Formulation of EPDM heat-resistant V-ribbed belt

X Ling¹, Y L Hu¹, W W Lai¹ and Y Wang¹,²

¹School of Materials Science and Engineering, Wuhan Institute of Technology, Wuhan 430073, China
E-mail: wangyan.wict@163.com

Abstract. As a major pillar industry of the national industrial economy, the automobile industry has been greatly affected by the increasingly strict requirements of environmental protection in recent years. With the constant promotion of new energy vehicles, further compression of costs and improved performance will enable enterprises to occupy a place in international competition. In terms of the belt material of automobile engines, HNBR and EPDM, which are better in performance, are gradually replacing the traditional CR to adapt to the more demanding working environment. Compared with HNBR, EPDM is cheaper. In this paper, the effects of carbon black N330 and nylon staple fiber and their dosage on the properties of EPDM wedge rubber were studied by orthogonal test method to find the best formula. Studies have shown that the nylon fiber content has a great influence on the physical properties of EPDM wedge rubber, and comes to the influence of carbon black N330 content. The interaction between them is not obvious. When the content of the nylon fiber is 5phr and the content of the carbon black is 65 phr, the rubber wear rate after vulcanization is 15.5%, and the storage modulus at 120°C is about 60% at room temperature, its strength, heat resistance and aging resistance are excellent.

1. Introduction

In recent years, with the emergence of high performance automotive products, the performance requirements of automotive parts have also increased, and so are automotive transmission belts. In the past, natural rubber and neoprene were used as rubber compounds for automotive transmission belts. Since the publication of the first patent of hydrogenated nitrile rubber (HNBR) in 1975, HNBR has gradually been the first choice as the world’s automotive transmission belt materials. However, the price of HNBR is very expensive. In response to the country’s promotion of new energy vehicles and further reduction of production costs, EPDM is increasingly being applied to power systems such as engine cushions and transmission belts [1, 2].

Generally, automotive transmission belts are divided into V-belts, flat belts, and V-ribbed belts. The V-ribbed belt combines the advantages of flat belt and V-belt. In the overall structure, the main base is flat belt, and a plurality of V-shaped wedges is closely arranged inside the contact with a gear such as a gear. Therefore, it has the stability of the flat belt, the firmness and the transmission performance of the V belt. Its structural composition is shown in figure 1, which mainly includes four parts: top cloth, cushion rubber, tensile body and wedge rubber.

EPDM is a terpolymer prepared by solution polymerization with ethylene-propylene as main monomers and addition of unsaturated monomers (non-conjugated diolefins). It is a non-polar saturated carbon chain rubber which is chemically stable and has excellent resistance to ozone and weathering, but it has low strength and poor self-adhesiveness [3]. In order to prepare a compound with superior comprehensive properties, it is often necessary to modify it.
Figure 1. Structure of the V-ribbed belt.

The combined modification of rubber materials can improve the mechanical properties of rubber, improve the processing performance and application performance of single rubber, which is not only simple and effective, but also economical [4]. Huang and others [5, 6] have shown that the addition of chlorosulfonated polyethylene (CSM) will increase the tensile stress and tensile strength of EPDM, and the physical properties after heat aging will be significantly improved. When the amount of CSM is 5 phr, the heat aging resistance of the rubber is the best.

In this paper, orthogonal experiments were carried out to study the effects of different contents of carbon black N330 and nylon short fibers on the physical and mechanical properties and dynamic elastic modulus of EPDM wedge rubber.

2. Experimental

2.1. Raw materials and formula

EPDM4640 (DowDuPont); CSM-40 (PetroChina Jilin Chemical Group Corporation); Dicumy peroxide (DCP) (Sinopharm Chemical Reagent Co., Ltd); Trially isocyanurate (TAIC) (Hunan Minhe Chemical Co., Ltd.); Nylon staple fiber (Heilongjiang Hongyu Short Fiber New Material Co., Ltd.); other raw materials and auxiliaries are common items in the rubber industry.

