Application of a new rubber processing aid in semi-steel tire tread

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Abstract: This article primarily investigates the application of rubber processing aids produced by Rhine Chemicals (Qingdao) Co. LTD. in tire tread formulations. The results indicate that when 2.5 parts of processing aid PP are added to the tire tread formulation, the Mooney viscosity of the tread compound can be effectively reduced by 6 to 10 values without significantly affecting the physical properties of the tread compound. At the same time, during the extrusion production of tread half-components, the molding temperature of the components decreases by approximately 3 °C. For multi-stage mixing formulations, the use of rubber processing aids can reduce the number of mixing stages and enhance efficiency, effectively improving production efficiency and reducing production costs. The only minor drawback is a slight decrease in carbon black dispersion.

Key words: semi-steel; rubber processing aid; tread; Mooney viscosity

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Mooney viscosity is a key indicator for measuring the processing performance of rubber, directly reflecting the molecular weight and plasticity of rubber. Its value has a significant impact on the processing technology and the performance of the final product. When the Mooney viscosity is too high, it usually indicates that the molecular weight of rubber is relatively large and the molecular weight distribution is relatively wide, resulting in poor fluidity and high viscosity of the rubber compound. This makes it difficult to mix evenly, extrude, or calender during processing, prone to issues such as increased energy consumption and aggravated equipment wear, and may even cause processing difficulties or product defects. When the Mooney viscosity is too low, it indicates that the molecular weight is relatively small and the distribution is relatively narrow. Although the fluidity of the rubber compound is good and it is easy to process and shape, the crosslinking density after vulcanization may be insufficient, leading to low tensile strength, poor wear resistance, or decreased dimensional stability of the product, affecting the mechanical properties and service life of the product. Therefore, the reasonable control of Mooney viscosity values needs to be balanced according to specific processing techniques and product performance requirements, in order to optimize the formulation design and ensure process stability and product quality consistency. To achieve a reasonable Mooney viscosity, some rubber compounds require multi-stage mixing, which to some extent affects production efficiency, occupies tooling, and increases production costs.

The processing aid PP used in this article is a new type of processing aid produced by Rhine Chemicals (Qingdao) Co., Ltd. Its main component is a saturated fatty acid zinc salt, which acts as a lubricant between rubber molecular chains, enhancing the mobility of rubber macromolecular chains, ultimately improving the fluidity of the rubber compound and reducing Mooney viscosity. Rhine Plastic PP is used in tread rubber, which can increase the tread extrusion speed, improve the dimensional stability of the extruded semi-finished products, and significantly reduce the air voids in the extruded tread cross-section. This work mainly studies the application effect of Rhine processing aid PP in tire tread formulations.

1 Experiment

Biography: Zhang Jinyang (1988-), male, is an assistant engineer, mainly engaged in research on radial tire production processes and product quality management.

1.1 Main raw materials and auxiliaries

Natural Rubber (NR), MTR20, a Malaysian product; BR9000, a product of Qilu Petrochemical Company; Carbon Black N234, a product of Jiangxi Black Cat Carbon Black Co., Ltd.; White Carbon Black 1115MP, a product of Qingdao Yinlide Company; Processing Aid PP, a product of Qingdao Rhine Chemical Company; Environmentally Friendly Oil V700, a product of Hansheng Company; and others are commonly used raw materials in the tire industry.

1.2 Recipe

The experimental formula is presented in table 1.

Table 1 Small-scale Coordination Test Plan

Component	Normal	Experiment
NR+BR9000	100	100
N234+1115MP	62	62
V700	5	5
Processing aid PP	0	2.5
The remaining components are the same		

1.3 Main equipment and instruments

X(S)M-1.5 small mixer, XK-160 open mill, and XLB-400-400 four-column flat curing press, products of Qingdao Kegao Rubber and Plastic Machinery Technology and Equipment Co., Ltd.; MV3000 Mooney viscometer, product of Montech Company in Germany; Zwick Z3130 hardness tester and Zwick Z010 tensile testing machine, products of Zwick Company in Germany; Rubber Processing Analyzer RPA2000, product of ALPHA Company.

