

TIRE TREAD SEPARATION - TWO THEORIES OF LIABILITY

By John D. Rowell

In this article I discuss two theories of products liability in tire tread separation cases.

The first theory, failure to use nylon cap plies, is based on the contention that including a nylon (or other synthetic) belt immediately above the steel belts in the tire, will eliminate or greatly reduce both corrosion. The nylon cap also acts to reduce the tendency of the edges of the steel belts to break free of the rubber in which they are embedded. The use of caps or strips in this fashion has been the subject of numerous patents and strips and caps have been used on some tires for more than 20 years. Almost all manufacturers now use strips or caps to increase tire endurance, although not necessarily in passenger tires.

The second theory discussed concerns the make-up and thickness of the tire's inner liner. The inner liner prevents the pressurized air in the tire from seeping through the tire. Inner liners are made of compounds which have thick molecular structures. These structures make it more difficult for air molecules to move through the material. If the inner liner is made of the right material and the material is thick enough, air and moisture migration is prevented. However, the materials used for the inner liner are the most expensive in tire production. Thus, tire manufacturers tend to make the inner liners as thin as possible. However, recent studies of tires in the field show that the tire manufacturing process apparently does not allow the manufacturers to meet these demanding specifications. As a result, the inner liner is measurably thinner than it should be, especially in the shoulder area. The result is an increase in air and moisture permeation. The problems with moisture are discussed above and below. Coupled with heat, air permeation causes a chemical reaction which breaks down the adhesive quality of the rubber. When this happens in the shoulder area, it combines with the natural tendency for micro cracking near the belt edge and results in separation. Studies by Exxon Mobile Chemical showed the direct connection between inner liner make-up and thickness and tread separation.

These theories are related and the effects of one design problem accentuate the effects of the other.

Belt Edge Separation, Tire Construction and Cap Plies

By the mid 1950s, Pirelli had recognized that the tendency for belt edge separation in SBR tires was due to the free cut ends of the steel belt's cords becoming detached from the rubber in which they embedded. This phenomenon, belt edge separation, was later acknowledged as the principal mode of failure in SBR tires.¹

At about the same time, Michelin recognized the belt edge separation problem² and by 1965 was describing it in the same terms as Pirelli, stating that folded belt edges could overcome belt edge separation when used with textile belts but not with steel belts because the steel belts would fracture at the point of the fold.²

In 1968, Michelin was still concerned with the problem of belt edge separation in SBR tires and proposed reinforcing the radial carcass in the transition region of the belt edges.³ At about the same time, Dunlop described the problem of belt edge separation in SBR tires causing tire failure and proposed to reduce or substantially eliminate it by overlaying the belt edge regions with strips of reinforced fabric.⁴

In 1971, Michelin listed the measures available at that time to prevent the breakdown of the bonding at the edges of the steel belts and thereby improve the capability of SBR tires to sustain higher speeds and stresses as follows:

- (a) Staggering the edges of the belts, making the inner ones wider than the outer so as to produce a gradation of rigidity which favors better belt edge bonding with the carcass.
- (b) Employing wedge shaped sections of rubber between the belt edge zones to cause radial divergence of edges of the belts.
- (c) Reinforcement of the tire carcass with a narrow cord or cable reinforced ply appropriately positioned at each edge as described in Michelin Patent 3,386,487.³

At the same time (1971) that Michelin was proposing these measures to prevent SBR steel belt edge bonding breakdown, Uniroyal (France) discovered a more comprehensive design solution to the problem applicable to passenger and heavy vehicle tires with two or more steel belts. This invention, described and illustrated in U.S. Patent 3,786,851,⁵ uses a band of fabric reinforced with parallel nylon cords to stabilize the steel cord tread belts ("cap ply")- During the tire building process, the band is wound tightly around the outside of the steel belt structure so as to overlie it and extend laterally beyond the steel belt edges.

During the tire curing process in which the tire is heated under pressure, the cap ply shrinks, cinching itself in place around the steel belts. As separations between the steel cords at the steel belt edges tend to form and grow during the use of the tire, particularly at turnpike speed and at high ambient temperatures, the cap ply keeps the steel belts and particularly the steel belt edges in place.

