NOTE

Cut and Chip Resistance of NR–BR Blend Compounds

CHANGWOON NAH,[1] BYUNG WOOK JO,[2] AND SHINYOUNG KAANG[3]

[1] R&D Center, Kumho Tire Co., Ltd., 555 Sochon-dong, Kwangsan-gu, Kwangju 506-040, Korea

[2] Department of Chemical Engineering, Chosun University, Kwangju, 501-759, Korea

[3] Department of Fine Chemicals and Process Engineering, Chonnam National University, Kwangju, 500-757, Korea

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INTRODUCTION

It was suggested that the B. F. Goodrich laboratory cut and chip tester can reasonably predict the cut and chip performance of off-the-road (OTR) and heavy-duty (HD) tires in service.[1] It was also suggested that the machine made possible the investigation of numerous factors in rubber compounding quickly and inexpensively using a small rubber specimen weighing only about 25 g, and some laboratory results of cut and chip experiments showed a good correlation with that of OTR treads in service.

In the tire industries, the polybutadiene (BR) has been widely used in a blend form with other rubbers, such as natural rubber (NR), styrene butadiene rubber (SBR), and ethylene propylene diene monomer (EPDM) for the sake of its high resilience and good abrasion resistance, especially at lower wear severity conditions.[2–4] Although the various mechanical properties of the blend rubbers, including BR, have been extensively studied,[5] relatively little attention has been given to the laboratory evaluation of cut and chip and its correlation with the field test.

In this study, the cut and chip resistance of NR–BR blend compounds was determined using the B. F. Goodrich cut and chip tester.[1] The field performance of cut and chip was also investigated using the test tires with two selected rubber compounds, and it was compared with the results of laboratory test. Some mechanical properties; strength, friction, and rebound were also investigated.

Correspondence to: C. Nah.

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EXPERIMENTAL

Preparation of Rubber Specimens. Rubber specimens for various physical testings, including the cut and chip test, were prepared by mixing the rubber compounds, except the curatives, in an internal mixer (Model 82BR, Farrel Co., USA) at about 120°C for 6 min. The cure agents were then added in a two-roll mill (Model M8422, Farrel Co., USA) at about 100°C for 7 min. The mixed rubber compounds were cured by the compression molding for 30 min at 145°C. The formulation of rubber compounds was shown in Table I.

Determination of Physical Properties. The hardness of rubber compound was determined by a hardness tester (Shore A). Tensile properties were measured based on the ASTM D412 procedure by a tensile tester (Instron 6021) using a dumbbell specimen at room temperature and at a crosshead speed of 500 mm/min. The rebound property of rubber was measured with a steel ball rebound tester (SR-1, MFG Co., USA) at room temperature according to the ASTM D2632 procedure. The de-

Table I Compound Recipes

Materials	Loading (phr)
Rubber (NR–BR)[a]	100
Carbon black[b]	48
ZnO	5
Stearic acid	3
Antioxidant[c]	2
Aromatic oil	6
Accelerator[d]	0.7
Sulfur	1.7
Cure time at 145°C (min)	30

[a] The blend ratio of NR–BR was varied from 100/0 to 0/100 with an increment of 10 phr. The type of NR and BR was SMR CV60 (Malaysian) and high *cis*-polybutadiene (Korea Kumho Petroleum Co.,), respectively.
[b] The type of carbon black was N220 and N375.
[c] *N*-(1,3-dimethyl butyl), *N'*-phenyl-*p*-phenylenediamine (6PPD).
[d] *N*-*t*-butyl-2-benzothiazol sulfenamide.

termination of the coefficient of friction between the rubber and a silicon carbide paper (60 Cw, Dae Sung Abrasive Co., Korea) was made over the temperature range from −10 to 60°C using a specially designed friction tester,[6] in which the thin rubber sheet was adhered to the three cylinders of triangular friction sled, and the sled is then pulled at a speed of 50 mm/min by means of the pulley and string system, connected to a load cell to measure the frictional force.

