Study on the Properties of Rubber with Different Contents of Carbon Black

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Abstract. In this paper, the rubber with different carbon black content was designed and its properties were tested to verify its effects on rubber properties. The results showed that with the increase of carbon black content, the hardness of rubber increased gradually, and the tensile strength, elongation and tear strength firstly increased and then decreased. The abrasive volume of vulcanization firstly decreased and then increased along with carbon black content. The heat generation of rubber increased slowly between 10 and 20 parts of carbon black content, while the heat generation of rubber increased rapidly between 30 and 40 parts of carbon black content. After thermo-oxidative ageing at 75°C for 96 hours, the hardness, tensile strength, elongation and tear strength of the rubber decreased to varying degrees. The properties of the rubber with carbon black content decreased rapidly between 10 and 20 parts, while the properties of the rubber with carbon black content between 30 and 40 parts decreased slowly.

1. Introduction
Rubber is used to make seals, tires, hoses and other products as a high elastic material. It is widely used in automobile, construction machinery, aerospace and other fields. In the process of rubber production, various fillers need to be added to make rubber have good elasticity, wear resistance, aging resistance, heat resistance and other properties. Carbon black is the main reinforcing filler in rubber industry [1]. Since carbon black was introduced into rubber industry as reinforcing agent in the 20th century, it has been the dominant reinforcing material in tires and other rubber products [2-4]. In ASTM standards, carbon black is classified as N100 to N900 [5-6]. Different grades of carbon black have different surface area, particle size and structure [7]. Peng Xu-dong [8] summarized the wear mechanism of tires, analyzed the corresponding operating conditions of different mechanisms and the impact on tire wear resistance. The results showed that the influence of carbon black on the rubber used in tire was changed with the change of tire usage and wear mechanism. Lu Yong-jun [9] studied the effects of rubber cushion type, carbon black type and silica on the compression fatigue competence of load wheel rubber. The results showed that 10-15 parts of silica improved the compressive fatigue heat generation performance, and 5-10 parts of cis-butadiene rubber had no effect on the compressive fatigue heat generation performance of rubber compound. The addition of carbon black with similar
structure and different particle size had an effect on the heat generation by compression. In this paper, the effects of carbon black on the hardness, strength, heat generation and aging resistance of rubber were studied by testing the properties of rubber with different carbon black content in order to provide guidance for future production.

2. Test materials and methods

2.1. Test materials
Natural Rubber (NR), Yunnan Agricultural Reclamation Yun Oak Investment Co., Ltd; Zinc Oxide, Shanghai Mogao New Materials Co., Ltd; Stearic Acid, Jinan Aoxing Chemical Co., Ltd; Carbon Black 330, Zhengzhou Juli Chemical Co., Ltd; Promoter TMTD, Products of Shanghai Chengjin Chemical Co., Ltd. The others were all commercial industrial products. The rubber formula was shown in Table 1.

| Component      | Formula 1# | Formula 2# | Formula 3# | Formula 4# |
|----------------|------------|------------|------------|------------|
| Natural Rubber | 100        | 100        | 100        | 100        |
| Zinc oxide     | 2          | 2          | 2          | 2          |
| Silicon dioxide| 6          | 6          | 6          | 6          |
| Sulfur         | 1          | 1          | 1          | 1          |
| Carbon black   | 10         | 20         | 30         | 40         |
| Stearic acid   | 0.8        | 0.8        | 0.8        | 0.8        |
| Promoter TMTD  | 1          | 1          | 1          | 1          |

2.2. Test methods and equipments
The natural rubber was plasticized in YZM-2L mixer, then stearic acid, zinc oxide, silicon dioxide were added to mix, and carbon black was added to mix finally. The vulcanizing agent was added to the XK-160 twin-roll mill starter, and the mixture was uniform, then the lower tablet was made. The samples were cured on YJ-450 plate vulcanizer after 24 hours. Vulcanization parameters were 150°C ×20min, 10MPa. The properties of vulcanized specimens were tested after being parked for 24 hours.

1) Tensile properties and tear strength were tested by ETM computer controlled electronic universal testing machine. Tensile properties were tested according to GB/T528-2009, and the tensile speed was 500 mm/min.

2) The tearing strength was tested according to GB/T529-2009 by the right-angled specimens. The tearing speed was 500 mm/min, and the testing temperature was \((23\pm2)\,^\circ\text{C}\)

3) The hardness was tested by Shore A rubber hardness tester according to GB/T531.1-2008.

4)MZ-4204D rubber compression heating tester was used to test rubber heating according to GB1687.3-2016.

5) The abrasion resistance of rubber was tested by MH-1689 clone machine and operated according to GB1689-2014.

6) JW-8001 ozone aging test chamber was used to carry out hot air thermal aging test at 75°C for 96h according to GB/T3512-2014.

