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Evaluation of Nylon 6 and Nylon 66 Cord Fabrics for Scooter Tyre Production under Different Curing Conditions

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Abstract

Cord fabric is a critical material used in the manufacture of tyres and various composite materials to increase durability and strength. The tyre consists of many layers of cord fabric, with each layer being referred to as a cord ply. These layers are strategically positioned within the tyre's internal structure, particularly in the tread and sidewall areas, to improve handling, durability and impact resistance. The cord fabric also serves a critical role in maintaining the structural integrity of the tyre, ensuring that it retains its contour and resists deformations under different operating conditions. This study discusses the advantages and disadvantages of using Nylon 6 (NY6) and Nylon 66 (NY66) cord fabrics in scooter tire production, with a focus on their mechanical behavior under varying curing temperatures and pressures. It was observed that while the curing time for both NY6 and NY66 remained consistent across different platen temperatures and pressures, their mechanical properties showed significant differences. NY6, known for its flexibility and impact resistance, exhibited greater changes in cord-breaking strength and elongation with increasing temperature, showing a marked decrease in breaking strength at higher temperatures. In contrast, NY66 maintained better stability and performance under similar conditions.

Keywords

Nylon 6, Nylon 66, Scooter Tyre, Cord Fabric, Mechanical Properties

1. Introduction

In tyre design, the type of cord is an important component that directly affects the durability, performance and driving comfort of the tyre. The cord is the part of the tyre that is inside the tyre's sewing threads, which contributes to the tyre's shape, durability and performance. The cord ensures the tyre's resistance to external influences and improves the tyre's resistance to punctures and abrasion. Different types of cord allow the tyre to withstand punctures, chafing and abrasion. Resistance to the elements. For example, steel cords are generally characterised by high durability and cut resistance [1]. Cord type, tyre handling and braking play an important role in the performance and cornering ability. Nylon and polyester cords generally offer better comfort, while steel cords are more likely to offer high speed and load carrying capacity [2].

The type of cord affects the weight and flexibility of the tyre. Lighter cords increase the overall weight of the tyre, which can improve fuel efficiency by reducing its weight. In addition, the flexibility of the cord structure affects the tyre's rolling resistance and fuel consumption [3]. Nylon cords contribute to a softer and more comfortable tyre that offers better driving and road-holding performance [4].

NY6 and NY66 are two common types of nylon used in tyre construction. NY6 has better flexibility at lower temperatures, but its performance at high temperatures and in aggressive chemical environments may not be as good as NY66 [5]. NY6 generally offers better flexibility and impact resistance. However, it has a lower temperature resistance than NY66. NY66 has higher temperature resistance and is more resistant to chemical attack, making it more durable in harsh conditions [6].

NY6 and NY66 offer different characteristics and advantages in tyre design. While NY66 provides greater strength, hardness, and chemical resistance, it is less flexible. Selecting the appropriate type of nylon based on design requirements can directly influence the performance and life of the tyre.

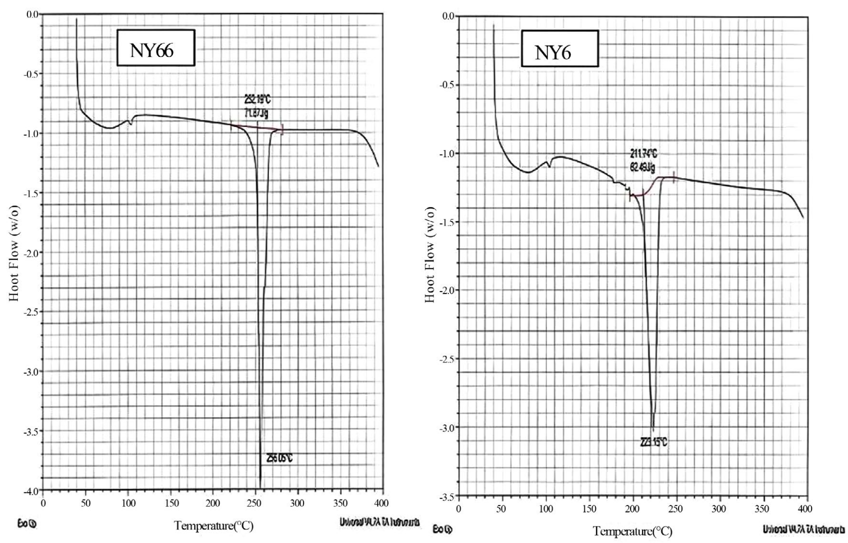

Figure 1. DSC graphs of NY6 and NY66.

