Engineering Analysis Report and Initial Decision

Regarding

EA00-023: Firestone Wilderness AT Tires

U.S. Department of Transportation
National Highway Traffic Safety Administration
Safety Assurance
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EXECUTIVE SUMMARY

The National Highway Traffic Safety Administration (NHTSA) has made an initial decision that a defect related to motor vehicle safety exists in certain P235/75R15 and P255/70R16 Firestone Wilderness AT tires manufactured before May 1998 that are installed on sport utility vehicles (SUV). This Engineering Analysis Report provides the basis for that decision.

Belt-leaving-belt tread separation failures of ATX and Wilderness AT tires manufactured by BridgestoneFirestone, Inc. (Firestone), have led to numerous crashes, injuries, and fatalities. In August 2000, Firestone determined that a safety-related defect existed in all Firestone P235/75R15 ATX tires and in Firestone Wilderness AT tires of that size manufactured at its Decatur, Illinois plant, and commenced a recall to replace those tires. Wilderness AT tires were the successor to ATX tires and are similar to them in many respects. NHTSA's Office of Defects Investigation (ODI) has conducted an extensive investigation to determine whether any other Wilderness tires contain such a defect, and whether they should be recalled as well.

The focus of ODI's investigation was on those non-recalled tires that are similar to the recalled tires; i.e., Wilderness AT tires of the size P235/75R15 and P255/70R16 manufactured by Firestone for supply to Ford Motor Company (Ford) as original equipment, as well as replacement tires manufactured to the same specifications ("focus tires"). Most of the focus tires were manufactured at Firestone's Wilson, North Carolina and Joliette, Quebec plants, beginning in 1994. In late 1998, Firestone began producing P255/70R16 Wilderness AT tires at Decatur, and in mid-1999, it began producing P235/75R15 Wilderness AT tires at a new plant in Aiken, South Carolina. Also, fewer than 100,000 P235/75R15 Wilderness AT tires were produced at Firestone's Oklahoma City, Oklahoma plant. The focus tires were predominantly used as original equipment on Ford Explorer SUVs and, to a lesser extent, on Ford Ranger compact pickup trucks, and as replacement tires for use on these and other SUVs and pickups.

ODI's investigation included, with respect to both Firestone tires and peer tires, thorough analyses of available data regarding the performance of tires in the field; shearography analysis to evaluate crack initiation and growth patterns and their severity in tires obtained from areas of the country where most of the failures have occurred; and observations, physical measurements, and chemical analyses. ODI also reviewed numerous documents and extensive test data submitted by Firestone and others.

Belt-leaving-belt tread separations, whether or not accompanied by a loss of air from the tire, reduce the ability of a driver to control the vehicle, particularly when the failure occurs on a rear tire and at high speeds. Such a loss of control can lead to a crash. The likelihood of a crash, and of injuries or fatalities from such a crash, is far greater when the tread separation occurs on a SUV than when it occurs on a pickup truck.

Tread separation claims included in the Firestone claims database involving the recalled and focus tires have been associated with numerous crashes that have led to 74 deaths and over 350 injuries (as of March 2001). Tread separation complaints from all sources included in the ODI consumer complaint database (including the Firestone claims data) that can be identified as

involving these tires have reportedly led to 192 deaths and over 500 injuries (as of September 2001).

The belt-leaving-belt tread separations in the recalled and focus tires generally occur only after several years of operation. Thus, since the focus tires have not been on the road as long as the recalled ATX tires, the absolute number of failures of those tires, and the unadjusted failure rate of those tires, are less than those of comparable ATX tires. Claims in the Firestone claims database involving the focus tires have been associated with 17 deaths and 41 injuries, with additional crashes and casualties reported in the ODI complaint database, including reports of six additional fatalities. However, on a plant-by-plant basis, the focus tires manufactured at the Wilson and Joliette plants have exhibited tread separation failure trends that are similar to those experienced by the recalled ATX tires at similar service intervals.

These failure trends indicate that it is likely that, if they are not removed from service, the focus tires – at least those manufactured before May 1998 – will experience a similar increase in tread separation failures over the next few years, leading to a substantial number of future crashes, injuries, and deaths. The tread separation failure experience of the focus tires is far worse than that of their peers, especially that of the Goodyear Wrangler RT/S tires used as original equipment on many Ford Explorers.

The belt-leaving-belt tread separations that have occurred and are continuing to occur in the recalled and focus tires begin as belt-edge separation at the edge of the second, or top, belt. This is the area of highest strain in a steel belted radial tire and is a region with relatively poor cord-to-rubber adhesion because bare steel is exposed at the cut ends of the cords. Once belt-edge separations have initiated, they can grow circumferentially and laterally along the edge of the second belt and develop into cracks between the belts. If they grow large enough, they can result in catastrophic tread detachment, particularly at high speeds, when the centrifugal forces acting on the tire are greatest.

ODI conducted a non-destructive analysis of numerous randomly collected focus tires and peer tires from southern states, where most of the failures have occurred, using shearography, which can detect separations inside a tire. This shearography analysis demonstrated that the patterns and levels of cracks and separations between the belts were far more severe in the focus tires than in peer tires. Many of the focus tires that were examined were in the later stages of failure progression prior to complete separation of the upper belt. The shearography results for tires manufactured at Wilson were similar to those manufactured at Joliette.

A critical design feature used by tire manufacturers to suppress the initiation and growth of belt-edge cracks is the "belt wedge," a strip of rubber located between the two belts near the belt edges on each side of the tire. The belt wedge thickness, or gauge, in the ATX tires and the Wilderness AT tires produced prior to May 1998 is generally narrower than the wedge gauge in peer tires, and the wedge gauge in cured tires was often less than Firestone's target for this dimension. The tires with this wedge did not adequately resist the initiation and propagation of belt-edge cracks between the steel belts. During March and April 1998, Firestone changed the material composition and increased the gauge of the wedge in its Wilderness AT tires (and some other tire models).

Another important feature of radial tires related to the prevention of belt-leaving-belt separations is the gauge of the rubber between the two steel belts, or "inter-belt gauge." The inter-belt gauge initially specified by Firestone for the focus tires is generally narrower than the inter-belt gauges in peer tires and is narrower than Firestone's original specification for the ATX tires in the early 1990s. Moreover, the actual measured gauge under the tread grooves in several of the focus tires measured by ODI was far less than Firestone's minimum design specification. Since an inadequate inter-belt gauge reduces the tire's resistance to crack growth and its belt adhesion capabilities, this narrow inter-belt gauge may be partially responsible for the relatively low peel adhesion properties of the focus tires compared to peer tires. In August 1999, after becoming concerned about the adequacy of the inter-belt gauge in the cured Wilderness AT tires, especially in the regions directly under the tread grooves, Firestone changed the inter-belt gauge specification back to the original dimension.

Another relevant feature is the design of the shoulder pocket of the focus tires, which can cause higher stresses at the belt edge and lead to a narrowing, or "pinching," of the wedge gauge at the pocket. The focus tires exhibit a series of weak spots around the tire's circumference, leading to the initiation and growth of cracks earlier than in competitor tires and in other Firestone tires produced for light trucks and SUVs. In addition, many of the focus tires exhibited shoulder pocket cracking similar to that which Firestone identified as a significant contributor to the risk of tread detachment in the recalled ATX tires.

Because the tread separations at issue in this investigation occur only after several years of exposure, almost all of the failures on which ODI's analysis of field experience was based involved tires manufactured before the May 1998, when Firestone increased the dimensions and improved the material of the belt wedge. In theory, these modifications to the wedge would tend to inhibit the initiation and propagation of the belt-edge cracks that lead to tread separations. If these modifications actually improved the resistance of the focus tires to belt-edge separations, the historical failure trends described above may not predict the future performance of the newer tires. However, because tread separation failures rarely occur in the focus tires until at least three years of use, it is not now possible to ascertain from field experience whether their actual performance has improved significantly.

The rate of tread separation failures on Ranger pickups is lower that the rate of such failures on Explorers for a variety of reasons, including the fact that the Explorer generally carries higher loads and is a more demanding application, and the tires on the Explorer had a significantly lower recommended inflation pressure (especially on the rear wheels). The risk of such a separation on Rangers remains a cause for possible concern. Nevertheless, because the likelihood of a crash due to a tread separation, and of deaths and injuries resulting from such a crash, is substantially lower when the separation occurs on a pickup than on a SUV, NHTSA's initial defect decision does not apply to focus tires installed on pickup trucks.

Under the National Traffic and Motor Vehicle Safety Act, in order to compel a manufacturer to conduct a recall, NHTSA has the burden of proving that a safety-related defect exists in the manufacturer's products. The record of this investigation supports a determination that a safety-related defect exists in the focus tires manufactured by Firestone prior to its 1998 modifications

to the belt wedge that are installed on SUVs. Although the agency has concerns about the possibility of future tread separations in focus tires manufactured after the wedge change, the available evidence at this time does not clearly demonstrate that a safety-related defect exists in those focus tires. NHTSA will, however, continue to closely monitor the performance of these tires.

Therefore, on the basis of the information developed during the ODI investigation, NHTSA has made an initial decision that a safety-related defect exists in Firestone Wilderness AT P235/75R15 and P255/70R16 tires manufactured to the Ford specifications prior to May 1998 that are installed on SUVs. These tires were manufactured primarily at Wilson and Joliette and, to a lesser extent, at Oklahoma City. The initial decision does not apply to the P255/70R16 tires produced at Decatur or any of the Wilderness AT tires produced at Aiken, since these tires were all manufactured after May 1998.

1 Introduction

The National Highway Traffic Safety Administration (NHTSA) has made an Initial Decision that certain Wilderness AT tires manufactured by BridgestoneFirestone, Inc. (Firestone) for use as original equipment on vehicles manufactured by Ford Motor Company (Ford), and other similar tires with the same construction codes that were produced for replacement market sales, contain a defect that relates to motor vehicle safety. The Initial Decision is based upon an extensive and detailed investigation conducted by NHTSA's Office of Defects Investigation (ODI). This Report describes that investigation and presents the rationale for the Initial Decision.[1]

2 Background and History of this Investigation

2.1 The Opening of ODI's Investigation in May 2000

On May 2, 2000, ODI opened an investigation of tire failures involving Firestone Radial ATX, ATX II, and Wilderness tires manufactured since 1991 (PE00-020). When the investigation was opened, ODI was aware of 90 reports alleging tread separation or sudden loss of inflation pressure (blowout), including 33 crashes, 27 injuries, and 4 fatalities. While most of those reports and crashes involved Radial ATX II tires of the P235/75R15 size that were designed to be used as original equipment on light trucks and sport utility vehicles (SUV) manufactured by Ford, the scope of ODI's investigation included all ATX and Wilderness tires produced by Firestone since January 1, 1991. The term "subject tires" will be used to refer to the tires covered by that investigation.

2.2 Firestone's August 2000 Recall

On August 9, 2000, Firestone announced that it would recall approximately 14.4 million P235/75R15 Radial ATX, ATX II, and Wilderness AT tires to remedy a safety-related defect. Firestone formally notified ODI of its recall action (Recall Number 00T-005) in a letter dated August 16, 2000. All of the ATX tires of that size were subject to the recall, regardless of production plant, while the Wilderness AT recall was limited to tires produced at Firestone's Decatur, Illinois assembly plant. Firestone estimated that less than half (6.5 million) of those tires remained in service in the United States when the recall was initiated.

Tread separation failures of the tires covered by this recall have been associated with numerous crashes, fatalities, and injuries.

2.3 ODI's Engineering Analysis

On August 31, 2000, ODI upgraded its investigation to an Engineering Analysis (EA00-023) to determine whether any of the other subject tires contained a safety-related defect; i.e., whether the scope of Firestone's August 2000 recall was adequate. ODI's investigation has involved

[1] The information upon which this Initial Decision is based is contained in the public file for this investigation, which is available in NHTSA's Technical Information Services office. Because of the volume of information, it has been placed on CD-ROM.

analysis of field data from Firestone and other sources, collection of information from peer tire manufacturers, hiring experts to assist in analysis of the relevant issues, review of "root cause analyses" performed by Ford, Firestone, and an independent expert retained by Firestone, analysis of test data generated by Firestone and Ford, and an extensive test program to assess the condition of certain Firestone and peer tires collected from regions of the country where the failure experience has been the most severe.

The focus of this Engineering Analysis has been on those Firestone tires that were not recalled and are most similar in design to the recalled tires. These are P235/75R15 and P255/70R16 Wilderness AT tires that Firestone designed for use on Ford products (primarily Ford Explorer, Mercury Mountaineer, and Mazda Navajo SUVs (for convenience, this Report will refer to all of these SUVs as "Explorers"), Ford Ranger and Mazda B-series compact pickup trucks, and Ford F-series full-sized pickup trucks). The term "focus tires" will be used to refer to the non-recalled P235/75R15 and P255/70R16 Wilderness AT tires manufactured by Firestone for supply to Ford as original equipment and tires with the same construction codes as those tires that were produced for replacement market sales.

Figure 1 provides a summary of the claims, crashes, injuries, and fatalities in the Firestone claims database as of March 2001 for the subject tires, recalled tires, and focus tires. Figure 2 provides a summary of the complaints, crashes, injuries, and fatalities in the ODI complaint database (from all sources) that can be identified as allegedly involving these categories of tires. ODI's database is a comprehensive compilation of all reported incidents involving crashes, including those found in Firestone's claims database, but not a comprehensive compilation of non-crash incidents. Unfortunately, many of the complaints in the ODI database do not contain sufficient information to identify the specific tire involved.[2]

2.4 The Alleged Defect

The alleged defect involves a belt-leaving-belt failure of a tire (often referred to as "tread separation"), resulting in complete or partial detachment of the tread and the outer belt (also referred to as the top belt or the second belt) from the tire's carcass and inner belt (also referred to as the lower belt or first belt). Detachment of the tread and second belt from the carcass significantly alters the lateral stiffness and other properties of the tire, with a consequent reduction in vehicle stability, which can lead to crashes, injuries, and fatalities.

Under the National Traffic and Motor Vehicle Safety Act of 1966 (Vehicle Safety Act, now codified at 49 U.S.C. Chapter 301), if a manufacturer of a motor vehicle or item of replacement equipment or NHTSA decides that a defect related to motor vehicle safety[3] exists in a vehicle or

[2] Despite extensive efforts by ODI to contact complainants in order to obtain as much information as possible, ODI has not been able to identify the type, size, production date, and/or production plant for many of the tires whose failure gave rise to the complaints.

[3] Under the Vehicle Safety Act, "'defect' includes any defect in performance, construction, a component, or material of a motor vehicle or motor vehicle equipment." 49 U.S.C. 30102(a)(2). "Motor vehicle safety" is defined as "the performance of a motor vehicle or motor vehicle equipment in a way that protects the public against unreasonable risk of accidents occurring because of the design, construction, or performance of a motor vehicle, and against unreasonable risk of death or injury in an accident . . . ."

equipment item, the manufacturer must provide owners with notification of, and a remedy for, the defect. 49 U.S.C. 30118-30120. For these purposes, all tires, even those that were installed on new vehicles, are deemed to be replacement equipment. 49 CFR 579.4.

United States v. General Motors Corp.("Wheels"), 518 F.2d 430 (D.C. Cir. 1975), is the seminal case on the definition of what constitutes a "defect." The court ruled that a vehicle or component is defective if it is subject to "a significant number of failures in normal operation." The court characterized "a significant number of failures" as a number that is "non-de minimus." The court observed that "a determination of 'defect' does not require any predicate of a finding identifying engineering, metallurgical, or manufacturing failures, but may be based exclusively on the performance record of the vehicle or component." Id. at 432.

The court explained that the question of whether a "significant" number of failures has taken place must be answered in terms of the facts and circumstances of each particular case, and that relevant considerations include the failure rate of the component in question, failure rates of comparable components, and the importance of the component to the safe operation of the vehicle. Id. at 438, fn. 84.[4] It specifically stated that "the number of failures need not be and normally will not be a substantial percentage of the total number of components produced." Id.

2.5 Development and Production History of the Subject Tires

The Radial ATX II P235/75R15 tires, which Firestone recalled in August 2000, were developed in the late-1980s as original equipment tires for various Ford light truck and sport utility vehicle applications including the Explorer, Bronco, F150, and Ranger. The ATX II tires were derived from an earlier radial tire produced by Firestone known as the Radial ATX. (For convenience, this Report will use the term "ATX" to refer to all subject Radial ATX and Radial ATX II tires.) Extra-load tires were used on the Bronco and F150 and standard-load tires were used on the Explorer and Ranger.

All of the recalled and focus tires, and the vast majority of the subject tires, are passenger car tires, even though they were designed for, and primarily used on, light trucks and SUVs. Because of handling and ride considerations, most vehicle manufacturers equip their SUVs (and some of their pickup trucks) with passenger car tires, which require lower inflation pressures and provide a less harsh ride than light truck (LT) tires. These tires have the letter "P" included in the designation/size of the tire and are often referred to as "P-metric" tires.

Firestone redesigned the P235/75R15 ATX tires supplied to Ford in 1994 to improve their ride and rolling resistance characteristics. The redesigned tire weighed slightly less than the original. According to Firestone, the weight reduction resulted from changes in the bead area and did not affect the belt-edge durability of the tire or its susceptibility to tread separation. ODI's analysis

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49 U.S.C. 30102(a)(8).

[4] The Wheels case involved a component that was expected to last for the life of a vehicle. The court recognized that other considerations could apply to cases involving equipment that is normally replaced during the life of a vehicle.

of claims data does not indicate a significant difference in failure rates for ATX tires produced before and after the 1994 change at a given plant.

In the early 1990s, the ATX tires were manufactured at Firestone's Joliette, Quebec and Wilson, North Carolina plants. In 1994, Firestone's Decatur, Illinois plant began providing an increasing share of the ATX shipments to Ford. A relatively small number of ATX tires were produced at the Oklahoma City, Oklahoma and Lavergne, Tennessee plants for aftermarket sales. Figure 3 shows the volumes of shipments of ATX tires to Ford for use as original equipment (OE) by Firestone assembly plant. In 1996, the last year Firestone produced the ATX tire as an OE tire for Ford, Decatur provided 84 percent of those tires.

Firestone began developing the Wilderness AT tire for Ford in 1993. These tires met improved snow handling and irregular wear targets established by Ford and had a different tread design than the ATX tires. While the Wilderness AT tires had a different subtread compound and steel belt angle, many other components and features of those tires were unchanged from those of the ATX tires.[5]

In early 1994, Firestone began producing the Wilderness AT P255/70R16 tire at the Joliette plant, and it began supplying the tire for certain versions of the model year (MY) 1995 Explorer in August of that year. Ford accepted the Wilderness AT P235/75R15 tire in May 1995, but it did not begin to use it on Explorers until the start of MY 1997 production in August 1996. Figures 4 and 5 show the OE shipment data to Ford for the Wilderness AT P235/75R15 and P255/70R16 tires.[6]

Table 1 shows the Firestone assembly plants that produced the recalled and focus tires, with the respective DOT codes for those plants and production volumes (both OE and replacement tires).

Ford built MY 1991 through 1994 Explorers at its Louisville, Kentucky assembly plant. When the vehicle was modified in MY 1995, production was expanded to Ford's St. Louis, Missouri plant. From 1995 to 1997 Ford used approximately 2.5 million Goodyear Wrangler RT/S P235/75R15 tires as OE on about half of the Explorers manufactured during that period. After 1997, Ford dropped Goodyear as a supplier and used only Firestone tires on the Explorer until MY 2001.