The maximum running speed that a SBR tire will sustain before the steel belt structure disintegrates is an accepted measure of the integrity or durability of the tire.⁶ In test comparisons of

otherwise similar SBR tires with and without such nylon bands, Uniroyal demonstrated that the use of such bands increased the tire failure speed by 56%.⁵

Figures Nos. 1 and 7 illustrates a SBR tire employing cap ply nylon belts taken from Uniroyal U.S. Patent 3,850,219.⁷ A modification of this concept to include folding of the edges of the cap ply belts in order to strengthen the shoulder regions of SBR tires and therefore prevent high speed edge separations is also described in another Uniroyal patent.⁸

Later development of the cap ply principle by forming the cap ply with single yarns rather than twisted cords was aimed at reducing the weight, thickness, and cost of the cap plies, reducing the build up of heat, and improving heat dissipation so as to further reduce belt edge separation.⁹

In another United States patent, Uniroyal summarized the status of the SBR belt edge separation problem as it existed at the beginning of 1973 by stating that such tires

"..frequently fail because separations occur in the shoulder zones of the tires where the edges of the belt plies are severely flexed as the tire tread moves into and out of contact with the road during each revolution and becomes detached from the surrounding rubber. The centrifugal forces acting on the tire and the heat build-up in

the tire also contribute significantly to this problem. Such separations are made even more likely by the fact that the cords or cables in the belt plies, being disposed obliquely to the median equatorial plane of the tire by virtue of the plies being cut obliquely with respect to the natural tendency to spread apart or open in a fan-wise direction at their cut ends. The edges of the belt thus constitute zones or regions where the cut and free ends of the reinforcing elements, i.e., the cords or cables, by friction and by cutting, cause breaks both at their juncture with the carcass plies and the tread rubber of the tire."¹⁰

By 1978, Uniroyal was still concerned with means of ameliorating the tread belt edge separation problem in SBR tires, stating that the nylon cap plies help to prevent belt edge separation:

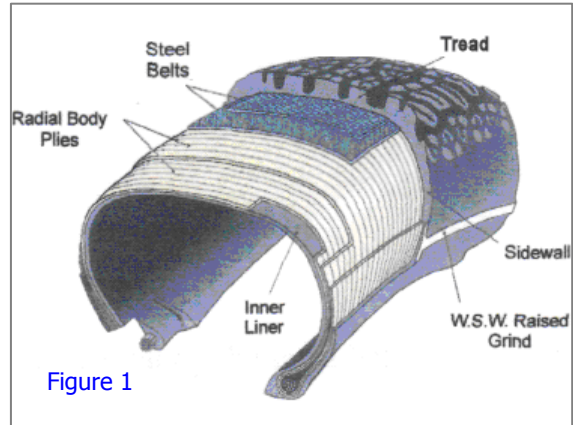


Figure 1

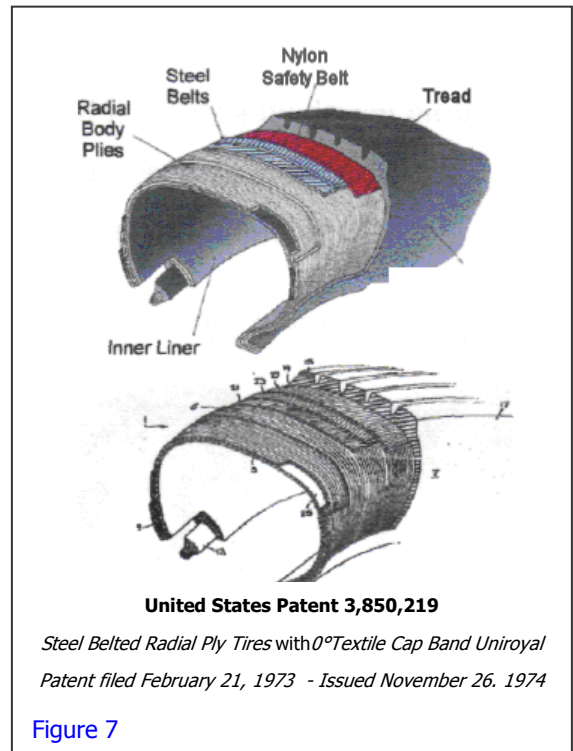


Figure 7

"a further increase in resistance to belt edge separation by cap plies alone is still desirable"¹¹ and was describing belt separation as a:

