Analysis and control measures for common quality defects in the formation of all-steel radial tires

Lei Taiwei, Yu Tianli, Zhao Yibin, Tian Weijuan, Song Qian

(Shaanxi Yanchang Petroleum Group Rubber Co. LTD., Xianyang 712000, Shaanxi, China)

Abstract: This article addresses the prevalent quality defects observed in our company's finished products, including shoulder bending, carcass joint opening, belt layer deviation from the centerline, excessive cord spacing, bubbles/delamination, bubbles in the second bead area, uneven tire interior, and exposed cord in the second bead area. We analyze the causes of these defects from various perspectives, including semi-finished components, equipment, processes, structure, operation, and environment, and propose corresponding preventive and control measures.

Key words: all-steel radial tire; X-ray; appearance; quality defects; control measures

Classification number: TQ330.491 **Article number:** 1009-797X(2026)10-0032-08

Document code: B **DOI:** 10.13520/j.cnki.rpte.2026.10.014

Since our company commenced production in 2010, we have encountered several long-standing quality issues that have plagued our production, such as shoulder bowing, excessive cord spacing, bubble delamination, uneven inner tube, and second-zone bubbles. After years of continuous research and efforts, we have achieved significant results. This work analyzes the causes of several common finished product quality defects in the molding process from the perspectives of semi-finished components, operation, process, equipment, and structural design, and proposes corresponding preventive measures.

1 Shoulder bend

Shoulder bend refers to the phenomenon where the tire shoulder cord lines exhibit local or full circumferential symmetrical or asymmetrical bending or wavy patterns on X-ray images (normal cord lines are straight). It is one of the common quality defects in all-steel radial tire X-rays. Generally, products with shoulder carcass steel cord bending of less than 4 cords are considered qualified, while those with ≥4 cords are deemed defective and rejected.

1.1 Analysis of Causes

(1) Tooling reasons: During the inflation and shaping process of all-steel radial tires on the building drum, the internal pressure causes a certain degree of yarn slippage in the carcass cord fabric. Practice has shown that there are certain differences in yarn slippage among different manufacturers' building drums, which results in variations in the curvature of the finished cord fabric on different building drums for the same specification and construction (as shown in Figures 1 and 2). Therefore, there are certain construction differences for the same specification on different building drums. Table 1 shows the current on-site construction difference values of the plane width of the building drums from various manufacturers in our company.

(2) Equipment accuracy The impact of equipment accuracy on shoulder bending primarily lies in the centering of the tread transfer ring, the centering of the carcass transfer ring, the flatness of the bead clamping claw, and the position of the clamping claw insertion. When the centering of the

Biography: Lei Taiwei (1985-), male, engineer, primarily engaged in the molding process and quality management of all-steel radial tires.

Table 1 Differences in setting of plane width of different forming drums

Molding drum manufacturer	TPV forming drum	Tianyang forming drum	University forming drum	Sai Xiang forming drum	VMI forming drum
Flat width value/mm	standard value	Standard value -4 (or -6)	standard value	Standard value -4 (or -6)	Standard value -4 (or -6)

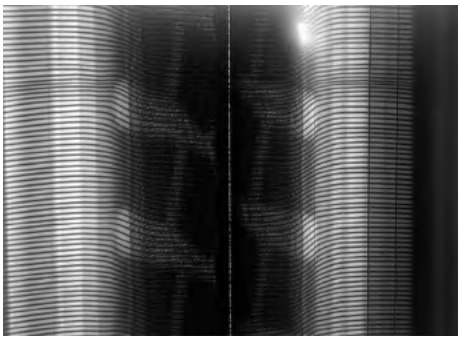


Figure 1 X-ray image of 16.00R20 two-drum 5# building machine

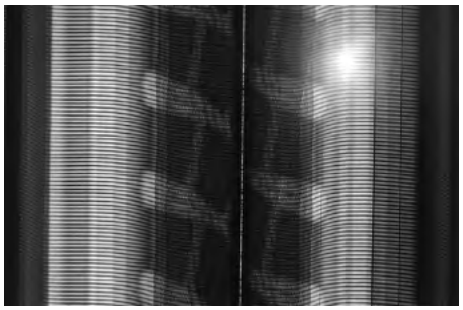


Figure 2 X-ray image of 16.00R20 two-drum 7# building machine

tread transfer ring exceeds the tolerance (generally ±1.0 mm), it results in asymmetric material distribution on both sides of the tire blank, causing shoulder bending on the side with more material due to the inability of the excess material to stretch the cord. The same applies to the carcass transfer ring. Different flatness of the bead clamping claw leads to variations in the length of the carcass cord at different points on the tire, resulting in localized shoulder bending. When the clamping position of the bead clamping claw is too high or too low, there are also differences in the internal width. The process requires that all bead clamping claws of the molding machine should be clamped at the root of the apex.