2.6 Failures of Focus Tires in Foreign Countries

In July 1997, Ford began receiving complaints of tread separations and crashes involving MY 1996 and 1997 Explorers equipped with Wilderness AT P255/70R16 tires that were sold and operated in Saudi Arabia and other Middle Eastern countries, where the ambient temperatures are often very high.[7] Similar complaints were later received with respect to Explorers equipped

[5] Some relevant design features and changes are discussed in Section 3.4 of this Report.

[6] A relatively small number of P235/75R15 Wilderness AT tires were manufactured at the Oklahoma City plant for aftermarket sales.

[7] Firestone had received its first claim involving a crash in the United States due to a tread separation of a subject tire in October 1993. An ATX tire manufactured at the Wilson plant failed at the left-rear wheel of

with Wilderness AT P235/75R15 tires in Malaysia and Thailand and with Wilderness AT tires of both sizes in Venezuela. When the number of tire failures and crashes (some involving injuries and fatalities) escalated in 1999, Ford's Automotive Safety Office opened an investigation. Shortly afterward, engineers from Firestone and Ford traveled to the Middle East to study the problems with the P255/70R16 tires. Firestone concluded that the tire was inappropriate for the market, that most of the tread separations were caused by "low inflation pressures, improper repairs, and long tread life," and that additional cases of tread separation were likely to occur.[8] Ultimately, Ford initiated field actions in the Middle East, Southeast Asia, and South America to address problems with Wilderness AT tread separation failures on Explorer vehicles in those markets. The scope and dates of these actions are described in Table 2.

While the countries involved did not have statutory provisions governing motor vehicle safety recalls, these field actions were similar to safety recalls in the United States, in that Ford offered to replace all of the Wilderness AT tires on the involved vehicles with new tires from other tire manufacturers at no charge. Ford did not notify ODI of these field actions until the summer of 2000, after the opening of PE00-020.

2.7 Ford's "Southwest Survey"

In March 1999, concerns about the experience of the Wilderness AT P255/70R16 tire in the Middle East led Ford to request information from Firestone about performance in the United States. Firestone responded with adjustment data indicating that the return rate was, in its view, "extremely low." Firestone also contended that the "tire performs exceptionally well in the U.S. market." Nevertheless, in July 1999 Ford opened an investigation of Wilderness AT P255/70R16 tread separation failures in the United States. In September 1999, Ford and Firestone began a survey of P235/75R15 and P255/70R16 Wilderness AT tires collected from dealers in four cities of the Southwestern United States.

Ford ultimately collected 243 tires from 63 vehicles. Firestone representatives visually inspected the tires, but only seven of the tires were cut apart to determine the amount of belt-edge separation. Separations were detected in six of the cut tires, including one with a 19 mm (0.75 inch) crack. Despite these findings, in an April 2000 memo, Firestone advised Ford that the survey tires "revealed no deficiencies" and that "the tires performed as expected." Ford was poised to close its investigation when ODI opened PE00-020 in May 2000.[9]

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an Explorer, resulting in a September 1993 crash. The first such fatal crash reported to Firestone occurred in April 1995, involving a Joliette-built ATX tire on a MY 1992 Explorer. The ATX tires were not used overseas. Figure 6 shows the history of fatal crashes for all tire failures involving the subject tires that have been reported to ODI and for those fatal crashes involving allegations of tread separation.

[8] See Ford's "Summary of Firestone Tire Inspection Trip 6/8/99 to 6/17/99."

[9] See April 20, 2000 entry in Ford's Critical Concern Review Group, File 5K00.

2.8 Ford's May 2001 Owner Notification Program

On May 22, 2001, Ford announced that it would conduct an Owner Notification program (ONP) under which it will provide free replacements for all Wilderness AT tires, regardless of construction code, on motor vehicles manufactured by Ford. Ford stated that it was taking that action because of its concern about the performance of Wilderness AT tires as they age and the possibility of safety risks to Ford customers. Ford acknowledged that some of the tires did not present a substantial risk of failure, but stated that it had decided to be inclusive to avoid any confusion on the part of its customers.

The Ford ONP does not moot the ODI investigation or eliminate the need for NHTSA to consider whether any of the focus tires contain a safety-related defect. First, the ONP only applies to tires on Ford vehicles (as well as certain Mercury and Mazda models). Although the vast majority of the focus tires were installed as original equipment on those vehicles, and it is likely that many, if not most, of the focus tires provided by Firestone for sale in the replacement market were also installed on Ford vehicles, many of those tires were purchased as replacement equipment by owners of other vehicles not covered by the ONP. This is confirmed by the fact that Firestone has received claims, and ODI has received complaints, of tread separation failures and crashes involving the focus tires on non-Ford vehicles, including non-Ford SUVs.

Second, Ford's ONP is not the same as a defect determination. Owners of motor vehicles and motor vehicle equipment are more likely to respond to a determination that a safety-related defect exists than to a mere offer by a manufacturer to provide a repair or replacement in the absence of such a determination. That is why NHTSA often opens defect investigations after becoming aware that a manufacturer has initiated a "service campaign" under which it is offering a remedy for what appears to be a safety problem without acknowledging that a safety defect exists. In those situations, NHTSA often persuades the manufacturer to conduct a true safety recall, including a supplemental notification to owners stating that a safety defect exists. Although it is difficult to quantify the effect of such a notification, it is clear that it is likely to encourage more owners to obtain a remedy and therefore reduce the safety risk associated with the defect. This is particularly true in situations such as this, where the "service campaign" is not being conducted by the manufacturer of the components in question (in this case Firestone), and where that manufacturer is strenuously insisting that its tires are safe and that no further action is needed or appropriate.

Finally, it has become clear throughout the course of this investigation that many members of the public, as well as many members of Congress, believe that it is critical for NHTSA, as an objective Government agency with no financial stake in the controversy, to state its conclusions with respect to the issue of whether any of the non-recalled Firestone subject tires contain a safety-related defect. NHTSA cannot be a referee in the ongoing dispute between Ford and Firestone as to which of those companies is responsible for the crashes, injuries, and fatalities that have occurred. Nor will any NHTSA decision resolve any legal disputes between Ford and Firestone involving product liability actions in courts or indemnification for expenses. However, NHTSA believes that, even apart from the safety considerations discussed above, it is appropriate for the agency to state the findings that it made and the conclusions that it reached during this investigation and provide an explanation of those findings and conclusions.

3 Description of Radial Tires and the Failure Mode at Issue in This Investigation

3.1 Steel-Belted Radial Tires

A cutaway view of a radial tire is shown in Figure 7. At the inside of the tire is an inner liner and then the casing ply, or "carcass," which is covered by two steel belts. The steel belts are covered with a thin coat of rubber, called the skim coat. The "inter-belt gauge" refers to the thickness of the rubber between the steel cords of the two belts. A thin strip of rubber, referred to by Firestone as the "belt wedge" or "wedge," is placed between the belts at both shoulders of the tire to increase the inter-belt gauge at the belt-edge region, in order to mitigate the strains that develop in that critical area during each revolution of the tire. In this Report, "wedge gauge" refers to the thickness of the rubber between the steel cords at the edge of the second belt.[10] The importance of the wedge, wedge gauge, and inter-belt gauge with respect to the failure mode of interest in this investigation will be discussed in greater detail later in this Report.

Another relevant design feature is the shoulder pocket, which is the cavity between the heavy ribs, or lugs, along the shoulders of the tire (Figure 8). The shoulder pockets of the ATX and Wilderness AT tires manufactured for Ford are larger than those in other Firestone and peer tires used in similar applications. A comparison with shoulder pocket designs of several other Firestone tires and peer tires is shown in Appendix B.

3.2 Failure Mode

The belt-leaving-belt tread separations that have occurred in the recalled and focus tires begin as belt-edge separation at the edge of the second belt. This is the area of highest strain in a steel belted radial tire, primarily due to the structural discontinuity created by the abrupt change in modulus[11] from steel to rubber. It is also a region with relatively poor cord-to-rubber adhesion because bare steel is exposed at the cut ends of the cords.[12]

Belt-edge separation is governed by two principal factors: (1) the resistance of the belt rubber to crack initiation and propagation; and (2) the forces driving the crack forward through the belt rubber (i.e., the strain state of the belt rubber at the crack tip). The crack growth characteristics of the belt rubber evolve over time from the effects of aging. There are many factors controlling

[10] In its wedge studies, Firestone measured the wedge gauge four cords in from the edge of the second belt. Firestone has stated that it did so because of variance of the wedge dimension at the belt edge. However, because the potential for such variation at this critical location is an important factor in the development of belt-edge separations, ODI determined that it is more appropriate to measure the wedge gauge at the belt edge. The thickness at this point is referred to as "Wedge A."

[11] The tensile elastic modulus, or Young's Modulus, is loosely defined as the force needed to elongate a material.

[12] Because rubber does not adhere well to steel, the cords are brass-plated to promote cord/rubber adhesion, but there is no brass on the cut ends of the cords.

this evolution, including base operating temperature, oxygen content, compound type, usage conditions, and manufacturing variance (e.g., compounding and cure systems). The primary source of oxygen content in the belt-edge area is from the diffusion of inflation air through the carcass.

The strain state of the belt rubber is determined by various factors, including tire design (e.g., mold shape), belt design (e.g., skim coat thickness and compound), manufacturing variance (e.g., belt placement and gauges), and usage conditions (e.g., load). The purpose of the wedge is to reduce the strain condition in the belt-edge area and suppress the initiation and growth of starter cracks.

Once belt-edge separations have initiated, they can grow circumferentially and laterally along the edge of the second belt and develop into cracks growing between the belts. Such cracks can form areas of separation at one or more locations around the circumference of the tire. The rate of crack propagation, and the size of separation at which catastrophic belt-leaving-belt failure can occur, are dependent on the evolved (i.e., aged) state of the belt rubber. Figure 9 shows an example of a large crack in a Wilderness AT P235/75R15 tire produced at the Joliette plant in May 1996.

The areas of separation develop in crescent, or semi-elliptical, shaped patterns at various locations around one or both shoulders of the tire. If they grow large enough, they can result in catastrophic tread detachment, particularly at high speeds, when the centrifugal forces acting on the tire are greatest. Figures 10 and 11 show the characteristic separation pattern that has resulted in failures of the recalled and focus tires. Figure 10 is a photograph of the carcass of a P235/75R15 Wilderness AT tire manufactured at the Wilson assembly plant in September 1996. The separation progressed from the shoulder (where the cracks initiated and grew) to the outer tread groove on the opposite side of the tread. Figure 11 shows a close-up view of the separation pattern on the underside of the tread from the same tire.

A more complete description of the progression of belt-edge separation and crack growth is furnished in Appendix A, which includes a depiction of the failure process and some examples of each stage of development.

3.3 General Design Approach to Minimizing Initiation and Growth of Inter-Belt Cracks

Fatigue crack initiation and propagation in cord-rubber composites and the potential for belt-edge separation are long-recognized and heavily-studied failure mechanisms in radial tires. The literature emphasizes the critical importance of the belt wedge in suppressing the initiation and growth of cracks in the belt edge area and the importance of using rubber that has good resistance to crack propagation in the belt skim coat and wedge compounds.[13]

[13] Firestone does not evaluate the crack growth characteristics of the belt skim coat and wedge compounds during its development of these compounds. It did so during its "root cause analysis;" the results are described in the report by Firestone's outside expert.

There are hundreds of patents, spanning several decades, describing various methods for improving the belt-edge durability of radial tires. One such patent, filed by Uniroyal in 1974, indicates the general state of knowledge around the time that radial tires entered widespread use:

> It is known that tires having a tread reinforced by a belt or breaker composed of superposed, mutually crossed, rubberized plies of parallel, essentially inextensible cords or cables, 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 longitudinal direction of the cords or cables therein, have a 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.[14]

By the late 1980s, the fundamental factors affecting belt-edge durability were well documented in the technical literature. For example:

> Central to the [fatigue failure] mechanism are the crack-growth characteristics of the material. The correlation of the rate of crack growth of both penny-shaped cracks and interply cracks to the crack-growth characteristics suggests that the crack-growth characteristics are a particularly valuable screening criterion for compound development.
>
> Product life may also be lengthened by design of the laminate construction to reduce the strain-energy release rate. For example, the use of a belt edge filler element which increases the interply laminate distance at the edges may be useful in reducing the strain-energy density locally at the cord ends, thus suppressing the initiation and retarding propagation of the penny-shaped cracks.[15]

This assessment is echoed in a book published in 1992 under the auspices of the Rubber Division of the American Chemical Society:

> The practical advice implications of this work are: (1) use rubber resistant to crack propagation; and (2) design the laminate to reduce the strain energy release rate. For example, an edge filler in the laminate increases the interply distance at the edges and may reduce the local strain energy density, thus retarding the formation of starter cracks.[16]

These papers and others stress the fundamental importance of the wedge gauge in suppressing or at least retarding the formation of belt-edge cracks, in order to enhance the fatigue life of the tire.

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[14] M. Bertrand, "Pneumatic Tire," U. S. Patent No. 4,062,393, December 13, 1977.

[15] Y. S. Huang and O. H. Yeoh, "Crack Initiation and Propagation in Model Cord-Rubber Composites," meeting of the Rubber Division, American Chemical Society, Cincinnati, Ohio, October 18-21, 1988.

[16] M. D. Ellul, in "Engineering with Rubber - How to Design Rubber Components," edited by A. Gent, Hanser Publishers, Munich, 1992.

3.4 Modifications of the Recalled and Focus Tires

The recalled and focus tires that were manufactured prior to May 1998 have relatively thin belt wedge and inter-belt gauges compared to other tires used as original equipment on sport utility vehicles. As noted in the technical literature above, the gauge of the belt wedge is important in suppressing the initiation and early growth of belt-edge separations. An inadequate inter-belt gauge reduces laminate crack growth resistance and belt adhesion capabilities (i.e., resistance to belt-leaving-belt type failures once a crack has developed and grown through the wedge area).

Beginning in March 1998, Firestone changed the material composition and increased the uncured, or "green tire" gauge[17] of the belt wedges used in the recalled and focus Wilderness AT tires and over 100 other passenger car tires that were used in light truck (LT) applications. (Firestone has told ODI that this change was not fully implemented in all of its plants until several weeks thereafter. Based on its measurements of wedge gauge in tires produced during that period, ODI is defining pre-wedge change tires as those made prior to May 1998; i.e., those produced in Week 18 of 1998 and earlier.) Firestone has characterized this change as a product of its "continuous improvement" process and has stated that the increase in the gauge was implemented to make the wedge gauge in its P-metric passenger car tires used in light truck applications consistent with the wedge gauge in its LT-metric tires. Firestone has also stated that the material composition was changed to increase the modulus of the wedge compound in order to reduce the strain energy at the belt edge.

With respect to the inter-belt gauge, Firestone had reduced the original nominal specification (i.e., the specification for the uncured "green" tires) for the ATX tires from 0.025 to 0.021 inches in 1993 and 1994. This reduced gauge was also used during the initial years of the focus Wilderness AT production. In August 1999, after Firestone became concerned about the adequacy of the inter-belt gauge in the cured Wilderness AT tires, especially in the regions directly under the tread grooves, it changed the specification back to the original dimension.

In September 2000, Firestone implemented three additional design changes in its passenger car tires used in LT applications for the stated purpose of enhancing the belt-edge durability of those products. The gauge of the inner liner (the inner surface of the tire) was increased by approximately 15 percent to improve its permeation resistance (i.e., its ability to prevent inflation air from reaching the belt rubber), with the goal of reducing the amount of oxidative aging in the belt-edge area. Second, Firestone changed the compound used in the belt-edge insert with the intent of reducing belt-edge operating temperatures. Third, Firestone chose to standardize the belt cord configuration for all large passenger car tires.

[17] Firestone does not specify a cured tire gauge for either the belt wedge or the inter-belt areas. Rather, Firestone specifies those dimensions for the green tire components (i.e., the belts and wedge strips used in assembling the tire prior to cure). However, the curing process can affect these gauges. Firestone compared its measurements of wedge and inter-belt gauges during its root cause analysis to "design," "minimum," and "target" values.

4 Field Data Analysis

4.1 A Tire's Tread Life Should Exceed Its Fatigue Life

It is a well-accepted principle throughout the tire industry that the fatigue life of a tire should exceed its tread life by some design/safety margin for reasonably foreseeable service conditions.[18] When the fatigue life of a tire does not exceed its tread life, a failure distribution will develop. When plotted as a cumulative failure frequency, the failure distribution will have the basic shape shown in Figure 12, with the life of the tire divided into three phases: (1) useful design life, where the risk of failure (other than failures due to road hazards or gross operator abuse) is small and independent of age; (2) failure phase, where the risk of failure increases with age; and (3) end of life, where all of the tires have either failed or worn out.

When comparing the failure frequencies of two different tire populations, it is important to understand the proportions of each population that fall into each phase of the failure distribution, as well as the numbers of tires exposed to different severity factors, such as hot climates or more severe applications. Firestone has asserted that the Wilderness AT focus tires have a lower failure frequency than the recalled tires. However, in doing so, has compared the recalled Decatur ATX tires to all of the focus tires, regardless of age. This is not an appropriate comparison.

4.2 Analyses of Tires' Field Failure Experience

In this investigation, ODI has based its analyses of tires' field failure experience on the tread separation claims experience of those tires. Firestone defines a "claim" as any input involving allegations of property damage in excess of the value of the tire or personal injury, or a lawsuit. Other tire manufacturers have similar definitions. In deciding which claims in Firestone's claims database involved tread separations, ODI included all claims where there was an allegation of tread separation or where Firestone had coded the failure as Service Condition Code 136 (belt-leaving belt) or 235 (belt-edge separation).

ODI considers the Firestone claims database to be the best available source of field failure data regarding the subject tires because of the completeness of its information (e.g., since the entire DOT identification number is present, the plant and date of manufacture can be ascertained), and because a catastrophic belt-leaving-belt tire failure often results in inputs to these systems. Other databases either often have less complete or reliable information about specific tires and incidents (e.g., the ODI's consumer complaints database) or are likely to include numerous entries that are not relevant to the failure mode at issue here (e.g., Firestone's adjustment database).

The anticipated future failure experience of the focus tires can be predicted on the basis of past failure trends. For example, Figures 13 and 14 show the increasing trend in claims involving the

[18] One expression of this principle appeared in a paper published by the Society of Automotive Engineers in 1989, which stressed the fundamental connection between tire fatigue life and vehicle safety. Excerpts from that paper are set out in Appendix C.

focus P235/75R15 and P255/70R16 tires, respectively, over the last several years. These Figures indicate that these tires are experiencing age-dependent fatigue failures that will create an escalating risk of crashes and injuries if they are not removed from service.

