Recycled Natural Rubber Latex Gloves Filled Chloroprene Rubber: Effects of Compatibilizers

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Abstract. In this study, the effects of the compatibilizers; trans-polyoctylene (TOR) and epoxidized natural rubber (ENR-50), on the cure characteristics and tensile properties of recycled natural rubber latex gloves (rNR-G) filled chloroprene rubber (CR) were investigated. Blends consisting of rNR-G in a weight ratio 20 phr in CR and The compatibilizers TOR and ENR-50 at different concentrations, i.e. 2, 4, 6, 8 and 10 phr, were prepared using a two roll mill. Incorporation of TOR resulted in a reducing of the cure characteristics, meanwhile ENR-50 increased them. On the other hand, both of TOR and ENR-50 were improved tensile properties. These effects are attributed to the enhanced interfacial adhesion between rNR-G and phases through the compatibilizing effect induced by TOR and ENR-50, and the good dispersion of the rNR-G phase in the CR matrix. The results confirmed that TOR and ENR-50 could potentially be used as compatibilizers for the recycled natural rubber latex gloves filled chloroprene rubber.

1. Introduction

Synthetic rubber has been extensively utilized for many products in various environments. That is due to its unique characteristics such as flexible elasticity, energy absorption, and fluid resistance [1, 2]. However, the life cycle of rubber and its performance remarkably damages over time owing to several physical and chemical factors, such as temperature, humidity, ozone and radiation [3, 4]. For example, chloroprene rubber (CR) is one of the common rubbers, this rubber maintains its performance over
time, and is used for high voltage electric wire covers and ignition line covers. Unfortunately, CR as other types of rubber becomes stiff and fragile after long-term utilizing under high-temperature conditions [3, 5].

At present, the natural rubber glove (NRG) becomes one of the most important necessities in the health demands. After its use, NRG is generally convert to waste rubbers which is difficult to biodegrade because polyisoprene chains of NR are crosslinked either by sulphur or peroxide system [6, 7]. The problem of NRG waste started in growing as a direct result of diseases diffusion and population growth. In addition to NRG waste from hospital and other toxic hazardous waste, more than 11% of NRG products considered as a rejected or defect products during the processing of latex rubber. All of the huge waste rubber quantities might cause serious environmental problem and great health risk to public [8-10]. To solve this problem, many research investigated the reuse of NRG waste in several applications such as mat and large tire [11].

Recently, the rNR-G started in use which blended with virgin synthetic rubber and NR [6, 8]. In this present work, the rNR-G waste was blended with CR by using TOR and ENR-50 as compatibilizers. As reported in the previous work concerning CR/ rNR-G, it was expected that the 20 phr addition of rNR-G resulted the optimum properties of CR/ rNR-G blend. As a result, this ratio was depended in this work to study the effect of different compatibilizers with different ratios.

2. Experimental

2.1. Materials
Recycled natural rubber latex gloves (rNR-G) waste was obtained from a local company, Top Gloves Co. Sdn Bhd, Malaysia. Chloroprene rubber (CR), trans polyoctylene (TOR) and epoxidized natural rubber (ENR-50) were purchased from RRIM Guthrie Group Sdn. Bhd. The compounding chemicals such as zinc oxide (activator), stearic acid (activator), sulfur (vulcanizing agent) and N-cyclohexyl-2-benzothiazole sulfonamide (CBS) (accelerator) were supplied by Anchor Chemical Co. (M) Ltd.