Examining the Differential Scanning Calorimetry (DSC) graphs (**Figure 1**) of

NY6 and NY66 are examined, it can be seen that the melting process of Nylon 6 starts at approximately 210˚C and is completed at 223˚C, requiring 62.49 J/g of energy. On the other hand, the melting process of NY66 starts at approximately 250˚C and ends at 256˚C, and the energy required for melting is approximately 15.01% higher than that of NY6, at 71.87 J/g, due to differences in its crystalline structure [5] [6].

This research differs from previous work on NY6 and NY66 by focusing on their application under specific curing conditions relevant to scooter tyre production, an area that has not been extensively studied. While previous studies have examined the mechanical properties of these materials in a more general context, our work provides new insights into their behaviour under varying pressures and temperatures during the vulcanisation process.

In addition, we introduce a novel methodological approach by systematically comparing the performance of NY6 and NY66 under real curing conditions that closely mimic actual manufacturing environments. These findings not only expand the understanding of NY6 and NY66, but also provide practical applications for tyre manufacturers seeking to improve product quality and sustainability.

Given that scooter tires are smaller and lighter than those of other vehicles, they still need to provide excellent road holding, ride comfort and durability. The cord fabrics used in tyre production play a crucial role in determining overall performance and longevity. This study investigates the potential of using NY6 and NY66 cord fabrics in the specific context of scooter tyre manufacturing and addresses key factors that influence their effectiveness.

2. Materials and method

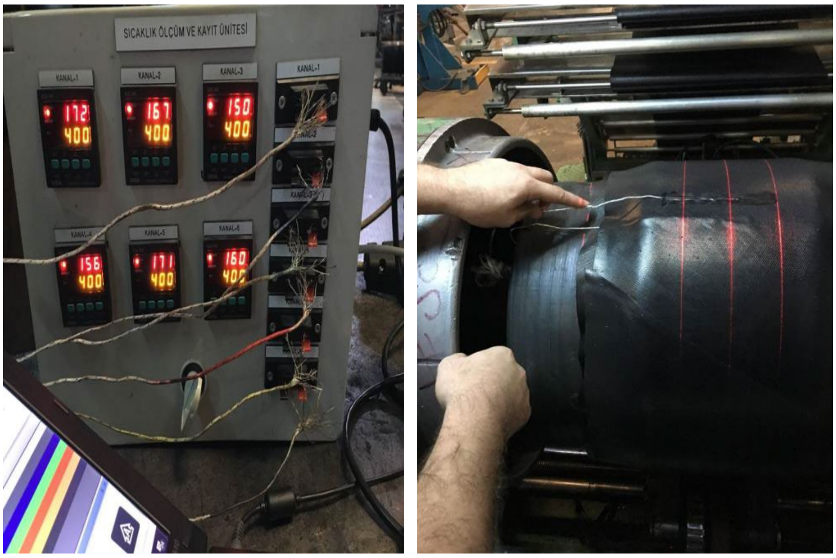

Figure 2. Thermocouple placement and temperature measurement process.

The nylon cord fabric used in the construction of scooter tyres is of great importance in terms of durability, flexibility, and the overall lifespan of the product.

In this study, cord fabrics with a 940 × 2 mesh density and 1050 industrial standard were used. Tests were carried out to measure the breaking strength of the textile cords in accordance with ASTM D885 on samples prepared by applying compounds of the same chemical composition to NY6 and NY66 cord fabrics, respectively.

Studying the behavior of NY6 and NY66 cords at high temperatures is crucial for optimizing tyre performance. This type of analysis is typically carried out using thermocouple sensors, allowing temperature changes within the material to be measured with high accuracy [7] (**Figure 2**).

The temperature distribution and changes over time in the areas containing NY6 and NY66 cords are monitored in detail using temperature sensors, allowing precise tracking of temperature changes within the internal structure of the material during curing. A peel test in accordance with TS 11190 was carried out to determine the adhesion strength between the tread components of the scooter tyre cured at both low (6.5 bar) and high (12 bar) pressure.

