Process and Reinforcement Mechanism about Dislocation Remanufacturing Retreaded OTR Tires by Using Waste Steel

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Abstract. In order to improve the bearing performance and anti-impale performance of retreaded OTR tires, production process of waste radial tire steel dislocation remanufacturing retreaded OTR tires was designed, by using waste radial tire steel wire as a reinforcing body and using the coating method, through copper-zinc plating process on the waste steel wire surface, mainly including: process of local repair and reinforcement engineering radial tire steel cord fracture layer and process of reinforcing radial waste tire steel wire cord layer between the old carcass and retreaded tire tread. Reinforcement mechanism about dislocation remanufacturing retreaded OTR tires by using steel wire of waste radial tire was analyzed, the adhesive of waste steel wire and tire rubber was effective realized, and the technology advantage of dislocation remanufacturing Retreaded OTR tires was analyzed, and the waste tires of 26.5R25 all-steel engineering mechanical radial were dislocatingly remanufactured and Retreaded by using vulcanization method. The results showed that bearing performance and anti-impale performance of waste steel wire dislocation remanufactured Retreaded OTR tires was further increased through user feedback, the service life was 1.2 times of the same type of ordinary retreaded tire, close to service life of the same type new tire, and comprehensive performance was good.

1. Introduction
Engineering tires mainly refer to the tire used in engineering automobile and engineering machinery, which is called OTR(Off The Road) for short. At present, the annual production of OTR tires in the world is estimated to be 10 million, accounting for about 0.5% of the total tire volume, in terms of sales, it accounts for about 5.5% of all tire sales. The specifications of OTR tires are relatively large, one weight is equivalent to the weight of several heavy-duty tires or dozens of car tires, moreover, the amount of rubber consumed has accounted for about 10% of the total amount of rubber used in tires, the added value is about 30% to 50% higher than that of the normal tires, therefore, OTR tires have become another economic growth point in today's tire industry.

OTR tires are used in open-pit mines and earthwork projects, among which open-pit mines can be said to be the most concentrated usage of OTR tires and the most demanding use conditions, where OTR tires are required to have the characteristics of puncture resistance, cutting resistance, wear resistance and low heat generation and so on. In general, an engineering car or engineering machine will have to change the tire 5 to 6 times a year, the price of a new OTR tire is in the thousands or even tens of thousands of RMB, therefore, it has a direct impact on the economic efficiency of engineering vehicles to effectively extend the tire service life or reduce the tire cost. The retreaded tires which maximize the service value of tires have become internationally recognized as rubber raw material.
saving, solved the black pollution of waste tires, and been a valuable way of recycling resources. Therefore, how to use OTR tires effectively is of great practical significance to engineering automobile users or an enterprise. However, the quality of the refurbishment OTR tires produced by Chinese engineering tire refurbishment enterprises is uneven, accidents such as single tire pressure explosion, bump explosion and puncture often occur during the work, thus the service life is relatively short. Frequent tire replacement has led to increased costs for OTR tires of transportation companies. For this reason, this study combined waste radial tire steel wire curtain cord with refurbishment OTR tires to do researches on retreaded OTR tire production process and reinforcing mechanism of dislocation remanufacturing of waste radial tire steel wire, and the reinforcement of OTR tire body and the repair of partial damage was realized. In addition, it could regenerate the fracture layer of some OTR tire body steel wire curtain cord, and the damaged OTR of tire body steel wire curtain cord can be Retreaded and reused without being scrapped directly. At the same time, the reuse of waste radial tire steel wire would be solved which could be said to kill two birds with one stone, and further effectively solved the problem of environmental pollution caused by waste tires. At the same time, a layer of radial tire waste steel wire curtain fabric layer was reinforced between the Retreaded tire tread layer and the waste tire body layer which has enhanced the carrying capacity and anti-puncture capacity of retreaded OTR tires, and would greatly promote the use of retreaded OTR tires with significant economic and social benefits.

