TIRE FAILURE ANALYSIS REPORT

In the case of:

Johnson v Hankook

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INTRODUCTION

I am by training and experience a tire failure analysis and tire design expert. I have been employed in the tire industry for 17 years with Dunlop Tire Corporation (later Goodyear-Dunlop Tires North America, Ltd.), designing, manufacturing, and testing steel belted radial tires and others. I have also examined numerous tires that have been involved in tread separation accidents since leaving my employment in the tire industry. My C.V. is attached.

THE TIRE MANUFACTURING PROCESS (passenger and light truck)

The raw materials required to produce a steel-belted radial tire include both synthetic and natural rubber types. In all, a single tire may have more than thirty five different processed component parts.

The tire will include chemicals to assist in the bonding of one component to another, to reduce the effects of oxygen and ozone degradation, to accelerate and activate chemical bonds and molecular cross-linking of polymers and fillers and salts, and to improve the process-ability of the rubber compounds through the Banbury mixing process, rubber mills, and extruders.

Ingredients called fillers are the building blocks of the rubber formulas. These include clays, carbon blacks, zinc oxides, silica, and others. They each provide strength to the rubber formulation, as well as other properties.

The Banbury is a giant blender which mixes rubber in large batches. Operators use a batch recipe for a specific rubber formulation type and add the proper number of bales of natural rubber, synthetic rubber, aromatic or naphthenic oils, wax, sulfur, and other curatives onto a weigh station conveyor which is fed into the Banbury. Loose items like carbon black or silica are conveyed in from outside silos to reduce the environmental impact of handling the dusts. Within the Banbury high heat and pressure is applied to the batch.

The rubber batch is removed hot from the Banbury, but as it cools it is processed as slabs of rough rubber stock.

The slab stock is further processed on breakdown mills, which masticate the rubber between pairs of rollers continuously until the compound can be properly worked onto another mill type called a feed mill. The feed mill prepares the milled stock to be fed through an extruder die to become components such as tread or sidewall stock.

Other rubber types are used for skim on fabrics used in the tire, such as polyester, nylon, and rayon. These could be nylons used as cap plies, body plies, bead bundle wraps or flippers, sidewall inserts, or chafers. In today’s radial passenger tires polyester and rayon are more highly utilized as body ply fabrics than nylon. The processing of rayon is not as environmentally friendly as polyester, but continues to be used heavily in the European market. Though some rayon is used as ply material in North American produced tires, the expansion is in polyester. Still other rubber formulations are used as skims on the steel belts.

After all calendered fabrics, extrudants, and calendered rubber are processed the tire can be assembled.

Bead

Once the correct links are inserted on the bead winder to hold the desired inside bead diameter, the specified bead configuration can be produced. The strands of wire are run through a cold-feed extruder to coat the wires in a layer of rubber. Whether by a taped bead assembly (turns and strands) or by a single wound bead (hexagonal or polygonal), the final bead assembly is a hoop of layered steel wires embedded in rubber.

Some manufacturers staple the loose end to the rest of the bundle. Some spiral a nylon thread around the splice point at the last wire end. Some wrap the entire wire bundle length in a coated nylon wrap. While some have increased the tack properties of the rubber coat sufficiently to keep the last turn of wire(s) from lifting off the hoop during tire building and curing.

The next process might be the application of a bead apex to the bead bundle. With a bead bundle width of four, five, six, or seven strands wide, a natural void occurs above the bead due to the difficulty of getting the plies to conform around the square or polygonal shape of the bead.
To remedy this, a rubber filler (apex) is installed atop the bead bundle. Dimensionally, these can range from as small as one half inch in height to several inches tall. Of course, the smaller the apex, the less performance it actually contributes in its ability to stiffen the lower sidewall and damp inputs, as discussed earlier under the tire design heading.

To countermeasure against the apex separating from the bead bundle in tire building, curing, or in-field service, some manufacturers utilize a coated nylon "flipper" material to wrap the bead bundle and adhere to the apex, reducing the likelihood of damage due to the handling involved in the tire manufacturing process, when the components are still "green" and not chemically bonded to each other during the curing of the tire.

At the tire building machine two bead assemblies (bead and apex), would be set in retainers outside the main tire building drum. These are held in place until after the innerliner and plies are assembled, then the beads are drawn in to the sides of the drum above the edges of the innerliner and plies. At this point the innerliner and ply edges would be folded over the bead (creating the ply turn ups for the green tire and locking the beads into position).

Innerliner

To eliminate the inner tube in radial tires, the innerliner was developed to sustain inflation pressure in the tire and be a rubber veneer cured directly to the plies. In the early 1980s, the innerliner was for many manufacturers purely a natural rubber component—the result being unfavorable long-term air retention. In the worst cases, new tires mounted on OE vehicles would be flat again before the vehicle left the shipping lot outside the vehicle manufacturer's property.

Clearly, synthetic chemical agents were required to assist the air retention properties. Halobutyls have since been used in higher and higher concentrations to improve resistance to air permeation. Chloro-butyls and bromo-butyls are popularly utilized in many of today's radial passenger and light truck tires.

The innerliner is prepared as a flat sheet. Some manufacturers may produce innerliner as a single pass material with a specified gauge. Others prepare it in two passes of nearly equal gauge resulting in the final specified gauge. While yet others differ the chemical composition of the two layers—one a natural rubber barrier and the other a butyl layer.

The innerliner is supplied to the building machine in a roll of fabric or vinyl liner. It is pulled through the servicing trays on a building machine and applied in one or more rotations around an expanded drum. Some tire makers would consolidate a chafer material (fabric or gum) to the ends of the innerliner width, in order to place this material in proper position to protect the tire from excessive rim chafing in use.

At the building machine the first component to be applied to the drum is the innerliner. Once the innerliner is applied to the drum and the drum is rotated one revolution (two if the innerliner gauge is processed at half gauge to eliminate a set up change in the area of innerliner manufacture), special care has to be taken with the innerliner to ensure the splice is properly sealed.

In the green state, the only seal of the splice is the tack level the innerliner has to itself, which should be assisted by roller stitching the splice location. If this is not properly done, the splice may open later to allow a conduit for oxidative attack on the internal components of the tire, resulting in chemical aging and degradation.

Also, if the splice is too blunt (lacking a skive angle), it creates a dam for trapped air during the curing process. This also can gather at the splice location to create an opportunity for air infiltration throughout the tire's use.

<u>**Plies**</u>

The body plies of the tire are also delivered to the tire building machine in a liner roll. In a two-ply tire, the plies are typically cut at a different width from each other. Care must be given to maintaining a minimum distance between the turn up heights of each ply (or any other component) so as not to create coincidental endings of materials. These act as hinge points during the flexing of the tire's sidewall region.

Establishing the first ply as the wider ply allows for the outer ply turn-up to protect all internal fabric endings beneath. This technique is not necessarily universally applied by the different tire manufacturers, however. Both plies typically are wider than the innerliner widths in a 2-0 construction.

When speaking of "radial" tires, we are speaking of the direction of the body plies in relation to the direction of travel. One convention of identifying the angle of radial tires is to specify the plies as being at 90 degrees within the tire.

The plies are applied over the innerliner on the building drum, (rotated) and spliced to ensure the plies do not "pop open" during the rest of the building sequence or at the time of curing. An inadequate splice will result in tire failure along the ply splice.

Sidewalls

The sidewalls which have been extruded through single, dual, triple, or quadruple head extruders are delivered to the building machine in rolls. These might be supplied to the building machine in separate rolls.

The use of a single-head extruder would imply the entire sidewall consisted of only one rubber compound. In a typical case, a sidewall formed through a dual extruder head may have a sidewall compound and a rim protector compound in the lower sidewall region. A triple extrusion might consist of a separate compound to be positioned under the belt edges as a belt cushion, a sidewall compound, and a rim protector compound. An example of a quadruple-head extruder would be the same as the three head extrusion, with perhaps a white sidewall compound included for the raised lettering or stripe in the tire.

Once the plies have been turned over the bead, the next component to be assembled is the sidewall. The drum is again rotated and the sidewalls are cut on a skive angle by a heated knife and the splice is stitched. After this step, automatic stitchers on the building machine may be used to increase the green tack among all components, while removing as much trapped air as possible between layers.

The resulting assembly resembles a rubber tube or sleeve. In the next stage the tire will be shaped more closely to the appearance of a final cured tire.

This completes what is termed the "first stage" building process. From here, the first stage body carcass is transferred to the second stage machine, unless a single-stage building machine is being utilized, where the same drum is used to complete all assembly.

At the second stage machine, the steel belts, nylon cap plies, and tread piece are applied onto a drum which is set to a larger diameter, in order to be later transferred onto the inflated first stage carcass.

Steel Belts

There are basically two methods in use to prepare a standard steel belt. The older method entails processing a roll of calendered steel and cutting six to nine inch pieces of the belt on a given bias angle. These individual strips are then zipper-stitched together to create a longer roll of belt material at the desired sheet width and belt angle to be used for a specific tire.

Prior to rolling up the stitched belt segments, a belt edge gumstrip or belt wedge component might be included on the first belt to consolidate tasks.

A length of this belt material adequate to cover the circumference of a tire might have six to nine wire splice locations. Some of the shortcomings of this technique are:

- <u>Poor guide control</u> on the zipper-stitcher operation allows for "floating" of the individual belt pieces along the conveyor. This creates irregular belt edge endings from one piece to the other. In the finished tire, these create opportunities for wires in the same belt to come into contact with each other during flexion. Obviously, this creates some level of "snaking" between belts, which can result in belt to belt contact.

