New Technology of Crumb Rubber Compounding for Recycling of Waste Tires

JIN KUK KIM, SUNG HYO LEE

Department of Polymer Science and Engineering, Research Institute of Industrial Technology, Gyeongsang National University, Chinju Gyeongnam 660-701, Korea

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ABSTRACT: Nowadays, waste tires are a significant problem with the increasing in the number of automobiles. Therefore, much research has been performed in this field. From environmental and economical perspectives, recycling is one of the popular methods for the treatment of waste tire. However, it is not easy to melt down and mold scrapped tires into new products because the tire rubber is a crosslinked polymer. Due to such difficulty, the recycled product is not economical. Therefore, the goal of this study is to develop high-value products from waste tires. In this paper, attention has been paid to an economic recycled technology using scrapped waste tires. This technology may be applied to manufacturing the end products such as a rubber block and a ballast mat for high-speed trains. © 2000 John Wiley & Sons, Inc. J Appl Polym Sci 78: 1573–1577, 2000

Key words: recycling scrap tire rubber; high-value products recycled technology

INTRODUCTION

Many attempts[1–3] to recycle waste tires have been undertaken for environmental reasons. Three methods for waste tires treatment—combustion, burying under ground, and recycling—have been developed. The method most paid attention to is recycling.[4] However, one of the obstacles of recycling is an economic problem. In recycling the waste tires, various methods, which are summarized in Table I, have been developed. A further, potentially attractive method is the utilization of powdered rubber. Commercially, one of the most popular applications of the powder utilization[3,5] is in golf range, industrial flooring, and pathways. The advantage of powder utilization is that it is easy to apply with simple equipment. Although much work[3,5–8] has been done, problems still remain. The difficulty in recycling of the waste tires is that the scrapped tire is a crosslinked polymer that is hard to melt and to process. This creates some special additive treatment for easy processing such as binder and devulcanizer.[9,10] Generally, polyurethane binder is commonly used in most commercial products.

The binder imparts very good adhesion but is very expensive. Therefore, this recycling method is not economical. In this research work, attempts have been made to produce a high value-added product from powdered rubber obtained from waste tires. We also tried to make a good and economic rubber sheet from scrapped tires without using binder in this study. We believe that this kind work is rapidly gaining attention as a valuable market for the rubber waste stream.

EXPERIMENTAL

Sample Preparation

The recipe for rubber compound is summarized in Table II. In Table II, the abbreviations LR and

Correspondence to: J. K. Kim.

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Table I Recycling Methods for Used Tires

Body Utilization		Processing			Heat Utilization	
Retreating	Products	Stripping	Reclaim	Powder	Pyrolysis	Incineration
Retreated tires	Dock fender, fish house, etc.	Flooring	Mat, belt	Flooring, pavement, ballast mat, rubber block, etc.	Gas (fuel), oil (fuel), carbon black (reinforcing material)	Cement material and fuel, boiler, etc.

KD are used because the company does not want to disclose the recipe. After mixing in a stirrer, the mixture was compressed by hot press.

We used a 50 ton hydraulic press equipped with hot platens to produce a rubber sheet. The temperature of 150°C was maintained for curing. The curing time was 15 min for crumb rubber compound. The last step of sample preparation was cutting by a cutter. After curing the rubber sample for 1 day, 3 dumbbell-shaped specimens were prepared for mechanical test.

Methods of Measurement

Measurement of the tensile properties was carried out using UTM (Instron series IX Automated Materials Testing System 7.25) equipped for tensile strength and elongation and tear strength in accordance with KSM (Korea Standard Method) 6518.

The instrument operated at 500 mm/min crosshead speed with 10KN load cell. The hardness test was carried out using a spring type (shore A) durometer. The reported value was the average value of four experimental results.

Electron micrographs were taken from the gold-coated sample using a scanning electron microscope operating at 5 kV for morphology study.

Table II The Recipe for Rubber Compound

Crumb rubber	100
LR	10 g
Sulfur	Varied
TMTD	Varied
DEG	30 mL
KD	10 mL

TMTD, tetramethyl thiuram disulfide; DEG, diethylene glycol.