2. Production process dislocation remanufacturing retreaded OTR tire by using waste radial tire wire

The waste radial tire steel wire was reused in the refurbishment of OTR tires to realize its remaining value, in addition to having its own steel wire curtain fabric layer, the steel wire curtain fabric layer of other scrapped tires was added as reinforcing layer after the refurbishment of OTR tires. For this reason, this study is called dislocation remanufacturing process of steel wire, and at present, no relevant results have been published at home and abroad. The key of the technology is to effectively realize the adhesion between the waste radial tire steel wire and the tire body substrate. The dislocation remanufacturing technology of steel wire mainly includes: (1) partial repair and reinforcement of the broken layer of engineering radial tire steel curtain cord could effectively solve the problem that damage of tire body steel wire curtain fabric layer cannot be Retreaded and is directly scrapped. The main process was to peel the damaged steel curtain fabric fracture layer from the old body and remove the damaged fracture layer, the steel wire layer at both ends of the damaged area was cut into an angle of 60 degrees from the cross section of the tire body, the exposed part of the tire body was polished and measured the size of the grinding part, the matched reinforcing steel curtain fabric layer was made, so the local reinforcing diagram is shown in Fig.1, thus reinforcing steel wire curtain fabric layer and old body steel wire joint were connected with intermediate glue for bonding. (2) Reinforce one layer of radial waste tire steel curtain fabric between the waste tire body layer and the rubber layer of Retreaded tread, the structure diagram is shown in Fig.2, the two sides of the steel curtain fabric layer were attached with buffer glue respectively, the steel wire curtain fabric layer surrounded the tire body, and made a 45 degree angle docking. In order to ensure the adhesion among the retreaded tread rubber, the two-layer buffer rubber, the steel curtain fabric layer and the old body layer (there may be some local reinforcing parts), it was necessary to grind and brush the butt joint of the steel curtain fabric layer and the butt joint of the retreaded tread layer, and inflatable tread compression technology with inflatable pressure of 0.20 MPa was adopted to ensure the steel wire curtain fabric joint and tread joint smooth. The vulcanization was carried out by an adjustable model vulcanizing machine, vulcanizing temperature was 150℃, vulcanization pressure was 0.5 MPa, and vulcanization time of 2.5h. The retreaded tire production technology process of waste radial tire steel wire dislocation remanufacturing is shown in Fig.3.
1- Old tire body  2- Steel wire curtain cord layer fracture zone  3- Old tire body surplus steel wire curtain fabric layer  4- Reinforcing steel wire curtain fabric layer

Fig.1 Diagram of waste radial tires steel wire was locally reinforcing damaged tire body steel wire fracture layer

1- Retreaded tread layer  2- Buffer layer  3- Belt layer  4- Old radial steel wire layer  5- Tire body layer  6- Sidewall layer  7- Toe mouth rubber layer  8- Steel wire ring

Fig.2 Dislocation remanufacturing OTR tires structure diagram of waste radial steel wire

Fig.3 Dislocation remanufacturing retreaded OTR tires process of waste radial steel wire
3. Dislocation remanufacturing retreaded OTR tire reinforcement mechanism of waste radial tire steel wire

The two sides of waste radial tire steel wire curtain fabric layer were bonded with two thin buffer layers first, then stucked with the tread rubber and body rubber respectively through the vulcanization. In order to effectively improve the adhesive degree, the rubber of buffer layer was different from that of the conventional retreaded tire in formula design, whose formula design is shown in table 1. In the formula, an appropriate amount of white carbon black was added to promote the bonding between rubber and steel wire, and increasing the dosage of plasticizer and the fluidity of rubber material were beneficial to the penetration of rubber material into the cracks of steel cord fabric layer and the effective bonding strength of rubber and steel wire. The amount of insoluble sulfur was increased, which increased the reaction point of double bonds in rubber molecular chain, promoted the formation of carbon-carbon bond crosslink chain, and improved the bonding strength of rubber and steel wire. Appropriate NOBS promoter was choosen, the coke burning of vulcanization time was increased, vulcanization induction period was extended, the scope of vulcanization curve flat was widen, and vulcanization rate was increased, which effectively prompted vulcanization to get to equilibrium among rubber, sulfur and steel wire copper plating layer. Vulcanization temperature was 140℃, vulcanization time of 15 min, hardness of 69 degrees, tensile strength of 21MPa, elongation at break of 504%, and the intensity of tread rubber for 30 kN/m, and adhesive strength of tire body layer rubber of 34 kN/m.

| Formula composition | Quality(g) | Formula composition | Quality(g) | Formula composition | Quality(g) |
|---------------------|------------|---------------------|------------|---------------------|------------|
| Natural rubber      | 100        | Antiage RD          | 2          | Promoter NOBS       | 3.5        |
| White carbon black  | 30         | Additives HNZ       | 1.5        | Promoter D          | 0.5        |
| Carbon black N660   | 45         | Insoluble sulphur   | 5          | Zinc oxide          | 5          |
| Cobalt naphthenate  | 2          | Plasticizer         | 2.5        | Total               | 197        |