- <u>Multiple cut lengths of wire</u> in each belt segment results in multiple wires per tire having inadequate rubber skim coverage.

- <u>Multiple wire overlaps</u> due to the splicing of those six to nine belt splices per belt means one or more wires in each segment per belt can have wire to wire contact, which eventually wears through any available belt skim in loaded tire operation.

- <u>Shelf life</u> is an issue with this technique because the time it takes to produce a belt length for even one tire is lengthened as compared to more recent methods. This involves the belt remaining in the roll or liner longer than other components, which in many cases results in liner pattern marks on the belt skim, which impede proper bonding to the next belt's skim during tire curing, resulting in imminent belt separation.

- <u>Humidity-controlled environment</u> also is an issue, because many times this equipment was not installed within the temperature and humidity controlled portions of the manufacturing facility resulting in early sulfur bloom of the belt skim stock and moisture attack on the exposed steel wires, both of which are known to result in a failure to create a properly bonded belt system in the tire.

- <u>Wire spacing</u> within a Steelastic belt is often inconsistently spaced. These irregularly spaced wires ultimately result in large enough voids between belts to require the available skim to flow into the voids during the curing process. The flow of skim into open splices or irregular wire spacings creates a reduction in the available skim gauge in those specific areas, which has generated unnecessary heat within the belt systems causing belt to belt separations in tires.

Another technique for preparing steel belts which has been available to the industry since at least the late-1980s, is the use of larger creel calenders to uniformly space the belt wires and to handle the wires in a temperature and humidity-controlled area. The creeled wires are fed through a combset (approximately four to six feet wide) to a mill where the skim is embedded into and onto the wires. This is rolled and delivered to a shear cutter which has been set to the desired belt angle. The belt is cut to width on the proper angle. Normally one cut is sufficient for the circumference of a tire of smaller overall diameter.

This method produces a uniform belt edge position for the entire cut. It involves only a single splice in the first belt and a single splice in the second belt. The belt edge gumstrip or belt wedge can also be consolidated on the rollup of the cut belts in the liner. Belt cuts for multiple tires can be achieved in the same time it takes to assemble several belt segments into a single tire belt on the Steelastic-type equipment, so that not only is their efficiency in the operation, but the belt material is not exposed to environmental effects any longer than necessary.

On the second stage drum, the first belt (perhaps with belt wedges) is applied first. The drum is rotated and the belt is cut with a hot knife along the path of the steel cords. The ends are butt-spliced together.

The second belt is now applied centrally over the first, rotated, and spliced the same as the first belt. In order to ensure proper positioning of the steel belts, a guidance system is normally applied to reduce variation in component placement. Such a guidance system may consist of automated component placement, laser lights to spot proper drum locations for components, etc. in order to maintain consistency between constructive features in the tire.

Nylon Cap Ply/Edge Bands

By whatever means used (jointless nylon band or full belt widths of nylon), the next component to be applied is the nylon cap ply and or nylon edge bands.

If using full widths, the material is supplied on a servicing tray on the backside of the second stage building machine drum. If nylon band strips are being used, the applicator head might be behind the operator near the tread servicer. By attaching a strip to the edge of the first belt on the building drum and using multiple drum rotations to tension the nylon as it winds on, the applicator head either steps across to cover the steel belts in increments or moves on a screw so that the spiraling continues, according to the patented techniques being utilized by a particular tire manufacturer.

Tread

Once the belts and/or nylon is applied, the last component to be assembled is the tread. Typically, rather than rolling a continuous piece of tread into a fabric or vinyl roll, these are cut to length and stacked in booking trucks and pulled to the second stage machine. The tread may consist of a tread cap on top, a tread base compound, a tread wing which is chemically compatible with the sidewall compound for tread edge adhesion, and an undertread.

The operator selects a tread and places it on the service conveyor which may have centering guides attached. The front edge of the tread is attached to the belt or nylon surface on the drum and the drum is rotated a full revolution. The tread splice is made by hand and should be further stitched to maximize green tack.

Now, the first stage carcass is fitted over an inflatable drum or chuck which will crown the center of the plies and hold the beads in place. Meanwhile, a transfer ring moves over the second stage drum and spring or pneumatically forced segments extend toward the drum to make contact with the belt/nylon/tread package. Once the segments are in place, the drum collapses, leaving the belt package suspended in the transfer ring segments. The transfer ring then glides over the inflated first stage tire carcass where the belt package is centered by laser indicators, released, and then dynamically stitched onto the carcass under some pressure.

At this point the green tire is completely assembled. The next step in the process would be to prepare the tire for curing. This step includes inside and/or outside tire paints, which protect and lubricate the innerliner and ply cords from the curing mechanisms as well as reducing the propensity for trapping air during the cure. These paints also assist in covering voids in the tire surface and allowing the air inside and on the surface of the tire to be evacuated more easily. Once the paint is dry, the tire can be cured.

The exact orientation of one component's splice in relation to others has been found to be significant to ride disturbances such as vibration and ride harshness. Due to the potential for this to generate complaints by customers, techniques to stagger the number of component splices around the tire are used.

Cure

Curing is another area in most tire plants in which at least some of the conditions are standardized for efficiency. In the case of many tire plants the curing factor which is most often standardized is the platen and curing temperature. For example, it would not be unusual for all tires produced in a particular type to be cured at a fixed temperature above 300 degrees, leaving mainly the amount of time as the variable factor for each specific design.

Prior to curing the tire, cure studies are typically conducted in which multiple thermocouples are placed on a green tire. Additional layers of tread stock are added to the surface to allow thermo-coupling for some depth, after this the tire is cured. By sectioning the tire, analysis of the point at which the rubber components are cured without the presence of porosity can be determined. This information will be used to formulate the cure specification for this tire.

Due to the high temperature curing that the tire undergoes, ultimately many of these different rubber components are bonded together in such a way that the individual parts meld together. The desired result of curing is not that the rubber components blend to the extent that they lose chemical integrity or identity, but that the rubber to rubber, rubber to fabric, and rubber to steel bonds produce an intact tire system by the degree to which each component becomes melded to the other. The desired result is that no interface between the components being bonded is weaker than the strength of the individual component, else a failure at that component interface is inevitable, and must be remedied.

Once the tire is cured, it will continue through an inspection process which might include X-ray, uniformity measurement, balance check, sidewall undulation measurement, and/or white sidewall buffing. There should be several opportunities before finally being delivered to a warehouse location for the tire to receive visual, tactile, and instrumented inspection.

DESIGNING A PASSENGER OR LIGHT TRUCK STEEL-BELTED RADIAL TIRE

Simply stated any tire's two main functions are to allow ease in rolling and to allow control of the mass of the vehicle on which it is mounted. This control translates into degrees of precision or handling response (ultra high performance tires being on the upper end of the scale) and the ability to stop (braking) the mass on different surface types in a variety of service and climatic conditions. In the most general of terms, almost every other performance expectation is a desired derivative of those two main functions, including the ability to sustain a certain load and inflation pressure and the ability to continue in service for a reasonable period of time without presenting safety-related modes of failure at the end of serviceable life, such as a tread separation. Consideration of these two primary functions should be incorporated into the tire design process.

As a practical matter, tire designers are given some latitude with variations in tread compounding and gauging, some sidewall compounding options and gauging, and usually fewer options for bead apex compounding. Usually a tire designer can expect more freedom to establish the belt widths, angles, and density, adoption of nylon, ply turn up heights and perhaps type of ply cord selected, and the dimensions of the bead apex. Beyond these, such items as innerliner, bead core coating, nylon chafer skim compound, rim protector compound, ply skim compound, belt skim compound, belt wedge compound, nylon skim compound, belt cushion compound, tread wing compound, and undertread compound are virtually never adjusted by individual designers or for specific tire design programs. These type rubber components (as well as body ply types, nylon types, and to some extent the types of steel used in bead bundles, steel belts, and sidewall inserts) are most often incorporated into every (or nearly so) tire of a given type produced in a given tire plant.

In manufacturing a tire, the beads, innerliner, body plies, and sidewalls are typically assembled in the first stage and the belts, nylon, and tread are assembled over the first stage carcass in the second stage tire building process. This separation of components by stage is also a point of consideration for the design engineer. It is somewhat rare to achieve the total performance requirement in the very first attempt, especially for OE applications. However, the designer must consider that it is somewhat easier to tune a design when the net stiffness of the first stage carcass matches the directional stiffness of the second stage components. For example, if the design requires an improved ride quality, the designer might soften the bead apex, lower the ply turn ups, and thin the sidewall gauges in order to allow the tire's carcass to flex suitably with each large road input.

By comparison the second stage components might include a higher belt angle and an increase in tread base gauge. This would allow the tire to crown in the center line, concentrating the contact area to the center of the tire to reduce road contact inputs across the face of the tread/belt package. The tread base typically has a high percentage of natural rubber content and at a lower hardness than the tread cap provides a cushion between the tread cap and the belts, further reducing transmission of road inputs. This technique of "balancing the tire stiffness" creates a baseline of performance by which the designer can then focus on specific performance changes from further tuning changes in the components, compounds, or gauges of future experimental tire specifications within a specific tire development program.