As one way of addressing Firestone's assertions about the relative performance of ATX and Wilderness AT tires, ODI compared the tread separation claims experience at similar service exposures for the recalled Wilson and Joliette P235/75R15 ATX tires and the Wilderness AT tires produced at each of those plants. Figure 15 shows the total number of tread separation claims, claims alleging crashes involving injury or fatality, and claim frequencies for the recalled ATX tires 56 months after the first tire was produced at each plant in comparison with the Wilderness AT tires after a similar period. The ATX data include incidents leading to claims that occurred prior to September 1, 1995; the P255/70R16 Wilderness AT data includes incidents that occurred prior to July 1, 1999 for Joliette tires and July 1, 2000 for Wilson tires; and the P235/75R15 Wilderness AT data includes incidents that occurred prior to April 1, 2001. This Figure shows that the claims frequency and crash experience of the Wilderness AT tires from Wilson and Joliette is equivalent to, and in some cases far worse than, that of the recalled ATX tires from those plants after the same period of time.[19]

It is important to recognize that virtually all of the tread separation claims in the Firestone claims database involving the focus tires involve tires that were produced in April 1998 or earlier.[20] This is not surprising, since belt-leaving-belt separations in these tires rarely occur until the tire is three years old (for Wilson tires) or four years old (for Joliette tires). However, this means that it is not now possible to utilize field failure data to determine whether Firestone's increase of the wedge gauge and improvement of the wedge's material properties in 1998 will lead to a reduction of tread separation failures in the focus tires as they age.

4.3 Cumulative Failure Frequency Analysis

Failure rates, expressed in claims per million tires produced (ppm), have been used by some people to characterize the field performance of various tires. However, as explained above, a valid comparison of the failure risk of different populations of tires must account for age and operational factors. Since tires used as original equipment on SUVs are likely to have relatively common operational experience, controlling for age is sufficient to allow a valid comparison of the failure experience of such tires.

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[19] Thus, the fact that the absolute number of claims to date with respect to the focus tires manufactured at Joliette is relatively low does not indicate the absence of a problem with those tires, since failures of the recalled ATX tires from Joliette eventually led to over 300 claims, involving 15 crashes, 22 injuries, and 9 fatalities.

[20] Firestone has received only one tread separation claim regarding the Wilderness AT P235/75R15 tires made at its Aiken, SC plant and no such claims regarding the Wilderness AT P255/70R16 tires made at the Decatur plant. These tires are still relatively new; the Aiken plant did not begin shipping these tires to Ford until August 1999, and the Decatur plant did not begin large scale shipments of the P255/70R16 tires to Ford until February 1999.

The cumulative tread separation claims frequency trends for the tires recalled by Firestone in August 2000 and the focus tires are shown by plant of production in Figure 16. These trends show a distinct ordering by plant.[21] These claims data show that the ATX and Wilderness AT tires manufactured at Decatur began to fail after between one and two years of service, with the ATX tires reaching a claims frequency of about 1,000 ppm. The failure trends for the Wilson tires began to develop after 2-3 years, with the claims frequency for the Wilson ATX tires approaching 200 ppm. The failure trend took longest to develop in the Joliette tires (after 3-4 years), with the claims frequency for the Joliette ATX tires approaching 100 ppm.[22]

As depicted in Figure 16, on a plant-by-plant basis, the focus tires have failure trends that are consistent with those experienced by the recalled ATX tires. For comparison, the almost nonexistent failure experience of the Goodyear Wrangler RT/S P235/75R15 tire used as OE on approximately 500,000 Ford Explorers in MY 1995-1997 is also shown in Figure 16.

4.4 Cumulative Hazard Function Analysis

An analysis of cumulative failure frequencies, in which the rates are based on total tire production, tends to understate a tire's true risk of failure at any later service intervals, since it does not account for attrition of the tires due to tread wear-out and prior failures. A more accurate assessment of this risk can be estimated using the cumulative hazard function, a statistical method that estimates the failure risk for units that have survived past a given service life interval. Figure 17 illustrates the differences in these two approaches by plotting the cumulative failure frequency and the hazard function for the Wilson P235/75R15 ATX tires. When the tires reach about 5 years of age, the curves begin to diverge significantly, since there are fewer tires in service that potentially can fail.[23]

Figure 18 shows the set of cumulative hazard function curves for the recalled tires. The focus tires from Wilson and Joliette (separated by size of tire) are added for comparison in Figure 19. The same patterns noted in the cumulative failure frequency plots are again seen here, with the Decatur tires starting to fail before the Wilson tires, followed by the Joliette tires, and with the risk of failure increasing substantially as the tires from all of the plants age.

Figures 16 and 19 both show that the focus tires from Wilson and Joliette have exhibited failure trends that are similar to those experienced by the recalled ATX tires from those plants at similar service intervals. As the recalled tires continued in use, a significant number of additional failures, crashes, injuries, and fatalities occurred. These trends demonstrate that is likely that, if they are not removed from service, the focus tires from these plants – at least those manufactured

[21] For each of the tires, the earliest failures and the highest failure rates occurred in the hottest states.

[22] Although ODI is aware of several differences in the manner in which tires were manufactured at the various Firestone plants, including differences in quality control, it has not identified specific reasons why the tires from the various plants begin to experience tread separation failures at different times.

[23] In calculating the hazard function curves, ODI used a tread wear attrition model provided by Firestone. Firestone's attrition model estimates that less than 40 percent of the focus tires will remain in service after five years of use.

before Firestone modified the wedge in the Spring of 1998 [24] – will experience a similar increase in tread separation failures over the next few years.

4.5 Peer Comparisons

To provide a basis for comparison with the tread separation claims experience of the focus tires, ODI collected production and claims data pertaining to competitor tires of similar age, size, and application; i.e., tires used as original equipment on sport utility vehicles.[25]

Table 3 shows a comparison of the data for the focus tires and peer tires predominantly used in SUV applications that were produced from 1995 through 1997. This production range was selected to be consistent with focus tire production (it actually includes tires that are a year or more older than the subject P235/75R15 Wilderness AT tires) and to exclude tires that have not had enough service history to begin to exhibit the failure mode at issue here.

The peer tire that is most suitable for comparison with the focus tires is the Goodyear P235/75R15 Wrangler RT/S, designed and manufactured for use as OE on Ford Explorers in MY 1995-1997. During this period, Ford used approximately the same number of these Goodyear tires as it did Firestone P235/75R15 tires (about 2.4 million tires), yet there has only been 1 tread separation claim involving an OE Goodyear tire on an Explorer compared to 486 such claims involving OE Firestone tires used on Explorers in during that period.

To provide a further comparison, the cumulative tread separation claims rate experience of this Goodyear tire is plotted on Figure 16 (cumulative failure frequency) and Figure 19 (cumulative hazard function). As would be expected given the low number of claims, the plotted lines for this tire are very low and essentially horizontal.

ODI also plotted the cumulative hazard function for the peer tire with the highest claim rate[26] on Figure 19. This plot demonstrates that the probability of a tread separation failure of even that tire is well below that of any of the focus tires from Wilson and Joliette.

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[24] As noted above, essentially all of the claims on which the curves for the focus tires are based involved tires manufactured before Firestone modified the wedge. Thus, if that change actually improved the resistance of the focus tires to belt-edge separations, these curves may not predict the future performance of the newer tires.

[25] The claims definitions, processing systems, and the failure modes that are included vary between tire manufacturers, but the differences are not significant for purposes of comparing the performance of peer SUV tires to that of the Firestone ATX and Wilderness AT tires. If anything, the differences are favorable to Firestone, since many of the claims included by the peer manufacturers would not have been included by Firestone. For instance, in its submissions to ODI, Firestone excluded claims in which the claimant did not provide a valid ten-digit DOT number for the failed tire, while many of the peer tire claims that were submitted to ODI had incomplete or missing DOT numbers.

[26] This was the Goodyear Wrangler RT/S P265/75R16 tire manufactured at Goodyear's Union City, TN plant. These tires were used as OE on certain Chevrolet Tahoe and GMC Yukon large SUVs.

On several occasions, Firestone has made assertions or presented data comparisons in which it addresses all Wilderness AT tires as a group. However, Wilderness AT tires made to the specifications of vehicle manufacturers other than Ford are significantly different from the focus tires and thus are more appropriately considered as peers. The Wilderness AT tires made for General Motors (GM) [27] and Toyota [28] are different from the focus tires in several respects, including: (1) different tread and shoulder pocket designs, (2) different tread and subtread compounds, and (3) different mold contours. The Firestone claims database contains 2 tread separation claims pertaining to the GM-spec P265/75R15 Wilderness AT tires and no such claims for the Toyota-spec P225/75R15 Wilderness AT tires. In addition, testing by Ford has shown that the tires manufactured for Toyota have lower operating temperatures than the focus tires.

4.6 The Relationship of These Tire Failures to Safety

A belt-leaving-belt tread separation reduces the ability of a driver to control a vehicle, whether or not the separation is accompanied by a loss of air. This is particularly true when the failure occurs on a tire mounted on a rear wheel and when the failure occurs while the vehicle is traveling at a high rate of speed, such as on an Interstate highway. According to the Firestone claims database, as of March 2001, tread separations of the recalled and focus tires have been associated with 260 crashes, 367 injuries, and 74 fatalities. See Table 3. Additional crashes, injuries and fatalities due to such tread separations have been reported to ODI by other sources.

Claims in the Firestone claims database involving the focus tires have been associated with numerous crashes, 17 deaths, and 41 injuries; additional crashes and casualties are reported in the ODI complaint database, including reports of six additional fatalities. These numbers are relatively low compared to the crashes and casualties involving the recalled tires, due to the lower number of focus tires that were produced and their limited exposure. Nevertheless, the fact that the plant-by-plant failure trends for the focus tires are similar to those of the recalled ATX tires demonstrates that, if they are not removed from service, the focus tires – at least those manufactured before the wedge change – will experience a significant increase in the number of crashes, injuries, and deaths over the next few years.[29]

4.7 The Comparative Safety Consequences of Tread Separations on SUVs vs. Pickups

A belt-leaving-belt tread separation is far more likely to lead to a safety problem when it occurs on a SUV than when it occurs on other types of vehicles. As shown in Table 7, approximately ten percent of the tread separation claims in the Firestone claims database that are related to subject tires on SUVs involved crashes, while only 2.3 percent of such claims regarding tires on

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[27] P265/75R16 tires supplied for C/K full-sized pickups (Silverado and Sierra) and SUVs (Suburban, Tahoe, and Yukon) since 1998.

[28] P225/75R15 tires supplied for the Tacoma pickup and the 4-Runner SUV since 1995.

[29] Firestone has never asserted that tread separations on Wilderness AT tires occur in a different manner than on ATX tires. Thus, it is appropriate to conclude that as tread separations of focus tires increase, the number of crashes, injuries, and deaths will increase proportionately.

pickups resulted in crashes.[30] Moreover, the crashes that occur due to a tread separation on SUVs are more likely to lead to injuries and deaths, primarily because an SUV is more likely than a pickup to roll over in a crash, regardless of whether the crash involves a tread separation.[31] Almost 75 percent of the SUV crashes in the Firestone claims database led to injuries and almost 25 percent led to fatalities; less than half of the pickup crashes led to injuries, and there was only one fatal crash.

Another measure of the relative safety risk is that 2.2 percent of the claims in the Firestone claims database involving SUVs were associated with a fatal crash, while only 0.1 percent of the claims involving pickups were associated with a fatality. Review of the ODI complaint data reveals similar differences in safety consequences. See Table 8.

It should be noted, however, that the claims data does not support Firestone's assertions that a tread separation on an Explorer is more likely to lead to a crash than a tread separation on other SUVs. Although the claims data is limited with respect to non-Explorer SUVs (since relatively few of the recalled and focus tires were installed on SUVs other than Explorers, and the failure frequency of other Firestone tires is relatively low), the rates of crashes per claim and rollover per claim are almost identical for Explorers and other SUVs.

5 Root Cause Analyses Prepared by or for Manufacturers

5.1 Firestone

On December 13 and 14, 2000, ODI met with Firestone in Akron, Ohio to review the results of Firestone's root cause analysis. Firestone's analysis found that a combination of design, manufacturing, vehicle, and use factors contributed to the field failures of the tires that were recalled in August 2000.

The following is a summary of Firestone's conclusions, as expressed in a December 19, 2000 press release:

- **Shoulder pocket design** - The shoulder pocket design of the P235/75R15 ATX tires could lead to cracking at the shoulder pocket bottom. This could become the starting point of a failure, which, when combined with the other factors, could result in a reduction of resistance against belt detachment.

- **Low inflation pressure** - Low inflation pressure in the recalled ATX, ATX II and Wilderness AT tire increased the running temperature of the tires and would contribute to a decreased belt adhesion level.

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[30] Since all of the subject tires were designed for use on light trucks and SUVs, the claims database obtained for this investigation does not include claims involving tires on passenger cars. However, ODI's experience is that tread separations on passenger cars are even less likely to lead to crashes or casualties.

[31] Two-thirds of the SUV crashes in the Firestone claims database involved a rollover, as compared to 23 percent of the pickup crashes.

- **Vehicle load** - Vehicle load levels combined with low standard tire pressure [26 psi] initially specified for the primary vehicle for which the tires were designed [the Explorer] led to a decreased margin of safety for tire performance.

- **Decatur belt adhesion** - ATX P235/75R15 tires and Wilderness AT tires of the same size produced at Decatur exhibited different belt adhesion characteristics, including lower initial adhesion, than those same size and line tires produced at other [Firestone] plants.

Firestone concluded that multiple factors contributed to the root cause of the failures that occurred in the recalled tires. Firestone found that many of the factors that it identified were also present in the focus tires, but it asserted that all of these factors were necessary before a tire could be found defective, and it contended that some important elements were not present in the focus tires. However, contrary to Firestone's contention, ODI found some of these factors in some of the focus tires it tested. For instance, ODI found evidence of shoulder pocket cracks in many focus tires. In some cases, as shown in Figure 20, the cracks had grown as far inward as the edge of the second belt.

5.2 Firestone's Expert

To obtain an independent analysis of the failures in the P235/75R15 ATX and Wilderness AT tires, Firestone commissioned a study by Dr. Sanjay Govindjee, a professor in the Department of Civil and Environmental Engineering at the University of California at Berkeley.
Dr. Govindjee's analysis focused on the two fundamental factors affecting crack growth in radial tires: (1) the capacity of the material to resist the propagation of cracks; and (2) the demands or forces that drive the crack forward.

Dr. Govindjee directed a variety of testing by Firestone to support his work, including: (1) vehicle testing to determine the range of load conditions and operating temperatures that the tires would experience in service usage on a Ford Explorer; (2) lab testing to assess the new and aged crack growth characteristics of the belt rubber compound used in the subject tires; and (3) experiments to assess the influence of compound processing differences in Decatur tires on the crack growth resistance of the belt rubber compound. He also used state of the art computer modeling tools to assess the strain energy release rates (i.e., crack tip driving forces) at various loads, inflation pressures, speeds, and crack sizes.

The experiments were unable to conclusively establish a relationship between the different compounding processes and lubricants used at the Decatur plant and the elevated field failure experience of tires manufactured there. Dr. Govindjee described his work and identified his findings and conclusions in a report released by Firestone on February 2, 2001. Some of the significant findings include:

- Somewhere between 10 to 25 mm of crack growth, crack tip release rates begin to increase in a non-linear fashion (i.e., reach "critical crack length"), resulting in accelerated crack growth rates per tire revolution.

- More cracks were detected in Wilson and Joliette tires than in Decatur tires.

- Climate effects appear to outweigh usage effects (e.g., inflation pressure) in the evolution of physical properties measured in ultimate elongation, 100% modulus, and peel adhesion tests.

- Vehicle loads play a more important role than inflation pressure and speed in crack tip driving forces.

On April 12, 2001, ODI met with Dr. Govindjee to review his report. His work provided useful context for ODI's shearography testing and subsequent cut-section analyses, discussed below. Dr. Govindjee's computer model estimates that a 1 mm deep crack that has developed around the full circumference of a focus tire will reach critical crack length within about 40,000 miles. This highlights the importance of suppressing crack initiation for as long as possible.

5.3 Ford

On December 11-12, 2000, ODI met with Ford in Dearborn, Michigan to review the preliminary root cause findings of Ford's Tire Team. Ford's analysis concluded that a complex interaction of tire design, manufacturing, and field conditions was responsible for the failures in the recalled tires. According to Ford, the designs of the P235/75R15 ATX and Wilderness AT tires generate high stresses and rates of strain at the belt edges, raising the operating temperature in this region. The higher operating temperatures accelerate the aging of the rubber, leading to reduction in fatigue life. The aging effects and high strain rates combine to produce early belt-edge separation and faster crack propagation. Ford also concluded that "unknown" manufacturing processes at Decatur resulted in further reductions in resistance to crack growth and tread detachment compared to the other Firestone plants.

Ford continued to analyze these issues and made another presentation to ODI on March 28, 2001. This presentation provided updated comparative analyses of field data, tire operating temperatures, wedge dimensions, belt peel strength, and computer modeling. In addition, Ford presented its analysis of the way in which a variety of vehicles respond to a belt-leaving-belt tread separation on a rear tire and a detailed review of the handling characteristics of the Explorer and several peer SUVs following such a tread separation.

As noted earlier in this Report, on May 22, 2001, Ford announced that it would provide free replacements for all Firestone Wilderness AT tires on its vehicles. Ford stated that it based its decision on (1) trends it observed in claims and crashes involving those tires and a comparison with similar failure data from peer tire manufacturers; and (2) differences in tire dimensions and performance in several tests it had conducted. Ford highlighted the differences in performance between the Firestone Wilderness AT tires and Goodyear Wrangler RT/S tires that were used as OE on the Ford Explorer.

In its press release, Ford noted that ". . . some of the tires . . . do not have a substantial failure risk." Nevertheless, Ford stated that it would provide free replacement for all Wilderness AT tires on Ford vehicles ". . . to avoid any confusion among our customers and eliminate any doubt about the quality of their tire."

Ford's press release also identified what it believes to be the most significant factors contributing to the potential for belt-leaving-belt failures in the Wilderness AT tires:

- **Tire operating temperature** - the Firestone tires run hotter than the Goodyear tires that were used on the Explorer.

- **Wedge dimension** - the Firestone tires have different size wedges between plants, and the wedges are generally smaller than the Goodyear wedge.

- **Peel strength** - the peel strength of the Firestone tires is consistently lower than that of the same size Goodyear tires.

Ford also conducted an extensive series of testing on indoor drums ("rig tests") on both new and aged Firestone and peer tires. The tests were conducted at varying loads, inflation pressures, and ambient temperatures starting at 75 mph. The speed is then increased in 5 mph steps, holding for 30 minutes at each step, until the tire has failed or completed the highest speed step (110 mph). When testing aged Firestone tires from the various assembly plants, Ford found a correlation between performance in the test and field failure data. New Firestone Wilderness AT tires from the Wilson and Joliette plants did not pass Ford's high-speed rig tests.

6 ODI's Testing and Analysis of Test Results

6.1 Description of ODI's Test Program

To help assess the prospective failure risk in the focus tires, ODI conducted a program of tire testing and a comprehensive analysis of testing performed by Firestone and Ford. The primary objective of the program was to assess the extent and severity of belt-edge separations in a randomly selected sample of focus tires from hot states, where most of the failures occurred. Testing was also done to compare the separation data with dimensional, physical property, and material property data gathered by Ford and Firestone and, to the extent possible, to identify design and manufacturing factors contributing to the failures. For comparison, several examples of peer tires used as original equipment on SUVs, primarily the Goodyear Wrangler RT/S P235/75R15 tire used as original equipment on Ford Explorers in MY 1995-1997, were subjected to the same analyses.[32]

Standards Testing Laboratory (STL) in Massillon, Ohio inspected the tires, measured the remaining tread depth, and conducted non-destructive analysis using laser shearography. Shearography is a method used to detect and document the pattern and severity of internal separations in a tire. It involves a double-exposure photographic recording, with the tire deformed under stress between exposures. Separations inside the tire are detected by the strain concentrations they produce on its surface. STL subjected over 300 tires to this process.

