Effect of Ground Rubber Powder on Properties of Natural Rubber

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Summary: Ground rubber powder (GRP) with three different sizes was incorporated into nature rubber matrix with different loading. Cure characteristics, swelling behaviour, crosslink density, tensile fractured surface, and mechanical properties have been studied. Based on the cure characteristics, it is evident that the processability of the rubber compounds has not changed obviously with the different GRP loading. The introduction of GRP in virgin rubber leads to the increase in swelling degree and the decrease in crosslink density. Tensile strength, hardness and abrasion resistant deteriorate with the increase of GRP loading, but the tear resistance gets better. If the ground rubber particles are smaller, the properties are more similar to the virgin rubber. Because of the phase separation of the GRP and matrix, the properties get worse with the bigger ground rubber powder.

Keywords: fillers; mechanical properties; recycling; rubber; waste

Introduction

The environmental problems caused by waste rubbers and discarded tires are becoming more and more serious. Many attempts to recycle waste tires have been undertaken, for both environmental and economic reasons.[1-5] The recycling of the waste tire can be divided into four categories: energy generation, utilization of whole tires, reprocessing and utilization as ground rubber.[6, 7, 8] The materials incorporated with ground rubber powder and virgin rubber, or thermoplastics have many possible applications.[9] When the ground rubber powder is incorporated into virgin rubber compounds, the physical properties, especially the tensile strength, is decreased compared to the virgin rubber.[10] The introduction of ground rubber powder also causes the changes of cure behaviour and crosslink density, which are the results of the migration of sulphur or accelerator between virgin rubber matrix and the ground rubber

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vulcanizates.[11, 12] In this paper, the effects of different GRP sizes and loadings on these properties will be discussed.

Experimental

Materials

The virgin nature rubber used as a matrix in this study is SMR5 obtained from Teknikum Oy, Finland. Three different sizes of ground rubber powder (GRP), GRPA: 0-0.2mm, GRPB: 0.71-1mm, GRPC: 4mm, were purchased from Genan A/B, Demark (in Figure 1). The rubber powders were prepared from passenger car and light truck tires from which the free fibre and metal have been removed, the loading amounts were 10, 30, 50 phr respectively.

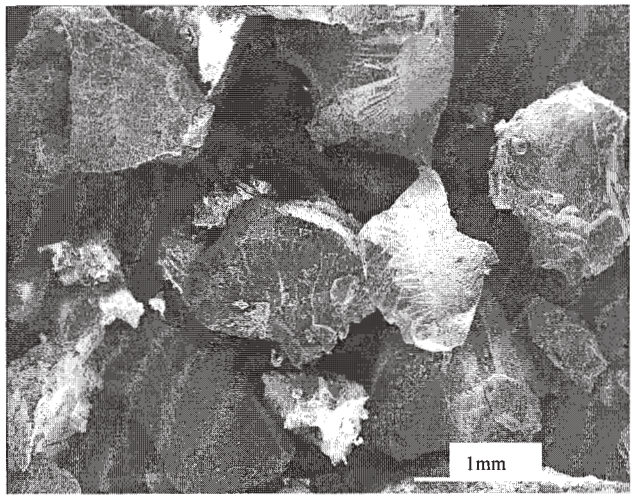

Figure 1. SEM of GRPB: 0.71-1mm .

Sample Preparation

The compound recipes are given in Table 1. The ground rubber powder was premixed with virgin rubber using an internal mixer at 60 °C, and then the ingredients except sulphur were incorporated. This was for better distribution and prevents the prevulcanization. The total mixing time was about 6 min. After which the premixture was softening in a two-roll mill at

60 °C and then sulphur was added, the mixing was continued for 2 minutes to get the sheet. The vulcanization was performed by compression moulding press at 160 °C. The vulcanization times, t_{90}, were determined using a linear Monsanto 100S rheometer.

Table 1. The compound recipes (phr).

Formulation (phr)	NR	GRP10	GRP30	GRP50
GRP(A,B,C)	0	10	30	50
SMR5	100	100	100	100
Zinc oxide	5	5	5	5
Stearic acid	2	2	2	2
N-220	35	35	35	35
CBS[a]	0.7	0.7	0.7	0.7
Sulphur	2.25	2.25	2.25	2.25

[a]:N-cyclohexyl-2-benzothiazyl sulphonamide.

Measurements

A Monsanto 100S oscillating disc rheometer was used to obtain the cure characteristics at temperature 160 °C according to ISO 3417. The tensile fractured surface of the compound was investigated with a scanning electron microscope (JEOL JSM–T100). Circular test pieces of diameter 10mm were cut from the vulcanized sheets (2 mm thickness), and soaked into toluene at room temperature (25 °C) until equilibrium to test the swelling degree. The crosslink density of the gels was calculated from Flory-Rehner equation.[13] The interaction parameter for the NR-toluene system is 0.39. Tensile strength and tear strength were performed with a Monsanto Tensometer 10 testing machine according to ISO 37 (Type 1) and ISO 34 (Type A). Abrasion resistance was carried out at Zwick with ISO 4649, an abrasive run of 40m, loading 10N. Hardness was tested based on ISO 7619 using a ShoreA durometer.