By the time that the developmental tire mold has arrived, the tire designer should have discussed with the factory process engineers the dimensions of the initial extrusion dies for the tread, sidewall, and bead apex. For the tread, the block width (area of tread to contact the road surface shoulder to shoulder) of the mold should closely match the block width of the extrusion, the split between tread cap and tread base should be informed, and if possible an initial extrusion trial should have been conducted in order to check the stability of the tread compounds (growth and swell out of the die). Meanwhile the chemical laboratory should have taken samples of the tread compounds, if using an experimental formulation, and analyzed the samples by Rheometric analysis, and dynamic strain or temperature sweeps to understand whether the initial batch is expected to deliver the proper performance, whether the rubber batch is thoroughly mixed at the Banbury, and some idea of the scorch temperatures for the new compound.

Much of this work happens simultaneously so that the tire designer may or may not be informed of every detail, but depends upon the factory process engineer to order the extrusion dies to meet his tire build schedule. Also, for those tire designs which are new sizes for a factory, the factory process engineer might coordinate the ordering of new tire building drums, linkages for the bead winder, and new curing bladders for the incoming mold. The materials members might be coordinating the arrival of new components such as silica, coupling agents, unique polymers, etc. if not already in use.

According to the size and type of tire, the tire designer might next consider the type and amount of bead wires used. After selecting the wire to be utilized, the designer should consider the stacking arrangement for the bundle.

If the facility only has taped bead constructions available, the decision becomes how many turns and strands the bead will have. All turns will contain an equal number of strands.

For those facilities which utilize hexagonal or polygonal shapes and single wound wrapping of bead wires, each row of bead wires can be somewhat unique from the layer above or below. Bead burst testing has indicated that the strongest band in any tire's bead should be the lowest strand. Therefore, consideration should be given to establishing an adequate base count and determining the best bundle type from that point.

One consideration in finalizing the bead bundle shape and wire count is the bead apex base width. The uppermost row of bead wires should make it possible to rest the base of the bead apex upon it.

Some of the functions of the bead apex are to generate lower sidewall stiffness centrally in the tire (over the bead). Stiffness outside of this, by sidewall compound alone, for example, doesn't generate the same level of handling precision as that directly over the bead bundle, since the bead bundle is the direct contact to the rim which assists in the transfer of steering inputs by the driver. Another function of the bead apex is to separate the carcass ply and its turn up. This in effect generates a higher degree of carcass tension, which aids in handling maneuvers and also relates to the tire's ability to support the belt and tread package. A third function of the bead apex is to damp vibration inputs before transmission from the road to the rim and into the vehicle's suspension system, floor-pan, and steering column. Once the bead bundle and the bead apex are selected, ply type and gauge, number of plies, and turn up heights are determined.

In developing a tire for an OEM, soon the tire designer begins to learn the performance preferences of the vehicle engineers he/she is working with. This knowledge comes to bear especially when determining the side stiffness of the tire (bead apex, ply turn up heights and cord type, and sidewall compound selection) along with the matching wire density, belt angle, and tread compound formulations. This being the case, several different tire sizes for different vehicle fitments of one vehicle maker could have relatively similar tire constructions.

OEM considerations aside, the tire designer's task is somewhat more straight-forward when designing for the aftermarket. When establishing designs for sale in tire retail outlets, the designer is tasked with proliferating a range of tires having basically the same features (allowing for size to size deviation in actual performance). As an example, 25 to 30 sizes might be included in the range under one line name. Once the number of sizes is selected, typically by marketing input, several of the sizes might be selected due to the expectation of sales volume they will generate and these might be determined to be the key sizes to receive the largest battery of tests. Other sizes for which marketing has predicted lower volume might not be specifically evaluated in benchmarking comparisons with competition or costly endurance testing until much nearer the time of product launch for the whole line of tires to the market. This isn't to say that the approach mentioned above is the universally accepted methodology for releasing a range of products, but it is one method employed from time to time in the tire industry.

I mentioned the designer's task in designing an aftermarket tire is more straight-forward because it is often the case that tire designers establishing a new line of tires will generate, in one form or another, a matrix for the entire line in which the designs for the key sizes are established based upon competitive analysis and perhaps incumbent products with which the designer is familiar. Once the key tire size designs are determined, the designs of the additional sizes are filled into the matrix by factorization; meaning, the component dimensions are factored up or down from the key sizes (or max and min sizes) based upon the dimensional relation of the specific tire sizes themselves.

In this way mold and design drawings can be rationalized (minimized) by overlaying several desired profiles onto one drawing, or utilizing one stamping drawing to demonstrate the placement and text on the sidewall for virtually the whole line of products. This is sometimes termed "embedding" designs.

Whichever approach is administered in the design of the tire, the tire designer still maintains the responsibility to ensure the tire meets all testing standards for durability, safety, and regulatory requirement before release to production. The initial production tires should be monitored and retested to confirm previous performance levels are maintained after mass production commences.

The next step in determining the initial design of a tire might be to decide on the belt materials and settings. Here again, the belt material is one of those components which can represent a "bottleneck" for a manufacturing site if multiple wire types are introduced. Multiple wire types in the manufacturing environment create complexity in the management of various wire types through creeling (stringing multiple spools of belt wires), calendering (applying belt skim to the creeled wires), belt roll storage, and cutting operations.

Design decisions regarding steel belt specifications could include:

- Belt angle orientation. For markets driving on the right-hand side of the road a standard has been established for which angles should be nearest the tread pattern. Apply these incorrectly and the tire may have a strong tendency to drift sharply off the road to the right-hand shoulder. Applied correctly, the tire should have some corrective tendency to either maintain a straight track or drift slightly against the grade of the road, even when the road has 1 to 3% cant angle. The reverse is true for markets in which vehicles are driven on the left-hand side of the road.

- Belt width should create an appropriate belt to belt step off. Too little difference in the widths of the 1st and 2nd belts and the potential for coincidental endings which generate higher heat on the belt edges due to the flexion occurring near the uncoated ends of the cut belts exists. Too large a difference in belt widths and the endurance of the tire is compromised when the 2nd belt does not cover the full tread width in contact with the road, creating higher loading on the point where the 2nd belt hinges to the 1st belt.

- Belt angle affects the final cured tread radius. The higher the angle the more "crowning" which will occur in the inflated tire. This is a result typically sought for tires meant to exhibit more ride comfort qualities than handling precision. Noise and rolling resistance are also improved in this manner as the shoulder drag is reduced when the center has more contact, and with the shoulder pressure reduced there are several frequencies of noise which are reduced in the road noise, belt edge resonance, and pattern noise frequency ranges (between 125 and 2000Hz).

- Typically belt skim and belt skim gauge for manufacturers who do not utilize unbalanced belts are standardized for a particular tire type. Therefore this element would not usually be decided by the tire designer. Again, the chemists and service compounders would be required to certify that the proper anti-degradants (anti-ozonants and anti-oxidants) were included in the belt skim mix in appropriate content to handle the heat and flexion encountered throughout the lifecycle of the tire. Also, these or additional anti-degradants are required to handle the potential for chemical aging and exposure to climactic elements during the lifecycle of a tire.

- Also, typically the belt cushion (whether designed as the upper taper of the sidewall extrusion or as an individually extruded wedge of rubber) is predefined by those involved in studying the green tire components based on the belt widths and overall tire height dimension provided by the tire designer. The gauge and width dimension of the belt cushion would be fairly consistent from tire to tire.

- Belt wedge or belt edge gumstrip is also rarely modified either in chemical composition or dimension.

Next, the designer must determine whether the tire should have a nylon band component over the belts due to usage, speed rating, load rating, DOT plunger test, or specific customer requirements for handling or noise control.

The nylon used in tire designs has excellent thermal-set properties to allow it to shrink with heating and apply additional resistance to a steel belt system, which ultimately tends toward lifting from the fabric-based carcass beneath it, due to differences in rigidity, steel spring memory, centrifugal forces, mechanical forces generating strain and stresses including compression and tension at various points around the tire and during each loaded revolution of the tire's use.

Before the advent of wound nylon strips, called spiral nylon over wrap or bands by some manufacturers, the inclusion of a full belt width of nylon created some challenges for tires. These included morning flatspotting for the first several miles of driving each day and the possibility for the splice to pull apart during the growth encountered when the tire was cured. This required the splice to be overlapped overly wide to ensure good final splice coverage.

With nylon strips, the heavy overlap is virtually removed. The result is the same qualities of nylon to sustain the belts, increased high speed performance, increased plunger strength, isolated road noises, increased handling response, and better management of heat under higher loads--while eliminating the periodic thumping of a heavy nylon splice—though flatspotting can still be an issue.

In the absence of a more economical and technically-capable belt bandage, nylon is certainly appropriate for a multitude of design considerations. Nylon hybrids and Kevlars are certainly available; but with limited use and adoption, it is not likely in the near term that these will compare to nylon on a cost per linear foot basis. I've expressed several applications for nylon, yet some manufacturers continue to refuse to adopt nylon due to the cost impact--though I know of no material substitute for it which even comes close to its cost, while providing a safer, alternative design.

I have explained some performances about which the tire designer must be aware during the development cycle for a new tire. I have discussed at some length the individual components and the decision process around some of them regarding selection to meet certain test criteria. In doing so, I believe I have mentioned several components which are nearly universally used in tires of a specific category, be it passenger and light truck or others. These might include innerliners, bead wire and skim, ply cord types, ply skim stocks, chafer fabric and skim stocks, belt wire, belt cushion, belt wedges, belt skim stocks, undertread compounds, tread base compounds, rim protector compounds, nylon cap ply fabric and nylon skim stocks.

The processing aids for any of these rubber components are oils, tackifiers, peptizers, plasticizers, and softeners. The curatives are accelerators, activators, and sulfur. The adhesion promoters are coupling agents, cobalt salts, brass on wires, and resins on fabrics. The anti-degradants are antioxidants, antiozonants, and paraffin waxes. The reinforcing materials are carbon black, silica, and resins.