2.2. Formulation and testing of CR/ rNR-G compounds
rNR-G waste was cut and masticated by using two-roll mill (X(S)K-160x320) at room temperature for 30 minutes to break the crosslinking of the latex glove, to be able for grinding. After the grinding process, the rNR-G were sieved to obtained filler with particulate size of 300 – 600 μm (fine size), and the rest was considered as coarse size fillers. After preparation the gloves waste in suitable sizes, the compounding was done as shown in table 1.

| Ingredients | Compounds (phr) |
|-------------|-----------------|
| Sample 1   | 2               |
| Sample 2   | 3               |
| Sample 3   | 4               |
| Sample 4   | 5               |
| CR         | 100             |
| Sulphur    | 2               |
| CBS        | 1               |
| ZnO        | 5               |
| Stearic acid | 2              |
| rNR-G      | 20 (Based on results in series 1) |
| Compatibilizers | 2             |

2.3. Characterizations and testing of CR/ rNR-G compounds
After preparing all the specimens, the cure characteristics were done by using the Rheometer Monsanto Model MDR 2000. By the cure test, the minimum torque (ML), maximum torque (MH), cure time (t90), and scorch time (t2) were studied. In addition, the tensile test was studied according to
the ASTM D412 method, which was done by using the universal testing machine Instron 5582. Tensile strength, elongation at break and the modulus at 100% elongation were investigated.

3. Results and discussion
Based on the results in the first series, 20 phr of fine rNR-G filler was chosen as the optimum loading and filler size to be implemented in this series. This series studies the effect of the type and concentration of compatibilizers on the 20 phr fine rNR-G filled CR. both of TOR and ENR-50 were utilized as compatibilizers with various concentrations (0, 2, 4, 6, 8 and 10 phr).

3.1. Cure Characteristics
Figure 1 shows the results of scorch time \( t_2 \) for CR/rNR-G with different loading of compatibilizers (TOR and ENR-50). It can be released that there is an increasing trend of scorch time as the loading of ENR-50 increased. On the other hand, the scorch time of CR decreased as the levels of TOR within CR increased. This results can be attributed to the low molecular weight of TOR, that was led to lowering the viscosity of CR/rNR-G, therefore the processing of CR became easier, thus resulting in faster scorch time as more TOR was incorporated into the compound [12]. On contrast, ENR-50 possesses a high molecular weight, as a result, the incorporation of ENR-50 raised the viscosity of CR/rNR-G which increased the scorch time as more ENR-50 was added.

From the results in figure 2, the cure time \( t_{90} \) without compatibilizers was higher compared to CR/rNR-G with compatibilizers. The increasing of TOR concentration led to decrease the cure time to steadily from 2 phr loading to 6 phr. However, after 6 phr loading, the cure time did not exhibit any increasing. Indicating that at 6 phr loading of TOR, further loading will have no influence on the cure time of CR/rNR-G. On the other hand, the increasing of ENR-50 loading yielded an increasing in the cure time.

![Figure 1](image_url)
Figure 2. Cure time ($t_{90}$) of CR/rNR-G compound with compatibilizers.

Table 2. The cure characteristic of CR/rNR-G compound with compatibilizers.

| Compatibilizers (phr) | $M_L$ (dNm) | $M_H$ (dNm) |
|-----------------------|-------------|-------------|
| 0                     | 7.79        | 50.17       |
| 2 TOR                 | 7.23        | 46.29       |
| 4 ENR-50              | 4.50        | 25.08       |
| 4 TOR                 | 6.47        | 41.36       |
| 6 ENR-50              | 5.89        | 34.29       |
| 6 TOR                 | 5.66        | 36.56       |
| 8 ENR-50              | 6.51        | 43.50       |
| 8 TOR                 | 4.88        | 31.76       |
| 10 ENR-50             | 7.30        | 47.60       |
| 10 TOR                | 3.42        | 30.77       |

Table 1 demonstrates the results of minimum torque ($M_L$) and maximum torque ($M_H$), the results showed an opposite effect for adding TOR and ENR-50, which with the increasing of TOR loading, the ML and MH values were decreased, that was owing to the processing aid effect of TOR, which it helps to reduce the amount of torque generated during the processing stage. Meanwhile, the adding of ENR-50 increased them.