Basic formula (unit: parts by mass): EPDM, 95; CSM 5; ZnO, 5.0; Antioxidant 4010NA, 1.5; Stearic acid (SA), 1; DCP, 5; S, 1; Promoter DM, 1.5; TAIC, 1; Paroline, 7; Carbon black N330 and nylon staple fiber are variables.

2.2. Equipment and instruments

SK160B double drum mixing machine (Shanghai Tuolin Rubber Machinery Factory); Miniature mixer (Wuhan Qien Technology Development Co., Ltd.); C2000E rotorless rubber vulcanizer (Beijing Youshen Electronic Instrument Factory); XLB-D pressure forming machine (Zhejiang Huzhou Dongfang Machinery Co., Ltd.); Punching machine and cutter (Jiangdu Tianyuan Testing Machinery Co., Ltd.); 401B heat aging test chamber (Shanghai Experimental Instrument Factory); TCS-2000 computer system tensile testing machine (Dongguan High-speed Railway Testing Instrument Co., Ltd.); TYLX-A Shore A Hardness Tester (Jiangdu Tianyuan Testing Machinery Co., Ltd.); MZ-4060 roller type abrasion machine (Jiangsu Mingzhu Testing Machinery Co., Ltd.); Dynamic thermomechanical analyzer (NETZSCH Instruments Germany).

2.3. Sample preparation

First of all, EPDM rubber is molded to the roll (roll spacing is 1 mm~2 mm). Then, add ZnO, SA, anti-aging agent, accelerator DM, and accelerator TAIC for mixing; After kneading uniformly, it is cut into small pieces and then mixed into an internal mixer for 3 to 5 min at an environment temperature of 160°C. After taking out, carbon black and paraffin oil are added for secondary mixing. After mixing again and cooling, add DCP and sulfur, thin the mixture to make the rubber compound evenly, and adjust the roll distance to 2 mm to obtain the rubber compound. After the rubber compound was placed for 1 d, the vulcanization curve test was carried out, and the rubber compound was molded and vulcanized. The vulcanized rubber was placed for performance test after being placed for 1 day.
2.4. Performance Testing
The vulcanization curve of the finished rubber at 160°C was measured, and the rubber compound was vulcanized at 160°C as the pressure increasing to obtain a vulcanized rubber compound, and a standard dumbbell-like spline was prepared under a punching machine. Aging test in accordance with ISO 188:1998, aging time and temperature were 24 h, 160°C. The measurement of Shore A hardness refers to the national standard ISO 7619-1:2004. According to ISO 37:2005 and GB/T3686-1998 (This test does not have a similar ISO standard), physical and mechanical properties such as tensile strength, elongation at break and permanent deformation of vulcanized splines were tested. The wear performance was measured in accordance with ISO4649: 2002. Finally, the dynamic properties of vulcanized rubber under shear condition are determined according to ISO 4464-1:2005.

3. Results and discussion
The experiment is a two-factor three-level orthogonal test, which mainly studies the effect of the amount of carbon black N330 and nylon on the performance of EPDM wedge rubber. After comprehensive consideration, the L₉(3⁴) orthogonal design was adopted, and the factors and levels of the test are shown in Table 1.

| Levels | Factors                        |
|--------|--------------------------------|
|        | A (The amount of carbon black N330) | B (The amount of nylon) |
| 1      | 55                             | 5                      |
| 2      | 65                             | 10                     |
| 3      | 75                             | 15                     |

The test arrangement, test results and data processing are shown in Tables 2 to 5 (The cutting of the test sample is in the L direction along the fiber direction, and the vertical fiber direction is the T direction):

