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Study on the Influence Law of Rubber Blending on the Wear Resistance of Tread Rubber

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Abstract: The wear resistance of tire tread rubber is an important indicator for evaluating tire performance. In response to the need for improving the wear resistance of tire tread rubber, this study investigated the influence of blending ratios of natural rubber (NR), styrene-butadiene rubber (SBR1502E), and polybutadiene rubber (BR9000) on the properties of tread rubber. Experimental results showed that in terms of vulcanization characteristics, elongation at break, and hardness, BR had the longest vulcanization time, NR had the highest elongation at break, and BR had the greatest hardness. After blending the rubbers, their properties fell between the two types of rubber and varied with the content. In terms of tensile strength, NR performed the best, while BR was weaker. However, when NR/BR and NR/SBR were blended in a ratio of 80/20, the tensile strength was significantly improved. In terms of wear resistance, BR performed the best, while SBR was weaker. However, when SBR/NR was blended, especially at ratios of 40/60 and 60/40, the wear resistance was significantly improved, with less wear than single rubber. This study not only revealed the influence pattern of different rubber blending ratios on the wear resistance of tread rubber, but also provided new ideas for the tire industry to improve wear resistance, reduce pollution, and extend service life.

1. Introduction

Tread rubber is the only part of a car that comes into direct contact with the ground. The abrasion debris produced by the friction between the tire and the ground will accompany the entire service life of the tire and is inevitable [1-3]. Abrasion debris poses potential hazards to the formation of haze in the atmosphere, soil pollution, and the survival of freshwater organisms, and is also a potential cause of lung inflammation in humans [4]. According to incomplete statistics, about 1.5 billion tires are scrapped worldwide every year, and the discarded tires are known as "black pollution," which not only represents a loss of people's property but also poses a threat to the environment [5]. Therefore, improving the wear resistance of tires to increase their service life and reduce pollution is of great significance to the green development of the tire industry.

Traditionally, the wear resistance of tread rubber is improved by adjusting its formula. For example, in terms of rubber, natural rubber (NR), styrene-butadiene rubber (SBR), and butadiene rubber (BR) are the most commonly used types of rubber for preparing tread rubber. During the preparation of tread rubber, the method of combining two or more types of rubber is often adopted, with the aim of synergistically enhancing the wet skid resistance, wear resistance, and rolling resistance [6-8]. However, researchers have not studied the influence of the mixing ratio of commonly used rubber types such as Natural rubber (NR), Butadiene rubber (BR), and Styrene-butadiene rubber (SBR) on the wear resistance of tread rubber.

2. Experimental

2.1 Materials

Natural rubber (NR), model SMR20, from Malaysia; Butadiene rubber (BR), model BR9000, from Beijing Yanshan Petrochemical Company, Ltd. of China Petroleum and Chemical Corporation; Styrene-butadiene rubber (SBR), model SBR1502E, from Jilin Petrochemical Company of China National Petroleum Corporation; Carbon black, model N110, from Tianjin Yihuilong Chemical Technology Co., Ltd.; The curing system comprised of N-tert-Butyl-2-benzothiazolesulfenamide (TBBS), Tetramethylthiuram disulfide (TMTD), and sulfur. N-cyclohexyl-N'-phenyl-p-phenylenediamine (4010NA) and n-cyclohexylsulfenylphthalimide (CTP) were purchased on the market.

2.2 Performance Testing of Tread Rubber

2.2.1 Vulcanization Properties of Tread Rubber

After adding sulfur to the mixing mill, leave it for 12 to 24 hours to allow the sulfur to disperse evenly. Then, follow the GB-9869-1988 standard. Measurements are taken using a rotor-free vulcanizing meter produced by Dongguan Zhenggong Precision Testing Instruments and Machinery Factory. The temperature of both the upper and lower mold cavities is set at 150 ℃. Measure each group three times and take the average value to obtain relevant parameters related to the vulcanization time. In this document, the vulcanization time without special instructions refers to the positive vulcanization time tc90.

