Study on the storage period of calendered semi-finished product–carcass ply PA1

An Cheng, Ma Jian, Liang Wei, Shen Hongna, Li Haiyan

(Shandong Fengyuan Tire Manufacturing Co. LTD., Zaozhuang 277300, Shandong, China)

Abstract: Carcass ply PA1, a calendered semi-finished product manufactured by Shandong Fengyuan Tire Manufacturing Co.Ltd., is selected as the research object. Utilizing a novel domestic method for accurately detecting the viscosity of rubber compound, the viscosity of carcass ply PA1 is analyzed through a specialized rubber compound surface viscosity rapid detection instrument, the TMA1000 rubber compound surface viscosity analyzer. Furthermore, an optimization study is conducted on its storage period, and a reasonable storage period for carcass ply PA1 is established. Simultaneously, the testing principle of the TMA1000 rubber compound surface viscosity analyzer and the test reproducibility of the semi-finished product are analyzed. The research results provide significant guidance for process production and can effectively enhance tire quality and safety.

Key words: calendering; semi-finished products; carcass ply PA1; storage period

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0 Preface

With the rapid development of China's tire industry and the increasingly fierce international competition, the international market has raised higher requirements for the quality of Chinese tires. The control of viscosity is an important factor in improving tire quality. It is not only closely related to tire safety, but also has a significant impact on the production and molding process of rubber semi-finished components. Rubber compound viscosity refers to the shear force generated on the contact surface after relative motion occurs when in contact with an object, also known as the viscous force of the rubber compound. Excessively high or low viscosity has a significant impact on the production process of rubber products. Poor surface viscosity can not only lead to quality issues such as crown delamination, carcass delamination, shoulder blisters, and poor outer edge dimensions of tires, but also threaten the safety of customers' lives and property . In addition, during tire production, poor surface viscosity can seriously affect production, even leading to the scrapping of entire batches of materials. Currently, over 95% of the detection of rubber compound surface viscosity is determined by subjective judgment, which leads to the drawbacks of quantifying the surface viscosity of rubber compounds inaccurately and lacking a basis for subsequent product quality traceability, making it impossible to achieve precise and strict control over product quality. Furthermore, in industrial production, the storage period for semi-finished products of different specifications is generally determined based on the physical property aging cycle of the rubber compound. However, the viscosity of the rubber compound is greatly affected by temperature, humidity, and other factors with seasonal changes. For rubber compounds with rapid viscosity decline, it is prone to the disadvantage of increased waste rubber volume. Therefore, establishing a reasonable storage period based on the viscosity characteristics of different rubber types is crucial for industrial production efficiency and cost savings. This article uses the TMA1000 Rubber Compound Surface Viscosity Analyzer developed by TETRO

Biography: An Cheng (1996-),mainly engaged in experimental research on rubber tires.

(Qingdao) Tire Technology Co., Ltd., which features high detection accuracy, fast speed, and simple operation. It is the most advanced method for accurately and quickly detecting the viscosity of rubber compounds in China. The calendered semi-finished product - carcass cord PA1 produced by Shandong Fengyuan Tire Manufacturing Co., Ltd. is selected as the research object to optimize its storage period and establish a reasonable storage period for calendered semi-finished product - carcass cord PA1. At the same time, the testing principle of the TMA1000 Rubber Compound Surface Viscosity Analyzer and the test reproducibility of the semi-finished product are analyzed, which has important guiding significance for process production and can effectively improve the quality and safety of tires.

1 Experimental process

1.1 Test setup

1.1.1 Selection of samples

This article selects the calendered semi-finished product - carcass ply PA1 produced on the process line of the component workshop of Shandong Fengyuan Tire Manufacturing Co., Ltd. as the sample for research. The test sample is required to have a length and width of not less than 15 cm×25 cm, and the carcass ply PA1 sample should have a smooth surface, be free of wrinkles, and be able to cover the testing area.

1.1.2 Experimental conditions and storage time requirements

The test conditions for the test require an ambient temperature of 20~30 ℃ and humidity of ≤45%. The test sample carcass ply PA1 should be stored under stable ambient temperature and humidity conditions for 2 hours, 4 hours, 72 hours, 96 hours, 120 hours, 144 hours, 168 hours, 240 hours, and 336 hours, respectively.

1.1.3 Selection of experimental equipment

The testing equipment used for viscosity testing is the TMA1000 rubber compound surface viscosity analyzer developed by Treto (Qingdao) Tire Technology Co., Ltd. (as shown in Figure 1).