[32] Other tires tested included: the Michelin XW4 and Uniroyal Laredo AWP P235/70R15 tires (used on the General Motors Jimmy/Blazer); the Goodyear Wrangler SRA P245/70R16 (used on the Jeep Grand Cherokee); the Goodyear Wrangler RT/S P225/75R15 (used on the Jeep Cherokee); the Goodyear Wrangler RT/S and the Bridgestone Dueler HT P265/70R16 (used on the Toyota 4-Runner); and the Bridgestone Dueler HT P255/65R16 (used on the Infinity QX4).

Many of the Firestone and peer test program tires were subsequently sent to Smithers Scientific Services, Inc. (Smithers) in Akron, Ohio for additional analysis. The objective of this analysis was to correlate the shearography results with actual belt-edge crack sizes and with the dimensional and physical property data that had been collected by Ford and Firestone. Each of these tires was cut into sections and subjected to thorough dimensional and physical analyses.

Smithers performed additional analyses on some of the test program tires. These included studies of wedge and inter-belt gauge variances within individual tires, an assessment of early crack growth patterns by completely removing the tread and the top belt (also referred to as a "tread pull") of tires in the early stages of belt-edge separation, and X-ray analysis.

A smaller sample of test program tires was sent to the Akron Rubber Development Laboratory (ARDL) in Akron, Ohio for a detailed analysis of dimensional, physical, and chemical properties. ARDL also analyzed a much broader set of data from over 1,000 tires that were tested by Firestone, Ford, and ODI to analyze correlations between the field performance of tires and changes in the material properties of their belt rubber.

6.2 Shearography

Shearography testing was used to assess the pattern and severity of separation progression within the focus tires and peer tires. The shearography results show that belt-edge separations develop earlier and grow larger for a given age and state of tread wear[33] in the focus tires than in the peer tires and provide evidence of a continuing potential for belt-leaving-belt failures in the focus tires. These differences are more pronounced in the focus tires produced before Firestone modified the wedge in 1998. These results are also consistent with differences in field experience between the Firestone tires and peer tires used as original equipment on other SUVs.

Based on the shearography results, ODI categorized each tire's separation pattern and severity into one of seven stages of failure mode progression described in Appendix A. Figure 21 shows the results of this analysis when comparing the focus tires and peer tires. The focus tires are significantly different from their peers, particularly with respect to the number of tires exhibiting severe stages of crack growth. Approximately 30 percent of the focus tires with at least 30 percent tread wear had patterns of separation in one of the four most severe categories, and about four percent were in the two most severe stages of separation. Only one of the peer tires (a Goodyear Wrangler RT/S P235/75R15) contained a separation in the fourth most severe category, and none were in the three most severe stages.

Figure 22 compares the separation patterns and severities shown by shearography in P235/75R15 focus tires produced before and after Firestone's wedge change. Only one post-change tire reached the third level of severity, and this occurred later in the tire's tread life than the stage at

[33] The fatigue failure mechanism of interest is driven by the number of cycles (i.e., tire revolutions). Ideally, mileage would be used as the best age parameter for tire cycles. Since mileage information was not available for many of the test program tires, tread wear was used as the best indicator of tire service cycles. Tire age is also a factor, particularly in the hottest climates, because the rubber becomes less resistant to fatigue crack growth with aging.

which the pre-change tires reached that level. Figure 23 provides the same analysis for the P255/70R16 focus tires. Only two of the post-change tires exceeded the second level of separation severity. None reached the fifth level or higher (a Joliette tire produced in October 1998 and a Decatur tire produced in April 1999 were categorized in the fourth level). These two Figures show similar patterns of separation development in Joliette and Wilson Wilderness AT tires in both tire sizes.

Figure 24 compares the focus tires produced after the wedge change with the peer tires. While the post-change focus tires are more likely than the peers to have some level of separation and, on average, they tend to reach the first and second levels at lesser amounts of tread wear, the difference between the two sets of tires is less obvious. It should be noted, however, that most of the peer tires were older than the post-change focus tires, and a much larger percentage of the peers were obtained from Arizona, where deterioration due to heat and aging is most severe. Thus, the difference between these focus tires and the peers is at least as great as that suggested by this Figure.

6.3 Wedge and Inter-Belt Gauge Analysis

The gauge of the rubber between the belts can be a significant factor affecting crack initiation, crack propagation, and final catastrophic belt-leaving-belt separation. Test program tires were sectioned to allow measurement of the gauges at various positions across the belts. ODI's analysis of this data, and data from dimensional studies conducted by Ford and Firestone, found two significant dimensional differences between the focus tires and peer tires used in similar applications: (1) the wedge gauge in the Firestone tires produced before the Spring 1998 wedge change is thinner than that of the peer tires; and (2) the inter-belt gauge in the Firestone tires produced before the August 1999 change is thinner than that of the peer tires.

As previously noted in this Report, belt wedge gauge is an important factor in delaying the formation of starter cracks in the critical region at the edge of the second belt. To help understand the influence of wedge gauge on this process, ODI compared the wedge dimensions of focus and peer tires by tire size, tire design (before and after the wedge change), and plant.

Figure 25 compares the range of wedge gauges measured in focus tires produced before the wedge modification in the Spring of 1998 to that of peer tires, including the Goodyear tires used as original equipment on the Explorer.[34] Figure 26 compares the wedge gauges for focus tires manufactured after the wedge gauge was increased in comparison with peer tires of similar sizes.[35] These two Figures show that the wedge gauges in the focus tires were thinner than those of the tested peers before the wedge change and within the range of those peers after the change.

[34] For an explanation of how to interpret the statistical analyses in Figure 24 and similar Figures, see Appendix D.

[35] The red horizontal lines on these Figures (and on Figures 35 and 36) correspond to Firestone's "targets" for the wedge gauge in cured tires before and after the Spring 1998 wedge change. They are included for ease of comparison, not because ODI considers them to be appropriate targets for this dimension.

Inter-belt gauge is a factor in the peel adhesion characteristics of a tire (a measure of a tire's resistance to catastrophic belt-leaving-belt failure) and can become a factor in propagation rates for cracks that have grown through the wedge area. Figure 27 compares the inter-belt gauges in the areas under the outer tread grooves in the focus tires produced prior to Firestone's inter-belt gauge change in August 1999 with those of peer tires.[36] This Figure shows that the inter-belt gauges of the Firestone tires produced before that change are generally thinner than those of the tested peers.

Some of the focus tires analyzed by ODI had significantly thinner inter-belt gauges than Firestone's minimum design specification of 0.018 inches (0.46 mm), particularly in the areas under the tread grooves. In some instances, the gauge in cured tires was so low that the wires were almost touching, thus providing little if any resistance to crack propagation. For example, Figures 28 and 29 show Wilson and Joliette tires manufactured in November 1997 with 0.05 mm (0.002 inches) measured inter-belt gauge in the area under the outer tread grooves.

6.4 Shoulder Pocket Characteristics

The design of a tire's shoulder pocket can be a significant factor in the development and propagation of cracks. Pocket geometry can affect the stress/strain state at the edge of the second belt, and ODI's dimensional analysis has shown that the pocket has an influence on the wedge gauge. The design of the shoulder pocket of the focus tires is notably different from that of peer tires and other Firestone tires used in similar applications (see Appendix B).

ODI's analysis of shearography results for focus tires exhibiting early stages of separation found a common pattern. Localized initiation sites had developed around the circumference of one or both shoulders at regularly spaced intervals, and there was a correlation between the initiation sites and the shoulder pockets on the tire.

On several focus tires showing patterns of early crack initiation and growth, ODI asked Smithers to peel the entire tread and second belt from the carcass to identify the locations and patterns of separation along the belt edges. Some of these peeled treads show distinct patterns of separation initiation and growth in the areas under the shoulder pockets. For example, Figures 30 and 31 show the shearography and tread pull separation areas from a tire exhibiting the earliest signs of incipient separation. Figures 32 and 33 show similar information from a tire with more progressive crack growth.

Measurement of tires that had little or no tread wear (so that crack initiation would not interfere with the analysis) found patterns of belt wedge "pinching" under the pockets and the development of starter cracks in that area. Figure 34 shows an example of this condition in a P235/75R15 Wilderness AT tire manufactured at the Wilson plant in November 1997. Figure 35 compares the wedge gauges under the shoulder pocket areas of recalled and focus Firestone Wilderness AT P235/75R15 and P255/70R16 tires made before the wedge change with peer tires of similar sizes. Figure 36 shows the same comparison for the Firestone tires made after the

[36] The red horizontal line on this Figure corresponds to Firestone's minimum inter-belt gauge for cured tires before the August 1999 change.

1998 change. In summary, there generally is a thinner wedge gauge in the pocket areas of the tested tires. However, comparisons of Figure 25 to Figure 35 and Figure 26 to Figure 36 shows that the lug-to-pocket variations are more pronounced in the focus tires than in the peers and are more pronounced in some Firestone tires size/plant combinations than in others.[37] Both before and after the wedge change, some of the measured gauges in the pocket areas were less than Firestone's targets for this dimension.

6.5 Comparison of Failed Tires vs. Test Tires

An example of a crack growth pattern in a failed P235/75R15 Wilderness AT tire is shown in Figure 37. Generally, on the failed treads, multiple localized semi-elliptical growth areas were observed with the failure initiated at the largest area. According to Dr. Govindjee's computer model, accelerated crack growth (i.e., critical crack lengths) can begin to develop when a circumferentially developed inter-belt crack has grown 10-25 mm in the lateral direction (i.e., across the tread).

Figure 38 shows the separation pattern on a P255/70R16 Wilderness AT tire, where belt-edge separation had developed to an intermediate level (the fifth level discussed in Appendix A), spreading around the circumference of the tire and beginning to grow laterally between the belts. Figure 39 shows the shearography results for the same tire. As such separations grow in size, their rate of propagation will increase at various locations around the circumference of the tire, creating the semi-elliptical areas shown on the failed tire tread.

6.6 Material Properties

As previously noted in this Report, the properties of the belt wedge and skim rubber compounds change as the tire ages. These changes reduce the compounds' resistance to fatigue crack growth and catastrophic failure. One measure of the degradation of the belt rubber is the peel adhesion test. This test is most directly related to the belt rubber's resistance to a final, catastrophic belt-leaving-belt failure.

Belt peel adhesion testing involves the preparation of a number of approximately 1-inch wide test samples cut laterally across the tread of the tire and then pulled in an Instron tensile test machine to measure the force required to "peel" the two belts apart.[38] Peel adhesion testing of Firestone tires has concentrated on tires from the Decatur, Wilson, Joliette, and, to a lesser extent, Aiken plants. The tests have consistently shown that the Decatur tires perform differently from tires from the other plants. However, ODI's analysis of peel adhesion data shows that, while Decatur tires start with much lower adhesion strength than the tires produced at the other Firestone plants, the Wilson and Joliette tires eventually converge to the level of the Decatur tires.

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[37] ODI also observed variance in the wedge gauge between the two shoulders on many tires.

[38] The samples are prepared with a small edge cut through the skim rubber on each side to ensure that the tear occurs through the rubber (i.e., the test is intended to measure the cohesive tear resistance of the rubber). There is no evidence of a belt wire-to-rubber adhesion issue in the Firestone tires investigated by ODI.

This convergence occurs more rapidly in the hottest climates, such as Arizona. Figure 40 shows a scatter plot of average "hot state" peel adhesion data for recalled and focus tires from Decatur, Wilson, and Joliette in comparison with the Goodyear tires that were used on the Explorer.[39] After 3 to 4 years of age, the Wilson and Joliette tire peel adhesion characteristics are not significantly different from those of the Decatur tires. The Goodyear tires consistently maintained higher peel adhesion characteristics at a given age than the focus tires.

ARDL conducted a detailed analysis of material property data gathered from recalled tires, focus tires, and various peer tires used in the Firestone, Ford, and ODI test programs. ARDL analyzed changes in tensile properties,[40] peel adhesion, and crosslink density[41] to assess the aging characteristics of the recalled and focus Firestone tires. These data were also compared, to the extent possible, with some peer tires, primarily the Goodyear Wrangler RT/S used on the Explorer.

The general pattern of change indicates that crosslink density evolution due to aerobic and thermal aging is the dominant aging factor. Some of the data points indicate that more severe aging mechanisms may have occurred in some of the tires. Based on this data and analysis, ARDL concluded that, while the Decatur tires exhibited different material properties than the tires from the other Firestone plants, "there is no reason to believe that the Wilson or Joliette tires can be expected to perform any better than the Decatur tires in severe environments." Also, the rubber in the focus tires exhibited deterioration due to aging that was more severe than that of the Goodyear Wrangler RT/S tires.

6.7 Operating Temperature

A tire's operating temperature is typically greatest in the belt-edge region. It will rise with increased load, speed, and ambient temperature and with decreased inflation pressure. A tire's design will determine its sensitivity to these factors. In general, higher operating temperatures contribute to tire aging.

ODI did not conduct operating temperature tests. Rather, ODI reviewed and analyzed temperature testing conducted by Ford and, later, Firestone. Although the results were not identical, both companies' tests show that the focus tires consistently have higher operating temperatures than the Goodyear RT/S P235/75R15 tire used on the Explorer under a wide variety of operating conditions.

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[39] A combination of ODI and Ford test data was used for this analysis.

[40] These properties include 100% Modulus (M_{100}, which is the modulus at 100% strain), elongation at break (E_b, which is the strain at break), and tensile strength (T_b, which is the stress at break). The modulus increases with age, while the elongation at break and tensile strength decrease with age.

[41] Crosslink density refers to the density of linkages connecting the polymer chains. The subject compounds use a sulfur cure system and, therefore, sulfur linkages. These linkages are formed during the curing process and will evolve in type (following a general trend from poly-sulfidic to mono- and di-sulfidic linkages) and density as the tire ages. Increases in modulus with aging are governed by increases in the crosslink density in the polymer.

Ford originally obtained its temperature data using a surface imaging technique. Firestone criticized that method and obtained its temperature data by inserting a needle pyrometer into the belt-edge area of the tire after it stopped running. Ford responded by conducting another series of tests using an imbedded thermocouple probe to obtain the temperature data. In ODI's view, the latter Ford method is likely to produce the most accurate results when measuring belt-edge temperature, since the temperatures are recorded when the tire is running, and there is greater control of thermocouple placement relative to the belt-edge area. Ford used data from this test program to validate its data from the surface imaging technique.

Ford's temperature testing shows that the focus tires have a greater sensitivity to load, speed, and inflation pressure than other tires it tested, including the Goodyear Wrangler RT/S and the Firestone Wilderness AT supplied as OE to Toyota. Figure 41 shows the temperatures for the focus Firestone Wilderness AT and Goodyear P235/75R15 tires over a range of inflation pressures at 75 mph and 1500 lb. load. For example, the Goodyear tire is cooler at 80 kPa (12 psi) than the Firestone tire is at 250 kPa (36 psi). Since it is undisputed that heat can have a deleterious effect on the capacity of the belt compounds to resist crack initiation and growth, this suggests that, even if all other things were equal, because they operate at relatively hot temperatures at the belt edge, the focus tires would be more susceptible to belt-leaving-belt separations than tires that run cooler.

7 Firestone Position and ODI's Response

Firestone maintains that the focus tires, and indeed many of the tires it recalled in August 2000, are safe and that there is no need to expand that recall to protect the public from additional risk of crashes and injury. Firestone's latest expression of its position, as set out in a July 19, 2001 press release, is summarized in four basic contentions. Those contentions, and ODI's responses to each of them, follow.

A tread separation is not a defect - Firestone asserts that a tread separation is one of the most common failure modes for any steel-belted radial tire, regardless of brand. It contends that all radial tires can experience tread separations for a variety of reasons related to use, such as low inflation pressure, a slow leak, an impact break, or a similar incident.

Firestone's contention that a tread separation is not a defect is inconsistent with its defect determination of August 2000, and with several other safety-related determinations that it made before and after August 2000 (Table 4).[42] ODI recognizes that such factors as road hazards and severe under-inflation can contribute to tread separations. However, such failures would occur randomly throughout the tire population and would not yield the age-dependent failure distributions that are evident in the recalled tires and in the focus tires.

[42] Other tire manufacturers have also made safety defect determinations and conducted safety recalls to address tread separation problems. There have been 38 such defect recalls conducted by other tire manufacturers since 1985.

Moreover, it cannot seriously be disputed that the belt-leaving-belt separations involved in this investigation are "related to motor vehicle safety" within the meaning of the Vehicle Safety Act (Section 4.6, above).

> **Wilderness AT tires are comparable to competitor's tires** - Firestone asserts that the tests it has performed show that "across the board, Firestone tires perform the same as, if not better than, similar competitor tires."

ODI does not agree that the performance of the focus tires in relevant tests is comparable to that of competitors' tires. The results of ODI's shearography testing and sectioning of tires demonstrated significant differences between the crack growth initiation and severity seen in the focus Firestone tires and that seen in their peers, particularly with respect to focus tires manufactured before Firestone's change to the belt wedge. ODI also identified relevant differences between the wedge and inter-belt gauges of the focus tires and their peers as well as differences in their shoulder pocket designs and the consequences of those design differences. The focus tires also compared unfavorably in peel strength and temperature testing with the Goodyear Wrangler RT/S tires used on the Explorer.

> **Wilderness AT tires have extremely low claims rates** - Although Firestone argues that claims rates alone are not an accurate measure of a tire's performance, it states that the claims history of Wilderness AT tires "is dramatically better than that of the recalled tires."

Firestone is simply wrong in asserting that the claims rates on the Wilderness AT tires[43] are "extremely low." As shown in Table 5, the tread separation claims rates for the focus Wilderness AT tires from each of the Firestone plants exceed those for other peer tires used on SUVs, in some cases by extremely wide margins. But even more important, and more troubling, the cumulative failure trends indicate a progressively rising failure risk in the focus tires.

Firestone's effort to compare the claims experience of the Wilderness AT tires to that of the recalled tires is both conceptually flawed and statistically invalid. Even if it were true that the focus tires performed "better" than the recalled tires, that would not necessarily end the inquiry, since Firestone has previously determined that the recalled tires were defective. More important, Firestone is improperly comparing tire populations of distinctly different ages. A valid comparison of the failure risk of two populations of tires must account for age exposure.

Figures 16 and 19 demonstrate that, on a plant-by-plant basis, the focus tires from the Wilson and Joliette plants have had tread separation failure trends that are consistent with those experienced by the recalled ATX tires at similar service exposure intervals.[44] Another way to

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[43] As discussed above, Firestone's calculations dilute the claims rate of the focus tires by including all Wilderness AT tires, including those supplied to other vehicle manufacturers. This is misleading, since the other Wilderness AT tires are significantly different from the focus tires in a number of relevant respects.

[44] The failure trend for the recalled Wilderness AT P235/75R15 tires from Decatur was somewhat better than the failure trend for the Decatur ATX tires, but it was certainly not "dramatically better," and it was far worse than the failure trends for the recalled ATX tires from Wilson and Joliette.

consider this issue is to compare the claims experience of the focus tires produced in 1996 with the recalled ATX tires produced at Wilson and Joliette in that year.[45] As shown in Figure 42, the failure experience of both the P235/75R15 and P255/70R16 Wilderness AT focus tires is worse than that of the recalled ATX tires.