2.2.2 Physical and Mechanical Properties Testing of Tread Rubber Tensile Strength

1).Tensile strength

The maximum tensile stress applied to the sample until it breaks is the tensile strength, which indicates the resistance of the vulcanized rubber to damage. In other words, the vulcanized rubber with greater tensile strength is less prone to damage. The test is performed on a high and low temperature rubber electronic tensile tester according to the GB/T528-2009 standard. The total length A of the dumbbell-shaped sample is 75 mm, the length C of the elongated part is 25 mm, the width D of the elongated part is 4 mm, and the thickness is measured using a vernier caliper with an accuracy of 0.02 mm, ensuring three significant digits. The sample is shown in Figure 1, and the testing equipment, the high and low temperature rubber electronic tensile tester, is shown in Figure 2. Measure at the thinnest part of the sample, measure three times, and take the average value. The testing speed is 500 mm/min, and the testing temperature is 20±2℃. The formula for calculating tensile strength is 1. Where: F is the maximum force borne by the sample when it breaks, in N (Newton); b is the width of the sample, and d is the thickness of the sample, in mm (millimeter); T is the tensile strength, in MPa (megapascals).

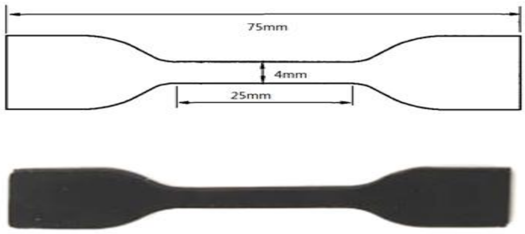


Figure 1: Schematic Diagram and Actual Image of the Specimen for Tensile Strength Testing

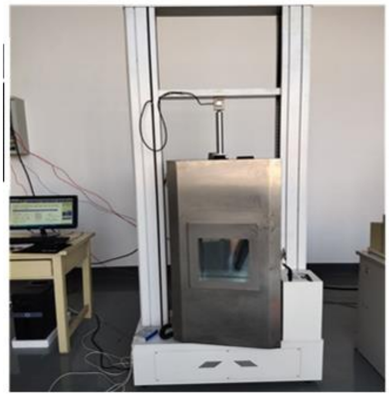


Figure 2: High and Low Temperature Rubber Electronic Tensile Testing Machine

$$T = \frac{F}{b \bullet d} \tag{1}$$

2).Elongation at Break

The elongation at break refers to the ratio of the elongation of the rubber material when it is torn to its original length. It indicates the maximum deformation range allowed when the vulcanized rubber is damaged. Vulcanized rubber with a higher elongation at break is less likely to be damaged by external forces than those with a lower elongation. The samples used are the same as those for tensile strength testing. The test is performed on an electronic universal tensile testing machine according to the GB/T528-2009 standard. The calculation of elongation at break is as shown in formula 2.

$$S = \frac{L_2 - L_1}{L_1} \times 100\% \tag{2}$$

3).Measurement of Vulcanized Rubber Hardness

Hardness refers to the degree of deformation of a material's surface under a certain amount of pressure, indicating its ability to resist deformation caused by external forces. There are various types of hardness measurements, such as Shore hardness and Shore scleroscope hardness, but Shore hardness is commonly used as a typical measure for rubber hardness. The Shore hardness tester for measuring vulcanized rubber is operated according to the national standard GB/T531-1999. Each sample is tested at three different locations, and the average value is taken as the final hardness value.

2.2.3 Testing of Tread Rubber Wear Resistance

According to the GB/T9867-2008 standard, the abrasion test is performed using a DIN abrasion tester. The samples are molded using a mold, and Figure 3 shows a physical representation of the mold and the DIN abrasion tester. The samples are cylindrical, with a diameter of 16mm±0.2 mm and a height ranging from 6 to 15 mm. The measurement travel distance is 40 meters. A weight of 750 grams is applied to the fixed end of the test piece. At least 3 samples are selected for the test, and each test sample is tested at least 3 times, with the final average value taken. The abrasion volume is calculated using formula 3, where ΔV_{rel} represents the abrasion volume of the test tread rubber in mm^3; $\Delta \mathrm{m}_{\mathrm{t}}$ represents the abrasion mass loss of the test tread rubber in mg; $\Delta \mathrm{m}_{\mathrm{cost}}$ is the fixed mass loss value of the reference rubber (200 mg); and $\Delta \mathrm{m}_{\tau}$ represents the actual mass loss value of the reference rubber in mg.

$$\Delta V_{\mathrm{rel}} = \frac{\Delta \mathrm{m}_{\mathrm{t}} \times \Delta \mathrm{m}_{\mathrm{const}}}{\rho \times \Delta \mathrm{m}_{\tau}} \tag{3}$$

Figure 3: DIN Abrasion Tester Sample Preparation Mold and Actual Product Image

2.2.4 Scanning Electron Microscopy (SEM)

Currently, scanning electron microscopy (SEM) is widely used in observing the morphology of material cross-sectional tissue, serving as an essential technical means in materials science research. In this study, a Hitachi scanning electron microscope (SU3500) was employed to observe the worn surface morphology of tread rubber. Since rubber samples are not conductive, they were first subjected to vacuum gold spraying for 30 seconds before observation.