1.2 Experimental principle and steps

1.2.1 Experimental principle

The TMA1000 rubber compound surface viscosity analyzer, developed by Teto (Qingdao) Tire Technology Co., Ltd., is a novel testing device that has been refined and improved based on the fundamental principles of the rolling ball method. The testing principle involves the small ball experiencing viscous and other forces as it rolls on the surface of the rubber compound, causing its rolling speed to decrease until it stops (as shown in Figure 2).

Figure 1 TMA1000 rubber compound surface tackiness analyzer

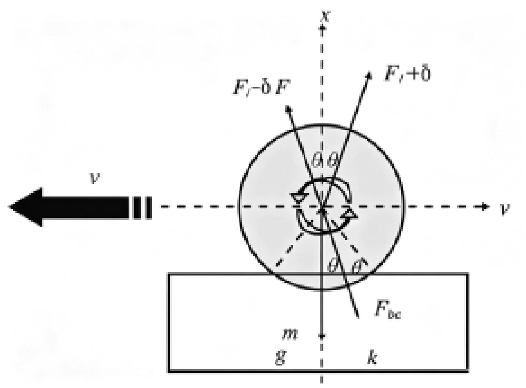

Figure 2 Schematic diagram of test principle and force

The small ball falls freely from a fixed height and, due to the force exerted on it on the rubber sheet, its speed decreases until it comes to a stop:

$$F=ma \tag{1}$$

Ftac=F/cosθ (related to the penetration degree θ and the hardness of the rubber compound) (2)

The TMA1000 rubber compound surface viscosity analyzer developed by Teto (Qingdao) Tire Technology Co., Ltd. is equipped with multiple sets of photoelectric detection sensors, which can accurately detect the motion state of small balls on the rubber compound. Through multiple sets of data feedback processing and statistical calculations, the surface viscosity Ftac of the rubber compound is obtained.

1.2.2 Experimental steps

(1)Divide the retrieved tire cord fabric PA1 samples into 9 equal parts, with 3 samples in each part as parallel samples. Place them in the test environment and let them stay for 2 hours, 4 hours, 72 hours, 96 hours, 120 hours, 144 hours, 168 hours, 240 hours, and 336 hours respectively.

(2)Utilize the TMA1000 rubber compound surface tackiness analyzer, developed by Tretel (Qingdao) Tire Technology Co., Ltd., to conduct tackiness tests at designated placement times. Upon completion of the test, the system automatically generates a test report and calculates the variation and relative variation of parallel determination values. The system can evaluate the results based on the control standards of the corresponding

(3)semi-finished products. The system has reserved interfaces, allowing the customer's MES system to read the test report from the fixed file storage area of the device. Refer to Figure 3 and Table 1.

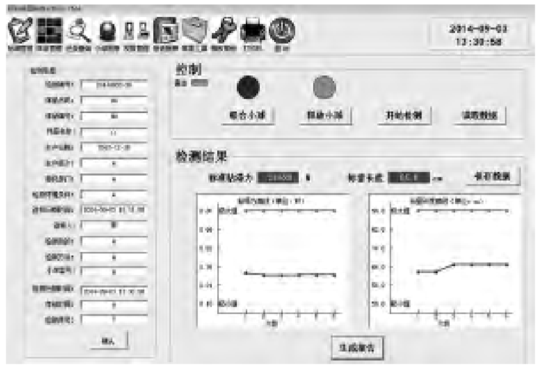

Figure 3 TMA1000 viscosity test

Table 1 TMA1000 viscosity test report
R&D Laboratory of Shandong Fengyuan Tire Manufacturing Co., Ltd
Physical property test report

Serial number	Testing Items	Rubber compound name	Scalar length (cm)	Viscous force (N)	Basis for detection
1		4.26C-NA1-1-1	148.5	0.173	
2		4.26C-NA1-1-2	188.3	0.139	
3		4.26C-NA1-2-1	152.6	0.169	
4		4.26C-NA1-2-2	160.8	0.160	
5		4.26C-PA1-1-1	92.6	0.275	
6		4.26C-PA1-1-2	78.4	0.321	
7		4.26C-PA1-2-1	78.2	0.318	
8		4.26C-PA1-2-2	75.1	0.333	
9	TMA surface viscosity test	4.26C-PA1-3-1	80.0	0.316	Customized by the enterprise
10		4.26C-PA1-3-2	74.3	0.339	
11		4.27C-PB1-1-1	62.1	0.400	
12		4.27C-PB1-1-2	62.7	0.379	
13		4.27C-PB1-2-1	69.0	0.362	
14		4.27C-PB1-2-2	80.0	0.318	
15		4.27C-PB1-3-1	86.7	0.292	
16		4.27C-PB1-3-2	81.0	0.314	
Remarks					

1.2.3 Stability of equipment

Repeatability tests were conducted on both sides of calendered semi-finished products - carcass ply PA1 and calendered semi-finished products - carcass ply PB1, which were left to stand for 2 hours. The test data is presented in Table 2.