1.4 Sample preparation

The small compounding test rubber compound is mixed in two stages. The first stage is conducted in an X(S)M-1.5X type internal mixer, with the feeding sequence being: raw rubber → small materials such as carbon black and stearic acid → oil addition at 110 ℃ → two extrusions at intermediate temperatures of 115 ℃ and 130 ℃ → rubber discharge at 155 ℃, and the sheet is placed under the mixer for 4.5 hours. The second stage is conducted in an XK-160 type open mill, with the feeding sequence being: the first stage mixed rubber compound → sulfur, etc. → add rubber sheet.

Normal rubber compound mixing involves a first stage of masterbatch mixing using the tandem mixer GK320, followed by a pressure-free supplementary mixing in the lower mixer. The second stage employs the F370 for the return mixing process, and the final mixing is carried out in the F270 mixer. The entire process utilizes an open mill for supplementary mixing, cooling, and collection.

The test rubber compound is mixed using a tandem mixer GK320 for the first stage of masterbatch mixing, with processing aids such as PP and other minor ingredients added together. After the first stage of mixing, it is directly mixed in the F270 mixer. The entire process is supplemented with mixing, cooling, and collection using an open mill.

1.5 Performance testing

The performance tests of rubber compound and finished tires are conducted in accordance with corresponding national standards or enterprise standards. The extrusion temperature is randomly measured using a needle thermometer, and the tread size and thickness are measured offline.

2 Results and discussion

2.1 Processing aid PP

The indicators for Rhine processing aids are shown in table 2.

Table 2 Technical indicators of processing aid PP

Name	Unit	Numerical value	Indicator range
Ash content (900±25℃)	%	12.05	12~13
melting point	℃	102.1	98~106

2.2 Comparison of rubber compound properties

2.2.1 Small coordination test

The small compounding scheme is shown in table 1. Both the normal rubber compound and the test rubber compound adopt a process where a segment of masterbatch is mixed and then directly subjected to final mixing and vulcanization. The performance is shown in table 3.

Table 3 Comparison of vulcanization characteristics of small compounds

Project	Normal	Experiment
Mooney viscosity [M_L(1+4)100 ℃]	64	58
Mooney scorch time t_5 (127 ℃/min)	15	14
F_L(dN.m)	2.5	2.1
F_{max}(dN.m)	17.9	17.9
t_{10}/min	4.5	4.1
t_{50}/min	6.0	5.6
t_{90}/min	10.4	9.3

As shown in table 3, after adding the processing aid PP, compared to the normal rubber compound, the FL and Mooney viscosity of the test rubber compound were significantly reduced, while Fmax remained the same, and the vulcanization rate was slightly faster. The above results indicate that adding the processing aid to the rubber compound can significantly reduce its Mooney viscosity and improve processing performance while maintaining its original vulcanization characteristics.

Table 4 Physical properties of vulcanized rubber (vulcanization conditions: 150 ℃ ×40 min)

Project	Normal	Experiment
Shore A hardness/degree	64	64
100% modulus at fixed extension/MPa	2.71	2.72
300% modulus/MPa	12.67	11.38
Tensile strength / MPa	26.51	25.51
Elongation at break, %	507	499
Permanent deformation after breakage/ %	18	16
Tear strength/(kN·m^{-1})	54	56
Resilience /%	49	52
Compression fatigue temperature rise/ ℃	20.7	21.2
Compression set / %	3.5	3.7
Akron abrasion/ (cm^{-3}/1.61 km)	0.145	0.136
Carbon black dispersion grade	7	7
Density/(kg·dm^{-3})	1.108	1.108

As shown in table 4: The hardness of normal rubber compound and test rubber compound is the same. The test rubber compound has slightly lower modulus and tensile strength than the normal rubber compound, but its Akron abrasion resistance, tear resistance, and rebound elasticity are slightly better. Overall, the performance of the two is similar.