| Factors | Tensile strength /MPa | Elongation at Break/% | Fixed tensile strength at 100%/MPa | Permanent deformation % |
|---------|------------------------|------------------------|-------------------------------------|-------------------------|
| A B AXB Blank |                          |                        |                                     |                         |
| 1 1 1 1 | 11.4                   | 197.6                  | 6.47                                | 7.48                    |
| 1 2 2 2 | 12.1                   | 97.3                   | 6.76                                |                         |
| 1 3 3 3 | 12.6                   | 111.5                  | 11.98                               | 9.66                    |
| 2 1 2 3 | 10.8                   | 149.6                  | 7.76                                | 5.6                     |
| 2 2 3 1 | 13.2                   | 109.2                  | 12.90                               | 5.24                    |
| 2 3 1 2 | 13.0                   | 101.3                  | 13.01                               | 7.88                    |
| 3 1 3 2 | 12.8                   | 148.8                  | 8.3                                 | 7.4                     |
| 3 2 1 3 | 13.5                   | 124.6                  | 11.9                                | 4.64                    |
| 3 3 2 1 | 14.3                   | 77.7                   | 8.64                                |                         |

| Factors | Tensile strength /MPa | Elongation at break/% | Permanent deformation % |
|---------|------------------------|------------------------|-------------------------|
| A B AXB Blank |                          |                        |                         |
| 1 1 1 1 | 8.54                   | 93.19                  | 4.12                    |
| 1 2 2 2 | 11.12                  | 64.69                  | 2                       |
| 1 3 3 3 | 13.78                  | 69.14                  | 5.24                    |
| 2 1 2 3 | 9.93                   | 87.75                  | 5.4                     |
| 2 2 3 1 | 7.57                   | 30.47                  | 2.56                    |
| 2 3 1 2 | 13.03                  | 61.52                  | 8.08                    |
| 3 1 3 2 | 12.20                  | 98.25                  | 6.6                     |
| 3 2 1 3 | 8.72                   | 47.35                  | 5.52                    |
| 3 3 2 1 | 16.55                  | 50.99                  | 6.4                     |
Table 4. Test arrangements and results before aging (T-direction).

| Factors | Tensile strength /MPa | Elongation at break/% | Fixed tensile strength at 100%/MPa | Permanent deformation /% |
|---------|-----------------------|-----------------------|------------------------------------|-------------------------|
| A 1 1 1 | 12.86                 | 220.50                | 4.19                               | 5.6                     |
| 1 2 2 2 | 12.44                 | 188.27                | 4.85                               | 6.9                     |
| 1 3 3 3 | 13.10                 | 187.55                | 6.27                               | 9.5                     |
| 2 1 2 3 | 14.56                 | 209.67                | 4.81                               | 8.64                    |
| 2 2 3 1 | 13.93                 | 174.32                | 7.09                               | 7.04                    |
| 2 3 1 2 | 13.65                 | 162.27                | 7.86                               | 5.08                    |
| 3 1 3 2 | 16.20                 | 184.88                | 6.05                               | 5.58                    |
| 3 2 1 3 | 14.33                 | 167.67                | 7.59                               | 4.74                    |
| 3 3 2 1 | 13.83                 | 146.99                | 8.41                               | 3.36                    |

Table 5. Test arrangements and results after aging (T-direction).

| Factors | Tensile strength /MPa | Elongation at break/% | Permanent deformation /% |
|---------|-----------------------|-----------------------|-------------------------|
| A 1 1 1 | 17.12                 | 210.16                | 5.85                    |
| 1 2 2 2 | 13.01                 | 138.04                | 9.15                    |
| 1 3 3 3 | 14.6                  | 166.67                | 8.04                    |
| 2 1 2 3 | 17.18                 | 181.58                | 6.69                    |
| 2 2 3 1 | 15.30                 | 139.34                | 10.56                   |
| 2 3 1 2 | 13.94                 | 171.97                | 8.67                    |
| 3 1 3 2 | 16.75                 | 184.28                | 6.01                    |
| 3 2 1 3 | 15.55                 | 168.47                | 8.44                    |
| 3 3 2 1 | 14.15                 | 156.76                | 7.34                    |

Above all, after visual analysis by simple process, it is shown that the change of fiber content is the main factor affecting the physical properties of EPDM wedge rubber. When the fiber content is 15 parts, it has a greater influence on the L-direction to the spline. The influence on the T-direction spline is huge, and the fiber content which has a great influence on the elongation at break of the spline is 5 parts; The fiber content of 15 parts has a great influence on the 100% fixed tensile stress of the rubber compound.