"major problem of paramount importance."¹²

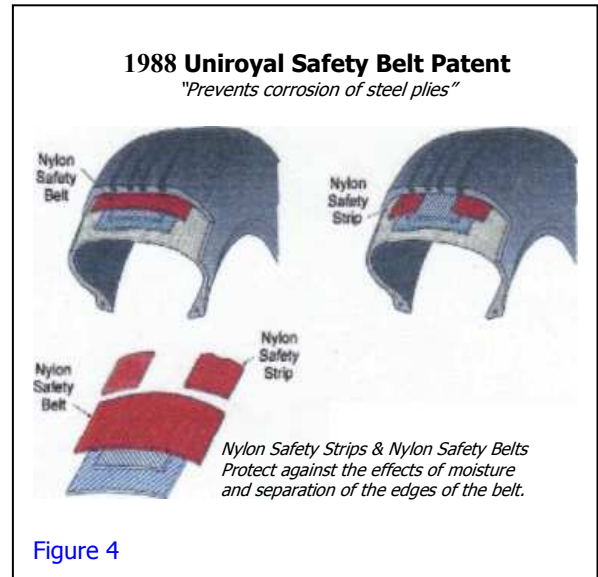
By 1988, 14 years after publication of its important invention of overlay cap bands for SBR tires,⁷ Uniroyal again revisited the problem of SBR tread separation and its control by design means. By then, Uniroyal was referring to such cap plies as "safety belts" and in a patented improvement¹³ on its previous invention of them reaffirmed their suitability as a design safety measure for SBR tires.

The improved safety belt design substituted monofilaments for the multifilament reinforcement elements previously recommended. The safety belts of this design could be in the form of complete belt overlays or as strips overlying only the critical edges, as illustrated by Figures Nos. 4 and 5.

Numerous other textile overlay structures designed to overcome the above described deficiencies and hazards of SBR tires pervade the patent literature including those of Goodyear^{14,15} and Bridgestone.¹⁶ The profusion of the many designs described in the patent literature to control the SBR belt separation underscores the magnitude and importance of the problem itself.

This review of the history of the tread separation problem and the existence of admittedly successful design means of mitigating it begs the question of why these means have not been put into more widespread use for the safety benefit of the ordinary motorist.

Only in the late 90s have some manufacturers, such as Bridgestone/Firestone, adopted the safety belt systems developed in the early 1970s in their ordinary tire product lines and used this safety advantage to promote their tires at point or sale with such literature as illustrated in Figures Nos. 2, 3 and 6. Even those applications were limited, the



vast majority of tires manufactured by Bridgestone and Firestone had no such upgrades.