It is vitally important to realize that when a specific tire product begins to show unacceptable performance, one common link to other products is the use of the universal components within a single factory or set of factories. This overview can help those investigating to isolate root cause effects from others, and hone in on the major factors involved.

Another link shared with the suspect tire is the historical performance of chemical ingredients such as the processing aids, curatives, adhesion promoters, anti-degradants, and reinforcing materials being used by a particular tire manufacturer or a specific factory. The way in which those specific ingredients are handled within the factory, the methods used to load them into the Banbury mixing process, the time given for the proper milling of the rubber stocks, the efforts taken to protect the prepared component from environmental contamination, blooming, or aging-all of these considerations may not be entirely evident from a single tire, yet by understanding the overall methodology involved at the manufacturing site, the tire designer, field service manager, or forensics analyst can better identify all the contributing factors surrounding the lack of performance, whether that is a product integrity issue or achieving a certain level of new tire performance.

It has been my experience that the category of passenger tires has transitioned from 13" and 14" tires in the late 1980s to now extend well into the 20" diameter range. The fitments for passenger tires have been extended to pickups and SUV's by the major OEM's of the world. Further the vehicle categories themselves have blurred from the standard categories offered in the 1980s, from sedans to sedan-type multi-use vehicles, from pickup trucks to six-passenger SUV's with payloads of three quarters of a ton.

Just as this transition has occurred in vehicle categories, some of the distinctions for the tire types being used have also been blurred creating similarities between (P-metric) passenger and (LT) light truck tire designs. The exceptions are typically in tread pattern depth and type. With the increase in passenger tire overall diameters, the tire building and curing machinery is basically identical between the two segments these days. The tire building personnel (tire builders and curing room operators) may build either type of tire interchangeably. The training they have had in either type of tire production being adequate for the other.

Having given thought and consideration to each of the design steps previously mentioned, the tire designer awaits the arrival of the mold, then initiates the first specification upon its delivery. Once the tire specification is produced, the tires might be footprinted for contact shape, sectioned for gauge and component placement confirmation, and evaluated for uniformity. If each of these is deemed to meet the specification, the tire might enter a more thorough testing battery. Otherwise, the process is restarted with perhaps three to five additional variants included in the new specification requests, until an acceptable specification is realized.

TIRE FORENSIC ANALYSIS METHOD

I examine tires that have been involved in tread separation accidents in a specific manner, which is the same manner used by other tire experts, both plaintiff and defense. I have confirmed this by meeting and discussing this topic with other tire experts. It is also the same manner that I used while working in the tire industry for Goodyear-Dunlop.

The objective is to try to determine the cause(s) of the tire failure. The examination starts with a visual examination of the outside of the tire, including sidewalls and beads, carcass, and tread. Tire markings and codes are noted. Any cuts, bruises, or other damage is noted. The tread and steel belts are inspected. Measurements are made of locations of markings and abnormalities. Then the inside of the tire is inspected visually. Close attention is given to any punctures, innerliner problems, including gauge, splices, cuts, or other abnormalities. At the same time, a tactile inspection is made. All surfaces, both exterior and interior, are felt for abnormalities.

Various devices are used in the tire examination, including spreaders, high intensity lights, magnifying devices, laser non-contacting devices, and microscopes. X-rays are done if appropriate. Shearography use is considered and ordered if appropriate. The companion tires at the time of the accident are examined if available. The subject wheel is closely inspected, as are the companion wheels, if available. Then I take photographs of the condition of the subject tire to document and show its condition. Also, as important as the positive findings on the tire, is the absence of signs on the tire. Most user-caused conditions will leave tell-tale signs on the tire. Their absence is strong evidence that the tire was not significantly, adversely affected by improper use or maintenance. This is the method that I used in the examination of the subject tire.

I also employ the scientific method in conjunction with my tire examination, experience, education, training, and scientific and technical literature, studies, and testing, as applicable, to reach my tire failure analysis and defect opinions in this report.

HISTORY/ INCIDENT:
According to the accident report, on Oct. 27, 2007, a 1998 Ford Explorer driven by Brandon Johnson was traveling southbound on I-55 south of the North Batesville exit (246) when the right rear tire blew out. The vehicle overturned. Johnson and Kianta Adams were ejected. A portion of the right rear tire came to rest north of the collision site. This crash led to the death of Brandon Johnson and injuries to four others.

FINDINGS:

Tire: LT235/75R15 104/101Q L.R. C SPORT KING A/T
DOT: T7TY JJS 4402 (Korea)
Construction: 2 ply polyester + 2 steel
Max. Inflation: 350 kPa (50 PSI)
Max Load Single: 900 kg (1985 lbs)
Max Load Dual: 825 kg (1820 lbs)
Tire Position: RR
98794
T0483

The subject tire and tread piece, and subject rim were received in separate boxes. The tire was dismounted when received and marked from previous inspection.

The DOT (found on the serial side of the tire's sidewall, called SS in my report) was considered the starting point or 0 degrees. Rotating clockwise around the sidewall, my inspection notes were taken in increments of 30 degrees. The opposite side of the tire was evaluated in the same way; however, rotating counterclockwise in order to be consistent side to side. The tread and carcass were also measured in increments of 30 degrees starting above the DOT.

SS INSPECTION

- No bead damage.
- Buttress cracking under flex.
- Rim groove (8.1 x 1.2)
- Chafer peaking.
- At 70 degrees, clip weight impression.
- At 215 degrees, radial split in upper sidewall.
- At 220 degrees, radial split in bead flange across carcass.

- At 240 degrees, orange accident scene paint.
- From 220 to 340 degrees, SS tread and both belts attached.
- From 340 to 155 degrees SS-tread and both belts lifted and attached at 340 degrees.

SOS INSPECTION

- No bead damage this sidewall.
- Rim groove (6.6 x 0.7).
- From 0 to 95 degrees SOS-tread and both belts lifted from carcass.
- From 95 to 120 degrees SOS-tread and #2 belt lifted from carcass.
- At 130 degrees, red uniformity mark.
- From 155 to 175 degrees, upper sidewall rubber attached to lifted tread flap exposing ply underneath.
- At 165 degrees, radial split.
- From 165 to 235 degrees, shoulder lug missing.
- At 205 degrees, radial split.
- At 225 degrees, radial split.
- From 205 to 230 degrees, orange accident scene paint on sidewall.
- From 275 to 330 degrees, shoulder lugs missing.

INSIDE

- At 165 degrees SS to C/L-radial split.
- From 180 to 260 degrees, approximately 14 radial splits.
- At 135 degrees C/L-puncture hole.
- At 345 degrees SOS-sep indication.

CARCASS/TREAD

- Partial tread separation with brassy exposed wires.
- At 0 degrees, tread and #1 and #2 belt lifted from carcass. SS and SOS shoulders of carcass poorly bonded with liner pattern marks on both sides. Waviness on both shoulders. SOS-rust on lower portion of #1 belt.
- From 0 to 150 degrees SS (and 0 to 90 degrees SOS)-heavy liner pattern marks on carcass.
- From 0 to 90 degrees SOS-lower #1 belt shows rust on tread piece.
- From 90 to 150 degrees SOS-rust and oxidation on #1 belt and on #2 belt of tread piece.
- From 105 degrees SOS to 180 degrees C/L-liner pattern marks on belt skim of carcass and tread piece.
- From 150 to 330 degrees SOS-oxidation on carcass beneath #1 belt.
- From 180 degrees SS-#1 belt ends are stripped and frayed, with belt step off ~14mm on SOS #2 belts are stripped frayed and oxidized.
- From 160 to 255 degrees, 14 radial splits.
- At 220 degrees SS-liner pattern marks on carcass.
- From 225 to 175 degrees SS cw-tread is attached/available.
- From 250 to 330 degrees SOS-#1 and #2 belts are stripped and frayed.
- Tread block width ~199mm.
- #1 belt width ~182mm.
- #2 belt width measured from 120 to 180 degrees ~159mm.
- At 90 degrees SOS-tread piece, #1 and #2 belt step off measures ~ 8.2mm.
- At 135 degrees C/L-nail in tire which punctures through carcass. No oxidation around puncture site.

TREAD A-ranges from 180 to 210 degrees.

- No breaks or punctures noted.
- Wires are rusted and frayed on both ends of the #2 belt.
- Liner pattern marks at centerline.
- Tread piece A partially covers 6 radial splits.
- Only #2 belt is attached to tread piece A.

Nail in tread was pressurized. Leak noted in the separated tread piece.

TREAD DEPTHS

	SS1	2	3
0	5.6	6.0	6.2
30	5.3	6.6	6.2
60	5.5	5.7	6.1
90	5.4	6.3	5.8
120	5.4	6.0	5.9
150	5.3	6.4	6.4
180	5.5	---	---
210	5.6	6.8	---
240	5.5	---	---
270	5.4	6.5	6.1
300	5.3	6.6	6.5
330	5.5	6.0	6.1

SUBJECT RIM

- 15 x 7J
- K4 #1 09 07 97
- 09 17 97
- Ford
- Inset 12
- F87A-1007-BC
- F16A
- Outboard: No clip weights attached, Valve stem, core and cap installed. Valve core checked for leaks—did not leak.
- Inboard: 1-0.5 MC14 clip weight installed. Minor flange abrasion.

SUBJECT RR TIRE X-RAYS

0 – 60 degrees:

- Irregular wire spacing.
- Wire to wire end contact.
- Gapped #1 and #2 belt splices.
- Scalloping.