2.3 Design and Preparation of Tread Rubber

To better reflect the properties of rubber, carbon black was chosen as the primary filler in this formulation, with a dosage of 30 parts to prevent excessive filler from overshadowing the performance of the rubber itself. NR, SBR, and BR rubber were combined in pairs, with the blending ratio varied while the amount of other fillers remained unchanged. Table 1 presents the formulation of the sample using natural rubber (NR) and polybutadiene rubber (BR9000), Table 2 shows the formulation of the sample using natural rubber (NR) and styrene-butadiene rubber (SBR1502E), and Table 3 details the formulation of the sample combining polybutadiene rubber (BR9000) and styrene-butadiene rubber (SBR1502E). All components are calculated by weight.

According to the formula, the raw rubber (NR, BR, SBR) was first added to a 1 L small rubber-plastic laboratory mixer with a rotor speed of 60 r/min and a temperature of 140 °C. After mixing under pressure for 180 s, carbon black was added, and the temperature was raised to 150 °C with the rotor speed maintained at 60 r/min for an additional 180 s of mixing. Finally, all other ingredients except sulfur were added, with the temperature maintained at 150 °C and the rotor speed at 60 r/min for 240 s of mixing before discharging the rubber. After a resting period of 8 to 12 hours, the rubber was placed on an open mill at 80 °C to add sulfur, cut into sheets, rested for another 8 to 12 hours, and then placed into the corresponding mold. Under a pressure of 10 MPa and a temperature of 150 °C for 30 minutes, the samples as shown in Figure 4 were prepared.

Table 1: NR/BR Blended Sample Formulation

Material Name	Sample				
	NR/BR-100/0	NR/BR-80/20	NR/BR-60/40	NR/BR-40/60	NR/BR-20/80
NR	100/0	80	60	40	20
BR9000		20	40	60	80
carbon black(N110)	30	30	30	30	30
ZnO	3	3	3	3	3
Stearic acid	2	2	2	2	2
S	1.8	1.8	1.8	1.8	1.8
TBBS	1.5	1.5	1.5	1.5	1.5
TMTD	0.3	0.3	0.3	0.3	0.3
ctp	0.1	0.1	0.1	0.1	0.1
4010NA	1	1	1	1	1

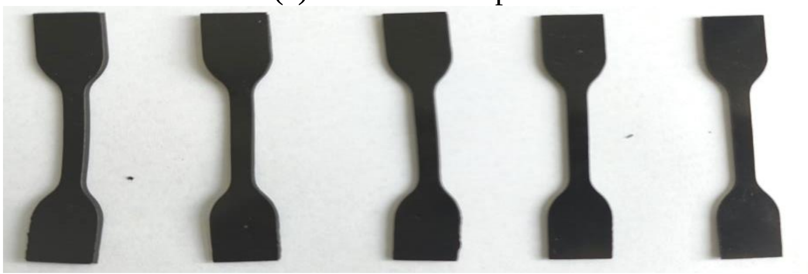
Table 2: SBR/NR Blended Sample Formulation

Material Name	Sample				
	SBR/NR-100/0	SBR/NR-80/20	SBR/NR-60/40	SBR/NR-40/60	SBR/NR-20/80
SBR1502E	100	80	60	40	20
NR		20	40	60	80
carbon black(N110)	30	30	30	30	30
ZnO	3	3	3	3	3
Stearic acid	2	2	2	2	2
S	1.8	1.8	1.8	1.8	1.8
TBBS	1.5	1.5	1.5	1.5	1.5
TMTD	0.3	0.3	0.3	0.3	0.3
ctp	0.1	0.1	0.1	0.1	0.1
4010NA	1	1	1	1	1