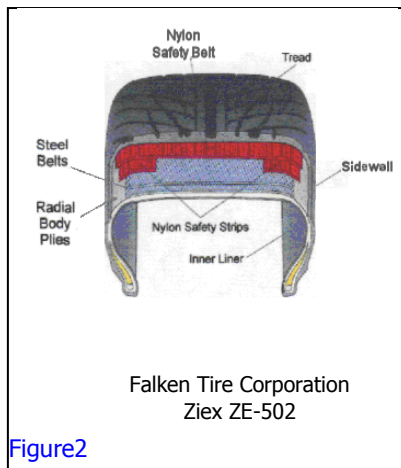


Figure 2

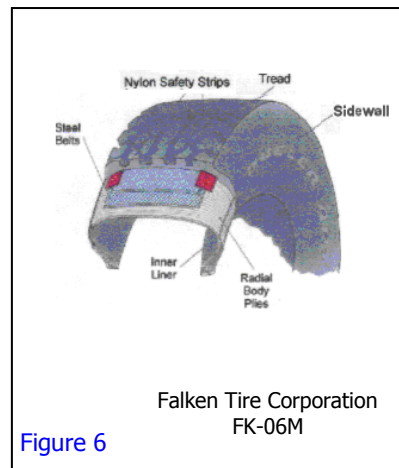


Figure 6

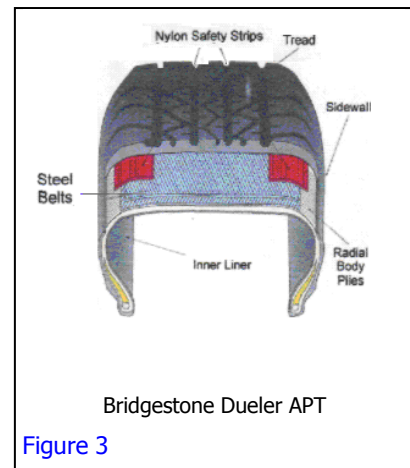


Figure 3

When, in 2000, Congress held hearings concerning the Explorer/Firestone tire fiasco, Bridgestone/Firestone finally, but secretly, decided to use nylon cap plies and strips on all tires used on SUV's. However, Bridgestone/Firestone took three years to implement this change. Most importantly, the company excluded previously certified original equipment tires from the upgrade. Bridgestone/Firestone did not tell any of the automobile manufacturers which were purchasing original equipment tires of this upgrade.

Tread Separation and Inner Liners

Rubber is porous. Anyone who has left an inflated balloon overnight can tell you that air seeps through rubber. Not only does the porous nature of rubber create a potential problem with tires becoming under inflated, when air seeps through a tire's rubber in the presence of heat, a chemical reaction occurs which degrades the adhesive qualities of the rubber used in the body of the tire. This, in turn, will lead to tread and belt separation as the tire becomes older.

In order to prevent seepage, tire inner tubes were made out of butyl compounds which were very resistant to air and water permeation. The first major use of butyl rubber was tire inner tubes. When the tire manufacturers went to tubeless radial tires in the 50s, it was necessary to include in the tire carcass itself an inner liner of material that was not as porous as plain rubber.¹⁷ By the 60s that portion of the tire, the inner liner, was generally composed of compounds which included butyl tube reclaim. This afforded some air retention because the chlorinated butyl rubber was less porous than the rubber compounds being used in the body of the tires.¹⁸ However, another problem arose. Increased heat during operation was causing the reclaim butyl inner liners to become brittle and crack, resulting in internal separation and increased porosity.¹⁷ This, in turn led to tread separation tire failures as more air seeped or migrated through the tire body. Compounding this problem was the fact that the loss in air pressure caused an increase in operating temperature.

Different compounds were tried. Chlorinated isoprene-isobutylene rubber (CIIR) blended with natural rubber was incorporated. In the 60s studies of CIIR and brominated isoprene-isobutylene rubber (BIIR) were conducted showing the benefits of using these compounds in inner liners.¹⁹

In the late 60s, tubeless radial tires were introduced in the United States. Some passenger tire manufacturers and all truck tire manufacturers used BIIR for inner liners from the outset. However, many passenger car tires used natural rubber (NR) based inner liners. Studies showed that NR blend inner liner tires degrade over relatively short periods of time. In one study, after 20 cycles (approximately 36,500 miles), the average tear strength of inflated tires was reduced from 100% to 34-38%.

Concurrently, N. Tokita was studying the effects of inner liner on belt edge separation, the most common precursor to belt/tread separation. Tokita's studies showed that "inner liner permeability and gauge were the most influential [factors] for BBS (belt edge separation); highly oxygen permeable inner liners re the most severe."²⁰ Studies in the 80s confirmed the findings of Tokita's study in the real world of normal consumer tire use.

By the late 60s CIIR/NR blend inner liners were in use by several U.S. tire companies and over the 70s and 80s CIIR and BIIR inner liners were adopted world-wide. The butly compounds had always exhibited excellent resistance to air and water permeation and good flex fatigue properties.