60--120 degrees:

- Irregular wire spacing
- Wire to wire end contact.
- Scalloping.
- 3 cord overlapped belt splice.
- Frayed wire ends on SOS side.

120--180 degrees:

- Wire ends are stripped and frayed on SS and SOS sides.
- Irregular wire spacing.
- Scalloping
- 1 wire overlapped splice.
- Nail in tread.

180 -- 240 degrees:

- Frayed wire ends.
- Irregular wire spacing.

240 -- 300 degrees:

- Wire ends frayed.
- Irregular wire spacing.
- Scalloping.

300—0 degrees:

- Gapped belt splice.
- Wire ends frayed and tangled.
- Scalloping.
- Irregular wire spacing.

TREAD A---180 to 210 degrees:

- Wire ends stripped and frayed.
- Irregular wire spacing.
- References position of #2 belt edge to tread block edge.

MATERIALS REVIEWED

The materials I reviewed, in addition to those listed in the "Reference Materials" and "Appendix" sections below and the subject tire and rim, include the following:

1. MS Uniform Crash Report

2. Plaintiff's Complaint

3. Photos by Gilbert Engineering

4. Deposition of Don Lee

5. X-rays of Subject Tire

<u>ANALYSIS</u>

Upon the examination of the subject tire, I made the following observations which, together with my education, background, training and experience and utilizing generally accepted methodologies and procedures widely utilized in the field of tire failure analysis indicate to me evidence of defects in the manufacture and/or design of the tire, which in my opinion *are* defects that caused or contributed to cause the partial tread separation on the subject tire that led to a loss of control and the resulting accident . Those observations are as follows:

1. <u>Inadequate bonding of the belt skim</u> is evidenced by poorly bonded rubber skim material between the steel belts and below the first steel belt (between carcass and #1 belt). As well as brassy, poorly bonded belt wires. Poor bonding was also observed through:

    - Liner pattern marks present on the belt skim material. These marks occur as the liner rolls used to transport the green tire materials within the tire manufacturing area are imprinted onto the uncured tire rubber stock. When green tire stock sits in the liner roll for a long enough duration, it both takes on the surface impressions of the liner and begins to dry out. When a tire fails in belt to belt separation mode and impressions such as liner pattern marks are observable on the separated surfaces, it is clear that the surface being observed is an original interface of the coated belt components. When these are observed in the tire post-cure, it is strong physical and observable evidence that a proper bond did not occur.

        - [***Unprotected testimony of Thomas Johnson of GDTNA in Gamez v Ramirez-Gatica,*** "Q: Okay. Now, in fact, in the kind of marks that we're talking about now, if they haven't disappeared from the process, that could very well mean that vulcanization somehow wasn't proper for that particular tire. Correct? A: It doesn't have to mean that the elements can vulcanized. It can just simply mean that—that there has been a lack of consolidation of the material before curing. But it doesn't have to –it—frankly, vulcanization is—vulcanization doesn't retain those imprints. It's got to be something that interferes between the contact between the respective components."

            - Q: Okay. Now, during your tenure as a quality assurance department, despite the—what I assumed you will tell the jury were very good techniques of manufacturing at Goodyear Dunlop, did you ever see these pattern tire marks in dissected tires? A: Well, that's pretty rare. And when we've had it, it's been when there's –we know a tire had a problem. It's trapped air and what have you. And one of the things you would see, if you dissected that tire, is you would see—I don't know about what these are, but you would see liner marks. Its almost unheard of in past decade."]

- **[*The Handbook of Rubber Bonding, RAPRA,* "**It is necessary to establish the greatest area of interface between the adherend and the adhesive mass. A high contact pressure between the adherend and the adhesive mass will ensure the formation of an interface despite the adherend being resistant to wetting purely on grounds of interfacial chemistry."]

- ***[The Investigator's Guide to Tire Failures, Rex Grogan.* "**Evidence of liner marks is a sign of separation between components for which no one but the manufacturer can be responsible."]

2. The presence of rubber reversion zones on the belt skims from <u>oxidative degradation</u> indicates that it was not capable of managing the heat, stress, strain, flexion, and oxygen exposure being generated between the steel belts of the subject tire. These conditions are normal and calculable considerations for the designer at the time the tire is designed and manufactured. Belt skim rubber is enriched with antioxidants. The function of those antioxidants is to chemically link to any oxygen attacking the rubber. This function maintains the original properties of the rubber until the antioxidants are depleted. At the point of effective antioxidant depletion, the rubber is affected in several ways including cracking, polishing, and reversion (a loss of elasticity). With a loss in elasticity, the belt skim cannot flex with the steel belts as they rotate into contact with the road, ultimately separating the belt wires from the rubber. A lack of adequate antioxidant remaining in the skim stock and/or in the original compounding of the skim stock rubber to allow a tire manufactured in 2002 to operate properly in 2007 contributed to the accelerated oxidative degradation of the tire.

- [***DEKRA-Technical Defects on Motor Vehicles 1986,*** "Separation due to over-aging of the tire…If the measured shore value is considered higher than 70 degrees, it is a warranted conclusion that the vulcanized material has become hardened and brittle. In most instances, this is a result of the aging of the rubber." "But modern rubber blends contain protective agents against aging that prevent the vulcanized material from becoming brittle prematurely. Nevertheless, a diffusion of oxygen molecules attaching themselves to the free binding ends of the moleculer chains still occurs; thus, even modern tires are subject to a certain amount of aging. This can translate into fine tears due to brittleness in the tire surface."]

- [***British Rubber Manufacturers Association, Tyre-Ageing June 5, 2001, "***Rubber compounds used in modern tyres contain anti-oxidising chemicals, which slow down the rate of ageing. However they cannot eliminate "ageing" altogether…Tyre ageing is often identified by small cracks (crazing) appearing in the tyre sidewall and other flex areas…However, tyre "ageing" may not exhibit any external indications and, since there is no non-destructive test to assess the serviceability of a tyre, even an inspection carried out by a tyre expert may not reveal the extent of any deterioration.”]

- [***Effects of Aging on the steel cord- rubber Interface, Bekaert June 27, 1985, ”***In most cases, the adhesion loss due to heat and mould aging is, at least partially, caused by rubber degradation. Oxidation may alter the bulk and interface rubber properties.”]

- [***Factors that Affect the Fatigue Life of Rubber: A Literature Survey, Mars, Cooper Tire and Rubber to American Chemical Society April 29, 2002, “***Oxygen influences mechanical fatigue behavior in at least two ways. First, exposure to oxygen decreases the mechanical fatigue crack growth threshold from its value in vacuum. Second, oxygen dissolved or diffused in the rubber may induce chemical changes over time to the bulk elastomer network structure; this process is commonly called oxidative aging. Oxidative aging causes embrittlement and reduced resistance to fatigue crack growth. Even for new rubber specimens with no prior exposure, the presence of oxygen increases the fatigue crack growth rate, at constant energy release rate.”]

- [***Belt edge deterioration in radial steel belted tires, by Uday Karmarker in Rubber and Plastics News, Nov. 27, 2006,*** “A new tire aging standard requires understanding the aging mechanisms in tires and devising an accelerated laboratory test to match field behavior…NHTSA has published data on tires collected from Phoenix. Thermo-oxidation has been cited as the root mechanism of tire aging…Time (field age), temperature (tire design and usage) and cavity gas partial pressure of oxygen (nitrogen purity in tire) are the critical external factors influencing the belt edge deterioration.”]

3. The <u>absence of a full nylon cap ply reinforcement</u> in this tire, which was a known and proven tire component at the time of the manufacture of the subject tire, is a design oversight in the absence of other countermeasures to belt separation and represents a design defect. The application of nylon provides enormous benefits to the steel belted radial tire in various areas of performance including: plunger strength in rough terrain, improved durability in standard operation, high speed performance, a barrier to migration, and due to its placement over the steel belts provides an improved restriction to movement within the underlying belts. Nylon banding reinforces the belt edges under load and resists centrifugal belt end lifting. It also helps to dissipate the load in the higher strain regions and protect the belts from movement against each other under those loads. While nylon cap plies may not be required to ensure durability in a properly manufactured and designed tire, it is clear that the subject tire would have benefited by the use of a nylon cap ply.

   By and large, certain of these manufactured defects would not be easily detectable by the consumer until a catastrophic failure ensued. Nylon cap plies are a design element that is known to both decrease the risk and increase the utility of steel belted radial tires. Nylon continues to represent a technology and material which was readily available, feasible, and known by Hankook. Given the other itemized weaknesses, such as belt snaking and widely spread cables, the lack of full nylon cap plies in this tire is a design defect. [See Appendix items Uniroyal, Goodyear, and Sumitomo patents describing the contribution of nylon cap plies in steel belted radial tires for reinforcement of the tread/belt package, aiding in improved durability, improved high speed performance, pre-tensioning of the steel belts during the curing process, and as a restriction to belt edge separation.] Additionally, recent marketing brochures from Michelin's BFGoodrich Long Trail T/A and Rugged Trail T/A tire lines indicate that nylon has been applied in these tires' designs to provide "equal tensioning". This pre-tensioning of the nylon occurs in the following way:

- During the tire building stage, the uncured tire is manufactured to be smaller than the mold it will be cured inside. This is to allow installation of the green tire into the mold without scraping the tread detail inside the mold.

- After the steel belts are applied, nylon cap plies or strips are applied. Then the tread is placed on the tire and the whole assembly is stitched together under pressure.