The intuitive analysis method is simple and easy to understand, and only requires a small amount of calculation to obtain the optimal result. However, this method cannot distinguish whether the data is the experimental results or the experimental error. Therefore, we need to estimate the reliability of the experimental results through analysis of variance further.

The sum of the tensile strength data levels and its analysis table of variance are shown in tables 6 and 9.

Table 6. The sum of the tensile strength data levels (L-direction).

| Factors \ Levels | 1  | 2  | 3  | Summation |
|------------------|----|----|----|-----------|
| A                | 69.62 | 67.56 | 78.06 | 215.24    |
| B                | 65.70 | 66.24 | 83.30 | 215.24    |
| AXB              | 68.22 | 74.81 | 72.22 | 215.24    |
| Blank            | 71.61 | 74.38 | 69.25 | 215.24    |

Table 7. Variance analysis table.

| Factors | Degree of freedom(f) | Sum of squared deviation (S) | F-ratio | Significant |
|---------|----------------------|------------------------------|---------|-------------|
| A       | 2                    | 10                           | 1.22    |             |
| B       | 2                    | 33                           | 4.01    | **          |
| AXB     | 2                    | 3                            | 0.36    |             |
| Blank   | 2                    | 2                            | 0.24    |             |
| e       | 9                    | 37                           |         |             |
| Total   | 17                   | 85                           |         |             |
Table 8. The sum of the tensile strength data levels (T-direction).

| Factors \ Levels | 1       | 2       | 3       | Summation |
|------------------|---------|---------|---------|-----------|
| A                | 83.13   | 88.56   | 90.81   | 262.5     |
| B                | 94.67   | 84.55   | 83.28   | 262.5     |
| AXB              | 87.45   | 85.18   | 89.87   | 262.5     |
| Blank            | 87.19   | 85.98   | 89.33   | 262.5     |

Table 9. Variance analysis table.

| Factors | Degree of freedom (f) | Sum of squared deviation (S) | F-ratio | Significant |
|---------|-----------------------|-----------------------------|---------|-------------|
| A       | 2                     | 5                           | 1.5     |             |
| B       | 2                     | 13                          | 3.9     | **          |
| AXB     | 2                     | 2                           | 0.6     |             |
| Blank   | 2                     | 1                           | 0.3     |             |
| e       | 9                     | 15                          |         |             |
| Total   | 17                    | 36                          |         |             |

From the above variance analysis of the tensile strength of EPDM V-ribbed wedge rubber, it is clear that whether the spline has T- or L-direction, the FB ratio is large. This means that the level change has a significant impact on the performance index, and this is a significant difference compared to the F distribution table. This result means that the fiber content has a great influence on its tensile properties. According to comprehensive and intuitive analyses, the fiber content of 15 parts has a greater influence on the L-direction, due to the large amount of fiber orientation, and the force that can be withstood in the orientation direction is strong; when the fiber content is 5 parts, the tensile strength in the T-direction is greatly affected. Since there are fewer fibers in the orientation direction, the effect on the transverse stretching is also small.

The sum of elongation data levels and its analysis table of variance are shown in tables 10 and 11.

Table 10. Sum of elongation data levels.

| Factors \ Levels | 1       | 2       | 3       | Summation |
|------------------|---------|---------|---------|-----------|
| A                | 1744.87 | 1578.99 | 1556.79 | 4880.67   |
| B                | 1966.31 | 1499.99 | 1464.38 | 4880.67   |
| AXB              | 1726.58 | 1549.63 | 1604.46 | 4880.67   |
| Blank            | 1607.25 | 1601.88 | 1671.55 | 4880.67   |

Table 11. Variance analysis table.

| Factors | Degree of freedom (f) | Sum of squared deviation (S) | F-ratio | Significant |
|---------|-----------------------|-----------------------------|---------|-------------|
| A       | 2                     | 1761                        | 0.36    |             |
| B       | 2                     | 26701                       | 5.48    | **          |
| AXB     | 2                     | 1368                        | 0.28    |             |
| Blank   | 2                     | 251                         | 0.05    |             |
| e       | 27                    | 65746                       |         |             |
| Total   | 35                    | 95827                       |         |             |

From the analysis of variance, the fiber content has a large influence on the elongation at break of EPDM wedge rubber, and it has the greatest influence at 5 parts, which is in line with the results of visual analysis.