> **A tire and vehicle are a complex, integrated system** - Firestone insists that "to truly understand the cause of these terrible accidents, the vehicle must also be investigated."[46] Firestone asserts that the Wilderness AT tires perform very differently on the Ford Explorer than they do on the Ford Ranger, and notes that other Wilderness tires have performed "virtually flawlessly" on other vehicles. It asserts that tread separations leading to rollovers and other accidents involving Explorers continue, no matter what brand of tire is on the vehicle. Firestone claims that the Explorer presents "significant loss of control issues," particularly after a tread separation, which Firestone characterizes as "a generally benign, foreseeable event, in which the driver safely pulls over to the side of the road and changes the tire."

ODI is considering Firestone's allegations regarding the Explorer independently from its investigation of the focus tires. Nevertheless, several points are worth noting regarding this Firestone contention. ODI does not agree with Firestone's assertions that tread separation failures are "generally benign, foreseeable events." ODI is not aware of any vehicle manufacturer that includes tread separation in its vehicle performance standards (manufacturers do typically test vehicle response to sudden air loss on one or two tires). Likewise, ODI is not aware of any tire manufacturer, including Firestone that has recommended such testing.

ODI agrees that tires and vehicles interact. However, under the regulatory structure of the Vehicle Safety Act and NHTSA's implementing regulations, the legal duty to conduct recalls to address tire failures that lead to vehicle crashes is on the tire manufacturer, regardless of whether the tires were installed as original equipment at the time of sale.[47] In other words, even if

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[45] 1996 is the only year for which this comparison can be made, since it is the only year in which there was significant production of both recalled tires and focus tires at those plants.

[46] In a May 31, 2001 letter, Firestone requested that NHTSA "open an investigation into the safety of certain models of Explorers." Firestone claimed that certain Explorer vehicles "are defectively designed in that they have an inadequate margin of control (due to insufficient understeer) to permit control by average drivers in the foreseeable events of tread separation during normal highway driving in most load and turning circumstances." In support of this assertion, Firestone submitted preliminary data from testing conducted by Dr. Dennis Guenther, a vehicle dynamics consultant it hired. Dr. Guenther advised ODI that he planned to do a substantial amount of additional testing of the Explorer and peer SUVs. Although some additional test data has been submitted, that testing is still not complete. ODI is currently reviewing the issues raised by Firestone's letter.

[47] This apportionment of recall responsibility is unique to tires. With other items of original equipment, the vehicle manufacturer is responsible for addressing any safety-related defects, even if the problem was caused by the supplier of the equipment. For example, if a fuel tank leaks due to improper welds by the manufacturer of the tank, the vehicle manufacturer has the legal duty to determine that a defect exists, to notify owners of the affected vehicles, and to provide a free remedy for the problem. Any subsequent efforts by the vehicle manufacturer to obtain indemnification from the supplier for the costs associated with the recall are totally separate from the vehicle manufacturer's duties under the Vehicle Safety Act.

Firestone's assertions regarding the difficulty of controlling an Explorer after a tread separation were correct, it would not affect Firestone's duty to recall defective tires. Of course, Firestone could seek reimbursement from Ford for the costs associated with such a recall, but that issue would be decided in the courts, without any NHTSA involvement.

With respect to the relative performance of Wilderness AT tires on Explorer SUVs and Ranger compact pickups, Firestone has claimed that the tread separation claims rate for ATX and Wilderness AT tires on Explorers is eight times as high as the rate on Rangers. In response, Ford has provided data indicating that most of the Rangers that were equipped with recalled or focus tires were shipped to Northern states, where the conditions are less likely to lead to belt-leaving-belt separations and where the overall claims experience for all of the subject tires has been significantly lower. Nevertheless, even if Ford's assertions regarding the geographical distribution of these tires on the Ranger are correct, the frequency of tread separation claims is higher for tires on Explorers than on Rangers.

This difference, however, is not unexpected, for several reasons. First, the Explorer is a more demanding application than the Ranger with respect to load and recommended inflation pressure. The unloaded vehicle weight of the heaviest Ranger is 3,647 lb, while the unloaded vehicle weight of the heaviest Explorer is 4,150 lb. The Gross Vehicle Weight Rating (GVWR) for the heaviest Ranger is 5,140 lb, compared to the Explorer's 5,660 lb. Moreover, as an SUV with a higher center of gravity, the cornering loads applied to the Explorer's tires on the outside of turns may be greater than those applied to the Ranger's tires.

With respect to inflation pressure, Table 6 shows Ford's recommended inflation pressures for each of the platforms that use the subject tires, as well as the loads that the tires can carry at the specified inflation pressures, as set forth in the 2001 Yearbook published by the Tire and Rim Association.[48] Most of the Explorers were equipped with P235/75R15 tires and Ford produced these vehicles with a recommended inflation pressure of 26 pounds per square inch (psi) for both the front and rear tires, apparently in order to meet its ride and handling objectives.[49] For Explorers equipped with P255/70R16 tires, Ford's recommended inflation pressure was 30 psi in both front and rear. Ford's recommended inflation pressure for the P235/75R15 tires on the Ranger was 30 psi in the front and 35 psi in the rear. While NHTSA is aware that many vehicle owners do not always inflate their tires to the vehicle manufacturer's recommended levels, it is

[48] Pursuant to Federal Motor Vehicle Safety Standard (FMVSS) No. 120, manufacturers of vehicles other than passenger cars must assure that the tires installed on the vehicle have load ratings that are adequate to support its weight. Moreover, when the manufacturer uses passenger car tires on such a vehicle, the tires' load carrying capacity must be reduced by dividing by 1.10.

[49] Firestone has contended that, in part due to this recommended inflation pressure of 26 psi, at least some Explorers had an insufficient reserve load, which allegedly reduced the safety margin of the tires. While inflation pressure is certainly a critical factor in determining how much of a load a tire can safely carry, Ford has submitted data indicating that the reserve loads for the majority of Explorer models, even at 26 psi, are not significantly different from those of other SUVs. In addition, the Goodyear Wrangler RT/S tires installed on Explorers had the identical recommended inflation pressure, yet their claims experience is negligible. Moreover, Firestone was aware from the outset that these tires were being installed with that recommended inflation pressure. If Firestone had any doubt about the ability of its tires to perform properly on the Explorer at that inflation pressure, it should have revised the tires' design accordingly.

likely that many of the focus tires on Rangers have been operated at higher inflation pressures than those on Explorers, particularly the rear tires, where there is either a five or nine pound difference in recommended pressure.

These differences in operating experience between Explorers and Rangers would be expected to result in relatively slower initiation and growth of belt edge cracks on Rangers compared to Explorers. The claims data confirm this. Thus, while the rate of tread separation claims for tires on Explorers began to grow within two to four years (depending on the plant where they were manufactured), the claims involving ATX tires on Rangers did not begin to rise to a significant level until 5 to 6 years. Accordingly, it is to be expected that there would be few claims involving Wilderness AT tires on Rangers. In fact, there have been three such claims involving recalled Wilderness AT tires from Decatur and none so far involving the focus tires.

There is no reason to believe that the focus tires on Rangers would experience tread separations at a different rate from that of the ATX tires on those vehicles. While that failure experience is lower than the failure experience of the ATX tires on Explorers, the rate of such failures is higher than that of almost all of the tires for which comparative claims data was obtained by ODI and thus is a cause for possible concern. See Table 5.[50] However, as discussed in Section 4.7, tread separations on pickups are far less likely to lead to crashes and casualties than such failures on SUVs. See Tables 7 and 8.

8 Initial Findings

1. Belt-leaving-belt tread separation failures of Firestone ATX and Wilderness AT tires manufactured for use on Ford vehicles have led to numerous deaths and injuries.

2. Most of these failures, deaths, and injuries involved ATX tires that were recalled by Firestone in August 2000. However, several different analytical methodologies demonstrate that, on a plant-by-plant basis, the tread separation claims experience of the focus Wilderness AT tires is similar to that of the recalled ATX tires after the same period of time in service.

3. The recalled ATX and Wilderness AT tires manufactured at Decatur began to fail in significant numbers after between one and two years in service; this period was 2-3 years for the recalled ATX and focus Wilderness AT tires manufactured at Wilson and 3-4 years for the recalled ATX and focus Wilderness AT tires manufactured at Joliette.

4. The tread separation failure experience of the focus tires is far worse than that of their peers, especially the Goodyear Wrangler RT/S tires used as original equipment on numerous Ford Explorers.

[50] As noted above, ODI obtained production and claims data only with respect to competitor tires used on SUVs. As explained in the Report, tires on SUVs would normally be expected to experience a higher rate of tread separation failures than those on compact pickups. Thus, the "peer tires" listed in Table 5 may not be true "peers" for purposes of analyzing the relative performance of ATX and Wilderness AT tires on Rangers.

5. The belt wedge thickness, or gauge, in the ATX tires and the Wilderness AT tires produced prior to May 1998 is generally narrower than the wedge gauge in the peer tires tested by ODI, and the wedge gauge in cured tires was often less Firestone's target. The tires with this wedge did not adequately resist the initiation and propagation of belt-edge cracks between the steel belts.

6. Firestone increased the dimensions of the belt wedge in the focus tires and improved its material properties in March and April 1998. In general, this increase brought the wedge gauge of the focus tires within the range of the tested peers.

7. The inter-belt gauge initially specified by Firestone for the focus tires is generally narrower than the gauges in peer tires, and the actual measured gauge under the tread grooves in several of the cured tires measured by ODI was far less than Firestone's minimum design specification.

8. The design of the shoulder pocket in the focus tires can cause high stresses at the belt edge and lead to a narrowing of the wedge gauge at the pocket. The focus tires exhibit a series of weak spots around the tire's circumference, leading to the initiation and growth of cracks in these tires earlier than in competitor tires and in other Firestone tires produced for similar applications.

9. Some of the focus tires exhibited shoulder pocket cracking similar to that which Firestone identified as a significant contributor to the risk of tread detachment in the recalled ATX tires.

10. Material properties testing indicated that the peel adhesion characteristics of the focus tires reached the low level exhibited by the Decatur tires after 3-4 years and were worse than the adhesion characteristics of the Goodyear Wrangler RT/S tires. Also, the rubber in the focus tires exhibited deterioration due to aging that was similar to that of the Decatur tires and that was more severe than that of the Goodyear Wrangler RT/S tires.

11. As reflected by shearography performed on randomly collected focus tires and peer tires from southern states, where most of the failures have occurred, the cracks and separations between the belts were far more prevalent and severe in the focus tires than in peer tires. Many of the focus tires were in the later stages of failure progression prior to complete separation of the upper belt. The shearography results for tires manufactured at Wilson were essentially the same as for those manufactured at Joliette. Although ODI did not test any tires manufactured at Oklahoma City, the design of those tires is identical to those made at Wilson and Joliette.

12. Belt-leaving-belt tread separations, whether or not accompanied by a loss of air from the tire, reduce the ability of a driver to control the vehicle, particularly when the failure occurs on a rear tire and at high speeds. Such a loss of control can lead to a crash. The likelihood of a crash, and of injuries or fatalities from such a crash, is far greater when the tread separation occurs on a SUV than when it occurs on a pickup truck.

13. Tread separation claims included in the Firestone claims database involving the recalled and focus tires have been associated with numerous crashes, which have led to 74 deaths and over 350 injuries. Tread separation complaints reported from all sources included in the ODI consumer complaint database that have been identified as involving these tires have reportedly led to 192 deaths and over 500 injuries.

14. Although there have been more failures and casualties associated with failures of the recalled tires than the focus tires to date (17 deaths and 41 injuries involving focus tires in the Firestone claims database), the fact that the plant-by-plant failure trends for the focus tires are very similar to those of the recalled ATX tires demonstrates that, if they are not removed from service, the focus tires – at least those manufactured before Firestone modified the wedge -- will experience a similar increase in tread separation failures over the next few years, leading to numerous future crashes, injuries, and deaths.

15. The rate of tread separation failures on Ranger pickups is lower that the rate of such failures on Explorers for a variety of reasons, including the fact that the Explorer generally carries higher loads and is a more demanding application, and the tires on the Explorer had a significantly lower recommended inflation pressure (especially on the rear wheels). The risk of such a separation on Rangers remains a cause for possible concern. Nevertheless, because the likelihood of a crash due to a tread separation, and of deaths and injuries resulting from such a crash, is substantially lower when the separation occurs on a pickup than on a SUV, NHTSA's initial defect decision does not apply to focus tires installed on pickup trucks.

16. Almost all of the tread separation failures of the focus tires that led to claims occurred after the tires were in service for at least three years and involved tires manufactured before May 1998, when Firestone improved the wedge. In theory, Firestone's modifications to the wedge would tend to inhibit the initiation and propagation of the belt-edge cracks that can lead to belt-leaving-belt tread separations. If these modifications actually improved the resistance of the focus tires to belt-edge separations, the historical failure trends described above may not predict the future performance of the newer tires. However, because tread separation failures rarely occur in the focus tires until at least three years of use, it is not now possible to ascertain from field experience whether their actual performance has improved significantly.

17. The record of this investigation supports a determination that the focus tires manufactured by Firestone prior to its 1998 modifications to the belt wedge that are installed on SUVs contain a safety-related defect. Although the agency has concerns about the possibility of future tread separations in focus tires manufactured after the wedge change, the evidence at this time does not clearly demonstrate that a safety-related defect exists in the focus tires manufactured with the improved wedge.

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Kenneth N. Weinstein Date
Associate Administrator for Safety Assurance

Tables

Plant	DOT Code	Radial ATX P235/75R15	Wilderness AT P235/75R15	Wilderness AT P255/70R16
Aiken, SC	8X	0	2,452,999	514,872
Decatur, IL	VD	2,452,792[a]	3,378,529[a]	576,111
Joliette, CAN	VN	4,471,474[a]	1,634,711	2,380,993
Lavergne, TN	W1	482,649[a]	0	0
Okla. City, OK	HY	1,346[a]	74,071	0
Wilson, NC	W2	3,498,100[a]	3,437,948	1,804,382

[a] recalled in 00T-005

Table 1 – Total production volumes of recalled and focus tires for OE and trade applications for vehicles using recalled and focus tires.

Firestone tire production data as of March 2001

	Middle East	Malaysia/Thailand	Venezuela, Columbia, & Ecuador
Date of action	Jul 1999	Feb 2000	May 2000
Scope	MY 1995-99 Explorer	MY 1997 Explorer	MY 1996-99 Explorer MY 1998-99 F150
Tire Model	Wilderness AT	Wilderness AT	Wilderness AT
Tire Sizes	P255/70R16	P235/75R15	P235/75R15 P255/70R16
Vehicles	6,755	316	39,324
Crashes Reported	19	2	50
Injuries Reported	10	0	72
Fatalities Reported	14	0	31

Table 2 - Ford's tire replacement campaigns in foreign countries

Tire Group	Plant/Model	Tire Size	Claims		Severity		
			No.	ppm	Crashes	Injuries	Deaths
Recalled Tires	Decatur ATX	P235/75R15	1,348	549.6	130	194	36
	Wilson ATX	P235/75R15	585	167.2	41	55	3
	Decatur AT	P235/75R15	305	90.3	38	52	9
	Lavergne ATX	P235/75R15	39	80.8	3	3	0
	Joliette ATX	P235/75R15	324	72.5	15	22	9
Focus Tires Pre-Wedge Change	Wilson AT	P235/75R15	77	54.2	16	19	8
	Wilson AT	P255/70R16	34	47.4	7	8	5
	Ok City AT	P235/75R15	0	0	0	0	0
	Joliette AT	P255/70R16	13	20.9	4	5	0
	Joliette AT	P235/75R15	8	10.4	4	6	1
Focus Tires Post-Wedge Change	Wilson AT	P235/75R15	3	1.5	2	3	3
	Wilson AT	P255/70R16	2	1.8	0	0	0
	Ok City AT	P235/75R15	1	16.5	0	0	0
	Joliette AT	P255/70R16	2	1.1	0	0	0
	Joliette AT	P235/75R15	0	0	0	0	0
	Aiken AT	P235/75R15	1	0.4	0	0	0
	Aiken AT	P255/70R16	0	0	0	0	0
	Decatur AT	P255/70R16	0	0	0	0	0

Table 3. Tread Separation Failure Experience and Severity, Recalled and Focus Tires.
Firestone Claims database as of March 2001

Recall		Tire		Defect Consequence
No.	Date	Model	Volume	
01T-006	2/01	Firehawk GTA-02	952,000	Possible belt edge separation that could result in loss of air pressure.
01T-001	1/01	Wilderness LE	8,000	Tread separation, possibly resulting in a vehicle crash, personal injury, or death.
00T-005	8/00	Radial ATX, Wilderness AT	14,400,000	Tread separation, possibly resulting in a crash causing injury or death.
87T-006	5/87	Firehawk GT	441	Tread separation could lead to loss of air, possibly resulting in loss of control
80T-011	7/80	Steel Radial 500	5,120,000	Tread separation could lead to loss of air, possibly resulting in loss of control

Table 4 - Firestone tread separation safety recalls.

Tire Line/Plant	Tire Size	OE Vehicle	Prod. Yrs	Claims	
				No.	ppm
Firestone VD ATX [a,b]	P235/75R15	Explorer/Ranger/F150	'95-'97	959	700.5
Firestone VD AT [a,b]	P235/75R15	Explorer/Ranger	'96-'97	273	253.5
Firestone W2 ATX [a]	P235/75R15	Explorer/Ranger	'95-'97	66	93.2
Firestone W2 AT	P255/70R16	Explorer/Expedition	'95-'97	35	63.8
Firestone W2 AT [b]	P235/75R15	Explorer/Ranger	'96-'97	71	62.1
Firestone VN ATX [a]	P235/75R15	Explorer/Ranger/F150	'95-'97	18	35.5
Firestone VN AT	P255/70R16	Explorer	'95-'97	13	28.1
Firestone VN AT	P235/75R15	Explorer/Ranger	'95-'97	7	10.7
Goodyear Wrangler RT/S [d]	P265/75R16	GM Yukon/Tahoe	'95-'97	9	10.2
Uniroyal Tiger Paw [b]	P235/75R15	GM Yukon/Tahoe	'97	7	3.4
Goodyear Wrangler RT/S [b,e]	P265/75R16	GM Yukon/Tahoe	'96-'97	4	2.3
Goodyear Wrangler AP [b]	P225/75R15	Grand Cherokee	'95-'96	3	1.9
Michelin XW4 [b]	P235/70R15	GM Jimmy/Blazer	'97	2	1.9
Goodyear Wrangler RT/S	P235/75R15	GM Jimmy/Blazer	'96-'97	1	1.8
Goodyear Wrangler RT/S	P265/70R16	Toyota 4-Runner	'96-'97	1	1.3
Goodyear Wrangler RT/S [b]	P235/75R15	Explorer	'95-'97	4	1.2
Goodyear Wrangler RT/S	P205/75R15	GM Tracker	'95-'97	0	0.0
Goodyear Wrangler Rad.	P215/75R15	Jeep Cherokee & Wrangler	'95-'97	0	0.0
Goodyear Invicta GL	P215/75R15	Jeep Cherokee & Gr Cherokee	'95-'96	0	0.0
Goodyear Eagle GA	P225/70R15	Jeep Cherokee & Gr Cherokee	'95-'97	0	0.0
Goodyear Eagle LS	P225/70R16	Jeep Cherokee & Gr Cherokee	'95-'97	0	0.0
Goodyear Wrangler Rad.[b]	P225/75R15	Jeep Cherokee & Gr Cherokee	'95-'97	0	0.0
Goodyear Wrangler RT/S	P225/75R15	Jeep Grand Cherokee	'96-'97	0	0.0
Goodyear Wrangler AP	P245/70R16	Isuzu Trooper/Rodeo	'95-'97	0	0.0
Goodyear Wrangler RT/S [b]	P265/70R17	Ford Bronco	'96-'97	0	0.0

[a] recalled tire
[b] over 1 million tires produced during this period
[c] also used on pickup truck platform
[d] manufactured at Goodyear's Union City plant
[e] manufactured at Goodyear's Napanee plant

VD = Decatur
W2 = Wilson
VN = Joliette

AT = Wilderness AT tire built to Ford specifications

Table 5 – Claims frequencies for recalled, focus, and selected peer tires used as OE fitments on SUVs (1995-1997 production years).