In summary, the addition of processing aids can effectively reduce the Mooney viscosity of the rubber compound while maintaining its original properties, thereby improving its processing performance.

2.3 Large material test

2.3.1 Comparison of Mooney viscosity during production process

Produce 20 batches of normal rubber compound and test rubber compound respectively, and measure the Mooney viscosity of each stage of masterbatch and final compound. The average values are compared as shown in table 5.

Table 5 Comparison of Mooney viscosity at various stages during the production process

Name	Mooney viscosity
A section of normal maternal glue	94.3
Normal second stage of mother rubber	73.5
Test base rubber	84.1
Normal final gel	60.0
Final gel test	62.5

As shown in table 5: After adding the processing aid PP, the Mooney viscosity of the test first-stage masterbatch is about 10 units lower than that of the normal first-stage masterbatch, and about 10 units higher than that of the normal second-stage masterbatch. In terms of the final rubber compound, the Mooney viscosity of the test final rubber is only 2.5 units higher than that of the normal final rubber.

2.3.2 Vulcanization characteristics of rubber compound

As shown in table 6, compared to the normal formula, the test formula has a Mooney viscosity 3.4 higher and a slightly shorter scorch time, but the vulcanization rate is similar.

Table 6 Comparison of vulcanization characteristics of rubber compounds (conditions: 150 ℃ ×40 min)

Project	Normal	Experiment
Mooney viscosity [M_L(1+4)100℃]	58.2	61.6
Mooney scorch time t_5 (127℃)/min	20.5	19.7
F_L(dN·m)	2.3	2.5
F_{max}(dN·m)	18.4	19
t_{10}/min	6.2	5.9
t_{50}/min	7.8	7.8
t_{90}/min	13	13.7

2.3.3 Physical properties

As shown in table 7, the hardness of the test rubber compound after segment reduction is consistent with that of the normal rubber compound, and its tensile strength and elongation are similar to those of the normal rubber compound. The elongation rate is slightly lower than that of the normal rubber compound due to the reduction of one segment of return mixing. The carbon black dispersion of the test rubber compound is one grade lower than that of the normal rubber compound, and its heat build-up is slightly higher, which may also be related to the deterioration of carbon black dispersion. The other properties are similar.

Table 7 Physical properties of vulcanized rubber (vulcanization conditions: 150 ℃ ×40 min)

project	normal	experiment
Shore A hardness/degree	65	65
100% modulus at fixed extension/MPa	2.68	2.75
300% modulus/MPa	13.42	13.72
Tensile strength / MPa	26.39	25.41
Elongation at break, %	500	477
Permanent deformation after breakage %	16	16
Tear strength / (kN·m^{-1})	52	54
Resilience /%	48	50
Compression fatigue temperature rise (in ℃)	20.8	22.2
Compression set/%	3.6	4.5
Akron abrasion/ (cm^3·1.61 km^{-3})	0.146	0.135
Carbon black dispersion grade	7	7
Density/(kg·dm^{-3})	1.107	1.107

The phenomenon where the dynamic modulus of filled rubber decreases sharply with increasing strain is known as the Panye effect. The better the filler dispersion, the less pronounced the Panye effect. To further investigate the impact of reducing the number of mixing stages on carbon black dispersion, a comparative test was conducted using RPA, and the results are shown in Figure 1.

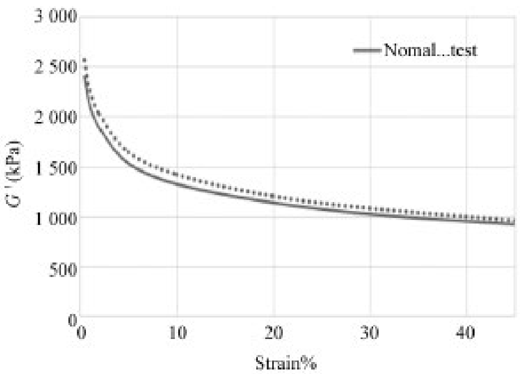

Figure 1 G'-strain curve of vulcanized rubber

Table 8 Comparison of RPA test results

Project	ΔG'	Max tanθ
Normal	1481.21	0.172
Experiment	1608.41	0.170

As shown in table 8 and Figure 1, the ΔG' of the normal rubber compound is 7.91% lower than that of the test rubber compound, indicating that the carbon black dispersion of the normal rubber compound is superior to that of the test rubber compound. The Max tanθ values of the two are similar, indicating that the reduction section does not affect the rolling resistance performance of the rubber compound.