Swelling Experiment

Take a 0.1–0.3 g sample from each of the cure level tensile piece and place in n-heptane for 48 h to swell. Quickly remove a swollen piece from n-heptane, blot off excess n-heptane, and weigh in a stoppered preweighed vial. Deswell the sample in a 60°C vacuum oven for about 3 h. Weigh the deswollen sample. We calculated the number of crosslinking chains per unit volume to find the crosslinking density by using weight differences from eq. (1):

$$\nu_e = -[\ln(1 - V_R) + V_R + \chi_1 V_R^2] \div [V_1(V_R^{1/3} - V_R/2)] \quad (1)$$

ν_e is the effective number of chains in a real network per unit volume (mole/m^3), V_1 the molecular volume of solvent (m^3/mole), V_{R} the volume fraction of rubber in swollen state, and χ_1 the parameter expressing the first neighbor interaction free energy.

Samples were aged in a oven for 24, 48, 72, and 96 h at 60°C to investigate the effect of aging.

RESULTS AND DISCUSSION

One of the obstacles in rubber recycling is the high production cost of the recycled rubber prod-

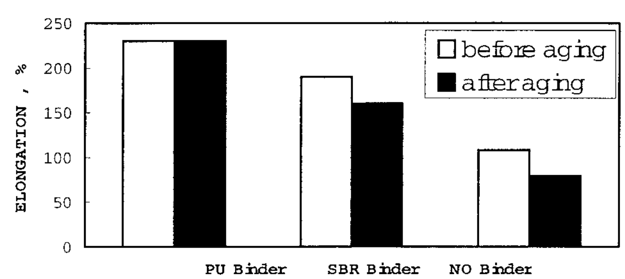

Figure 1 Elongation at break with various binder systems.

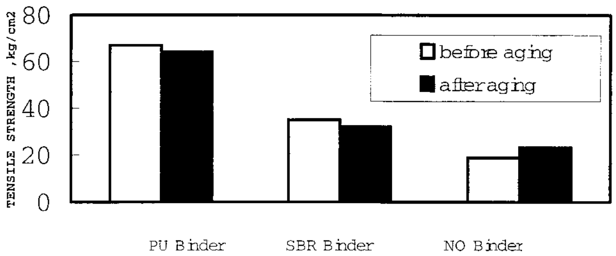

Figure 2 Tensile strength with various binder systems.

ucts. One of the popular commercial products in recycling of the waste tires is the rubber block. Normally the rubber block has been compounded with polyurethane binder, which induces a high cost.

Therefore, we tried to replace the polyurethane binder with a low cost material. First, our effort was given to the use of styrene–butadiene rubber (SBR) latex instead of the polyurethane binder. The second effort was the development of no binder system.

Figure 1 shows comparisons of the elongation at break of the samples before aging and after 24 h aging with different binder systems. More than 200% elongation is obtained in the polyurethane (PU) binder system but the elongation is lower in the SBR binder system. The value of elongation is down to 130% in no binder system. The elongation decreased by aging for both SBR binder and no binder systems. However, we could not find any aging effect in PU binder system.

Tensile strengths of the rubber vulcanizates are shown in Figure 2. The results show similar tendency to the elongation at break of the rubber compounds. From these experimental results, the mechanical properties (tensile strength and elongation of break) are impaired in the system without binder, but the cost of the recycled rubber block can be down to 50%.

The standard requirements of the properties of rubber block are shown in Table III.All three samples meet the requirements. Therefore, no binder system product may be a high valuable recycled product. Now our effort moves to how we can make a good quality product in no binder system. We considered the curing system of the rubber compounds.

Figure 3 shows the effect of sulfur content on the mechanical properties of the rubber vulcanizate. According to the figure, the optimum content of sulfur was 10 phr.

We tried to determine the optimum accelerator content in rubber samples containing 10 phr of sulfur. Figure 4 shows the effect of the accelerator (TMTD) content on the mechanical properties of no binder system with 10 phr of sulfur. The results show that mechanical properties of the vulcanizate increased with increasing the amount of TMTD until 2 phr and decreased afterward. Therefore, we found that 10 phr of sulfur and 2 phr of TMTD showed the best result in the view of the mechanical properties for the no binder system.

It was very strange results for us. With this condition, we also investigated the aging effect and the results are shown in Figure 5. The elongations at break decreased and hardness increased with increasing aging time as we expected. However, the tensile strength increased with time. Therefore, we tried to find the answer for these phenomena by checking the crosslinking density.