Table 3: BR/SBR Blended Sample Formulation

Material Name	Sample				
	BR/SBR-100/0	BR/SBR-80/20	BR/SBR-60/40	BR/SBR-40/60	BR/SBR-20/80
BR9000	100	80	60	40	20
SBR1502E		20	40	60	80
carbon black(N110)	30	30	30	30	30
ZnO	3	3	3	3	3
Stearic acid	2	2	2	2	2
S	1.8	1.8	1.8	1.8	1.8
TBBS	1.5	1.5	1.5	1.5	1.5
TMTD	0.3	0.3	0.3	0.3	0.3
ctp	0.1	0.1	0.1	0.1	0.1
4010NA	1	1	1	1	1

(a)DIN wear samples



(b) Tensile strength

Figure 4: Physical samples

3. Results and Discussion

3.1 Analysis of Vulcanization Properties of Tread Rubber

As seen in Figure 5, on the NR/BR blending curve, with the increase of BR, the vulcanization time becomes longer, indicating that the vulcanization time of BR is longer than that of NR. On the SBR/NR blending curve, as NR increases, the vulcanization time decreases, showing that the vulcanization time of SBR is longer than that of NR. On the BR/SBR blending curve, as SBR increases, the vulcanization time decreases, demonstrating that the vulcanization time of SBR is shorter than that of BR. The vulcanization time of single rubbers can also be observed from the coordinates with blending ratios of 100/0, ultimately confirming that the vulcanization time of single rubbers from longest to shortest is: BR, SBR, NR. This is primarily because BR9000 belongs to unsaturated rubber containing double bonds, which has slightly lower chemical activity compared to natural rubber and styrene-butadiene rubber, resulting in a slower vulcanization reaction rate. Therefore, in blended rubber compounds with high requirements for vulcanization time precision, various rubbers should be processed separately, and the vulcanization time of each rubber can be adjusted through accelerators to ensure optimal performance during vulcanization.

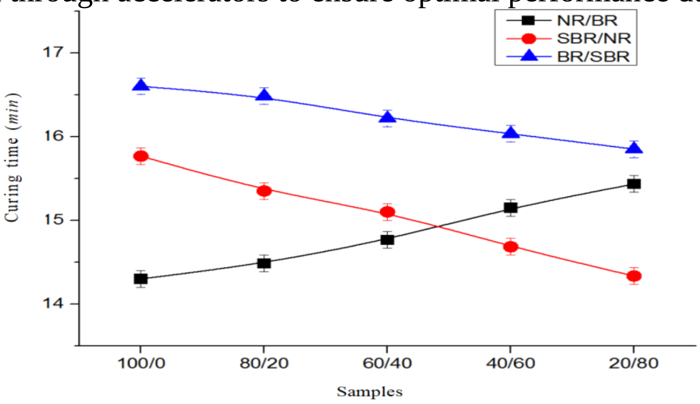


Figure 5: Curve Showing the Variation of Vulcanization Time of Tread Rubber with the Blending Ratio of Rubbers

3.2 Analysis of Physical and Mechanical Properties

3.2.1 Tensile Properties of Tread Rubber

Tables 4, 5, and 6 present the physical and mechanical properties of the blended rubber compounds with a carbon black loading of 30 phr (parts per hundred rubber). It can be observed that the tensile strength of single rubbers decreases in the order of NR, SBR, and BR. In NR/BR blends, as the amount of BR increases, the tensile strength of the tread rubber first increases and then decreases. It reaches a peak of 30.96 MPa at a blending ratio of 80/20, which is higher than the tensile strength of NR and BR used alone. This indicates that the tensile properties of the two rubbers are synergistically enhanced at this blending ratio, resulting in a significant increase in tensile strength. In SBR/NR blends, as the amount of NR increases, the tensile properties of the tread rubber gradually improve, reaching a maximum tensile strength of 30.17 MPa at a blending ratio of 80/20, which is also higher than the tensile strength of NR and SBR used alone. This suggests that blending BR or SBR with NR significantly enhances the tensile strength. However, when BR and SBR are blended together, their tensile strength is reduced compared to BR alone, even at the optimal blending ratio of 20/80. The tensile strength is weaker than that of single SBR and only slightly stronger than BR. This analysis suggests that NR exhibits good blending performance, enhancing the tensile strength when blended with BR or SBR, but blending BR and SBR does not result in tensile strength enhancement.