2.4 Efficiency improvement

From table 9, it can be seen that the total time for producing one truck of final rubber compound with the normal formula is around 395 seconds. Without adjusting the process and only reducing the number of stages, the total mixing time of the test rubber compound is shortened to 287.5 seconds, which means the mixing efficiency can be improved by about 27.2%. Reducing one stage of return can also reduce the occupation of tooling during the intermediate process.

Table 9 Comparison of mixing time before and after segment reduction

Name	First–stage	Second–stage	final mixing	Original mixing time	Total time after segment reduction	Efficiency improvement
Production line	8#	6#	3#	=205×0.89+160×0.67 +105=395 s	=205×0.89+105=287.5 s	=1–287.5/395=27.2%
Weight	235	315	210			
Mixing time/s	205	160	105			
The usage ratio	0.89	0.67	1			
Name	First-stage	Second -stage	final mixing			

2.5 Extrusion process performance

Table 10 Comparison of tread extrusion data

Name	Normal	Test 1	Test 2
Mooney viscosity of rubber compounds	63	65	65
250 extruder speed ($r.min^{-1}$)	14.2	14.2	16.2
Linear velocity (m/min)	25.3	25.3	27.5
Extrusion temperature / ℃	120	117.4	119.5
Tread length	183.65	183.60	183.44
Tread center thickness	9.65	9.70	9.77
Shoulder thickness	11.58	11.55	11.63

Selecting the same specification tread for extrusion, the comparison is shown in table 10. Although the Mooney viscosity of the test rubber compound is 2 higher than that of the normal rubber compound, its extrusion temperature is still 2.6 ℃ lower under the same extruder speed. When the speed is increased by 2 revolutions, the extrusion temperature is similar to that of the normal rubber compound, and the tread dimensions are similar. This indicates that processing aids can not only effectively reduce the Mooney viscosity of the rubber compound without affecting the tread dimensions, but also effectively reduce the extrusion temperature, thereby allowing for an increase in speed and improving production efficiency.

2.6 Performance of finished tire

High-speed and durability tests were conducted on tires of 235/50 R17 specification produced with test rubber, and the results are presented in table 11.

3 Conclusion

(1) Adding processing aid PP to the tread formula can effectively reduce the Mooney viscosity of the rubber compound. Leveraging this characteristic, coupled with process adjustments, can enhance the efficiency of the rubber compound. For a 3-stage rubber compound, reducing the re-mixing of the first stage masterbatch after returning can increase efficiency by approximately 27.2%.

(2) The use of processing aids does not significantly affect the physical and dynamic properties of the rubber compound,

Table 11 Indoor performance test of finished tire

	Test item/specification	Test tire
High-speed performance	Accumulated driving time/min	1 h 25 min
	Accumulated driving mileage / (km·h^{-1})	330.5 km
	Speed at the end of the test (km/h)	270
	Check the condition of the tire after the test	270
	Test conclusion	The tire is not damaged
Durability performance	Accumulated driving time/h	through experimentation
	Accumulated driving mileage / (km·h^{-1})	44 h
	Test standard value/h	5 313.9 m
	Standard value of low air pressure test /h	34
	Check the condition of the tire after the test	10
	Test conclusion	The tire is not damaged

but the dispersion of carbon black after segment reduction is somewhat deteriorated.

(3) The use of processing aids can effectively reduce the tread extrusion temperature, thereby increasing the extrusion speed, enhancing production speed, and boosting output.