3. Test results and analysis

3.1. Effects of Different Carbon Black Content on Tensile Strength and Tear Strength of Rubber
As can be seen from Table 2 and Figure 1, with the increase of carbon black content, the hardness of rubber increased gradually, while the tensile strength, elongation and tear strength firstly increased and then decreased. The entanglement point of rubber macromolecular chain increased with the increase of carbon black content. The number of crosslinking bonds increased along with crosslinking density.
When the content of carbon black increased to 30 parts, the tensile strength, elongation and tear strength decreased slightly. The reason was that the interaction between carbon black and rubber is saturated. Carbon black-carbon black formed a filler-filler network structure, which made the molecular mass no longer increase and the rubber harden. Tensile strength even decreased slightly.

**Table 2.** Physical and mechanical properties of rubber with different carbon black contents

| Test items          | Formula 1# | Formula 2# | Formula 3# | Formula 4# |
|---------------------|------------|------------|------------|------------|
| Shore A hardness    | 62.5       | 66.0       | 73.5       | 79.0       |
| Tensile strength /MPa | 18.3       | 23.5       | 27.3       | 27.0       |
| Elongation /%        | 304        | 356        | 421        | 407        |
| Tear strength /kN/m  | 15.2       | 22.3       | 27.9       | 32.6       |

**Fig. 1** Effects of carbon black content on tensile strength and tear strength of rubber

3.2. **Effects of Different Carbon Black Content on Rubber Wear Resistance**
From Figure 2, we found that the abrasive volume of vulcanization first decreased and then increased. This was due to the increase of carbon black, the increase of entanglement points and molecular weight. Carbon black and molecular chains formed a filler-rubber network structure, which increased the hardness of rubber and improved the wear resistance of rubber. When the content of carbon black was more than 30 parts, the abrasive volume of vulcanization increased slightly. The uneven distribution of secondary structure condensate was produced in natural rubber, which made its wear resistance decline.
3.3. Effects of Different Carbon Black Content on Compression Heating of Rubber
As can be seen from Figure 3, the calorific value of rubber increases with the increase of carbon black content. When the carbon black content was between 10 and 20 parts, the heat generation of rubber increased slowly, while the heat generation of rubber increased rapidly between 30 and 40 parts. The increase of carbon black hindered the movement of macromolecular chains, resulting in increased friction and heat generation between fillers and macromolecular chains. Carbon black content in certain range of 10-30 parts had a relatively stable calorific value. After more than 30 parts of this range, the calorific value increases rapidly. When the content exceeded 30 parts, the calorific value increased rapidly. This was due to the uniform distribution of carbon black as filler in natural rubber at 10-30 parts. Under the external force, the friction between carbon black and carbon black, carbon black and molecular chain was small, so the heat generation was slow. When the content of carbon black reached 30 parts, the secondary structure aggregates were formed, and the friction between carbon black and molecular chains increased, and the heat generation increased rapidly [10].

3.4. Effects of Different Carbon Black Contents on Aged Properties of Rubber
Table 3 and Figure 4 were comparisons of the properties of natural rubber with different carbon black content after thermo-oxidative ageing at 75 ℃ for 96 hours. After thermal oxidation aging, the hardness, tensile strength, elongation and tear strength of the samples decreased in varying degrees.
The properties of rubber with carbon black content between 10 and 20 parts decreased rapidly, while the properties of rubber with carbon black content between 30 and 40 parts decreased slowly. In addition to oxygen concentration, sample thickness and oxygen diffusion rate, the main factors affecting aging properties of rubber were molecular structure and temperature of rubber. There were carbon-carbon double bonds in natural rubber molecule. Oxygen could easily react with rubber molecule to form free radicals under thermal action, and the main chain of rubber molecule was broken by oxidation reaction. So the hardness, tensile strength, elongation and tear strength of rubber decreased to different degrees.

Table 3. Mechanical properties of rubber aged with different carbon black contents

| Test items         | Formula 1# | Formula 2# | Formula 3# | Formula 4# |
|--------------------|------------|------------|------------|------------|
| Shore A hardness   | 58.8       | 62.5       | 69.4       | 73.5       |
| Tensile strength /MPa | 13.3       | 19.8       | 25.3       | 24.2       |
| Elongation /%      | 258        | 319        | 382        | 375        |
| Tear strength /kN/m | 10.1       | 16.7       | 24.6       | 27.7       |

4. Conclusion
1) With the increase of carbon black content, the hardness of rubber increased gradually, and the tensile strength, elongation and tear strength firstly increased and then decreased.
2) The abrasive volume of vulcanization firstly decreased and then increased along with carbon black content. The heat generation of rubber increased slowly between 10 and 20 parts of carbon black content, while the heat generation of rubber increased rapidly between 30 and 40 parts of carbon black content.

3) After thermo-oxidative ageing at 75℃ for 96 hours, the hardness, tensile strength, elongation and tear strength of the rubber decreased to varying degrees. The properties of the rubber with carbon black content decreased rapidly between 10 and 20 parts, while the properties of the rubber with carbon black content between 30 and 40 parts decreased slowly.

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