Figure 6 shows the changes of the crosslink density with the aging time. The results showed that crosslink density of the aged samples increases with increasing aging time. The ten-

Table III Requirement of Properties for Rubber Block

Mechanical Properties		Quality: High Grade	Quality: Low Grade
Tensile properties	Tensile strength (kgf/cm^2)	50 over	25 over
	Elongation at break (%)	150 over	120 over
Hardness (shore A)		55 over	55 over

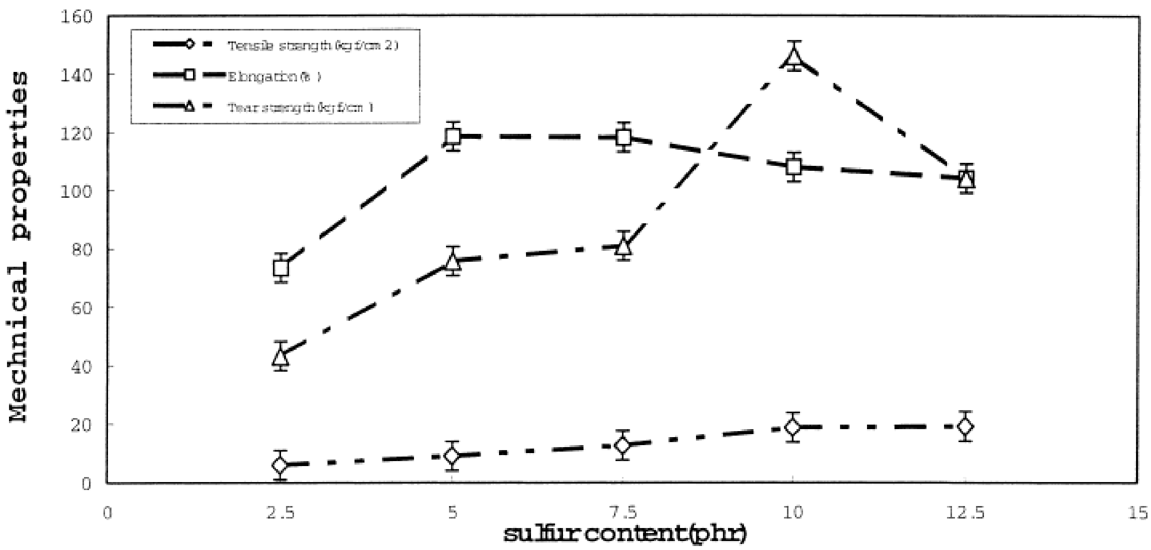

Figure 3 Effect of sulfur content on properties.

dency was very similar to that of tensile strength.

Figure 7 shows the scanning electron microscopy photographs with different sulfur contents in rubber compound. The results reveal that the optimum content of sulfur is 10 phr.

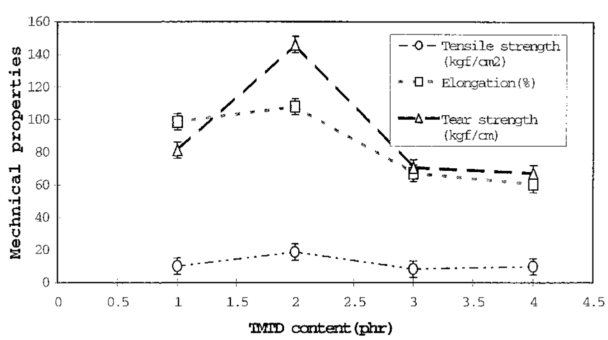

Figure 4 Effect of TMTD content on properties.

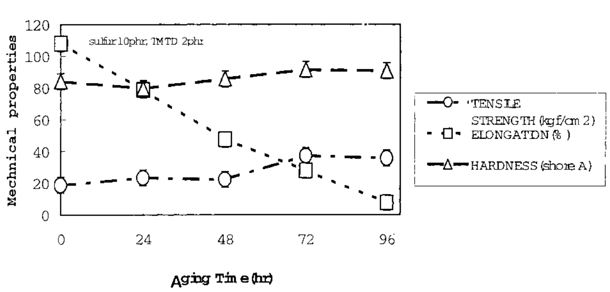

Figure 5 Effect of the aging time on properties.