The values for curing time, internal pressure, temperature, and platen pressure applied to the NY6 and NY66 cord fabrics are presented in **Table 1**.

Table 1. Curing (vulcanization) conditions of the samples.

Parameters	NY6 940X2-1050		NY66 940X2-1050	
	Case 1	Case 2	Case 1	Case 2
Curing time (minutes)	13.25	11.25	13.25	11.25
Internal pressure/Temperature (bar/˚C)	12/192	12/192	12/192	12/192
Platen pressure/Temperature (bar/˚C)	6.5/168	12/192	6.5/168	12/192

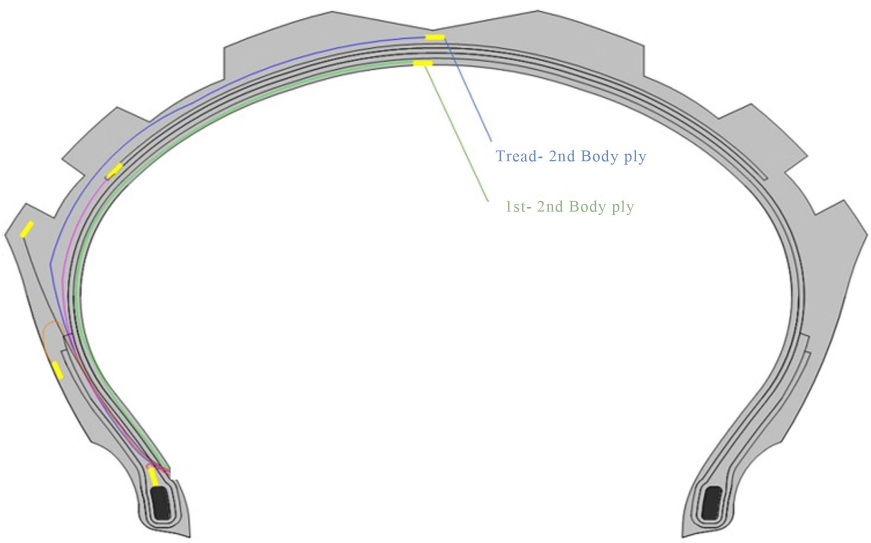

Figure 3. Thermocouple lead connections.

The green tyres produced were cured under two different conditions, as shown in **Table 1**. The curing time for both samples was 13.25 minutes in case 1 and

11.25 minutes in case 2. The internal pressure and temperature were kept constant at 12 bar and 192˚C in both scenarios. However, the platen pressure and temperature differed, with 6.5 bar/168˚C in case 1 and 12 bar/192˚C in case 2. These varying conditions were applied to investigate the effects of the vulcanization process on the mechanical and thermal performance of the cord fabrics used in the tyres.

Thermocouple tips were placed in the tyres, as shown in **Figure 3**, to determine the temperatures to which the components were exposed. The average and maximum temperatures of the components during curing were measured using the thermocouple tips and are shown in **Table 2**.

Table 2. Temperature values between the tyre layers.

Zone	Parameter	Case 1	Case 2
Tread-2nd body ply (center)	Average temperature (˚C)	145	153
	Maximum temperature (˚C)	175	190
1st body ply-2nd body ply (center)	Average temperature (˚C)	146	154
	Maximum temperature (˚C)	176	191

The data in **Table 2** indicate that the temperatures measured in the central areas of the tyre increased in both average and maximum values in Case 2. In the tread ply region, while the average temperature in Case 1 was 145˚C and the maximum temperature was 175˚C, these values rose to 153˚C and 190˚C, respectively, in Case 2. Similarly, in the 1st layer-2nd layer region, the average temperature in Case 1 was 146˚C, and the maximum temperature was 176˚C, increasing to 154˚C and 191˚C, respectively, in Case 2. These increases suggest that the higher platen pressure and temperature applied in Case 2 accelerated the vulcanization process and caused a rise in internal temperatures.

3. Results and Analysis

3.1. Tyre Peeling Test Results

Table 3. Peeling test results of cured samples.