Vehicle Platform	Tire Size	Inflation Pressure, (psi)		Tire & Rim Association Rated Load (lb)	
		Front	Rear	Front	Rear
Explorer	P235/75R15	26	26	1,753	1,753
	P255/70R16	30	30	2,100	2,100
Ranger	P235/75R15	30	35	1,653	2,028
F150	P235/75R15	35	41	2,028	2,183
	P255/70R16	29	32	2,072	2,172
Bronco	P235/75R15	35	41	2,028	2,183
Expedition	P255/70R16	30	35	2,100	2,271

Table 6 - Load and load carrying capacity of tires on Ford light trucks and SUVs equipped with subject tires at inflation pressures recommended by the vehicle manufacturer.

Vehicle Group	Claims	Crashes				Safety Risk		
		Total	Rollover	Non-Fatal Injury Crashes	Fatal Crashes	Crashes (per 100 claims)	Fatal Crashes (per 100 claims)	Rollovers (per 100 crashes)
Explorer/Mount/ Navajo	2,287	220	149	167	53	9.6	2.3	67.7
Other Compact SUV's	151	17	9	9	1	11.3	0.7	52.9
Large SUV's	104	7	4	4	1	6.7	1.0	57.1
ALL SUV's	**2,542**	**244**	**162**	**180**	**55**	**9.6**	**2.2**	**66.4**
Ranger/B Series	66	5	1	1	0	7.6	0.0	20.0
Other Small Size P/U's	73	1	1	1	0	1.4	0.0	100.0
Full Size P/U's	820	16	3	8	1	2.0	0.1	18.8
ALL P/U's	**959**	**22**	**5**	**10**	**1**	**2.3**	**0.1**	**22.7**

Table 7 - Consequences of Tread Separation of Subject Tires On Various Types of Vehicles.

Firestone claims database as of March 2001

Vehicle Group	Reports	Crashes				Safety Risk		
		Total	Rollover	Non-Fatal Injury Crashes	Fatal Crashes	Crashes (per 100 Reports)	Fatal Crashes (per 100 Reports)	Rollovers (per 100 crashes)
Explorer/Mount/ Navajo	2,197	343	254	260	78	15.7	3.6	74.1
Other Compact SUV's	114	16	11	12	4	14.0	3.5	68.8
Large SUV's	161	10	5	5	2	6.2	1.2	50.0
ALL SUV's	**2,472**	**369**	**270**	**277**	**84**	**14.9**	**3.4**	**73.2**
Ranger/B Series	231	16	9	5	1	6.9	0.4	56.3
Other Small Size P/U's	44	3	2	3	0	6.8	0.0	66.7
Full Size P/U's	405	12	3	3	1	3.0	0.2	25.0
ALL P/U's	**680**	**31**	**14**	**11**	**2**	**4.6**	**0.3**	**45.2**

Table 8 - Consequences of Tread Separations of Subject Tires on Various Types of Vehicles*

ODI Database as of September 5, 2001

*This Table includes non-duplicative reports to ODI from consumers and safetyforum.com and incidents derived from the Fatal Analysis Reporting System (FARS). It does not include the Firestone claims database or complaint data received from Ford or State Farm.

Figures

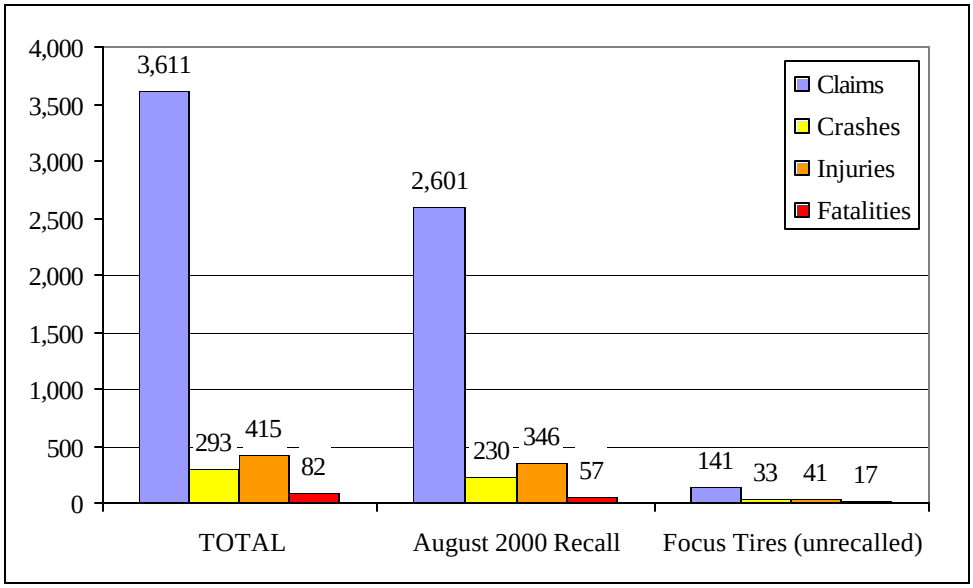


Figure 1 – Summary of claims, crashes, injuries, and fatalities in the Firestone claims database.

Firestone claims database as of March 2001

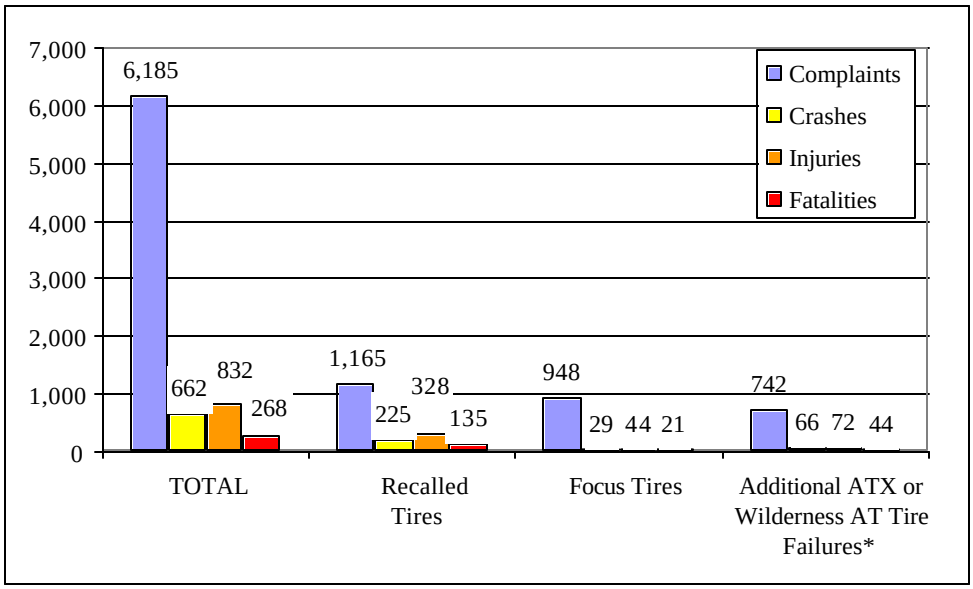


Figure 2 – Summary of complaints, crashes, injuries, and fatalities in the ODI complaint database.

* NOTE: The data for the Recalled tires and the Focus tires are limited to reports where sufficient information was provided to allow ODI to categorize the tires appropriately

ODI complaint database as of August 2001

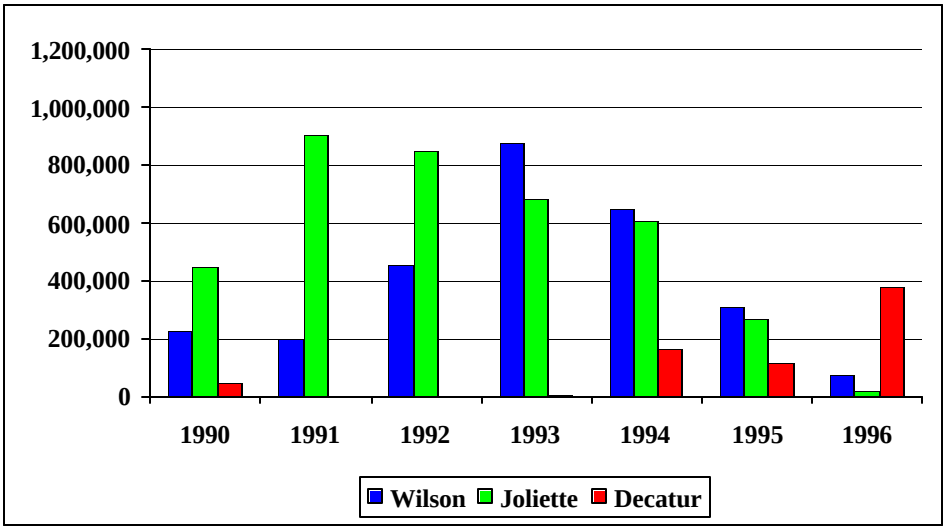


Figure 3 - P235/75R15 ATX OE tire shipments by plant/year.

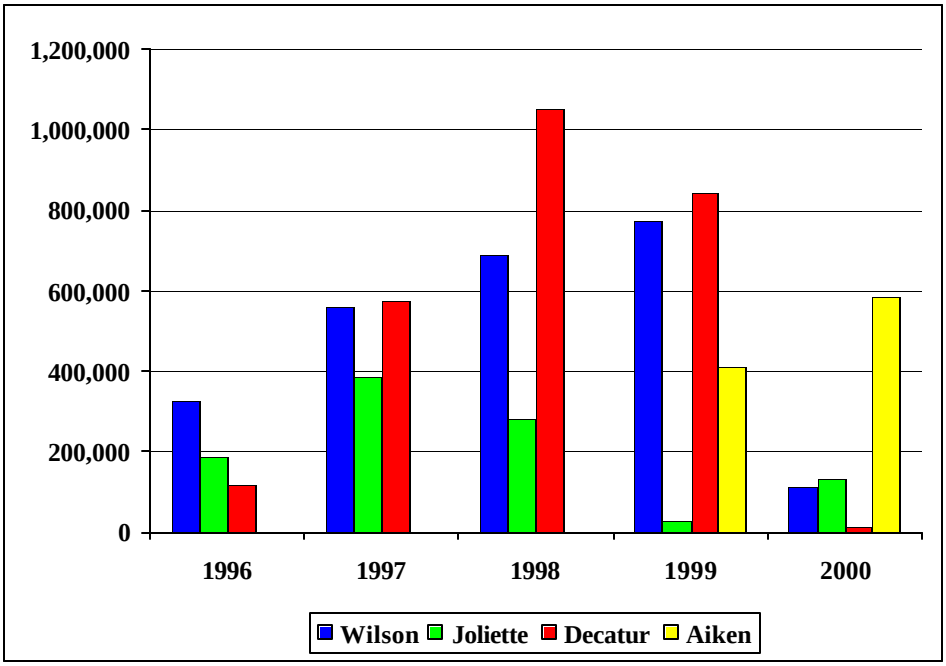


Figure 4 - P235/75R15 Wilderness AT OE tire shipments by plant/year.

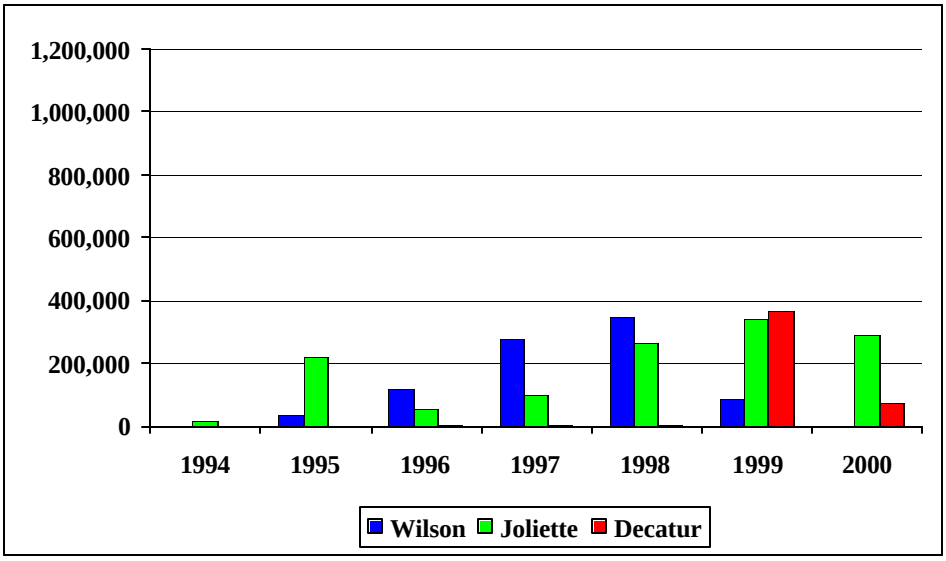


Figure 5 - P255/70R16 Wilderness AT OE tire shipments by plant/year.

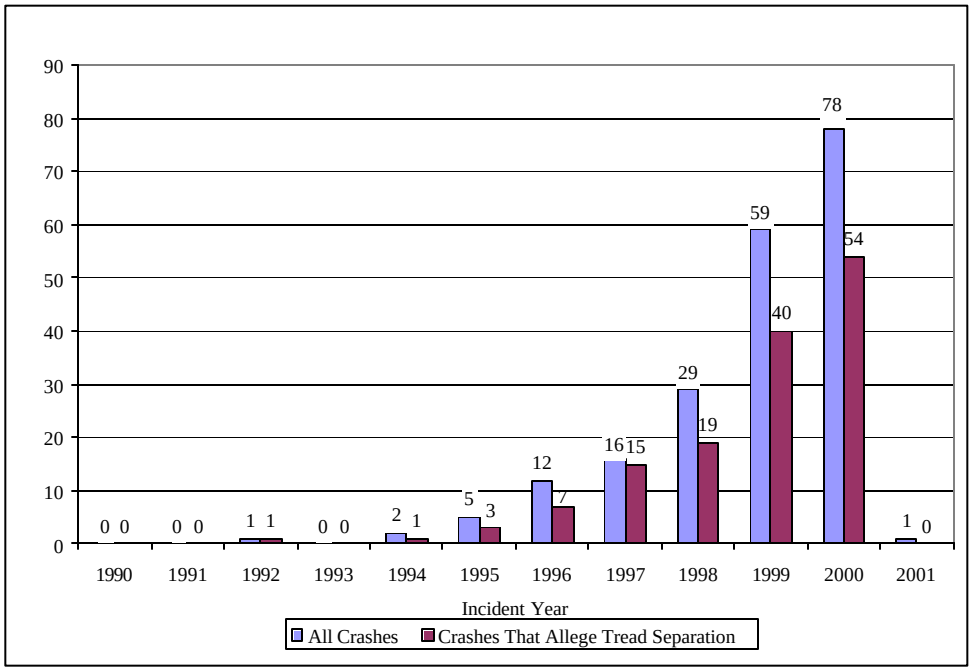


Figure 6 – Fatal crashes involving subject Firestone tires, by incident year, all vehicles.

ODI complaint database as of August 2001

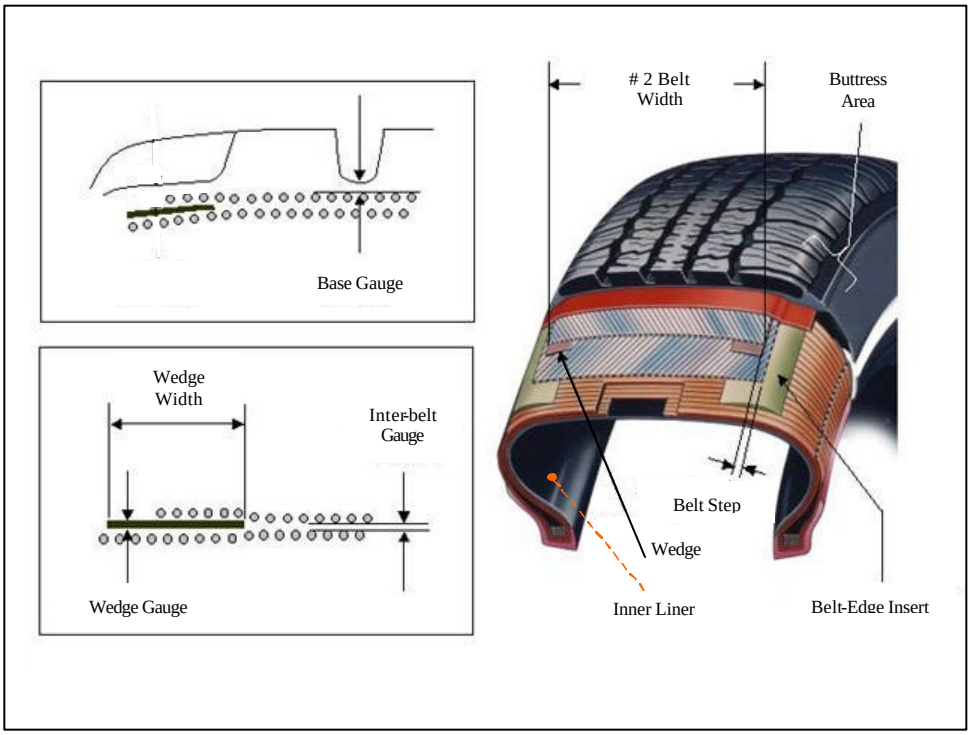


Figure 7 – Radial tire construction.

Figure 8 – Shoulder pockets in ATX and Wilderness AT P235/75R15 Tires manufactured for Ford.

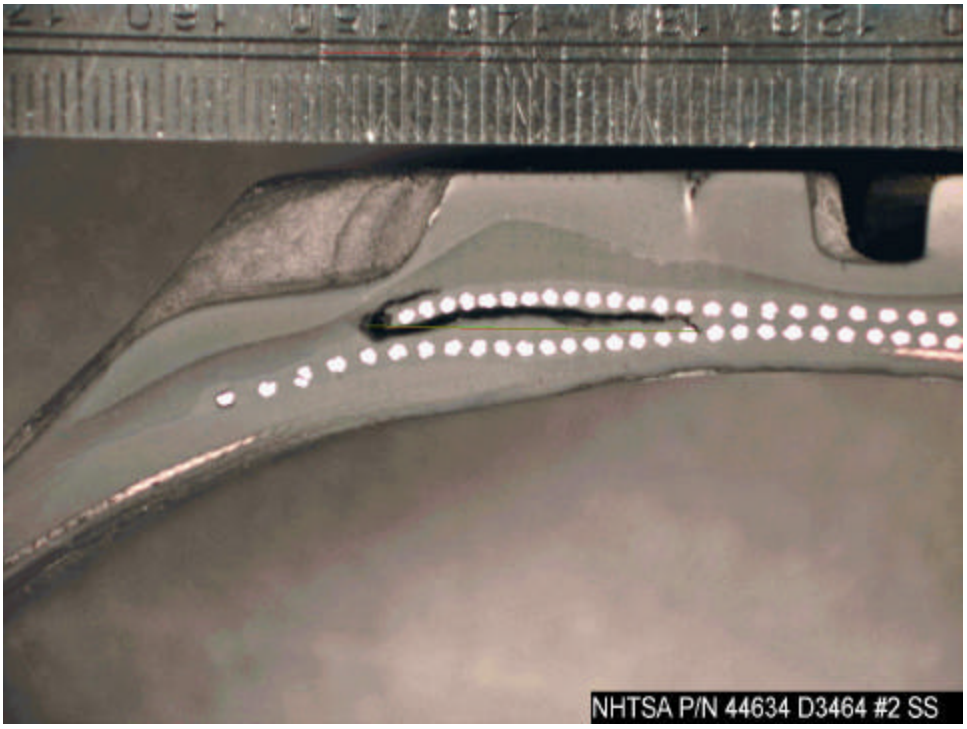


Figure 9 – Crack found in a Joliette P235/75R15 Wilderness AT tire, manufactured in May 96 (VN 196).