- When the green tire is installed into the mold, heat and steam pressure are applied to the green tire. Once the tire begins to heat it is made more compliant and is held at high enough pressure that it grows into the mold at a percentage change to the overall diameter of between 1 and 5% growth. During this growth, the nylon's influence to restrict the "belt stretch" intensifies its restriction on the belts to move. This restriction is the "pre-tensioning" mentioned in the BFGoodrich brochures and U.S. Patents.

    - [***Summary of Firestone and Ford tread sep problem with discussion of nylon caps in Venezuela, Professor Jain, University at Buffalo, New York, "***In January, 1999, Ford asked Firestone to submit a design for a tire with a nylon cap ply, a safety feature often used in Europe and Latin America to make tires more durable…His report stated that when the two companies realized that the Firestone tire with which Explorer was equipped had problems, they, 'in most absolute secrecy' agreed to add a nylon layer to the tire to prevent the tire tread-separation."]

    - [***The Role of Cap Plies in Steel Belted Radial Tires, David Osborne, 2003, "***The cap ply is a mechanical device that acts as a kind of tourniquet and restricts the amount of growth due to the centrifugal load on the tire…The physical restriction of the cap ply causes the movement of the belt edge to be significantly reduced and this has three very important and significant consequences: (1) It reduces stresses and fatigue and loss of properties in the rubber surrounding the belt edges. (2) It reduces the growth of microscopic separations (sockets) that can develop into larger separations. (3) It reduces tire temperatures—heat is the enemy of tires—it weakens rubber through a process known as ageing. The result is that tires with cap plies are more durable, less likely to fail from belt separations and therefore safer than those without.”]

- [***US Patent 4,284,117 Steel Belted Radial Ply Tires with Cap Plies Employing Single Yarn Reinforceing Elements, Pogue.1981. “***This results in a reduction of the weight of the cap ply. Such reduction in the weight has a major effect on the life of the tire…The accumulation of heat in the area of the cap ply is likewise substantially reduced. Such improved dissipation of heat has a favorable effect on the bonding of the edges of the plies forming the tire belt or breaker…It is known in the art to provide an additional cover or cap ply of textile cords overlying the belt…a cap ply is disclosed which is made of a heat shrinkable nylon cords. The shrinkage stresses developed in such cords are utilized to apply compressive pressure to the underlying belt plies and to absorb some of the stress present in the tire during operation.”]

- [Unprotected Testimony of Beale Robinson in <u>Frankl v Goodyear</u>:

11:Q2:54 “Did the application of the nylon overlays to these tires across the Load Range E allow you to reduce the tread throw problem significantly?
11:A3:09 You’re backing up taking a macro view of this whole issue?
11:Q3:15 Right.
11:A3:15 Yes, it does.
11:Q3:17 So would it be fair to say that the ultimate ability of the tires to withstand stresses from whatever conditions, including their manufacture and their use, has improved significantly with the use of the nylon overlay?
11:A3:41 Yes.
11:Q3:41 And would the nylon overlays help the tire to perform in the field for a longer period of time even though there might be some anomaly or problem, for example, minor differences in curing or compounds that without the overlays may have been causing the failures?
11:A4:06 It’s a more robust construction and as such, gives us a greater safety margin for abuse.”]

4. The subject tire and companion Hankook tires exhibit belt irregularities. The belts show evidence of irregular wire spacing, scalloping, wire to wire contact, heavy gapped and overlapped splices. The impact of this irregularity in spacing is that these contribute to heat generation and increase in stresses and strains along and surrounding these points of poor splicing. This lack of process control is a manufacturing defect.

    - [***What's Riding on Your Tires?, Jill Bartel, NTIAC, Department of Defense, Volume 25 No. 5, "***Tires are a laminated process—layers of vulcanized rubber and corded fibers bonded together. If these layers are flawed in some way, they can cause the tire to fail catastrophically. A number of factors can lead to defective tires: (a) abnormal cord spacing. (b) wander, snaking, scalloping, necking, and flare in belt…"]

5. The <u>ratio of belt width to tread width</u> is a defect in the subject tire. The belt widths of the subject tire inadequately support the full road-contacting width of the tread. This lack of support from the underlying belt structure exacerbates an increase in stress, strain, and heat generation in an area (belt ends) already understood to be the highest stress/strain region in a steel belted radial tire. The ratio of the upper belt to the tread should then approximate 100%. The subject tire's #2 belt width to tread width ratio is defective as determined by my inspection.

ELIMINATION OF OTHER CAUSES TO TREAD SEPARATION

As part of my standard methodology and the accepted methodology in the tire industry, I also evaluated other potential or alternative causes (or theories of causation often offered by opposing parties within the course of litigation) for the tire failure other than the manufacturing or designed defects described above. I considered the following:

1. Whether there may have been an impact that may have caused this failure. I observed:

- It is not generally accepted in the tire community that impact damage can cause the specific form of tire failure known as tread separation. There are no authoritative tests or literature on the subject of impacts causing tread separation. In fact, after consultation with industry groups offering test protocols for tire impact/tread separation evaluation the government's National Highway Traffic Safety Administration (NHTSA) tested and concluded the protocols were inadequate at the present time. The subject tire undoubtedly suffered a tread separation. Therefore, it is extremely unlikely—from a general proposition—that the subject tire suffered its failure as the result impact damage.

Given my observations, coupled with my background, training and experience using generally accepted methodology in tire failure analysis, it is my opinion that impact played no role in the tread separation of this tire eliminating impact as a causal factor in the failure of this tire.

2. Whether under-inflation, over-inflation, or over-loading caused this failure. I observed:

- No significant abrasion ring around upper sidewall and tread buttress area.
- Rim grooving in the bead flange area, although in my experience these happen normally as a result of inflated seating to the rim. The rim grooves in the subject tire were dimensionally consistent with that of many other tires that can be observed in service, as well as tires I have tested under proper inflation and loading as described in my peer-reviewed paper, "Rim Compression Grooving-An Objective Measurement Technique".

Given my observations, coupled with my background, training and experience using generally accepted methodology in tire failure analysis, it is my opinion that impact played no role in the tread separation of this tire eliminating under-inflation as a causal factor in the failure of this tire.

3. Whether nail puncture caused this failure. I observed:

- No significant abrasion ring around upper sidewall and tread buttress area.
- Oxidation to belts at belt edges and not emanating from the puncture site.

Given my observations, coupled with my background, training and experience using generally accepted methodology in tire failure analysis, it is my opinion that the nail puncture played no role in the tread separation of this tire eliminating oxidation from the puncture site as a causal factor in the failure of this tire.

SUMMARY OF OPINIONS

1. The subject tire exhibits inadequate bonding between belts as evidenced by liner pattern marks between #1 and #2 belts and between carcass and the #1 belt on the separated surfaces. The subject tire exhibits brassy, poorly bonded belt wires. These are manufacturing defects.

2. The subject tire exhibits premature oxidation of the belt skims. This is a defect in the subject tire absent outside causations.

3. The subject tire exhibits belt irregularities. These are manufacturing defects.

4. The subject tire lacked a nylon cap ply absent other robust design considerations to countermeasure tread separation. This is a design defect.

5. The subject tire exhibits narrow #2 belt to tread contacting width. This is a defect in the subject tire which increases stress and strain at the belt edge.

6. The combination of the above stated defects caused or contributed to cause the subject tire to suffer a catastrophic tread separation which led to a loss of control of the vehicle.

SAFER, ALTERNATIVE DESIGNS

With respect to manufacturing and design defects mentioned, there were safer, alternative designs and manufacturing processes and know-how available to Hankook at the time the subject tire was produced. These meet the litmus test of being both economically and technologically feasible for a tire manufacturer. Had they been employed in the manufacture of the subject tire they would have either eliminated or significantly reduced the likelihood for failure in the observed modes.

These safer, alternative design elements include, but are not limited to:

- Proper application of material shelf life standards.
- Improved rubber to wire bonding.
- Improved chemical AO package in the belt skim rubber to resist premature oxidation.
- Better placement of belt materials.
- Application of a full width nylon cap ply.
- Proper dimensions of belt materials to support contact width of tire.

The inherent weaknesses and defects as described above in this tire caused or contributed to cause its failure, and therefore a combination of alternative design measures were warranted to elevate the tires overall endurance and prevent failure.

The above are my stated opinions regarding this incident tire and the materials and information made available to me at the time of my evaluation. Those materials include the subject tire and rim, X-rays, the accident report, photographs, my training, and various experiences with tire designs and efforts to improve performances based on analysis of test results and failure analysis, my education, and articles, studies, publications read, and tires I have personally inspected, including the subject tire in the Cortez v Hankook matter which was a Sport King A/T tire of the same size/type manufactured in 2000. I inspected Hankook's Daejon, Korea plant in 2009. I have seen the belt material liner materials utilized in the tire manufacturing process. I also videotaped and photographed various aspects of the component preparation, tire manufacturing and inspection processes of the plant which would be useful in fairly representing to a jury how and why some of the defects noted in the subject tire came to be found there in the first place. Additional opinions, observations, and conclusions are stated elsewhere in this report.

This report is based upon my experiences with product development and failure analysis.

I reserve the right to supplement findings and opinions expressed in this report should information be produced through discovery by Hankook or others in this case about Sport King A/T tires (or sister tires to the Sport King A/T) tire materials or documents related to other similar instances of Hankook tire failures.

Depending upon the opinions offered by Hankook's experts, I reserve the right to rebut any opinions provided on behalf of the defendants. All of my opinions above are to a reasonable degree of engineering and scientific certainty.