Test	Zone	NY6 Case 1	NY6 Case 2	NY66 Case 1	NY66 Case 2
Peeling (N/mm)	Tread-2nd body ply	18.66	19.10	18.36	18.41
	1st body ply-2nd body ply	16.29	14.32	14.98	13.32

The tyre samples were subjected to a peeling test in accordance with the TS 11190 standard. This test method was used to assess the differences between the tyre components, specifically between the tread and the second ply, and between the first and second plies. Adhesive forces were measured in both the tread ply and ply ply areas. According to the standard, the adhesion force between the tread and the ply must be at least 7 N/mm, while the adhesion force between the plies must be at least 6 N/mm. The results obtained (as shown in Table 3) indicate that the peel test results for the specimens tested exceed these reference values.

According to the data in Table 3, the peeling test results of the cured tyres show a small increase in the tread-ply adhesion forces at high temperatures for the NY6 and NY66 samples. However, when examining the ply ply adhesion forces, a 12% - 13% decrease was observed under high temperature conditions. Nevertheless, all results indicate that the tyres comply with the TS 11190 standard. Furthermore, since peel tests can show variations of ±15% between two tyres produced under the same curing conditions, the 13% decrease observed in the high temperature samples is considered to be within acceptable limits.

3.2. Analysis of Cords Removed from the Tyre

Breaking strength, elongation, EASL (Elongation at Specified Load) and LASE (Load at Specified Elongation) values were compared for the cords removed from the tyre plies and the raw cords according to ASTM D885.

3.2.1. Breaking Strength Test

Breaking testing is a method used to evaluate the mechanical strength of materials by determining the maximum stress a material can withstand before breaking under an applied breaking force. This test is particularly important for elastomeric and composite materials as it helps to predict their load carrying capacity and service life [8].

Table 4. The breaking strength test results.

Test	Zone	NY6 Case 1	NY6 Case 2	NY66 Case 1	NY66 Case2
Breaking strength (kg)	1st body ply cord	14.32	11.74	14.17	14.14
	2nd body ply cord	14.10	12.00	14.46	14.13
	1st and 2nd body ply average	14.21	11.87	14.32	14.14
	Raw cord (Aver.)	14.00	14.00	14.60	14.60
	Rate of change compared to raw cord (%)	101.5	84.8	98.0	96.8
	Rate of change compared to case 1 (%)		16.5% decrease		1.3% decrease

Table 4 shows the breaking load results and rate of change for cords taken from cured tyres. When comparing the test results of cords and raw cord ropes from tyres cured at low and high plate temperatures, the breaking load values of NY6 and NY66 remained almost unchanged at low temperatures. However, at high temperatures, a reduction of 16.5% for NY6 and 2% for NY66 was observed. This indicates that high temperatures have a negative effect on the breaking load of NY6, whereas the breaking load of NY66 is not affected by the temperatures studied.

3.2.2. Elongation at Break Test

The elongation at break test is an important mechanical method used to assess the deformation of a material to the point of failure. This test measures how much the material can elongate under breaking load, providing an indication of its flexibility and ductility [9].

Table 5. The elongation at break results.

Test	Zone	NY6 Case 1	NY6 Case 2	NY66 Case 1	NY66 Case 2
Elongation at break (%)	1st body ply cord	24.41	23.58	21.57	21.57
	2nd body ply cord	24.39	23.32	20.95	20.89
	1st and 2nd body ply average	24.40	23.45	21.26	21.23
	Raw cord (Aver.)	22.60	22.60	20.50	20.50
	Rate of change compared to raw cord (%)	107.90	103.80	103.71	103.56
	Rate of change compared to case 1 (%)		3.9% decrease		0.15% decrease

Table 5 presents the elongation at break results and rates of change for cord ropes from cured tyres. At low temperatures the elongation values increased by 7.9% for NY6 and 9% for NY66. At high temperatures, the elongation values increased by 3.8% for NY6 and decreased by 3.9% for NY66 compared to the low temperature results. NY66 showed similar behaviour at both temperature levels, with the change in elongation at high temperature mirroring that observed at low temperature.

As can be seen from the results, the superior elongation properties of NY6 [6] are negatively affected when exposed to high temperatures. This finding is consistent with previous scientific studies which have shown that NY6 undergoes significant changes in its mechanical properties with increasing temperature [10].

3.2.3. EASL (Elongation at Specified Load) Test

The EASL test is a mechanical test method used to determine how much a material can elongate under a given load. This test is critical in evaluating the load carrying capacity and deformation behaviour of the material [11].

Table 6. EASL test results of samples under 4.5 kg load.