Figure 10 – Separation pattern on the tire carcass of a failed Wilson P235/75R15 Wilderness AT tire, manufactured in Sep 96 (W2 396).

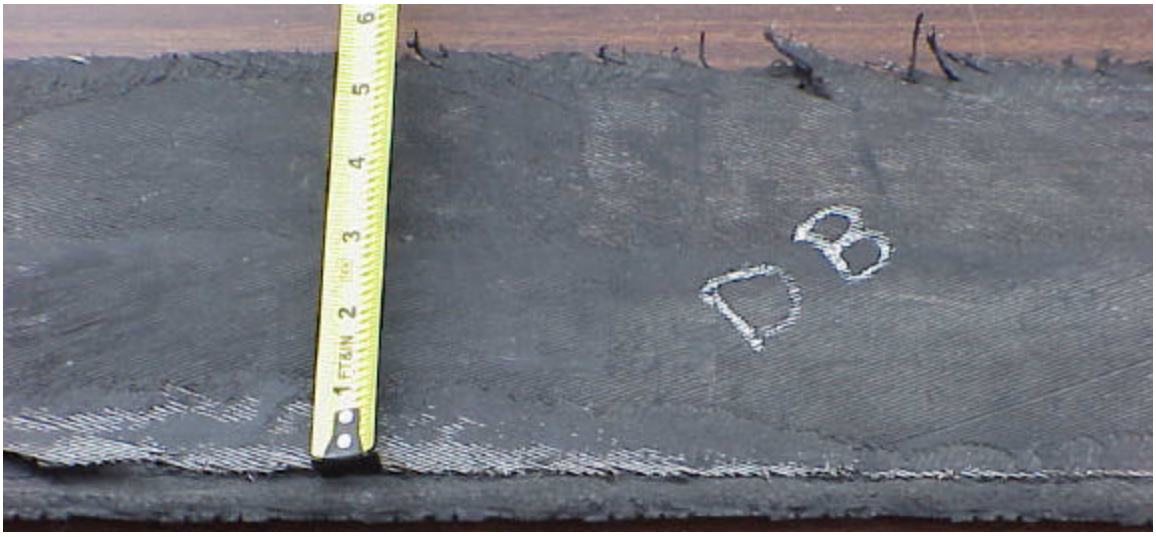


Figure 11 – Separation pattern on the tread of the same failed Wilderness AT tire.

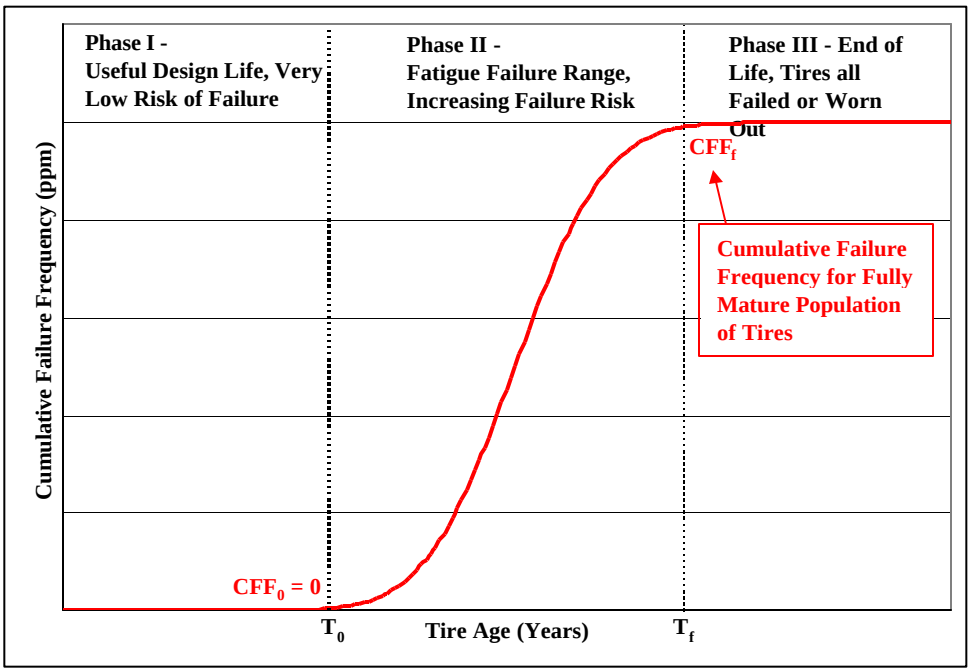


Figure 12 – Fatigue failure theoretical model.

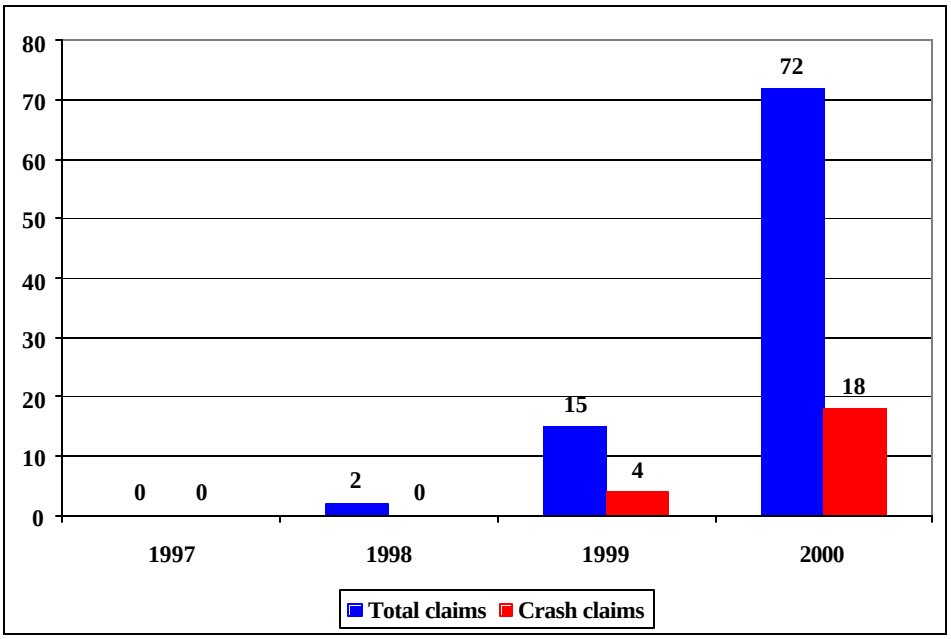


Figure 13 – Wilson and Joliette Wilderness AT P235/75R15 tires; claims/crash trend, by date of incident.
Firestone claims database as of March 2001

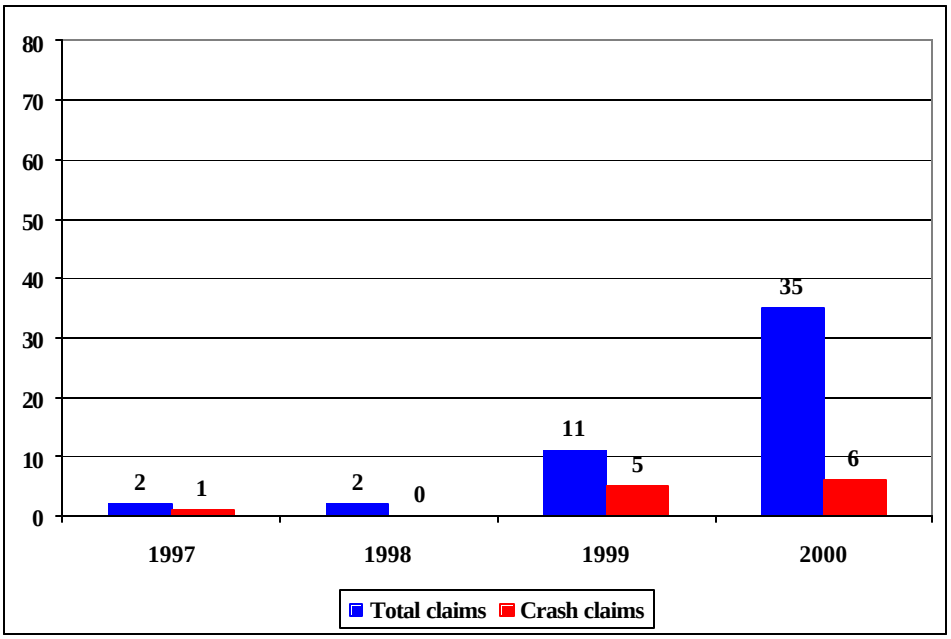


Figure 14 – Wilson and Joliette Wilderness AT P255/70R16 tires; claims/crash trend, by date of incident.
Firestone claims database as of March 2001

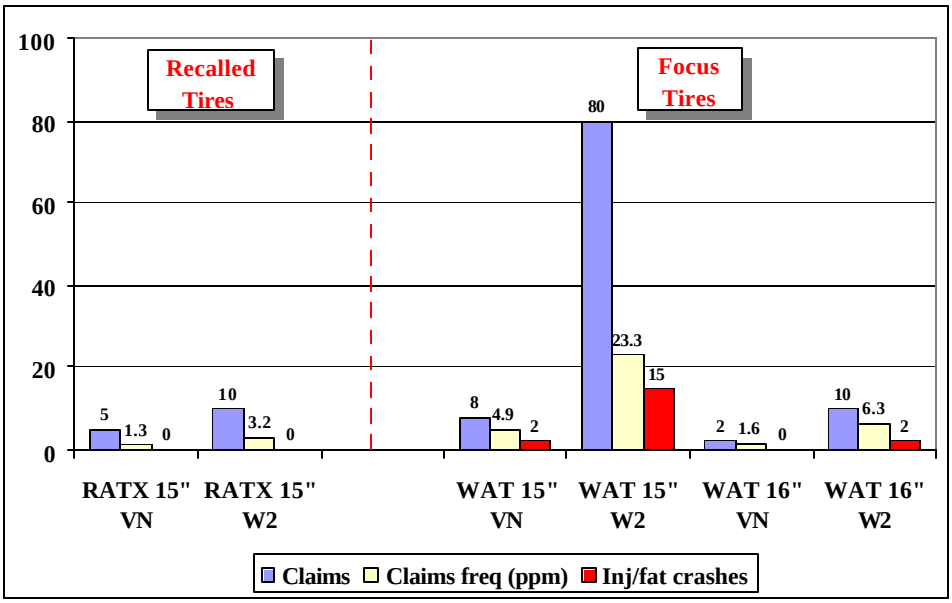


Figure 15 – ATX vs. Wilderness AT, failure experience comparison, by plant; 56 months after first tire produced.

Firestone claims database as of March 2001

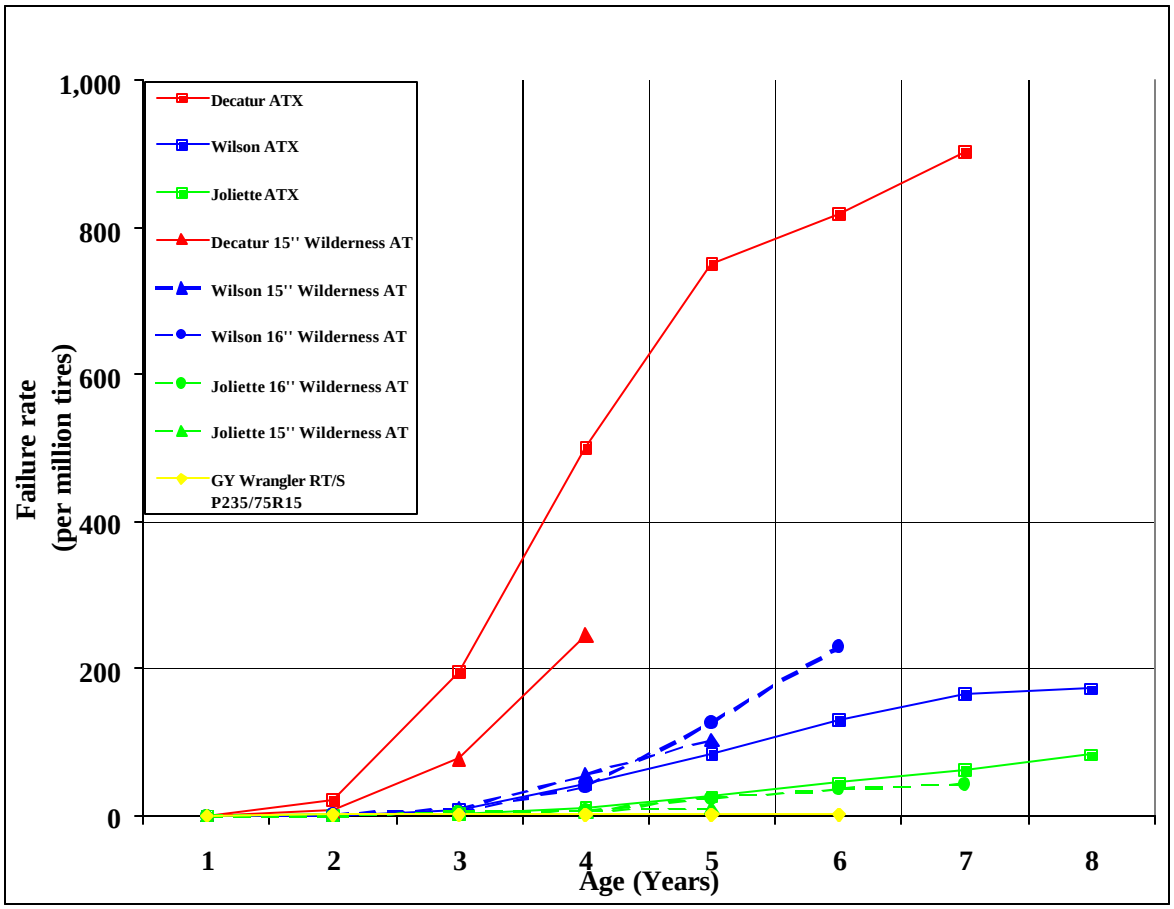


Figure 16 – Cumulative failure frequencies. Recalled and focus tires by model, size, and plant vs. Goodyear Wrangler RT/S

Firestone claims database as of March 2001
Goodyear claims as of December 2000

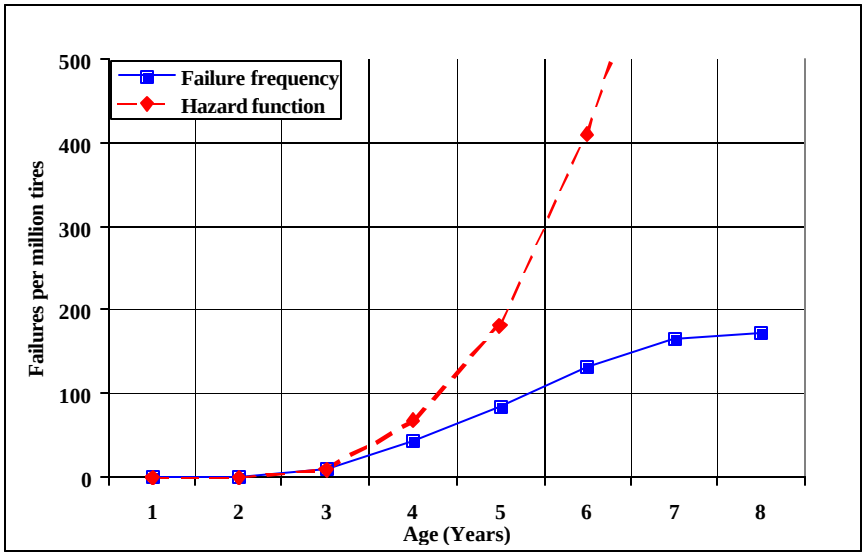


Figure 17 – Comparison of cumulative hazard function vs. cumulative failure frequency, Wilson ATX P235/75R15 tires.