Troy W. Cottles
Resume

Forensic Tire Failure Analyst
Tire Design and Manufacturing Consultant: **(7/2005 – present)**

Education:

Bachelors of Science, Mathematics/Physics minor, Athens St. University, 1988.
Mechanical Engineering Study, University of AL Huntsville
Additional Training:
3-month design study with Sumitomo Rubber Ind., Ltd. Kobe, Japan
MSOffice Suite; MSProject; AutoCad; Taguchi Techniques (DOE)
Management Skills for Engineers
Design Failure Mode and Effects Analysis (DFMEA)

Technical Focus:

My 17 years of experience in the tire and rubber industry culminated with a promotion to the position of technical director of tire development for Goodyear-Dunlop Tires N.A. Ltd. I provided direct technical input into products specific to passenger and light truck OE products from 1997 onward and most recently, OE and aftermarket lines of ATV products (both bias ply and radial constructions).

Professional Experience:

Goodyear-Dunlop Tires N.A., Ltd. (Buffalo, NY)
Technical Director **(6/2005 to 7/2005)**

- Responsible for all joint venture development programs (motorcycle, ATV, passenger).
- Responsible for meeting annual financial goals through product development management and cost improvements.
- Administration of the annual divisional capital and expenditure budgets.
- Negotiating technical support for outsourcing ATV products.
- Initiated technology thrusts for ATV products, including innovative ply and belt materials.
- Supporting OEM commitments through inter-company prioritization.
- Technical support on product liability issues (review claim tires, provide documentation and drawings, interpret technical specifications, and provide background on original design requirements).

Goodyear-Dunlop Tire N.A., Ltd. (Buffalo, NY)
Senior Technical Manager **(1/2003 to 6/2005)**

- Responsible for ATV and OEM passenger program activities.
- Product integrity test laboratory. Testing including: endurance, regulatory, and force/moment measurement.

- Achievement of annual financial goals through product development, cost improvement efforts.
- Guidance/countermeasures for product performance improvements as required per internal, regulatory, or customer standards.

Goodyear-Dunlop Tire N.A., Ltd. (Akron, OH)
Senior Manager-OEM Passenger Development (8/2001 to 1/2003)

- Integration of the OE passenger technical development team of Dunlop Tire Corp. into Goodyear Tire and Rubber Company's technical headquarters in Akron, OH.
- Responsible for OEM passenger/light truck tire design programs in support of Toyota and Honda per scope of the joint venture.
- Manage an annual departmental budget, including cash flow.
- Departmental staffing, annual performance reviews, and associate training.
- Conduct program kickoff meetings and design reviews with Sumitomo, OEM, and internal management in compliance with TS standards.
- Responsible for profitability of all OEM production programs.
- Formulation of countermeasures for any in-service product concerns.

Goodyear-Dunlop Tire N.A., Ltd. (Huntsville, AL)
Senior Manager-OEM Engineering (9/1999 to 8/2001)

- Responsible for OEM passenger/light truck tire design programs for Mercedes, Toyota, Nissan, and Honda.
- Supervision of development engineering, CATIA support staff, Detroit liaison office, and inventory control personnel.
- Manage an annual departmental budget, including cash flow.
- Introduction (by presentation) of new technologies to technical executive management of all OEM customers.
- Departmental staffing, annual performance reviews and associate training.
- Global negotiation with counterparts regarding technical roles for OE business based in Japan, Europe, or North America (semi-annual to quarterly meetings overseas).
- Formulation of countermeasures for any in-service product concerns.

Dunlop Tire Corporation (Huntsville, AL)
Senior Manager-OEM Engineering (10/1997 to 9/1999)

- Responsible for OEM passenger/light truck tire design programs for Mercedes, Toyota, Nissan, and Honda.
- Supervision of development engineering, CATIA support staff, Detroit liaison office, and inventory control personnel.
- Manage an annual departmental budget, including cash flow.
- Introduction (by presentation) of new technologies to technical executive management of all OEM customers.
- Departmental staffing, annual performance reviews and associate training.
- Global negotiation with counterparts regarding technical roles for OE business based in Japan, Europe, or North America (semi-annual to quarterly meetings overseas).
- Formulation of countermeasures for any in-service product concerns.

Dunlop Tire Corporation (Huntsville, AL)
OEM Senior Development Engineer **(8/1996 to 10/1997)**

- Responsible for all Dunlop N. American OEM tire development program technical activities.
- Customer interface for technical issues.

Dunlop Tire Corporation (Los Angeles, CA)
Customer Liaison Manager **(11/1994 to 8/1996)**

- Technical and field service representative to Japanese OEM R&D and service organizations.
- Negotiation of field service policies with customer corporate service management groups.
- Inspection of field returns at regional and corporate customer sites. Determination on legitimacy of claims.
- Organization of field tire surveys, JDPower roundtable conferences, and auto show surveys.
- Technical representative to FAA (Long Beach) on regulatory requirements for new aircraft tire submissions on Boeing 777 and Lockheed programs for Sumitomo Rubber Industries.

Dunlop Tire Corporation (Huntsville, AL)
OEM Design Engineer **(7/1988 to 11/1994)**

- Program development support to Japanese automotive manufacturers.
- Preparation of CAD tire design drawings, manufacturing specifications, and tire designs.

Steelcase Inc. (Athens, AL)
Production Operator **(1987 to 1988)**

- Manufacturing of office equipment.

Midsouth Testing, Inc. (Decatur, AL)
Waste Water System Operator **(1986 to 1987)**

- Titration of industrial waste water to eliminate metals.
- System repair and maintenance.

Eaton Corporation (Athens, AL)
Engineering Technician **(1984 to 1986)**

- Prototype engineering of electromechanical temperature control switches.
- Process engineering improvements—new raw material certification.
- Product engineering—environmental laboratory and field verification testing.

Cottles Consulting Inc.

Tire Design Consultant | Tire Failure Analyst

Send evidence to: 21848 East Limestone Rd., Toney, AL 35773
Send correspondence/mail to: 25884 Katpaugh Lane, Toney, AL 35773

Office: PH/FAX 256-444-0854
Cell: 256-777-0562
H: 256-423-8338
tcottles@mchsi.com

Fee Schedule

- **Effective:** Jan. 1, 2010
- **Min. Retainer:** $4000--Required at time of inspection for subject tire. Non-refundable.
- **Standard rate:** $400/hour (Additional inspections, analysis, reports, research, teleconferences, and all other, except as noted).
- **Depositions/court appearances:** $400/hour
- **Travel rate:** $400/hour (door to door)
- **Courier rate: By Quotation**
- **All Expenses**
- **Testing: By quotation**

The following testing capabilities are available:

- **Non-contacting 2D laser profile scanning**
- **Expandable (13" to 20") tire inflation/leak detection**
- **T&RA Rim Tapes**
- **Radial Runout**
- **Tire X-Rays (coordinated locally for most sizes)**

*Payment is due upon receipt of invoice. After 90 days, a 20% late charge will be applied for any outstanding balances.

PUBLICATIONS/PATENTS

Statement dated 22-Aug-2010:

Publications:

"Compression Rim Grooving—An Objective Measurement Technique", presented August 13, 2010 at the HIFI Tire Tech Conference, Houston, TX.

Patents:

I currently have applied for no patents.

DEPOSITION TESTIMONY HISTORY

Date	Type	Case	Venue
3/21/06	Deposition	Underwood v. Bridgestone	Gwinnett, GA
8/3/06	Deposition	Loza v. Cooper	Maricopa, AZ
1/30/07	Deposition	Thorne v. Ford, et al.	Montgomery, AL
2/19/07	Deposition	Werner v. BSFS	New Mexico
3/9/07	Deposition	Loza v. MNA	Tucson, AZ
3/30/07	Deposition	Scifres v. Ford	USDC, OK
4/11/07	Trial	Thorne v. Ford, et al.	Montgomery, AL
5/30/07	Deposition	Holmes v. Ford	Atlanta, GA
8/23/07	Deposition	Cleminson v BFS	S. Carolina
9/17/07	Deposition	Seville v. Cooper	Florida
9/25/07	Deposition	H. Johnson v. BFS	Alabama
10/4/07	Deposition	Guzman v. CTNA, et al.	Texas
11/13/07	Deposition	Hughes v. MNA, et al.	Atlanta, GA
12/4/07	Deposition	Tuffly v. Cooper, et al.	Texas
12/14/07	Deposition	Lujan v. Cooper	New Mexico
1/4/08	Deposition	Telusme/Pierre v. Cooper	Florida
1/23/08	Deposition	Whitten/Green v. Isuzu, MNA	Tennessee
2/1/08	Deposition	Sherwood v. MNA, Ford	Georgia
2/13/08	Deposition	Joyner v. MNA	S. Carolina
2/26/08	Deposition	Rodriguez de Garcia v. MNA	Texas
3/10/08	Trial	Keddington v. MNA, et al.	Provo, UT
3/17/08	Trial	Telusme/Pierre v. Cooper	W. Palm Beach, FL
4/8/08	Deposition	Orozco v MNA	Texas
4/24/08	Deposition	McDonald v BFS	Georgia
4/30/08	Deposition	Gonzalez v Pirelli	Florida
5/14/08	Deposition	Bickerton v Cooper	Texas
5/22/08	Deposition	Zuniga v MNA	Texas
6/19/08	Deposition	Cortez v Hankook, et al.	Texas
7/10/08	Deposition	Mizenko v BFS, et al.	Montana
7/18/08	Trial	Holmes v. Ford, et al.	Savannah, GA
7/24/08	Deposition	Solovey/Pavenko v. Cooper, et al.	Los Angeles, CA
7/29/08	Deposition	Soto v. Sangara Dodge, et al.	Albuquerque, NM
8/7/08	Deposition	Martine v. Yokohama, Quality Pontiac	Albuquerque, NM
8/28/08	Deposition	Stallings/Woods v. MNA	Georgia
9/4/08	Deposition	Wright v. LHMiller	Salt Lake City, UT
10/21/08	Deposition	Allen v. MNA, et al.	Orlando, FL
11/4/08	Deposition	Wilkinson v. BFS, et al.	Wyoming
12/9/08	Deposition	Perrett v. MNA	Texas
12/19/08	Deposition	Guzman/Flores/Cruz v. MNA	Texas
12/30/08	Deposition	Deal v MNA	Nevada
1/7/09	Deposition	Zacchary Smith v MNA	Ohio