Results and Discussion

Cure Characterization and Morphology

The effect of GRP loading and particle size on the cure characteristics is shown in Figure 2 and Figure 3. As seen in Figure 2, the minimum torque (M_L) increased and maximum torque

(M_H) decreased on the rheometer curve with a higher loading amount of GRP. While, the scorch time (t_{s2}) and the optimum cure time (t_{90}) were slightly shorter when GRP was added to the NR matrix as shown in Figure 3.

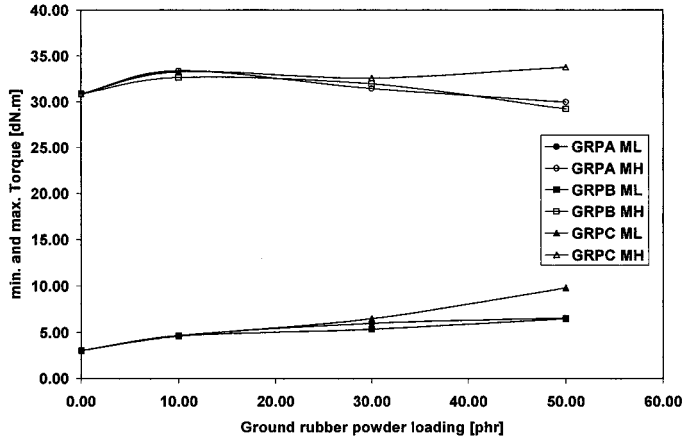

Figure 2. M_L and M_H *vs.* GRP loading.

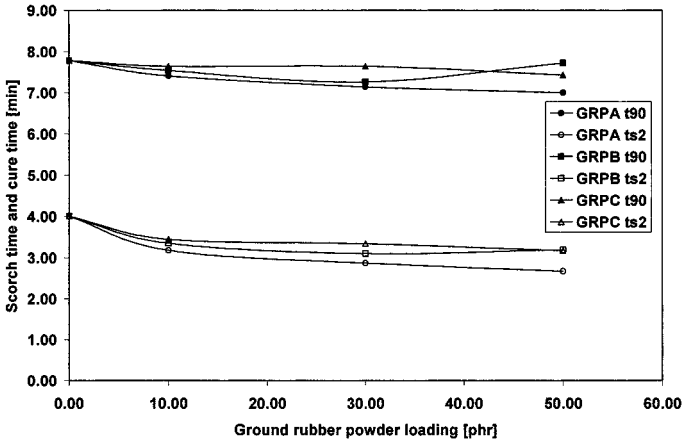

Figure 3. t_{s2} and t_{90} *vs.* GRP loading.

This is due to the migration of sulphur from the matrix rubber to the ground vulcanizates and the migration of accelerator fragments from the ground vulcanizates to the matrix.[14] However, at the same GRP loading, particle size does not affect the processability obviously. The morphology of the tensile fractured surface for GRPA 10 in Figure 4 shows the phase separation of GRP and matrix,[15] it is evident the deterioration of the mechanical properties for GRP introducing, particularly the tensile strength.

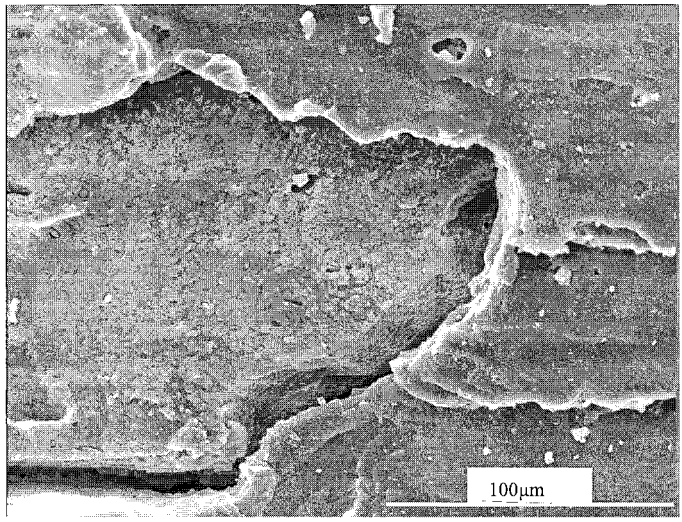

Figure 4. SEM of GRPA 10 tensile fractured surface.