(3) Process Parameters The process parameters that affect shoulder bending mainly include flat width, drum width, internal pressure, and lock block pressure. Among them, the flat width parameter is the most direct construction parameter affecting shoulder bending. The flat width directly determines the length of the inner contour tire cord. When the flat width is too large, the excess tire cord cannot be accommodated by the tire inner contour, resulting in shoulder bending. Conversely, it leads to exposed cord in the tire. The drum width value is closely related to the molding drum (drum width = flat width - molding drum parameter). The drum width affects the length of the steel cord in the tire. When the drum width value is too large or too small, it can cause the steel cord to land on the inner or outer slope of the lock block, resulting in relative displacement between the steel cord and the tire body, which leads to changes in the length of the steel cord in the tire. Internal pressure affects the amount of tire cord extraction and the circumference of the tire blank. When the lock block pressure is constant, the greater the internal pressure, the greater the amount of tire cord extraction and the circumference of the tire blank, resulting in the tire cord being too long to stretch and causing shoulder bending. Currently, our company's light truck tires (below 19.5') have an internal pressure of 0.8~1.0 bar, and other specifications have an internal pressure of 0.9~1.2 bar. The magnitude of lock block pressure affects the diameter and locking force of the lock block. Generally, the lock block pressure is required to be ≥7.0 bar, and the upper limit can be adjusted according to needs. Our company's 16.00R20 specification frequently encounters shoulder bending issues when using Tianyang drums. After increasing the lock block pressure to 10 bar, the incidence of shoulder bending significantly decreased.

(4) Half-component quality: When the thickness or weight of the half-component, especially the tread/pad rubber, exceeds the standard, it may cause the shoulder of the finished tire to bend.

1.2 Solutions

(1) Determine appropriate process parameters (such as flat width, drum width, internal pressure, locking block pressure, etc.) for different equipment (forming drums).

(2) Conduct routine spot checks on equipment accuracy to ensure that the tread/carcass transfer ring, the flatness/concentricity of the clamping claw, and the clamping position of the bead claw meet the process standards.

(3) Adjust relevant parameters in a timely manner based on the degree of shoulder bending, risk, and frequency of

occurrence.

(4) Strictly control the dimensions and weight of the semi-finished parts and handle them according to the regulations for handling non-conforming products.

2 Carcass joint opening

"Carcass joint opening" refers to the condition where the cord is open or the cord spacing is ≥1/2 wire at the molded or straight-cut joint, which is one of the common defects observed in X-ray inspection of all-steel radial tires.

2.1 Analysis of causes

(1) Reasons for straight cutting There are mainly two reasons. Firstly, the process of cutting and trimming the cord fabric is unstable, resulting in exposed steel wires or excessive rubber, which leads to faulty joints [4]. Secondly, the distance between the lower baffle of the jointing device and the edge of the cord fabric should be uniform on both sides (based on the edge of the cord fabric just touching the baffle), to avoid inconsistent spacing between the steel wire cords on the left and right sides of the joint. Thirdly, improper adjustment of the gear spacing or pressure of the jointing device can cause faulty joints. Fourthly, unqualified joints are not marked as required.

(2) Reasons for formation: The excessive spacing between the forming stitchers causes the spacing between the joint steel wires to be too large or results in a loose joint opening. During the forming process, the cut length of the carcass ply is too short or there is too much excess rubber when cutting the joint. The straight-cut carcass ply bends, causing the steel wires at the joint to bend, and after suturing, the spacing between the steel wires becomes too large.

2.2 Solutions

(1) Improve the quality of large coil winding, ensuring that the deviation of large coil winding is ≤3mm; adjust the trimming blade torque to avoid exposed steel wires and excessive glue; check that the spacing between the edge of the cord fabric and the baffle of the splicer is uniform on both sides, and adjust the conveyor belt in a timely manner if there are abnormalities; regularly inspect the spacing between the gears of the splicer; check the pressure of the sewing machine at the beginning of each shift to ensure it meets the standard; mark the unqualified splices during straight cutting.