Determination of Laboratory Cut and Chip Resistance. The determination of cut and chip resistance was made using the B. F. Goodrich tester,[1] for which the schematic diagram is shown in Figures 1 and 2. The frequency of the stroke of the cut and chip indentor was 1 Hz, and the rotation speed of the rubber wheel was set to be 750 ± 10 rpm. The corresponding speed at the surface of rubber wheel is about 1.25×10^5 mm/min. The diameter loss D_l was measured for 20 min, and the loss was divided by the number of strokes n to represent the average rate of cut and chip per stroke R_{cc}. This value was adopted as the measure of cut and chip characteristics. The radial impact force F_i was constant for each stroke. Thus, the frictional force F_f will be different for each rubber compound, depending on its frictional characteristics (Fig. 2). The surface temperature of the sample was found to rise rapidly during the cut and chip experiment; that is, it rose from room temperature to about 50°C just 2 min after the starting of the experiment. The final temperatures of black-filled natural rubber (FNR) and black-filled polybutadiene (FBR) were 55 to 65°C, respectively.

Evaluation of Field Cut and Chip Performance. Two tread compounds based on the NR = 100 and NR–BR = 80/20 rubbers were selected for the field tire test. The test tires of 11R22.5 in size for heavy-duty truck were then built using the selected compounds. The test tires were run on a rural road (about 20% paved), and the worn surfaces were investigated for an appropriate time interval.

RESULTS AND DISCUSSION

Laboratory Cut and Chip Resistance. Figure 3 shows the rates of cut and chip R_{cc} of the NR–BR blends. As the

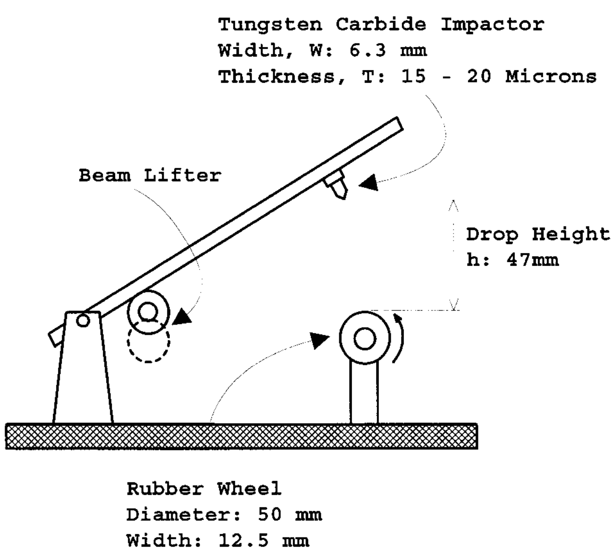

Figure 1 A sketch of the B. F. Goodrich cutting and chipping tester.[1]

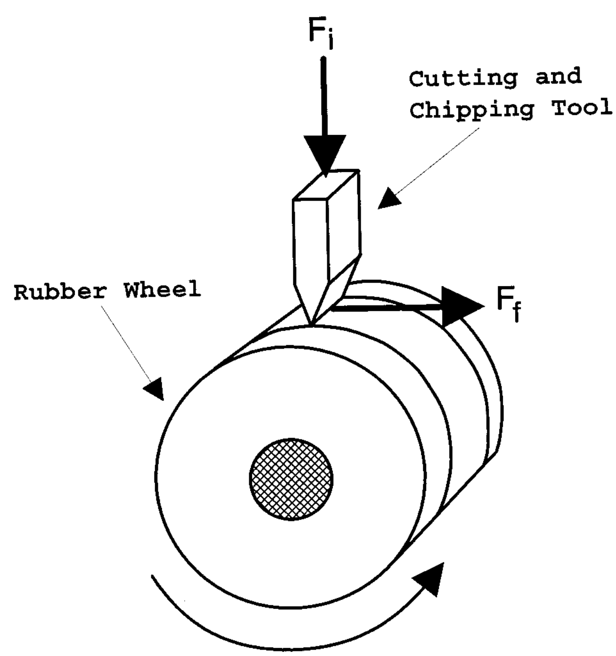

Figure 2 A close-up sketch showing the cutting and chipping part and acting forces of the B. F. Goodrich cutting and chipping tester.