CONCLUSIONS

From the experiments, the following conclusions can be drawn. The crumb rubber without binder whose recipe is shown in Table I may be prospective a high valuable recycled product in economic view. However, it is not applied to producing the product required high mechanical properties. We determined the following optimum curing system of the products without binder: temperature: 150°C; time: 15 min; sulfur content: 10 phr; accelerator content (TMTD): 2 phr. We also tried to explain mechanical performance of this product with morphological study.

In this study, we developed a recycling technique to produce a high-valuable recycled product. We believe this technique contributes to developing the recycling industry.

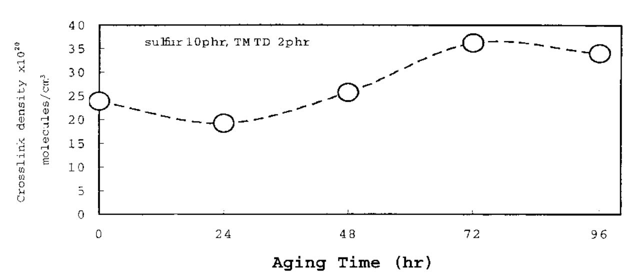

Figure 6 Effect of aging time on crosslink density.

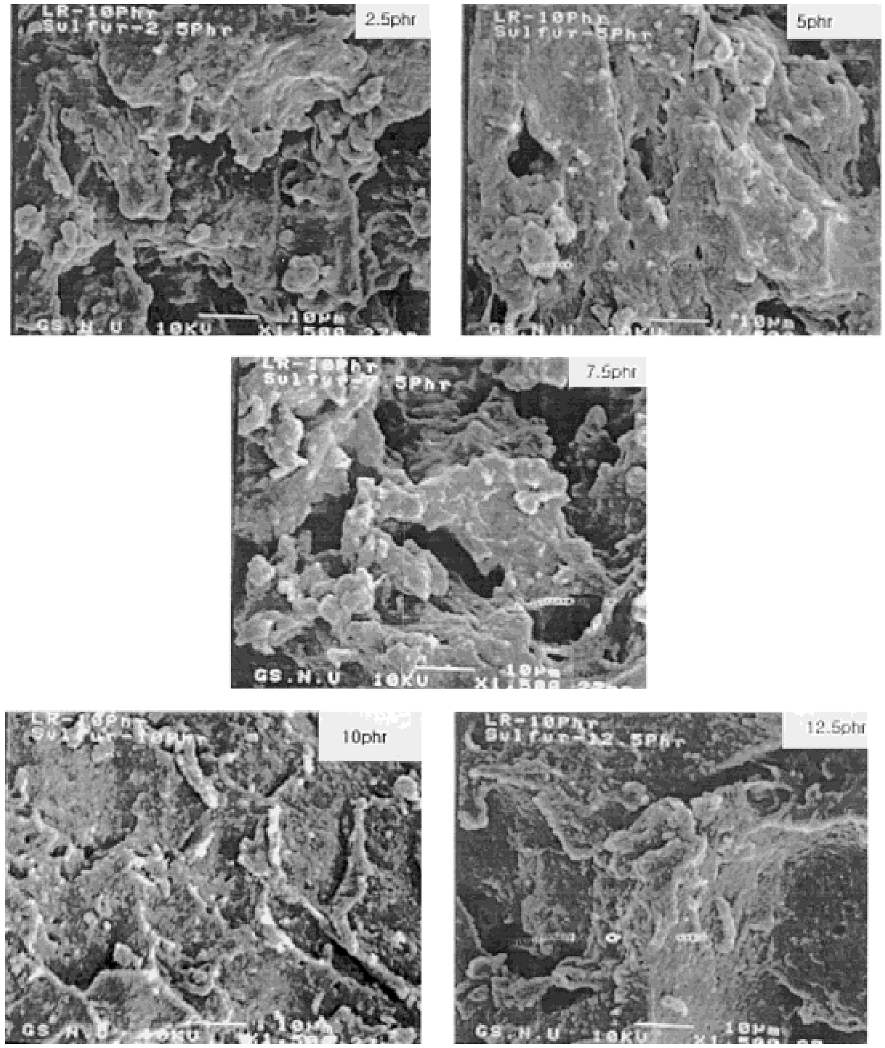

Figure 7 Microphotographs with different sulfur contents in no binder system.

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