(2) During the molding and starting inspection, check the suture spacing (approximately the thickness of 3 transfer cards) and ensure that the joint sutures are free from openings or pinched steel wires. If any abnormalities are found, promptly adjust or repair the suturing device. When cutting the carcass, cut an additional 1-2 steel wires to avoid cutting too short, which could result in excessive spacing between joint steel wires. Cut off the bent parts of the carcass cords to prevent joint openings.

3 Belt layer deviates from the centerline

Deviation of the belt layer from the centerline is also a common X-ray defect in production, which can manifest as overall deviation, local deviation, local deviation of a single belt layer, or overall skewing of the belt layer. The main causes include equipment, semi-finished parts, operational, and process issues.

3.1 Reason analysis

(1) Equipment reasons: The crown position or the position of the upper belt layer is skewed during molding due to the transfer ring. This manifests as a whole-circumference skew of all belt layers, which is generally rare. The local skew of the belt layer is mainly caused by the non-conformity of the roundness of the tread transfer ring clamping block or the oversized diameter of the clamping block, resulting in local skew of the tread molding drum.

(2) Technological reasons: The mismatch between the inflation and contraction speeds of the forming drum, especially when the inflation speed of the forming drum is slow while the shoulder contraction speed is too fast, can easily lead to severe local deflection of the tread, resulting in local deviation of the belt layer from the centerline. Generally, it is necessary to maintain the tire cord in an extended state throughout the entire inflation process to avoid the tire cord being in a wavy shape and causing local deflection of the belt layer.

(3) Half-component reason: The width of the belt layer is unqualified. On the X-ray image, it is manifested as asymmetric differences between the left and right sides of the belt layer, or overall or partial deviation or indentation at the edge.

(4) Operational reasons: During the molding and bonding process, if the partial bonding of the belt layer is skewed and the width of the belt layer exceeds the standard, and the

positioning is still done on one side, it may cause the other side to be skewed and exceed the tolerance, resulting in the belt layer deviating from the centerline.

3.2 Solutions

(1) For each shift, conduct an initial inspection of the tread transfer ring's alignment (with a deviation of ≤1mm) and promptly adjust any non-compliant equipment.

(2) Adjust the shrinkage speed of the forming drum, as well as the inflation time and pressure, to ensure that the carcass cords are in an extended state.

(3) Inspect the width of the bias-cut and molded reinforced belt layer to avoid non-conforming belt layer width and uneven width.

(4) Train employees to pay attention to both the left and right sides when applying the belt layer, ensuring that the positioning deviation on both sides is ≤2mm, and overcome the operational habit of positioning on one side only.

4 Excessively large cord spacing

Excessive cord spacing is also one of the more common defects observed during X-ray inspection of finished products, mainly referring to the phenomenon where the spacing between two or more adjacent carcass cords is greater than the normal cord spacing.

4.1 Reason analysis

(1) Joint reasons: The joint of the tire side inner liner pad is large and open. When the joint is large, the excess rubber compound at the joint is squeezed and penetrates into the steel cord under the pressure of the bladder, resulting in excessive spacing between the steel cords of the tire body. During the cracking process of the tire side inner liner pad joint, the cords will move synchronously under the adhesive force, causing excessive spacing between the steel cords.

(2) Carcass stretching: The speed of the fitting drum does not match the speed of the carcass feeding template, meaning that the rotational speed of the fitting drum is greater than the speed of the carcass feeding template, resulting in stretching of the carcass cord. This is manifested as excessive spacing between local sections of the carcass cord. Manual stretching, when handling straight-cut joints or cutting carcass with a shorter length, often leads to stretching of the cord at the joint, manifested as excessive spacing at the joint. If employees do not operate according to standards, and the required distance between adjacent carcass joints is ≥200mm, when the actual distance between adjacent joints is too close (≤50mm), the cord between the joints is prone to excessive spacing.

(3) Other reasons: When the steel wire of the carcass cord and the rubber compound delaminate, the steel wire becomes separated from the rubber compound during inflation, resulting in excessive spacing between the steel wires.

4.2 Solutions

(1) Train employees to strictly follow standard operating procedures. Incorporate tire blank quality into daily inspections, with a focus on controlling tread, sidewall, and inner liner joints to avoid large or open joints.

