Testing the Application of Nano-Reinforcing Agent PF87 in Inner Liner Formulations

1. Formulation Table

Material Name	1	2	3	4	5	6
NR (Natural Rubber)	23.35	20	20	23.35	20	20
Chlorobutyl Rubber	56.8	60	60	56.8	60	60
SBR 1712 (E-Styrene Butadiene Rubber)	19.45	×	×	19.45	×	×
Butyl Reclaimed Rubber	×	20	20	×	20	20
Modified CSM (MCSM)	5	5	5	5	5	5
Light Calcium Carbonate	22	22	35	×	×	×
SL-1801 Resin	2.5	2.5	2.5	2.5	2.5	2.5
Homogenizing Agent FLM-191	6	6	6	6	6	6
Stearic Acid	1	1	1	1	1	1
Antioxidant TMQ	2	2	2	2	2	2
Carbon Black N660	60	60	54	60	54	45
Aromatic Oil	1.65	7	10	1.65	10	15
Nano-Reinforcing Agent PF87	×	×	×	22	35	50
Subtotal 1	199.75	205.5	215.5	199.75	215.5	226.5
Masterbatch R901-1						
Highly Dispersed Zinc Oxide	4.6	5	5	4.6	4.6	4.6
Accelerator CBS	1.5	1.5	1.5	1.5	1.5	1.5
Accelerator TBzTD	0.2	0.2	0.2	0.2	0.2	0.2
Soluble Sulfur	0.5	0.5	0.5	0.5	0.5	0.5
Curing Agent WF5	0.71	0.71	0.71	0.71	0.71	0.71
Subtotal 2	207.26	213.41	223.41	207.26	223.01	234.01

Experimental Content:

1. 160°C Rheometer, 127°C Scorch
2. Before & After Aging: Conventional properties, Elasticity, Tear strength, Compression heat generation, Density (Curing condition: 160°C×15min; Thermal aging condition: 100°C×48h)
3. Air-tightness Test (Curing condition: 160°C×15min)**
4. DMA (Curing condition: 160°C×15min)

2.Mooney , Rheological Properties, Scorch Test Results

Item	1	2	3	4	5	6
ML (1+4)100℃	-	-	-	-	-	-
ML (dN·m)	1.79	1.87	1.45	2.05	1.44	1.28
MH (dN·m)	10.34	9.94	7.78	10.56	8.41	7.77
TS1 (min)	2:24	2:03	2:20	2:36	2:21	2:17
TS2 (min)	2:52	2:33	2:55	3:11	2:56	2:54
T10 (min)	2:18	1:55	2:03	2:28	2:05	1:59
T50 (min)	3:40	3:28	3:37	4:05	3:54	3:47
T90 (min)	7:37	9:21	9:21	8:33	10:21	10:15
t5 (min)	11.5	10.9	12.7	11.9	11.5	12.6

Summary: Compared with calcium carbonate, PF87 shows slower curing rate but equivalent scorch performance.

3.Basic Physical Properties

Property	1	2	3	4	5	6
100% Modulus (MPa)	3	2.58	2.28	2.97	2.77	2.42
200% Modulus (MPa)	4.94	4.19	3.34	5.29	4.33	3.6
300% Modulus (MPa)	6.8	5.59	4.38	7.14	5.39	4.8
Tensile Strength (MPa)	8.97	6.97	6.54	10.41	6.82	6.68
Elongation at Break (%)	445	434	549	514	466	518
Hardness (Shore A)	-	-	-	-	-	-
Density (kg/cm³)	1.23	1.25	1.26	1.23	1.27	1.28
Tear Strength (kN/m)	32	30	24	34	27	25

Summary: Compared with calcium carbonate, PF87 demonstrates better strength and tear performance.

4.Basic Physical Properties After Aging

Property	1	2	3	4	5	6
100% Modulus (MPa)	4.4	4	3.4	4	4.2	3.9
200% Modulus (MPa)	6.5	6.2	4.9	6.7	6	5.4
300% Modulus (MPa)	/	/	5.7	8.1	/	6.4
Tensile Strength (MPa)	7.4	7	6	8.4	6.5	6.4
Elongation at Break (%)	237.5	271.6	339	331.8	256	317
Hardness (Shore A)	-	-	-	-	-	-
Density (kg/cm³)	1.23	1.25	1.26	1.23	1.27	1.28
Tear Strength (kN/m)	27	27	25	29	27	25

Summary: After aging, PF87 demonstrates better strength and tear performance compared to calcium carbonate.

5.DMA Dynamic Properties: -40°C to 62°C

Parameter	1	2	3	4	5	6
Tg (°C)	-26.4	-24.1	-25.2	-27.2	-26.9	-27.2
tan δ (Tg)	0.654	0.653	0.639	0.628	0.638	0.654
tan δ (0°C)	0.516	0.52	0.528	0.492	0.496	0.486
tan δ (20°C)	0.37	0.377	0.385	0.374	0.365	0.371
tan δ (60°C)	0.228	0.229	0.227	0.263	0.252	0.275
E' (MPa) @0°C	39.9	48	47	49.5	55.4	56.8
E' (MPa) @20°C	20.2	24.2	22.4	26.1	29.1	30.6
E' (MPa) @60°C	9.5	11.4	9.5	12.1	13.5	13.6

Summary: PF87 shows increased storage modulus (E') at 20°C.

6.Air Permeability Test

Parameter	1	2	3	4	5	6
Thickness (μm)	2275	2290	2265	2265	2332	2108
Gas Transmission Rate ($\times 10^{-13}$ cm³·cm/cm²·s·Pa)	2.208	1.779	1.67	2.16	1.61	1.619
Permeability Coefficient ($\times 10^{-16}$ cm³·cm/cm²·s·Pa)	4.615	4.073	3.781	4.902	3.775	3.413

Summary: PF87 demonstrates comparable air barrier performance to calcium carbonate. The air permeability improves with increasing PF87 content.

Summary:

1.Compared with calcium carbonate, PF87 exhibits higher strength, better tear resistance, and equivalent air barrier performance, making it suitable for replacing calcium carbonate in inner liner applications. Increasing the PF87 content improves air barrier properties.

2.When replacing calcium powder with nano-reinforcing agent PF87 (20.0-50.0 phr): Compared to Formula #1, the compound shows reduced ML and MH, extended scorch time, improved modulus and tensile strength, enhanced aging resistance, slightly decreased Tg, a moderate increase in Tan δ @60°C (indicating slightly reduced rolling resistance), and air permeability that initially decreases before increasing, with a net improvement range of (-6.2%~26.0%). Adopting Formula #6 can generate significant annual economic benefits.