1/20/09	Deposition	Ramirez v MNA	Texas
2/4/09	Deposition	Papandopoles v BFS	Florida
2/10/09	Deposition	Beauchard v MNA	Florida
2/18/09	Deposition	Hathcock v Hankook	Texas
2/25/09	Deposition	Martinez v Cooper	Texas
3/3/09	Deposition	Jose Guzman v MNA	Texas
3/23/09	Trial	Deal v MNA	Nevada
3/31/09	Deposition	Alexander v Cooper	Alabama
4/14/09	Deposition	Hathcock v Hankook	Texas
5/6/09	Deposition	Navarro v Cooper	Arizona
6/23/09	Deposition	Holmes v BFS	Florida
7/10/09	Deposition	Lamar v Cooper	Florida
7/14/09	Deposition	Toe v Cooper	Iowa
7/20/09	Deposition	Martinez v Cooper (cont'd)	Texas
8/27/09	Trial	Hathcock v Hankook	Texas
8/31/09	Trial	Guzman/Cruz v MNA	Texas
9/9/09	Deposition	Joseph West v MNA	S. Carolina
9/24/09	Deposition	Vaughn v BFS, Ford	Georgia
10/1/09	Deposition	Trenado v Cooper	Texas
10/13/09	Deposition	Alamo v Cooper	Texas
10/21/09	Deposition	Wilharm/Eaton v CTNA, et al	Georgia
10/22/09	Deposition	Mezinko v BFS, et al. (2nd)	Montana
10/29/09	Deposition	Dorce/Pierre v Cooper, et al.	Florida
11/10/09	Deposition	Rodriguez v Cooper	Texas
11/19/09	Deposition	Lester v Smith/Yokohama Rubber Co.	Alabama
11/24/09	Deposition	Mizenko v Ford, BFS, et al	Montana
12/1/09	Deposition	Kaldas v MNA	S.Carolina
12/8/09	Deposition	Figueroa v Cooper, et al.	Arizona
12/22/09	Deposition	Bernardez v MNA, et al.	Florida
1/08/10	Deposition	Greathouse v BFS	Indiana
1/13/10	Deposition	Trenado v Cooper	Texas
2/3/10	Deposition	Whitfield v BFS	Georgia
2/16/10	Deposition	Martin v Cooper	Georgia
2/22/10	Trial	Toe v Cooper	Iowa
3/4/10	Deposition	Mezinko v BFS, Ford	Montana
3/11/10	Deposition	Martinez v MNA, et al.	Georgia
3/17/10	Deposition	Estua Botas, Dominguez v MNA	Florida
3/30/10	Deposition	Heavrin v BFS, et al.	Georgia
4/3/10	Deposition	Hector v Wilrae, et al.	Illinois
4/19/10	Deposition	Saucier v BFS	Mississippi
5/18/10	Deposition	Hector v Wilrae, et al.	Illinois
5/27-28/10	Deposition	Torres v BFS, Ford	Texas
6/24-6/28/10	Trial	Mezinko v BFS, Ford, et al	Montana
8/10/10	Deposition	Allen v MNA	Florida
8/20/10	Deposition	Martin v Cooper	Georgia
8/24/10	Trial	Trenado v Cooper	Texas

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The materials used in support of conclusions formed in this preliminary report were from the following sources:

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U.S. Patent on Asymmetrica Pneumatic Vehicle Tire, 3,834,439, Mirtain, 9/10/1974, Uniroyal.

U.S. Patent on Steel Belted Radial Ply Tires With Cap Plies Employing Single Yarn Reinforcing Elements, 4, 284, 117, Poque et al., 8/18/1981, Fed. Rep. of Germany.

U.S. Patent on Belted Pneumatic Tires, 3,831,656, Senger, et al., 8/27/1974, Uniroyal.

U.S. Patent on Breaker Structures of Radial Tires, 3,973,612, Mezzanotte, 8/10/1976, Pirelli.

U.S. Patent on Tire Casing with Reinforced Sidewalls, 3, 386,487, Massoubre, 6/4/1968, Michelin.

U.S. Patent on Pneumatic Vehicle Tire, 4,724,881, Poque et al., 2/16/1988, Uniroyal.

U.S. Patent on Pneumatic Tire, 4,062,393, Bertrand, 12/13/1977. Uniroyal.

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U.S. Patent on Reinforcing Plies for Tires, 4,791,973, Davisson, 12/20/1988, Goodyear Tire and Rubber.

<u>The Aging of Tires and Similar Objects in Open Air Storage,</u> E. Tuval, A. Thurrn, Z. Rigbi, Tel-Aviv. Israel. Vol. 19, 1999.

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Halobutyl Innerliners Offer Best Tire Durability by D. Tracey, W. Waddell in Rubber & Plastics News, 5/30/05.

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Tire-Belt Durability by Don Lee at HIFI Tire Tech Conference, 8/13/2010.

An Analysis of Bead Compression Grooves by Dennis Carlson at HIFI Tire Tech Conference, 8/13/2010.

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The Hazard of Tire Failure on a Towed Trailer by Charles Kuentz at HIFI Tire Tech Conference 8/13/2010.

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Tread Separation-Human Factor Issues by Larry Wilson at HIFI Tire Tech Conference 8/13/2010.

Failure Modes of Tires Run Over-deflected on Wheel Fatigue Tests by Bill Woehrle and presented by Keith Brown at HIFI Tire Tech Conference 8/13/2010.

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APPENDIX

Nylon Cap Plies (Reinforcement):

- U.S. Patent 4,407,347 Oct. 4, 1983 (Uniroyal)
- U.S. Patent 4,284,117 Aug. 18, 1981 (Uniroyal)
- U.S. Patent 4,724,881 Feb. 16, 1988 (Uniroyal)
- U.S. Patent 3,850,219 Nov. 26, 1974 (Uniroyal)
- U.S. Patent 4,934,430 June 19, 1990 (Sumitomo)
- U.S. Patent 3,831,656 Aug. 27, 1974 (Uniroyal)
- U.S. Patent 4,062,393 Dec. 13, 1977
- U.S. Patent 3,786,851 Jan. 22, 1974
- U.S. Patent 4,791,973 Dec. 20, 1988 (Goodyear)

Tire Aging:

- "Tire Aging: Nothing Lasts Forever…and Tires Are No Exception" www.tirerack.com.
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- "Tires: Aging Dangerously" by S. Kane (Strategic Safety).
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- Michelin Technical Bulletin PM-06-02 "Service Life of Passenger Car and Light Truck Tires Including Spare Tires".
- Cooper Service Bulletin No. 112 (Service Life)
- "Research Report to Congress on Tire Aging"-NHTSA, Aug. 2007

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Liner Pattern Marks :

- "Watch for the Diamonds" by M. Bozarth in Tire Retreading/Repair Journal 9/1993.
- RAPRA Handbook of Rubber Bonding
- The Tire Investigator's Guide to Tire Failures by R.J. Grogan
- Communication from Ronald Smith on liner pattern marks and other topics dated 1/25/2000. [See following document.]

January 25, 2000

Mr. Bruce R. Kaster
Green, Kaster and Falvey, P.A.
Attorneys At Law
125 N.E. First Avenue
Ocala, FL 34470

The following opinions and conclusions are based upon my education and analysis of tires which have failed in actual use:

1. The presence of bare wire in a tire which has experienced a tread belt separation is an indication of poor adhesion.

2. One should not normally observe a brassy color to wire that has been exposed due to a separation. The observance of a brassy color on exposed wire is an indication of very poor adhesion. When wire is exposed in a delamination it should have a dark color rather than a brassy color

3. Nylon strip overlays or Nylon safety strips are effective in eliminating belt edge separations. They are not universally used in steel belted radial passenger tires due to the additional cost factor.

4. Manufacturing plant conditions can have adverse effects on tire performance or early failures initiated by belt edge separation. High humidity and/or high levels of ozone in the manufacturing area can cause undesirable oxidation of exposed wire surfaces resulting in lowered cured adhesion and undesirable dynamic adhesion problems. Excessive use of solvent "freshener" on rubber surfaces prior to tire fabrication can result in a contamination of the surfaces by a thin film of rubber that can adversely affect long term adhesion of rubber surfaces.

5. Improper curing conditions can lead to tread belt separation. One indication of improper curing conditions would be the presence of certain markings on the separated surfaces. These markings, caused by the imprint of temporary liners used in the factory to separate components before building the tire, indicate that the tire component surfaces had never completely fused together during cure. Another indication of faulty cure would be extensive areas of exposed wire in the delaminated surface of the used tire failure.

Sincerely,

Ronald W. Smith
2450 Clarke Drive
Lake Havasu City, AZ 86403
(520) 855-8723