(2) Adjust the speed of the equipment template to avoid stretching of the curtain; train employees on operating techniques, such as cutting 1-2 extra steel wires to prevent short connectors from being stretched; ensure that the spacing between adjacent connectors is ≥200 mm.

(3) The large coil of steel wire has delamination that needs to be cut off, and the joint area with slight delamination should be treated by attaching a 30×0.6 mm rubber sheet.

5 Sidewall bubble/delamination

Bubbles/delamination are the most significant appearance defects of our all-steel radial tires. Bubbles and delamination belong to the same category of defects. Bubbles refer to the internal bulging of finished products due to air accumulation, which may occur between two components or within the component rubber.

5.1 Reason analysis

(1) Half-component reasons: The main reasons are moisture in the half-component (commonly found on the surface of the extruded half-component or under the rubber sheet, at the rubber sheet joints, and in the pleated areas of the rubber sheet), and impurities in the half-component (such as impurities from plastic pads, paper scraps, adhesive tape, dust, small chemical particles, and internal mixing release agents).

(2) Technological reasons: It mainly involves three aspects: the position, speed, and pressure of the rolling of the apex/sidewall. The rolling position is required to be as close to the sidewall or the root of the apex as possible, and the apex should be rolled as much as possible. Theoretically, the rolling

speed should be as slow as possible, but in practice, production efficiency needs to be taken into account. The rolling speed for two-drum/three-drum racing drums is generally in the range of 300~600 mm/min, and for high-efficiency three-drum/four-drum racing drums, the rolling speed for the sidewall is 10~20. To prevent delamination between the apex and the carcass, the rolling speed of the apex is about 1/2 of the sidewall speed. Generally speaking, the bubble count in tubeless specifications is higher than that in tube-type specifications, so the rolling speed is slower in tubeless specifications.

(3) Environmental Reasons: Based on the analysis of the relationship between the number of bubble delaminations and seasons in recent years, summer (May to August) is the high-incidence season for bubble delamination in our company, while the number of delaminations in other months is relatively low. The reason for this is that under high temperatures in summer, the thermal expansion coefficients of rubber and internal steel cord differ, leading to increased interlayer stress. The rubber expands faster, while the metal cord expands less, which can easily cause interfacial separation, forming bubbles or delaminations. At the same time, the adhesive between the rubber layers softens at high temperatures, reducing the bonding strength. Continuous high temperatures may accelerate the aging of the adhesive, causing it to lose its bonding effect. Some specifications of tire blanks are prone to delamination at the bead area in summer. During vulcanization, bubbles expand in volume at high temperatures and move towards the thinnest part of the tire sidewall along the horizontal axis under the compression of the vulcanization bladder. Due to the adhesive force between the apex and the carcass, the bubbles cannot be discharged, resulting in bubble delamination between the bead apex and the carcass.

(4) Other reasons: The viscosity of semi-finished components, especially the sidewall, carcass, and apex rubber, has a significant impact on the delamination of the sidewall and inner tube. Poor viscosity can reduce the adhesive force between components, leading to the formation of delamination bubbles during vulcanization or at high temperatures in summer.

5.2 Solutions

(1) Preventive measures mainly involve checking whether there is any release agent on the rubber sheet joints of the final rubber compound during the initial lap joint, inspecting the storage time of semi-finished parts, water stains, and various impurities on site, promptly cleaning them to avoid being carried into the tire embryo, and increasing the inspection of impurities on the cutting pad cloth.

(2) Check whether the tire sidewall/triangle rubber pressing roller is loose and swinging, and whether the starting position, pressure, and speed of the roller pressing are within a reasonable range.

(3) The main preventive and control measures for delamination bubbles in summer include controlling the inventory of tire blanks, implementing a first-in, first-out (FIFO) system for tire blank requisition, limiting the number of vulcanized tire blanks, and controlling the duration of their placement in the vulcanization area.

(4) Use large rolls according to first-in, first-out (FIFO) principle, adjust the formula or rubber mixing process to improve the viscosity of the rubber compound.

6 Bubbles in bead area 2

Bubbles in the second bead area are a common appearance quality defect in all-steel radial tires, mainly occurring in the area between the bead toe and heel, as well as at the bead toe. They once accounted for half of the company's quality defects, but significant progress has been made through continuous research and efforts in recent years.