The sum of the 100% fixed elongation strength data levels and its analysis table of variance are shown in tables 12 and 13.

From the variance analysis of the tensile strength of the EPDM wedge rubber, it is known that the FB ratio is large regardless of orientation direction. That is, the level change has a significant influence on the performance index. And compared to the F distribution table, it also has a greater significance.
### Table 12. Sum of the 100% fixed elongation strength data levels.

| Factors \ Levels | 1   | 2   | 3   | Summation |
|------------------|-----|-----|-----|-----------|
| A                | 38.34 | 45.68 | 43.85 | 127.87 |
| B                | 33.61 | 47.68 | 46.59 | 127.87 |
| AXB4             | 42.59 | 41.25 | 44.02 | 127.87 |
| Blank            | 43.43 | 42.59 | 41.85 | 127.87 |

### Table 13. Variance analysis table.

| Factors | Degree of freedom (f) | Sum of squared deviation (S) | F ratio | Significant |
|---------|-----------------------|------------------------------|---------|-------------|
| A       | 2                     | 5                            | 1.18    |             |
| B       | 2                     | 21                           | 4.97    | **          |
| AXB     | 2                     | 1                            | 0.24    |             |
| Blank   | 2                     | 1                            | 0.24    |             |
| e       | 9                     | 19                           |         |             |
| Total   | 17                    | 47                           |         |             |

The sum of permanent deformation data levels and its analysis table of variance are shown in tables 14 and 15.

### Table 14. Sum of permanent deformation data levels.

| Factors \ Levels | 1   | 2   | 3   | Summation |
|------------------|-----|-----|-----|-----------|
| A                | 70.6 | 71.38 | 62.48 | 204.46 |
| B                | 69.74 | 56.6 | 78.12 | 204.46 |
| AXB4             | 65.16 | 64.78 | 74.52 | 204.46 |
| Blank            | 61  | 67.38 | 76.08 | 204.46 |

### Table 15. Variance analysis table.

| Factors \ Degree of freedom (f) | Sum of squared deviation (S) | F ratio | Significant |
|-------------------------------|------------------------------|---------|-------------|
| A                             | 2                            | 4       | 0.52        |             |
| B                             | 2                            | 20      | 2.6         | *           |
| AXB                           | 2                            | 5       | 0.65        |             |
| Blank                         | 2                            | 10      | 1.3         |             |
| e                             | 27                           | 104     |             |             |
| Total                         | 35                           | 143     |             |             |

From the analysis of variance, the effect of fiber content on permanent deformation is significant, which is inconsistent with the results of visual analysis. Since the analysis of variance is more accurate, the influence of carbon black can be ignored, and the influence of fiber is the most important.

Finally, we did a supplementary test on the splines before aging, including hardness test, wear reduction test, etc. The test results are as follows.

The effect of different content of carbon black and fiber on the Shore A hardness of EPDM wedge rubber is shown in figure 2.

As can be seen from figure 2, as the carbon black content increases, the hardness of the rubber of different fiber contents increases, and as the fiber content increases, the hardness of the rubber of the same carbon black content also increases. There is no other filler reinforcing agent in the formula of wedge rubber. Under the reinforcing effect of carbon black and fiber, the effect on rubber hardness is the same, which increases monotonously with the increase of the amount of reinforcing agent.