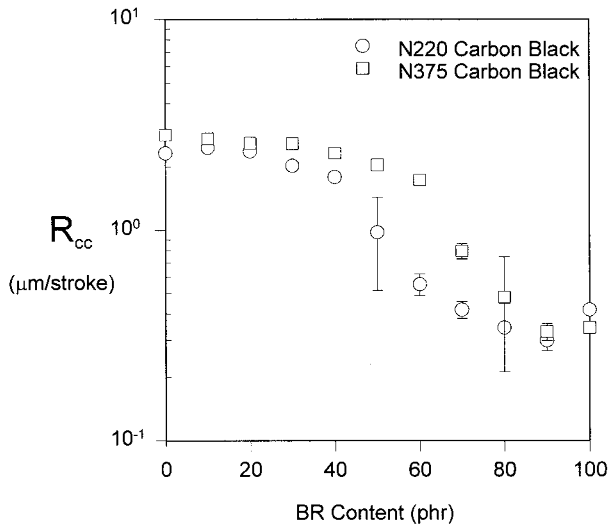

Figure 3 The rates of cutting and chipping R_{cc} of NR–BR blend compounds as a function of blend ratio.

BR content was increased, the rate decreased slightly in the range of BR content up to about 30 phr, and it dramatically decreased between 30 to 80 phr and then it leveled off. This result suggests that the cut and chip resistance of BR is considerably higher than that of NR. A similar trend was also reported for SBR–BR blend compounds by Beatty and Miksch.[1] They found that the addition of BR to SBR improves laboratory cut and chip resistance remarkably. The observed result was explained by the fact that the BR has a superior resistance against abrasion to that of SBR.[2–4] But it should be noted that the severity of the test conditions of the cut and chip test is not the same as those of abrasion tests. Generally, it is severer for the cut and chip test.

Tensile, Frictional, and Rebound Properties. In an attempt to explain the observed results on the cut and chip resistance, some physical properties were also measured for the NR–BR blends. Figure 4 shows the tensile properties together with hardness. As the BR content was increased, hardness, stress at 300% elongation, and stress at break decreased considerably. For example, the ultimate tensile strength σ_b of BR compound was only two-thirds of that of the NR one, and an even lower (one half) value was found for stress at 300% elongation, σ_{300}. On the other hand, only a slight decrease was found for the hardness with the increased BR content. It is also known that the tear resistance of BR is inferior to that of NR,[7–10] as shown in Table II. Based on these results, it may be concluded that BR is weaker than NR, at least in the ultimate mechanical strength point of view. Thus, the superior resistance of BR to laboratory cut and chip is very interesting to note.

One plausible reason for the superior resistance of BR is the frictional characteristics of rubber against the cut and chip indentor. To examine such a possibility, a set of frictional measurements was made for both FNR and FBR in the temperature range from −10 to 60°C at a constant sliding speed of 50 mm/min. The observed