6.1 Analysis of causes

(1) Structural design reasons: The main issue is that the transition layer of the inner liner adopts a flat roller, resulting in a thicker edge of the transition layer, which leads to a noticeable step-like appearance in the second bead area, making it prone to trapping air and causing bubbles in the second bead area. Secondly, the distribution of component endpoints at the bead area is unreasonable. For some specifications, the overlap or distance between the inner liner and the sidewall rubber sheet is too close, and the distance between the inner liner rubber sheet and the inner liner endpoint is too close, which is not conducive to bubble dispersion.

(2) Process reasons: Mainly due to semi-finished parts and operational issues. The semi-finished parts mainly involve the width of the inner liner, positioning of the rubber sheet, and positioning of the sidewall rubber sheet. Operational reasons

mainly include the positioning of the sidewall/inner liner and the formation of steps due to the overlapping of steel cord bead wire connectors.

(3) Equipment reasons: Different equipment poses varying risks of bubble formation in the second bead area due to their different forms. Currently, our company's equipment includes three-drum building machines with two different structures: in-machine compounding and single-on-sidewall lining. Statistical results show that these two different structural forms of building machines have different incidences of bubble formation in the second bead area for the same specification. Practice has shown that the in-machine compounding building machine structure has a lower incidence of bubble formation in the second bead area. There are two differences in tracking the machines: firstly, the in-machine compounding building machine structure features a compounding roller that can roll the differential edge areas of the upper and lower layers of the lining, reducing the probability of bubble formation in the second bead area. Secondly, the in-machine compounding lining has smaller dimensional changes (the stretching amount of the in-machine compounding lining is 1~2 mm, while the stretching amount of the single-on-sidewall lining is 3~5 mm). Therefore, the in-machine compounding building machine generally has a lower incidence of bubble formation in the second bead area.

6.2 Solutions

(1) Structurally, the component endpoint positions are adjusted for the specifications of the second zone where bubbles are prone to occur: the sidewall rubber sheet maintains a certain distance (generally more than 15 mm) from the inner liner to avoid overlap between the inner liner and the sidewall rubber sheet; the distance between the inner liner rubber sheet and the transition layer (or the edge of the airtight layer) is at least more than 10 mm;

(2) During the production process, it is necessary to improve the quality of semi-finished parts, such as the width and grade of the inner lining, as well as the positioning of the rubber sheet. In terms of molding operations, the focus should be on ensuring accurate positioning of the semi-finished parts and proper connection of the steel wire bead wrap joints. Supervision should be carried out to ensure the width and grade of the inner lining.

(3) Equipment should be enhanced with sidewall puncture holes and tire stripper piercing rollers for prevention. In equipment selection, priority should be given to the structure where the inner lining layer is compounded within the machine, and the forming drum should be of a seamless drum structure.

7 Unevenness in the womb

"Tire unevenness" refers to the phenomenon of uneven protrusions on the inner surface of the tire, mainly occurring in the shoulder area. The main causes include process parameters, 0° tension, tread bonding width, and sidewall turnup height.

7.1 Reason analysis

(1) 0° belt tension: The 0° belt has a counteracting effect on the expansion of the tire blank. During the vulcanization process, the tire blank's circumference increases due to the expansion force of the bladder. Excessive 0° belt tension can cause the shoulder and mid-section to expand asynchronously, resulting in a reverse curvature at the shoulder, visually manifesting as uneven tread. Currently, effective measurement of 0° tension is not feasible. The visual inspection method involves observing the floating roller above the 0° feeding frame to ensure normal up-and-down floating, avoiding tightness during the 0° bonding process.

(2) Tread bonding width: If the tread bonding width is too small, there will be too little material at the shoulder area during vulcanization, causing the inner liner and carcass rubber compound to move outward and fill in, resulting in thread exposure and reverse curvature at the corresponding part of the tire; if the tread bonding width is too large, there will be excess material at the belt end or middle of the tire crown, forming reverse curvature inside the tire during molding. Therefore, it is necessary to monitor the tread shoulder width and the tread bonding width of the molded tire embryo to ensure compliance with standards. The tread bonding width is affected by various factors such as the hardness, thickness, temperature, shape, rolling (parameters, procedures, roller form, trajectory) of the tread rubber compound. Generally, for light trucks, the tread shoulder width increases by 10~15 mm before and after bonding, while for other specifications, the difference is 20~25 mm.