Swelling Behaviour and Crosslink density

The swelling degree increases with the GRP loading in NR matrix as shown in Figure 5. The experiments indicate that the swelling degree increases with the bigger GRP particle size. This is attributed to the difficult diffusion of sulphur in the rubber matrix caused by ground vulcanizates.[12] The crosslink density also decreased with the GRP loading and bigger particle size, it is consistent with the result from cure characteristics.

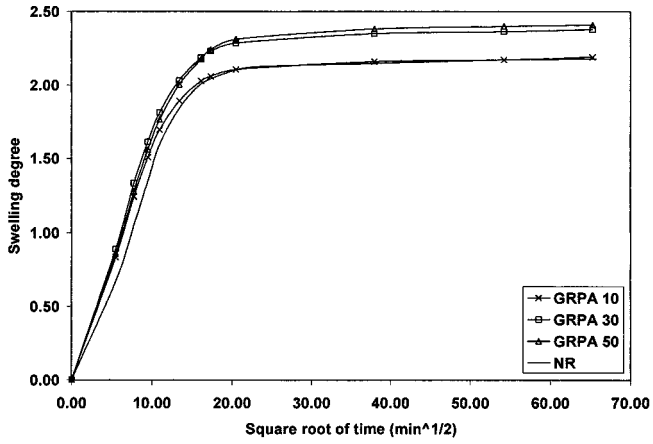

Figure 5. Swelling degree with GRPA loading.

Mechanical Properties

Tensile strength, tear strength, hardness and abrasion resistance are used to evaluate the mechanical properties of the system. The rubber compounds generally tend to become weak and brittle with as increasing loading volume and particle size. In spite of the general decrease in mechanical properties with increasing GRP loading, the properties retention values range from good to excellent at 10 phr loading with smaller particles especially with tensile strength and abrasion resistance as shown in Figure 6 and Figure 7.

Conclusion

It is evident that the processability of the system has not been changed obviously with the GRP loading from the cure characteristics. With the introducing of GRP in virgin rubber, it leads to the increase in swelling degree and the decrease in crosslink density. Tensile strength, hardness and abrasion resistant deteriorated with the increase of GRP loading. However, the tear resistance was improved. If the ground rubber particles are smaller, the properties are more similar to the virgin rubber. Because of the phase separation of the GRP

and matrix, the properties got worse with the bigger ground rubber powder and higher loading.

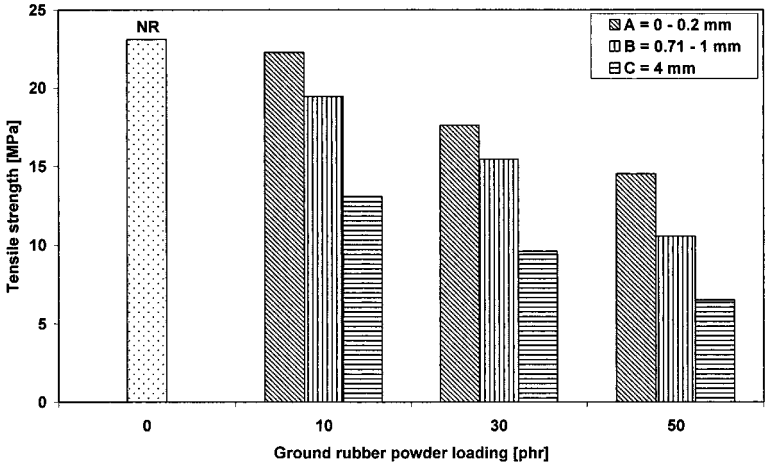

Figure 6. Tensile strength *vs.* GRP loading.

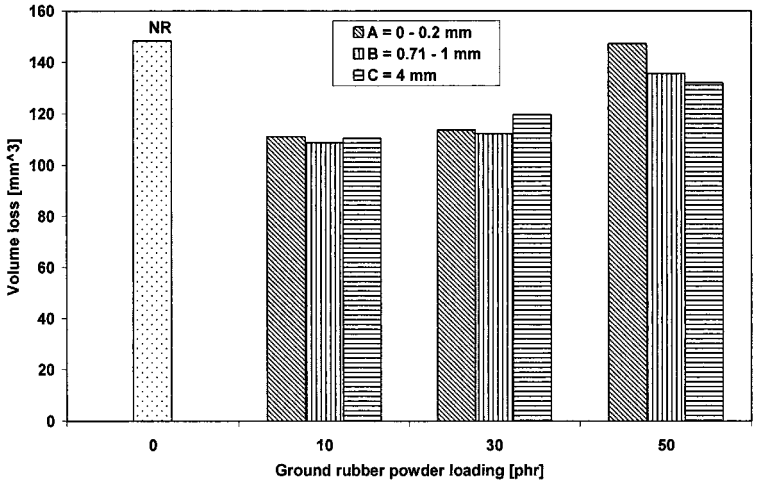

Figure 7. Volume loss *vs.* GRP loading.

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