. Summary
The presence of SMR L as a compatibilizer has enhanced the overall properties of ENR25/rSC/SMR L compounds. The curing time and scorch time have decreased as SMR L increased in the vulcanizates and also improved the torque. Besides, the physical and tensile properties of the compounds were improved as SMR L added. However, elongation at break reduced due to the increased stiffness of the vulcanizates.

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