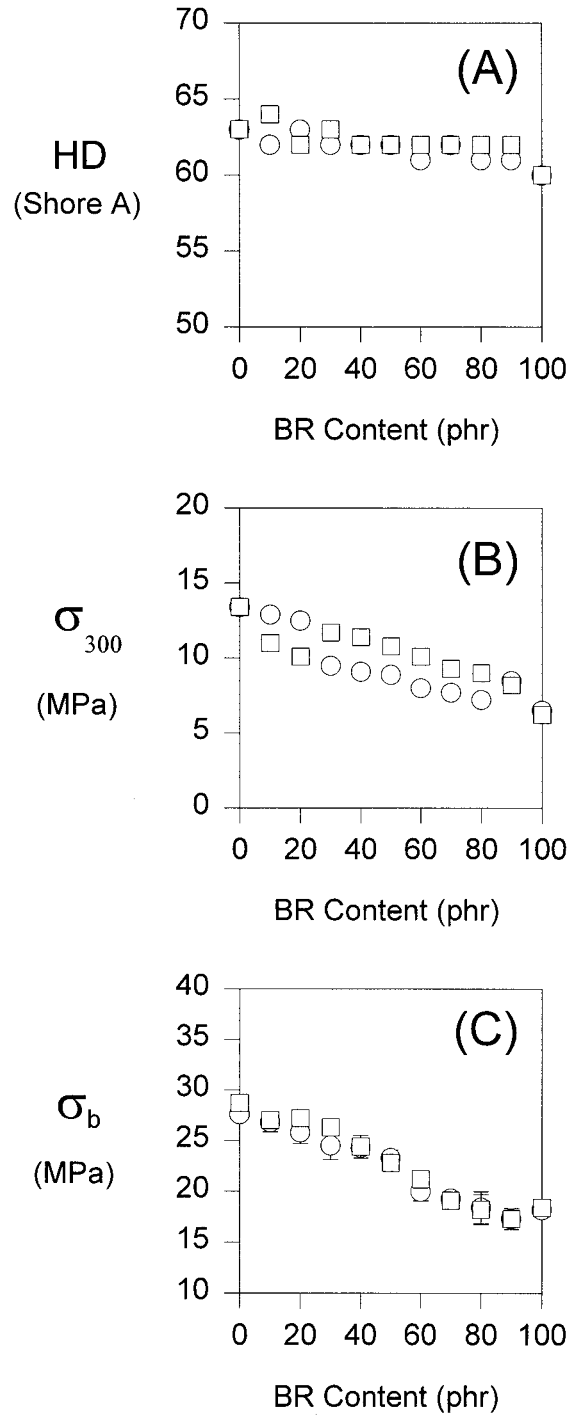

Figure 4 (A) Hardness (HD), (B) stress at 300% elongation (σ_{300}), and (C) for stress at break (σ_b), as a function of blend ratio for NR–BR blend compounds. The symbols ○ and □ represent the compounds with N220 and N375 carbon blacks, respectively.

Table II Comparison of Tearing Energy G_c for Carbon Black-Filled Natural Rubber (FNR) and Polybutadiene (FBR)

Materials	G_c (kJ/m^2)
FNR	20–100[a]
FBR	5–80[b]

[a] Values between room temperature and 70°C obtained from the literature,[7–9] based on the Trouser method.
[b] Values between room temperature and 70°C obtained from Henry[10] based on the Trouser method.

results are given in Figure 5. The frictional coefficient of FNR was about two times higher than that of FBR. This strongly suggests that much higher frictional works (severer frictional conditions) are subjected on the surface of FNR compared to FBR since the applied normal impact pressures are same for both cases. Moreover, the given frictional energy might be more effectively applied on the surface of FNR specimen due to an edge effect of its coarser worn surfaces.[4] Generally, it was known that a power law relation exists between the abrasive loss of rubber and the applied frictional energy.[2,3,11–15] Thus, a higher possibility of frictional abrasive failure might be expected for FNR.

Another possible cause for the superior cut and chip resistance of BR is the subsequent free vibrations or rebounds, followed by the first impact of the cut and chip indentor. They are mainly dependent of the resilience of rubber. Figure 6 shows a rebound property of NR–BR blends. The rebound increased considerably with increasing BR content. Thus, the rebounded height of the cut and chip indentor followed by each impact will be higher for the rubbers having higher resilience, with FBR, in this case, leading to the lower number of cycles of impact (shorter contact times per each stroke). This might lead a lower cut and chip loss.