In order to effectively improve the adhesion performance of rubber and steel wire curtain cord, the surface of waste steel wire was plated with brass. In other words, the surface of waste radial tire steel wire was copper-galvanized, and the ratio of copper to zinc content in the steel wire coating was 65:35, so double coating layer of copper-zinc was formed on the surface of steel wire. Steel wire cord surface coated with copper had a layer of oxide layer, when steel wire coated with copper was drawn, zinc ions spread to the surface, spreading between the two layers, formed overlay copper oxide layer of zinc oxide (ZnO) on the surface, thus formed a brass alloy, and called brass plating. The specific structure is shown in Fig.4, where the Cu2O thickness is 0.5nm, the thickness of CuO+ZnO is 10nm, and the thickness of CuZn+ZnO is 50nm.

![Fig.4 Surface structure model of copper plating steel wire cord](image)
The structural model of rubber reinforcement mechanism of steel tire dislocation remanufacturing OTR tires is shown in Fig.5. Copper sulfide (CuS) layer and zinc sulfide (ZnS) layer formed by the way that copper ions (Cu²⁺), zinc ions (Zn²⁺) and free electrons (e⁻) diffused to the surface of copper wire through cation, when brass-plated steel wire was at the beginning of vulcanization. Because Cu⁺ had a higher oxidation potential than Zn²⁺, Zn²⁺ was more likely to react with sulfur to form ZnS layer. If copper had copper oxide on its surface, the ZnS layer was quickly covered by the generated CuS layer, and CuS layer was beneficial to improve the adhesion between rubber and steel cord fabric layer, whose thickness had an optimal value, if it was too thick and easy to fall off the copper surface, resulting in decreasing adhesion force; if it was too thin and couldn’t fully permeate with rubber materials, this lead to the reduction of adhesive force. Under the action of vulcanization, CuS layer permeated the rubber material, and was firmly bound by the rubber adhesive material, so the rubber adhesive material and the CuS layer were combined by the sulfur bond to form the adhesive layer, whose binding force of the adhesive layer exceeded that of the rubber itself. According to the test, the adhesive strength between the two could reach 41kN/m. The vulcanization reaction process of rubber and sulfur yellow is as follows:

\[
\text{Rub} + \text{Sy} \xrightarrow{\text{NOS}^2} \text{Rub—Sy} \quad \text{Rub—Sy} + \text{Rub} \rightarrow \text{Rub—Sy—Rub}
\]

Adhesion reaction process of rubber and steel wire brass plating:

\[
\text{CuZn} + 2\text{S} \rightarrow \text{CuS} + \text{ZnS} \quad \text{CuS} + \text{Rub—Sy} \rightarrow \text{CuS—S—Sy—Rub}
\]

Fig.5 Reinforcing mechanism structure model of dislocation remanufacturing OTR tires rubber

4. Conclusion

Dislocation remanufacturing OTR tires technology of waste radial tire steel wire not only could solve the problem of environmental protection, and opened up a new way of utilization of waste radial tire, which could make the utilization rate of old tires from 10% to more than 20%, and turn the waste into wealth. In addition, it could effectively solve the technical problem that the damaged tire body steel wire cord fabric of OTR tire couldn’t be retreaded. The refurbishment production of 26.5R25 all-steel mechanical radial tire was carried out adopting mold vulcanization method and using retreaded OTR tire production process and reinforcing mechanism of waste radial tire steel wire dislocation remanufacturing. The retreaded OTR tires have been tested for physical and mechanical properties, and their indicators meet the retreaded OTR tire standard of HG/t3979-2007. The penetration rate of the finished product was reduced from 40% (ordinary retreaded OTR tires) to 20% (dislocation remanufacturing retreaded OTR tires) in the open pit. At the same time, the user feedback information also indicated that the anti-penetration and anti-puncture capability of the 26.5R25 retreaded OTR tires of waste radial steel wire dislocation remanufacturing has been greatly improved, whose overall performance was better and service life was about 12 months. However, the service life of the same type of general retreaded OTR tires is about 10 months, while that of the same type of new OTR tires is about 12 months. The service life of dislocation remanufacturing retreaded OTR is 1.2 times that of ordinary retreaded tire, which is basically the same as the service life of the new tire of the same type, and the total cost is only 40% of that of the new tire.
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