TEST	Zone	NY6 Case 1	NY6 Case 2	NY66 Case 1	NY66 Case 2
EASL @4.5 kg (%)	1st body ply cord	10.21	12.33	8.88	8.70
	2nd body ply cord	9.87	12.47	8.47	8.49
	1st and 2nd body ply average	10.04	12.40	8.68	8.60
	Raw cord (Aver.)	8.00	8.00	7.40	7.40
	Rate of change compared to raw cord (%)	125.50	155.00	117.23	116.15
	Rate of change compared to case 1 (%)		23.5% increase		0.92% decrease

The data in **Table 6** presents the EASL test results for NY6 and NY66 samples under a 4.5 kg load. For the NY6 samples, there was a significant increase in the percentage elongation of the 1st and 2nd ply cords in Case 2 compared to Case 1. The elongation of the 1st ply cord increased from 10.21% to 12.33% and the elongation of the 2nd ply cord increased from 9.87% to 12.47%, an increase of 23.5%. In contrast, the EASL values for the NY66 samples remained almost constant between Cases 1 and 2, with a slight change from 8.88% to 8.7% for the 1st ply cord and from 8.47% to 8.49% for the 2nd ply cord, representing a decrease of 0.92%. The rate of change compared to the raw cord ranged from 125.5% to 155% for the NY6 samples and from 117.23% to 116.15% for the NY66 samples. These results indicate that NY6 tends to elongate more under high temperature conditions in case 2, while NY66 has a more stable performance against temperature variations.

Table 7. EASL test results of samples under 6.8 kg load.

Test	Zone	NY6 Case 1	NY6 Case 2	NY66 Case 1	NY66 Case 2
EASL @ 6.8 kg (%)	1st body ply cord	13.25	15.78	12.01	12.05
	2nd body ply cord	12.83	15.51	11.30	11.14
	1st and 2nd body ply average	13.04	15.65	11.66	11.60
	Raw cord (Aver.)	10.60	10.60	9.70	9.70
	Rate of change compared to raw cord (%)	123.02	147.59	120.15	119.54
	Rate of change compared to case 1 (%)		19.98% increase		0.51% decrease

The results of the EASL test under a 6.8 kg load are shown in Table 7. The data show significant differences between the NY6 and NY66 samples. For the NY6 specimens, there was a marked increase in elongation percentages from the 1st to the 2nd ply. The elongation of the 1st ply cord increased from 13.25% to 15.78% and the elongation of the 2nd ply cord increased from 12.83% to 15.51%. The average elongation of the 1st and 2nd ply cords increased from 13.04% to 15.65%, an increase of 19.98%. In contrast, the elongation rates for the NY66 samples remained almost constant between Cases 1 and 2, with only a slight change from 12.01% to 12.05% for the first ply cord, from 11.30% to 11.14% for the second ply cord, and a slight decrease from 11.66% to 11.60% for the average of the first and second ply cords, representing a decrease of 0.51%. When examining the rate of change in relation to the raw cord, the NY6 samples showed an increase from 123.02% to 147.59%, while the NY66 samples showed a very slight decrease from 120.15% to 119.54%. These results are consistent with those observed in Table 6.

Table 8 shows the elongation percentages and rates of change for cord ropes extracted from cured tyres under a 9.1 kg load. The data are consistent with the results presented in Table 6 and Table 7. Overall, a reduction of 1.3% was observed in the NY66 samples. When examining the rate of change relative to the uncured cord, NY6 showed an increase from 120.31% to 145.50% while NY66 showed a decrease from 119.75% to 118.19%.

For NY6, an increase of approximately 20% in elongation percentages was observed under loads of 4.5 kg, 6.8 kg and 9.1 kg compared to those cured at low temperatures, whereas no significant change in values was observed for NY66.

Table 8. EASL test results of samples under 9.1 kg load.

Test	Zone	NY6 Case 1	NY6 Case 2	NY66 Case 1	NY66 Case 2
EASL @9.1 kg	1st body ply cord	15.87	19.68	14.67	14.78
	2nd body ply cord	15.41	18.15	13.83	13.35
	1st and 2nd body ply average	15.64	18.92	14.25	14.07
	Raw cord (Aver.)	13.00	13.00	11.90	11.90
	Rate of change compared to raw cord (%)	120.31	145.50	119.75	118.19
	Rate of change compared to case 1 (%)		20.94% increase		1.3% decrease

3.2.4. LASE (Load at Specified Elongation) Test

The Load at Specified Elongation (LASE) test is a mechanical method used to measure the load required for a material to reach a specified elongation. This test is essential for investigating the stress-strain relationship, particularly in elastomers and composites [12].