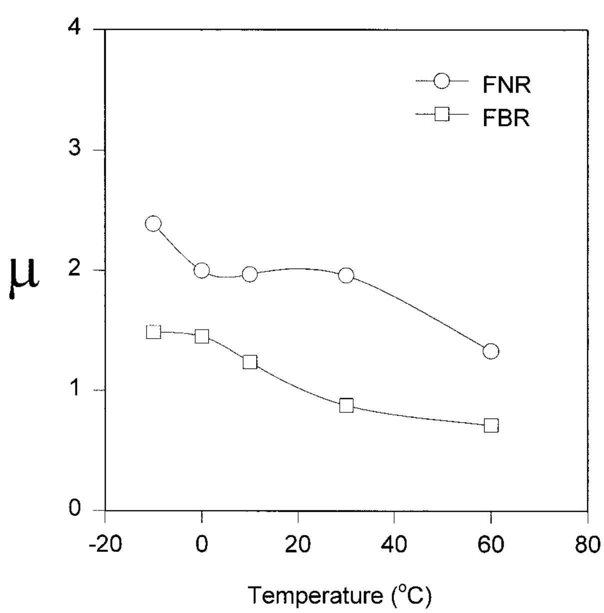

Figure 5 The coefficient of friction μ between rubber and silicon carbide paper as a function of test temperature for FNR and FBR.

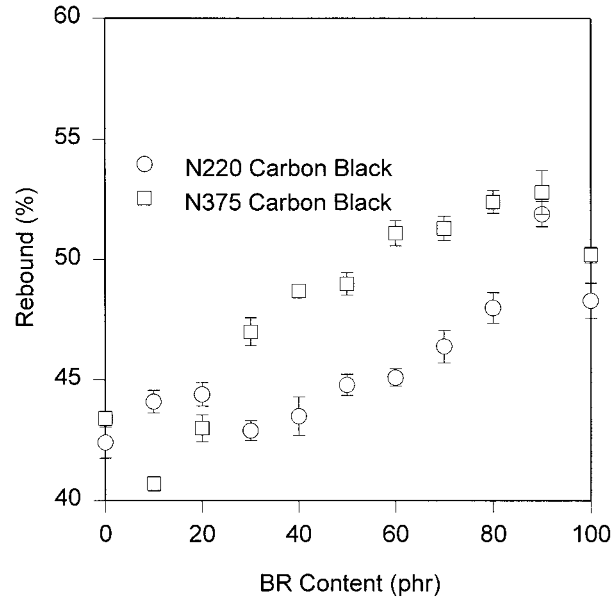

Figure 6 Rebound property at room temperature of the NR–BR blend as a function of the blend ratio.

Comparison with Field Performance. In order to verify the superiority of BR compound, a field evaluation was performed using a heavy-duty truck tire of 11R22.5 in size in which two selected tread compounds based on the NR and NR–BR = 80/20 rubbers were applied. A typical worn surface of the test tires are given in Figure 7. The surface of NR–BR tread was covered with the numerous cutting and chipping marks, whereas that of NR tread wore in a typical wear fashion, indicating the better resistance to cut and chip of the NR compound rather than that of the NR–BR one. This trend is completely opposite to that from the laboratory cut and chip tester. Thus, a further study is necessary to explain the observed paradoxical result.

SUMMARY

Laboratory cut and chip resistance of NR–BR blend compounds was investigated. The resistance to cut and chip of BR was considerably higher than that of NR. Hardness, stress at 300% elongation, and stress at break decreased considerably with an increasing BR content. The frictional coefficient of FNR was about two times higher than that of FBR, indicating that much higher frictional energies were subjected to the FNR specimen. The rebound increased considerably with increasing BR content. An opposite trend of cut and chip

(left) (right)

Figure 7 Typical worn tread surfaces of test tires: (left) NR tread and (right) NR–BR (80/20) tread.

resistance was found for NR–BR blend compounds between the laboratory measurements and the real-world performance.

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