Figure 3 shows the cure rate index (CRI) of CR/ rNR-G with different loading of compatibilizer TOR and ENR-50. It can be seen that the cure rate of the rubber matrix increased with higher loading of TOR. This phenomenon was due to the characteristic of TOR itself, which possesses smaller particle size, low surface area, chemically active surface, porous surface, high moisture content and uneven shapes, which lead to maximization of interaction area between filled rubber and compatibilizer [13]. In addition, the results showed that the decrease of cure rate as higher loading of ENR-50 was incorporated. This is due to ENR-50 is a polymer with high molecular weight. Thus the incorporation of ENR-50 will increase the viscosity of the filled CR, and then lowering the CRI.
3.2. Tensile Properties

Table 3 shows the result of tensile strength, Elongation at break and tensile Modulus at 100% elongation of CR/rNR-G with different loading of compatibilizer TOR and ENR-50. It can be noticed that there is an increasing in the tensile strength values with the increasing of compatibilizers loading. But the incorporation of ENR-50 showed higher tensile strength of the CR compared to TOR. Both of TOR and ENR-50 helped to improve the distribution of the rNR-G filler within the CR. With the better distribution, the interaction between rubber-filler would improve [14, 15]. Thus, the tensile strength improved with the incorporation of compatibilizers. The lower tensile strength of TOR was probably attributed to the weak stress transfer from the matrix to filler although there was still some interfacial adhesion. On the other hand, ENR-50 enhanced the interfacial bonding between the CR and rNR-G filler, thus the interfacial layer can transfer the stress and the bonding after the deformation occurred. Therefore, the incorporation of ENR-50 would increase the tensile strength more than TOR.

The trend showed that the elongation at break increased as the loading of compatibilizers increased. From the results, ENR-50 showed better improvement compared to TOR. That is because ENR-50 possesses a high molecular weight comparing to TOR. As a result, ENR-50 has a good ductility and toughness which can load large deformation before experiencing failure. Therefore, it can be deduced that the incorporation of ENR-50 improves the ductility and toughness of the filled CR, then it improved the elongation at break more than TOR. Finally, both of caused an increasing in the modulus values. However, ENR-50 granted the filled CR higher modulus compared to TOR. This probably due to ENR-50 giving better dispersion of rNR-G filler in the matrix CR. Therefore, a promoting the rubber-filler interaction was occurred, which improved the modulus of the filled CR [16].

Table 3. The tensile characteristic of CR/rNR-G compounds with compatibilizers.

| Compatibilizers (phr) | Tensile Strength (MPa) | Elongation at break (%) | Modulus at 100% (MPa) |
|-----------------------|------------------------|-------------------------|-----------------------|
| 0                     | 1.92                   | 175.23                  | 209.86                |
| 2                     | 2.15                   | 176.33                  | 210.87                |
| ENR-50                | 2.38                   | 178.66                  | 211.61                |
| 4                     | 2.34                   | 178.94                  | 211.23                |
| ENR-50                | 2.51                   | 180.16                  | 213.54                |
| 6                     | 2.47                   | 180.46                  | 213.89                |
| ENR-50                | 2.73                   | 182.64                  | 214.44                |
4. Summary
According to the results obtained, it can be concluded that by taking the optimum loading of fine rNR-G filler which was 20 phr, TOR and ENR-50 effect CR differently. In the cure characteristics, TOR improved the processing time by lowering the scorch time and cure time. Not only that, the filled CR also became easier to process, as TOR also lowers the minimum and maximum torque. On the other hand, ENR-50 increased the processing time and made the processibility more difficult. This is especially obvious as the CRI of TOR increased and ENR-50 decreased as both respective loadings increased. However, both compatibilizers exhibited improvement for the tensile test, which they increased tensile strength, elongation at break and tensile modulus at 100% elongation.

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|    | TOR  | ENR-50 | TOR  | ENR-50 |
|----|------|--------|------|--------|
| 8  | 2.61 | 182.87 | 214.37 |        |
| 10 | 2.89 | 184.32 | 215.46 |        |
| 10 | 2.93 | 186.78 | 218.42 |        |