Table 2 Data from repeatability tests

Test Station	Carcass ply - PA1 (positive)	Carcass ply - PA1 (reverse)	Carcass ply - PB1 (positive)	Carcass ply - PA1 (reverse)
	Viscous force/N			
1	0.437	0.329	0.400	0.309
2	0.434	0.333	0.397	0.310
3	0.434	0.336	0.394	0.302
4	0.429	0.330	0.399	0.306
5	0.432	0.334	0.401	0.305
6	0.437	0.331	0.403	0.304
Variance	0.000007833	0.000005833	0.000008333	0.000007667
average	0.434	0.332	0.399	0.306

From Table 1, it can be concluded that the variances of the test data for all six stations reach 10-6. Therefore, the stability of the test equipment meets the requirements for the test.

2 Results and analysis

This article selects the calendered semi-finished product - carcass ply PA1, and conducts periodic testing and research analysis on it after placing it in the test environment for 2 hours, 4 hours, 72 hours, 96 hours, 120 hours, 144 hours, 168 hours, 240 hours, and 336 hours, respectively. The experimental data is obtained and analyzed. The test data is shown in Table 2.

Table 3 Change in viscous force of PA1 with storage time

Time / h	Viscous force / N			Average
	PAI（1）	PAI（2）	PAI（3）	
0.50	0.413	0.409	0.411	0.411
1.00	0.525	0.521	0.519	0.522
1.50	0.485	0.479	0.480	0.481
2.00	0.439	0.431	0.433	0.434
4.00	0.426	0.427	0.429	0.427
72.00	0.419	0.421	0.419	0.420
96.00	0.397	0.395	0.399	0.397
120.00	0.395	0.389	0.390	0.391
144.00	0.391	0.389	0.378	0.386
166.00	0.31	0.313	0.325	0.316
240.00	0.305	0.311	0.299	0.305
336.00	0.288	0.300	0.286	0.291

Based on the test data presented in Table 3, a graphical analysis was conducted, as illustrated in Figures 4 and figure 5.

From Figure 4, it can be observed that the variation of the viscous force of PA1 with storage time from 0 to 4 hours is not easily discernible. To gain a clearer and more straightforward understanding of the changes in the viscous force of PA1 with storage time from 0 to 4 hours, the curve relationship between 0 and 4 hours in Figure 5 was enlarged and analyzed to produce Figure 5.

From Figure 5, we can clearly observe that the viscous force of the calendered semi-finished product - carcass ply PA1 is 0.411N at 0.5 h. As time increases, the viscous force reaches its maximum at 1 h, with a viscous force of 0.522N. However, it then begins to decrease, reaching 0.481N at 1.5 h. From 2 h onwards, the viscous force values become relatively stable, with a viscous force of 0.434 N at 2 h. Combining this with Figure 5, it is concluded that the viscous force of the calendered semi-finished product - carcass ply PA1 is 0.386N at 144 h, but then experiences a significant decrease, reaching 0.316 N at 166 h. Afterwards, the change in viscous force becomes relatively stable. Comprehensive observation and analysis of Figures 5 and 6 indicate that the viscous force of the calendered semi-finished product - carcass ply PA1 reaches its maximum value of 0.522 N after being stored for 1 h, and then begins to decrease. By 2 h, the decrease in viscous force enters a plateau period. However, after the PA1 is stored for 144 h, its viscous force enters a significant decrease, and thereafter, the change in viscous force becomes relatively stable. Therefore, for the calendered semi-finished product - carcass ply PA1 produced by Fengyuan Tire Manufacturing Co., Ltd., the