Table 9. Table of force values at 3% elongation.

Test	Zone	NY6 Case 1	NY6 Case 2	NY66 Case 1	NY66 Case 2
LASE 3% (kg)	1st body ply cord	1.38	1.20	1.66	1.66
	2nd body ply cord	1.43	1.25	1.69	1.62
	1st and 2nd body ply average	1.41	1.23	1.68	1.64
	Raw cord (Aver.)	1.66	1.66	1.60	1.60
	Rate of change compared to raw cord (%)	84.64	73.79	104.69	102.50
	Rate of change compared to case 1 (%)		12.81% decrease		2.09% decrease

Table 9 presents the strength values and rates of change at 3% elongation for cord ropes extracted from cured tyres. A 12.81% decrease in LASE (3%) values was observed for the NY6 cord fabric cured at high temperatures compared to those cured at low temperatures, while the decrease for NY66 was 2.09%.

Table 10. Table of force values at 10% elongation.

Test	Zone	NY6 Case 1	NY6 Case 2	NY66 Case 1	NY66 Case 2
LASE 10% (kg)	1st body ply cord	4.38	3.36	5.28	5.28
	2nd body ply cord	4.66	3.22	5.69	5.72
	1st and 2nd body ply average	4.52	3.29	5.485	5.5
	Raw cord (Aver.)	6.29	6.29	7.0	7.0
	Rate of change compared to raw cord (%)	71.86	52.31	78.36	78.57
	Rate of change compared to case 1 (%)		27.21% decrease		0.27% increase

Table 10 shows the strength values and rates of change at 10% elongation for cord ropes extracted from cured tyres. A 27.21% decrease in LASE (10%) values was observed for the NY6 cord fabric cured at high temperatures compared to those cured at low temperatures, while for NY66 the decrease was limited to only 0.27%.

Table 11. Table of force values at 20% elongation.

Test	Zone	NY6 Case 1	NY6 Case 2	NY66 Case 1	NY66 Case 1
LASE 20% (kg)	1st body ply cord	12.25	9.08	13.34	12.90
	2nd body ply cord	12.36	9.96	13.95	14.30
	1st and 2nd body ply average	12.31	9.52	13.65	13.60
	Raw cord (Aver.)	12.70	12.70	13.60	13.60
	Rate of change compared to raw cord (%)	96.89	74.96	100.33	100.00
	Rate of change compared to case 1 (%)	22.63% decrease		0.33% decrease	

Table 11 presents the strength values and rates of change at 20% elongation for cord ropes taken from cured tyres. For the NY6 samples, a reduction of 22.63% was observed between Cases 1 and 2, with the LASE value for the first ply cord decreasing from 12.25% to 9.08%. In contrast, the NY66 specimens showed minimal change with a reduction of only 0.33%. While NY66 largely maintained its LASE values in Case 2, the LASE performance of NY6 decreased significantly under high temperature conditions. These results suggest that NY66 is more stable under load, whereas NY6 loses flexibility at higher temperatures.

4. Conclusions

Determining the appropriate cord fabric and vulcanization system for tire production is essential to ensuring optimal performance and durability. This scientific study evaluated the performance of NY6 and NY66 cord fabrics under various temperature and load conditions, and the key findings are summarised below.

➢NY6 cord fabric shows a significant decrease in elongation at break at high temperatures, while NY66 shows a more stable performance.

➢NY6 cord fabric undergoes significant changes in its mechanical properties when exposed to high temperatures, in particular, a reduction in elongation and breaking strength. In contrast, NY66 maintains its thermal and mechanical stability despite increased load and temperature.

➢This study suggests that NY66 offers longer life and reliable performance in harsh environments, while NY6 may be more suitable for lower temperature and lighter load applications.

➢This study is limited by its focus on specific curing conditions and the use of only NY6 and NY66 cord fabrics, which may not fully reflect the diversity of materials and manufacturing environments in the tyre industry. Future research could investigate a wider range of materials and conditions to gain a more complete understanding of their performance.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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