The effect of different content of carbon black and fiber on the wear reduction of EPDM wedge rubber is shown in figure 3.
The wear resistance was measured in this experiment. It can be seen from the above figure that the sample has the best wear resistance when the carbon black content is 65 parts and the fiber content is 5 parts. The wear resistance of rubber is essentially dependent on its strength, elasticity, hysteresis properties, fatigue and friction. Generally, the tensile strength is an important index that determines the wear resistance of the rubber, and the abrasion resistance generally increases with tensile strength. In addition, the wear reduction increases with fiber content. This is because the amount of fiber and the degree of dispersion also have a certain influence on the wear reduction of the rubber. Any factor that can enhance the bonding of the rubber is beneficial to its wear resistance. When the amount of fiber is increased, the bonding of the rubber will cause stress concentration due to agglomeration of the fibers.
which reduces the bonding of the rubber, thereby increasing the wear reduction.

In summary, the results of orthogonal experiments show that the fiber content has a great influence on the tensile strength, elongation at break and 100% modulus of EPDM wedge rubber. When the fiber content is 5 parts, the elongation at break and the tensile strength are both large and the abrasion loss is the smallest, and the 100% fixed elongation strength is large when the fiber content is 15 parts. By drawing analysis, the wear resistance is the best when the carbon black content is 65 parts. In summary, when the fiber content is 5 parts and the carbon black content is 65 parts, the vulcanized rubber has good mechanical properties.

Finally, we tested the dynamic mechanical properties of the best formulated vulcanized rubber. The results are shown in figure 4.

![Figure 4. DMA test chart for 65 parts of carbon black and 5 parts of fiber.](image)

As seen in figure 4, when the carbon black is 65 parts and the fiber is 5 parts, the storage modulus and the loss modulus decrease with the increase of temperature, and the loss factor increases first and then decreases with the increase of temperature. It peaks at 56°C which is the glass transition temperature. Its storage modulus drops by 44% with an increase from room temperature to 120°C.

The results obtained are summarized in table 16:

| Factors                  | Dosage/phr | Effect            | Tentative        | L-direction | T-direction |
|--------------------------|------------|-------------------|------------------|-------------|-------------|
| Carbon black             | 65         | Main influence    | Tensile Strength | 10.8 MPa    | 14.6 MPa    |
| Nylon fiber              | 5          | Secondary impact  | Elongation at Break | 150%        | 210%        |
| Carbon black and nylon fiber |        | Almost no effect  | Permanent Deformation | 5.6%        | 8.64%       |

4. Conclusions
In this experiment, the wedge rubber formula of EPDM was studied, and the following conclusions were drawn:

- The addition of carbon black N330 and nylon staple fiber can improve the tensile strength, elongation at break, wear resistance and high temperature resistance of the vulcanized rubber.
- The content of nylon fiber has a great influence on the physical properties of EPDM wedge rubber and the content of carbon black N330 is small, and the interaction between the two is not obvious.
- When the content of nylon fiber is 5 parts and the content of carbon black is 65 parts, the rubber after vulcanization has good mechanical properties. The wear rate of the rubber after
vulcanization is 15.5%, the storage modulus at 120°C is about 60% at room temperature, the elongation at break in the T-direction is more than 200%, the elongation at break in the L-direction is more than 150%, and the T-direction is pulled. The tensile strength exceeds 14 MPa. The physical-mechanical properties were optimal in all nine groups of formulations.

References
[1] Xie Z L 2007 Progress in materials for automotive tapes China Rubber Industry 54 310-3
[2] Li Z M and Yu J L 1993 Materials and coordination of rubber products for automobiles Special Purpose Rubber Products 1993 19-22
[3] Coran A Y and Patel R 1980 Rubber-thermoplastic compositions Part I. EPDM-polypropylene thermoplastic vulcanizates Rubber Chem. Technol. 53 141-50
[4] Qi X G et al 2007 NR/EPDM combined rubber research World Rubber Industry 34 16-21
[5] Huang M L and Tian X L 2013 Effect of chlorosulfonated polyethylene on heat aging resistance of EPDM Rubber Science and Technology 11 21-3
[6] Marković G, Dević S, Marinović-Cincović M et al. 2009 Influence of carbon black on reinforcement and gamma-radiation resistance of EPDM/CSM CR/CSM rubber blends Kgk-kaut Gummi Kunst 62 299-305