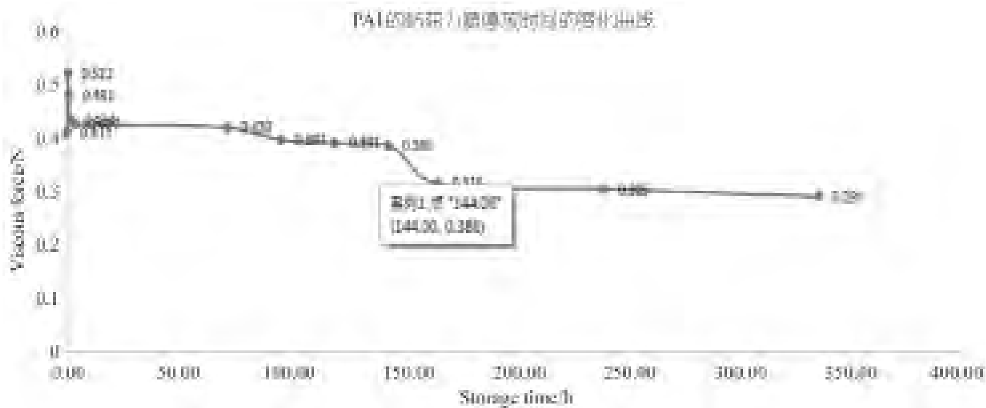

Figure 4 Curve of viscous force of PA1 varying with storage time

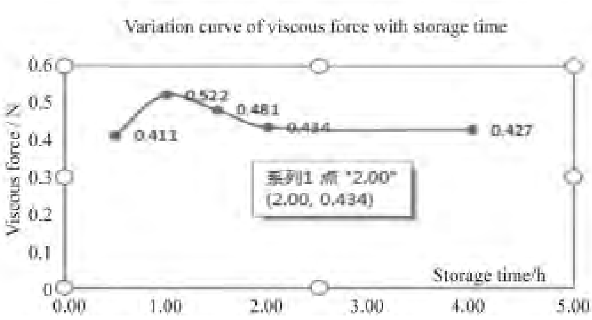

Figure 5 Change in viscous force of PA1 with storage time (0~4 h)

minimum storage time should be 2 h. After the calendered semi-finished product - carcass ply PA1 is stored for 144 h, the surface viscosity of the ply decreases significantly.

The test storage time for semi-finished rubber compound components of Shandong Fengyuan Tire Manufacturing Co., Ltd. is detailed in Table 4.

Table 4 Detailed table of test storage time for semi-finished rubber compound components

Name of semi-finished rubber compound component	Storage time of semi-finished rubber compound components		
	Minimum storage time	Maximum storage time/days	Maximum aging period/days
Tread	When XA/XB/XC/XD four tread rubber types are left to stand for 2 hours, and the remaining tread rubber types are left to stand for 4 hours	4	——
Extrusion of tire sidewall	Park the tire side for 2 hours	5	——
Cut belt cord fabric	Zero storage	5	8
Calendered carcass ply	PA1/PB1 for 2 hours, and other items to be left for 4 hours	7 days (168 hours)	10
Cutting carcass ply cord	Zero storage	4	6
Calendered crown belt cord	NX1 crown belt cord is to be stored for 2 hours, while other crown belt cords are to be stored for 4 hours	5	8
Cutting the crown layer	Zero storage	4	6
Calendered belt layer rubber sheet	4 h	5	20
Longitudinally cut rubber sheet belt	Zero storage	5	8
Rubber-covered steel wire ring	Zero storage	5	8

Compared to the requirements for the storage duration of semi-finished products from Shandong Fengyuan Tire Manufacturing Co., Ltd. as stated in Table 3, the minimum storage duration for calendered tire cord fabric PA1 is 2 hours, while the maximum is 168 hours (7 days). Based on the research conducted in this paper on the viscosity of calendered tire cord fabric PA1 as a function of storage duration, the optimized maximum storage period for calendered semi-finished product - tire cord fabric PA1 is 2 hours for the minimum storage duration and 144 hours (6 days) for the maximum storage duration. This is basically in line with the requirements. After further discussion, the maximum storage duration for tire cord fabric PA1 will be reduced by 1 day to ensure the stability of its quality.

3 Conclusion

This article employs the TMA1000 rubber compound surface viscosity analyzer developed by Treto (Qingdao) Tire Technology Co., Ltd. to investigate the relationship between the storage duration and viscosity change of the calendered semi-finished product - carcass ply PA1 produced by Shandong Fengyuan Tire Manufacturing Co., Ltd. Through batch comparison experiments, it is concluded that the stable storage period for the viscosity of the calendered semi-finished product - carcass ply PA1 is: a minimum storage time of 2 hours and a maximum storage time of 144 hours (6 days). This has certain guiding significance for the current production process of Shandong Fengyuan Tire Manufacturing Co., Ltd., and effectively improves the quality and safety of tires.