Bromobutyls (BIIR) had several advantages over CIIR and NR. BIIR compounds had better adhesion, and worked better in tires which had higher surface area to air volumes (lower profile tires). BTIR compounds were lighter. BIIR compounds also worked better with higher air pressure tires, such as truck, light truck and space-saver spares, and had better flex cracking resistance.¹⁷ These butyl compounds were halogenated, speeding up curing rates and increasing polarity, in turn favorably impacting ease of use in the tire manufacturing process and impermeability.¹⁷ Halogenated butyl rubber compounds are sometimes referred to as halobutyls (HIIR).

These compounds used in inner liners are the most expensive components of the tire. Because HIIR/BIIR was more resistant to air permeation, it could be applied at half the thickness, reducing cost.¹⁷ In 2005, Exxon Mobil Chemical, the major manufacturer of HHR/BIIR published testing results which showed the comparative performance of inner liners manufactured with 100-phr BUR and 80/20 and 60/40 blends of BIIR/NR in identical radial passenger tires. Cured inner liner thickness averaged 1.0 mm. These tests concluded:

"Halobutyl rubber inner liners are the best at retaining pressure, both air and moisture, and minimize the temperature dependence of air permeability. They are approximately an order of magnitude less permeable than other elastomers.

The integrity of the tire is improved significantly by using a 100-phr bromobutyl rubber formulation in the inner liner, since it minimizes inflation pressure percent loss per

month, minimizes the development of intracarcass pressure which could lead to belt edge separation and adhesion failures, and maximizes tire durability as determined by measuring the hours to failure by a belt-to-belt separation on indoor road wheels."²¹

For the last twenty years, ExxonMobil has been testing various tire designs with halobutyl. In each test cycle, each tire manufacturer is asked to generate copies of a particular size tire. The copies are identical in construction, except for halobutyl content of the inner liners. The inner liners are 100phr halobutyl, 80phr halobutyl, and 60phr halobutyl. The gauge or thickness of the inner liner is kept the same as the tires marketed by the manufacturers. These tests conclusively show that (1) the higher the halobutyl content, the more effective the inner liner as a barrier, and (2) the thicker the inner liner, the more effective the barrier.²¹ An inner liner which is insufficiently thick, does not work as well. Each tire is represented and the results set forth. The study carefully avoids identifying the tire by manufacturer, but each tire is also identified by tire construction (number of steel belts, number of poly plies, whether cap or cap strips are used and what configuration) which will afford some clues as to manufacturer. The tires are grouped according to market, with the U.S. tires separated from Asian tires and European tires. Because these test tires are specialty manufactured, they do not vary from the manufacturer's specifications. The same is not true in the field. An in field study has been conducted over the last three years by tire experts not affiliated with the industry. Used tires are cut and the thickness of the inner liners at various points measured. The results show that most tires vary considerably from the manufacturer's intended specification. Tires that have suffered tread separations tend to vary more from the intended thickness and, predictably, that variance tends to result in portions of the inner liner being too thin. These tires also exhibit "cord shadowing," while the tires which are within specification may not.

A thin or uneven inner liner can cause eventual separation by itself or in conjunction with the other defects identified above.

Conclusion

Your expert can tell you if any forensic evidence exists in the tire or tire tread and belt remnants which would support any of these three theories. Corrosion and inner liner thickness can be determined from examination of the tire and tire remnant (although the type of bonding agent used will have to wait for discovery). The lack of cap plies is obvious from the design or from cutting an exemplar. (Remember to cut OE Bridgestone/Firestone tires as Bridgestone/Firestone's replacement tires may include nylon caps even though the OE does not.)

Understanding the above theories should be of significant help in your discussions with tire and metallurgy experts. There are, of course, a number of manufacturing defects, not discussed above, which can lead

to tread separation. It is always important to listen to your expert. The above discussion should help in understanding the how and why of the most common defect theories. Of course, more detailed information is available. Manufacturer-specific evidence supporting these theories is out there, usually protected by non-sharing protective orders. These cases are difficult and technically challenging.

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