3.2.2 Elongation at Break of Tread Rubber

The elongation at break exhibits a similar trend to tensile strength. The elongation at break of single rubbers NR, SBR, and BR decreases gradually, with values of 576%, 383%, and 233%, respectively. When NR is blended with BR or SBR, the elongation at break increases, especially at a blending ratio of 80/20, where the improvement is most significant. However, blending synthetic rubbers SBR and BR does not result in an increase in elongation at break.

3.2.3 Shore Hardness of Tread Rubber

The Shore hardness of single rubbers decreases in the order of BR, SBR, and NR. The hardness values of blended rubbers fall between the hardness values of the two single rubbers. For example, the hardness of NR/BR blends falls between 54.5 and 60. There is no significant increase or decrease in the hardness of the blended rubber.

Table 4: Physical and Mechanical Properties of NR/BR Blended Rubber

Performance Names	NR/BR				
	100/0	80/20	60/40	40/60	20/80
Tensile Strength (MPa)	26.12	30.96	25.79	21.99	11.87
Elongation at Break (%)	576	576	553	483	356
Shore Hardness(A)	54.5	56	57.5	59	60

Table 5: Physical and Mechanical Properties of SBR/NR Blended Rubber

Performance Names	SBR/NR				
	100/0	80/20	60/40	40/60	20/80
Tensile Strength (MPa)	11.58	19.77	23.75	27.21	30.17
Elongation at Break (%)	383	544	543	549	556
Shore Hardness(A)	59.5	59	57.5	56.5	55

Table 6: Physical and Mechanical Properties of BR/SBR Blended Rubber

Performance Names	BR/SBR				
	100/0	80/20	60/40	40/60	20/80
Tensile Strength (MPa)	7.85	6.81	7.34	8.5	10.92
Elongation at Break (%)	233	138	189	211	358
Shore Hardness(A)	61.5	60.5	59	58	57

3.3 Analysis of Wear Resistance of Tread Rubber

As shown in Figure 6, at the blending ratio of 100/0, the abrasion loss of single rubbers can be obtained at this point. The abrasion loss from high to low is SBR, NR, BR. Therefore, it can be concluded that the wear resistance of pure rubber, i.e., single-type tread rubber, is in the order of BR, NR, and SBR from strongest to weakest. In NR/BR blended rubber, as the amount of BR increases, the abrasion loss of the tread rubber decreases, and the wear resistance improves. In SBR/NR blended rubber, with the increase of NR content, the abrasion loss of the tread rubber first decreases and then increases. When the blending ratio is 40/60 and 60/40, the abrasion loss is less than that of single NR tread rubber and SBR tread rubber. It is concluded that when the mixing ratio of SBR/NR is close to 1:1, the wear resistance is enhanced, resulting in lower abrasion loss.

From the wear images of tread rubber in Figures 7, 8, and 9, it can be observed that the wear surface of BR is relatively smooth, while the wear surfaces of NR and SBR are relatively rough, with deep wear patterns and obvious tearing marks. Some areas even show curling abrasion, leading to higher abrasion loss. The main reason is that the thermal stability between carbon black and the polybutadiene rubber matrix is good, resulting in excellent wear resistance. When worn, the wear patterns are shallower, and the particle size of the wear debris is also smaller. Another reason is that the hardness of BR after vulcanization is higher than NR and SBR, which makes the contact area between BR and the sandpaper surface smaller under the same pressure compared to NR and SBR, resulting in lower abrasion loss [9-10].