(3) Sidewall turnup height: When the sidewall turnup

is low, the corresponding part has insufficient vulcanization time and the material is too thin, causing the inner liner rubber compound to migrate outward, resulting in exposed threads in the corresponding part of the tire cavity. When the sidewall turnup is high, there is too much rubber compound in the sidewall area, leading to unevenness in the corresponding part of the tire cavity. Generally, the sidewall turnup height for light truck specifications is 0 to -15 mm, and for other specifications it is 0 to -25 mm.

(4) Process parameters The main process parameter affecting the unevenness of the tire inside is the circumference of the auxiliary drum. When the circumference of the auxiliary drum is too small, it can result in a smaller circumference of the tire blank. Under the expansion force of the curing bladder and the clamping force of the belt layer, unevenness in the middle or shoulder area of the tire inside is prone to occur. Adjusting the circumference of the auxiliary drum is one of the effective measures to solve the unevenness of the tire inside.

7.2 Solutions

(1) Adjust the 0° detection switch or the feeding template, as well as the rotational speed of the auxiliary drum, to maintain vertical floating during the feeding process of the 0° belt with floating rollers, thereby avoiding the phenomenon of the 0° belt being pulled straight and taut.

(2) Adjust the pressure and speed of the tread press roller to ensure that the tread bonding width of the tire meets the standard.

(3) Check the width and positioning of the tire sidewall, adjust the inflation size of the turn-up boosting bladder or add a mechanical drum turn-up finger to ensure that the turn-up height of the tire sidewall meets the standard.

(4) On the basis of confirming that the 0° tension, tread bonding width, and sidewall turnup height are all qualified, the circumference of the auxiliary drum can be appropriately adjusted. Generally, an increase of 5~10 mm can solve the problem.

8 Exposed wire in the second bead area

Exposure of cord in the second bead area is a common appearance defect in all-steel tire production. The fundamental reason for the occurrence of this defect is that the diameter of the tire embryo bead is smaller than that of the vulcanized steel bead.

8.1 Cause analysis

(1) Design reasons: The thickness of the wear-resistant rubber is too thick, and the diameter of the steel wire ring is too small, resulting in a smaller diameter of the molded tire blank;

(2) Tooling reasons: The main issue is the diameter of the locking block support for the forming drum. Practice has shown that different manufacturers often have different locking block support diameters. Taking our company's 16.00R20 specification as an example, the inner diameters of the tire bead rings in the TPV forming drum and Tianyang forming drum are φ512 and φ506 respectively, with a diameter difference of up to 6 mm. Therefore, when processing the forming drum, it is necessary to clarify the tire bead ring diameter standards with the forming drum manufacturer. Table 2 shows the current standard range of tire bead ring diameters for various specifications in our company:

(3) Operational reasons: When the positioning of the sidewall compound is skewed, or when the sidewall or inner liner is excessively skewed, it can lead to an increase in material thickness at the bead area and a smaller inner diameter, resulting in exposed threads in the second zone after vulcanization.

Table 2 Reference standards for the circumference of the tire bead

Rim diameter / inch	16'	17.5'	19.5'	20'	22.5'	24.5'
Bead circumference of tire/mm	1 250~1 260	1 350~1 360	1 520~1 530	1 600~1 610	1 740~1 750	1 880~1 890

(4) Other reasons: deformation of tire blank, etc.

8.2 Solutions

(1) Adjust the thickness of the wear-resistant rubber on the tire sidewall or appropriately increase the inner diameter of the steel wire bead ring in terms of structure.

(2) Appropriately increase the pressure of the molding lock block or increase the thickness of the capsule bead area by 1~2mm. For newly purchased molding drums, specify the diameter requirements for the lock block support or the standard requirements for the tire bead.

(3) During the molding production process, inspect the alignment of the tire sidewall, inner liner, and transfer ring to ensure proper centering, avoiding any uneven material distribution that may affect the diameter of the tire bead.

(4) Use tire blank carts of different sizes according to the tire blank specifications, or use pallets to store them to reduce bead deformation. Follow the first-in, first-out principle when using tire blanks to avoid deformation caused by long-term storage.

9 Conclusion

Through analyzing the above-mentioned appearance quality defects of our company's main finished products X, as well as the continuous improvement efforts made in recent years and the promotion of standardized operational work in the company, the main difficulties that constrained the company's product quality have been effectively improved. The pass rate of finished products has increased from 99.73% to 99.79%, achieving good economic and social benefits.