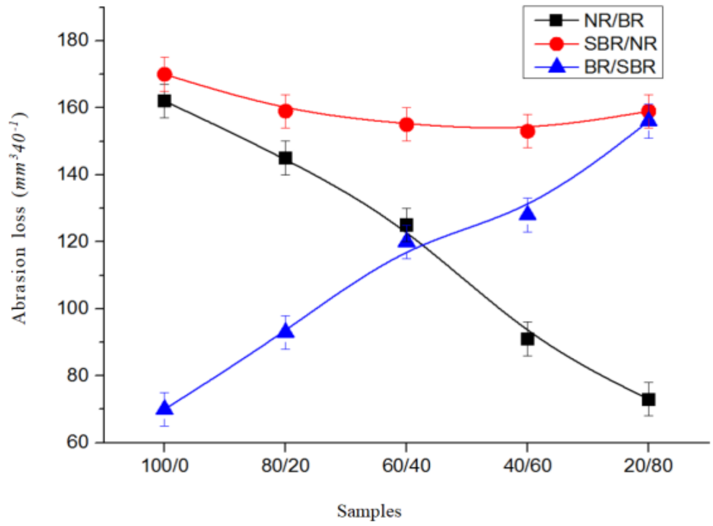


Figure 6: Abrasion Resistance Characteristic Diagram of Blended Rubber

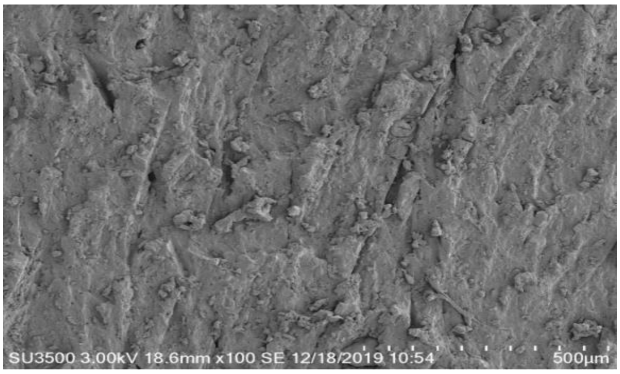


Figure 7: Surface Morphology of BR after Abrasion

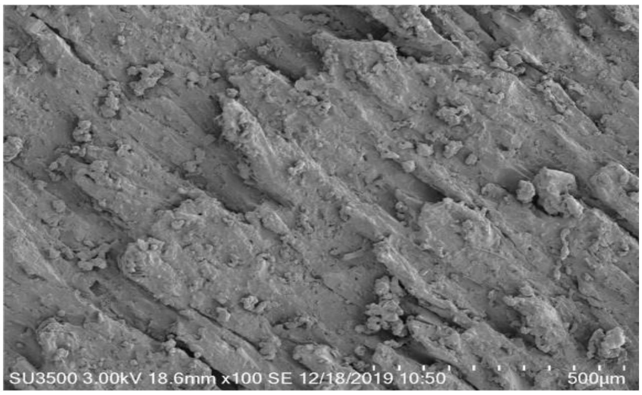


Figure 8: Surface Morphology of NR after Abrasion

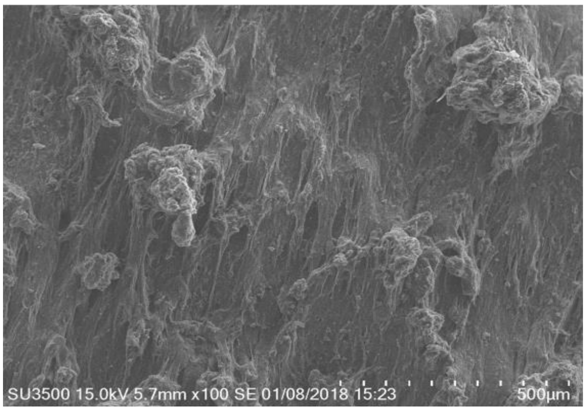


Figure 9: Surface Morphology of SBR after Abrasion

4. Conclusion

Based on the processing and performance characteristics of natural rubber (NR), styrene-butadiene rubber SBR1502E, and butadiene rubber BR9000, this article determined three blending schemes for these rubbers and obtained the following conclusions through experiments:

(1) In terms of vulcanization characteristics, elongation at break, and hardness, the performance of single rubbers is: vulcanization time from longest to shortest is BR, SBR, NR; elongation at break from longest to shortest is NR, SBR, BR; Shore hardness from highest to lowest is BR, SBR, NR. The blending of rubbers does not increase or decrease these properties, and the properties of the blended rubber are between the two types of rubber, varying with their respective content.

(2) In terms of tensile strength, the strength of single rubber types from strongest to weakest is

NR, SBR, BR. In the NR/BR and NR/SBR blended rubbers, when the blending ratio is 80/20, the tensile strength of the blended rubber is significantly improved.

(3) In terms of wear resistance, the strength of single rubber types from best to worst is BR, NR, SBR. The blending of SBR/NR rubber performs the most prominently, producing a synergistic enhancement effect. The wear loss of the blended rubber with blending ratios of 40/60 and 60/40 is less than that of single rubbers NR and SBR.

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