Firestone claims database as of March 2001

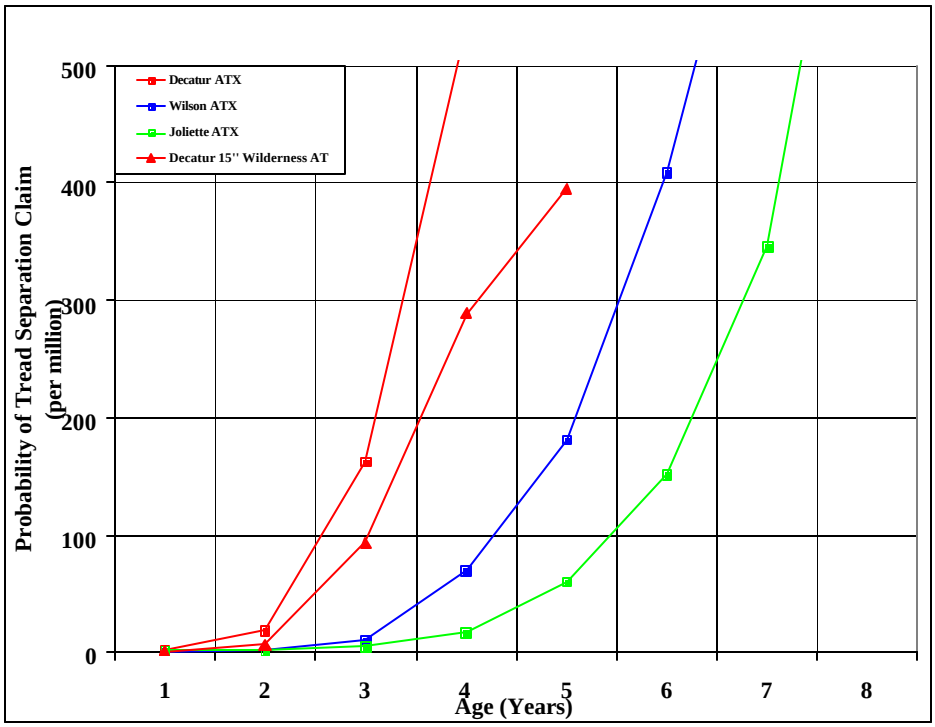


Figure 18 – Cumulative hazard function, recalled tires, by model and plant.
Firestone claims database as of March 2001

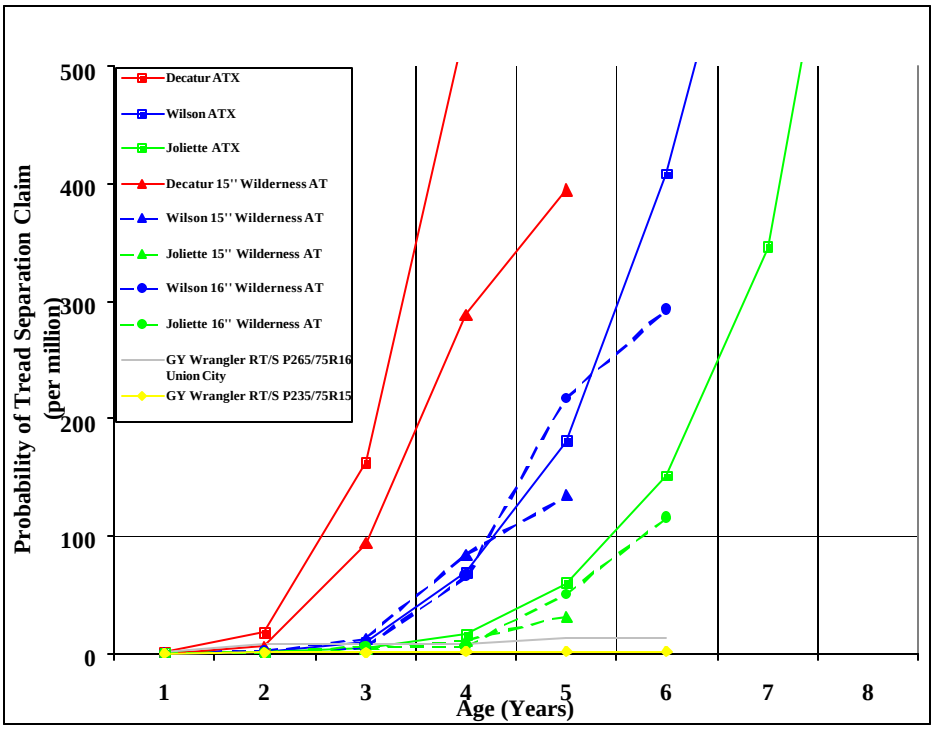


Figure 19 – Cumulative hazard function, recalled tires, with focus tires, and two peer tires.
Firestone claims database as of March 2001
Goodyear claims as of December 2000

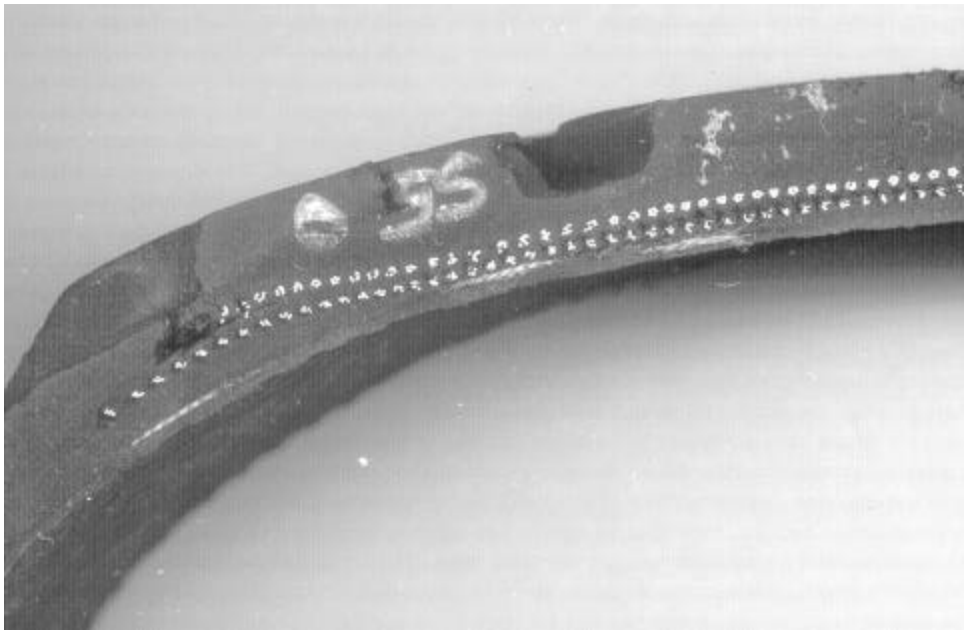


Figure 20 – Wilderness AT pocket crack growth to edge of No. 2 belt
Wilson P235/75R15 Wilderness AT tire,
manufactured in Oct 97 (W2 417).

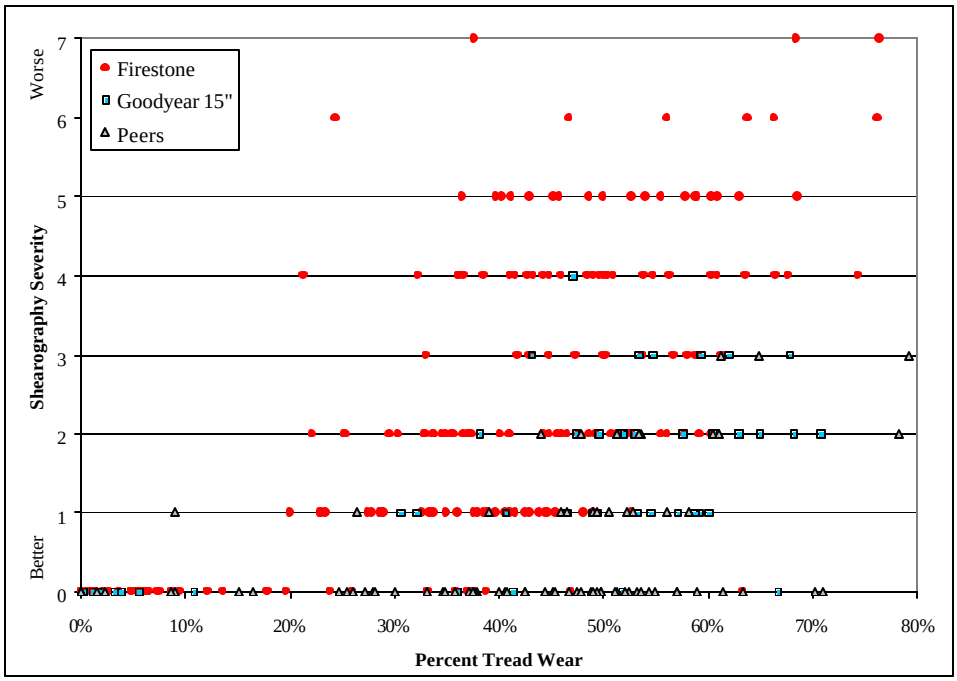


Figure 21 – ODI shearography analysis comparing Firestone focus tires and their Goodyear and non-Goodyear peers by belt edge separation severity.
Separation categories are defined in Appendix A

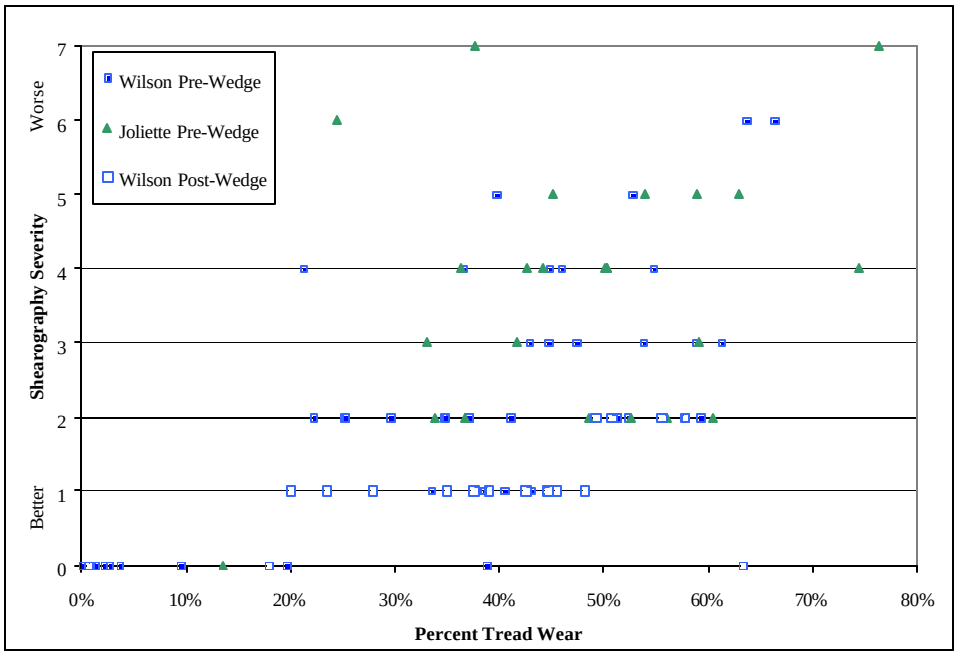


Figure 22 – ODI shearography analysis comparing P235/75R15 pre- and post-wedge change focus tires by belt edge separation severity.
Separation categories are defined in Appendix A

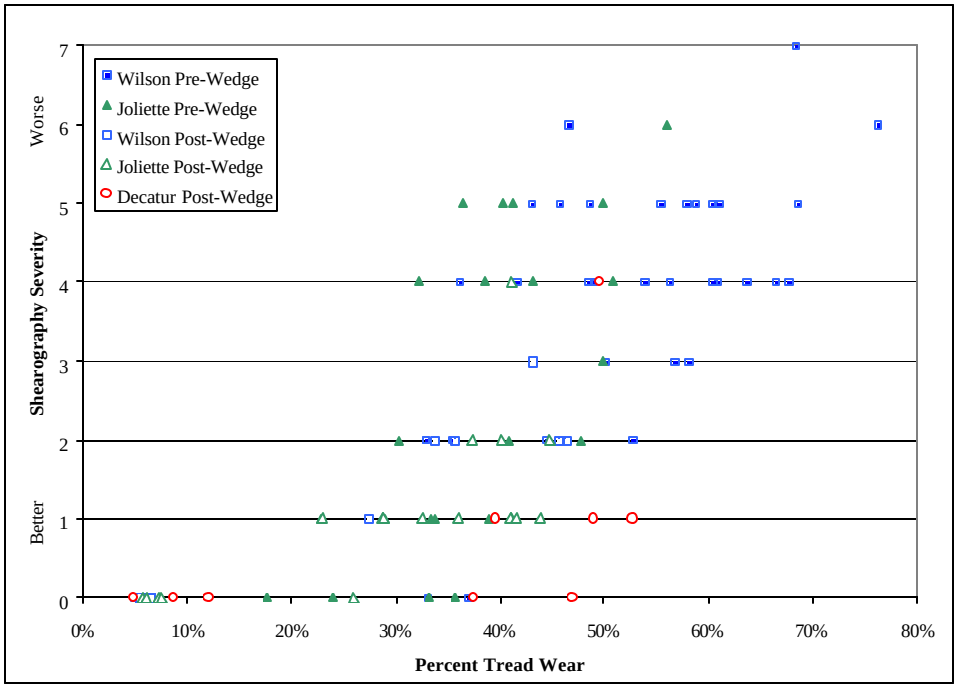


Figure 23 – ODI shearography analysis comparing P255/70R16 pre- and post-wedge change focus tires by belt edge separation severity.

Separation categories are defined in Appendix A

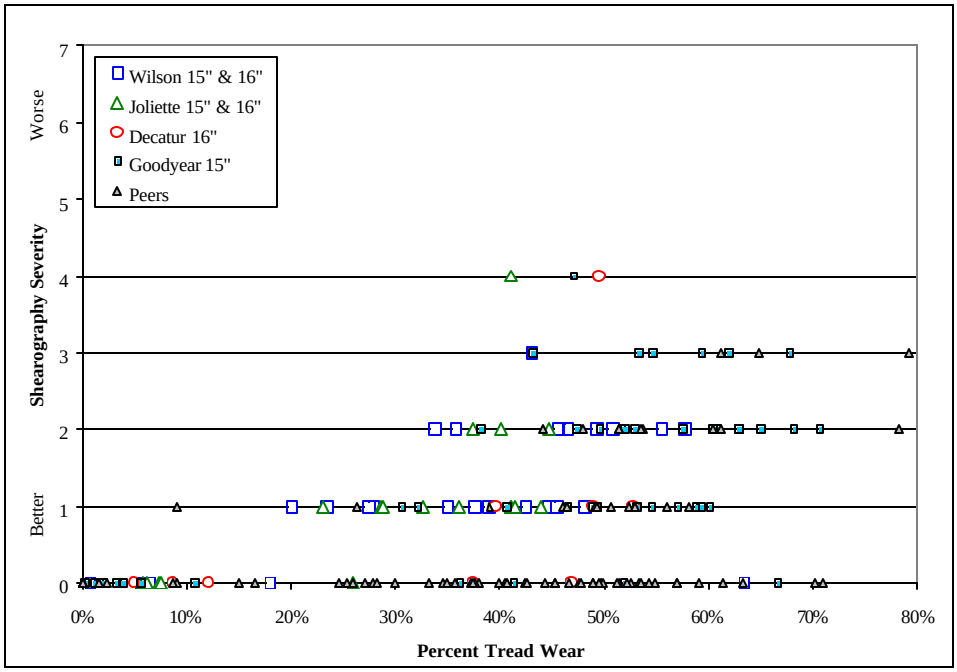


Figure 24 – ODI shearography analysis comparing all post- wedge change focus tire to their peers by belt edge separation severity.

Separation categories are defined in Appendix A

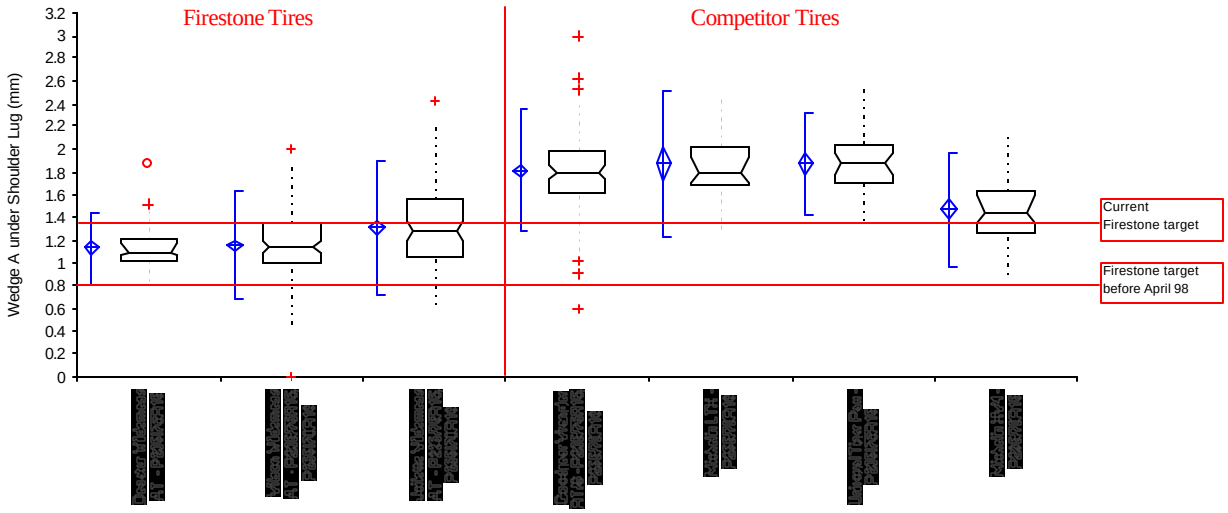


Figure 25 – Wedge gauge under shoulder lugs, Focus tires (prior to 1998 design change) vs. peers.

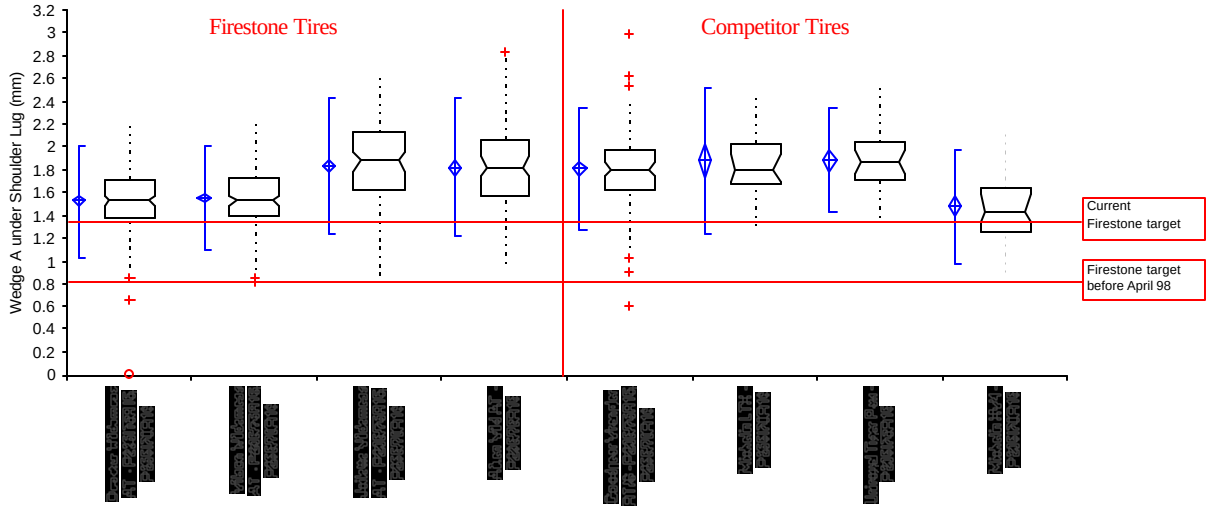


Figure 26 – Wedge gauge under shoulder lugs, Focus tires (after 1998 design change) vs. peers.

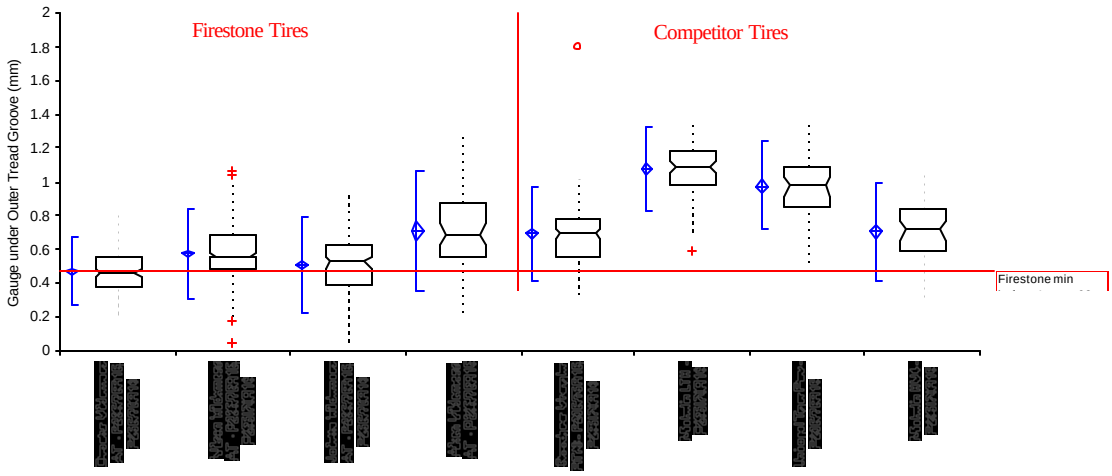


Figure 27 – Inter-belt gauge under outer tread grooves, Focus tires (before the August 1999 design change) vs. Peers.

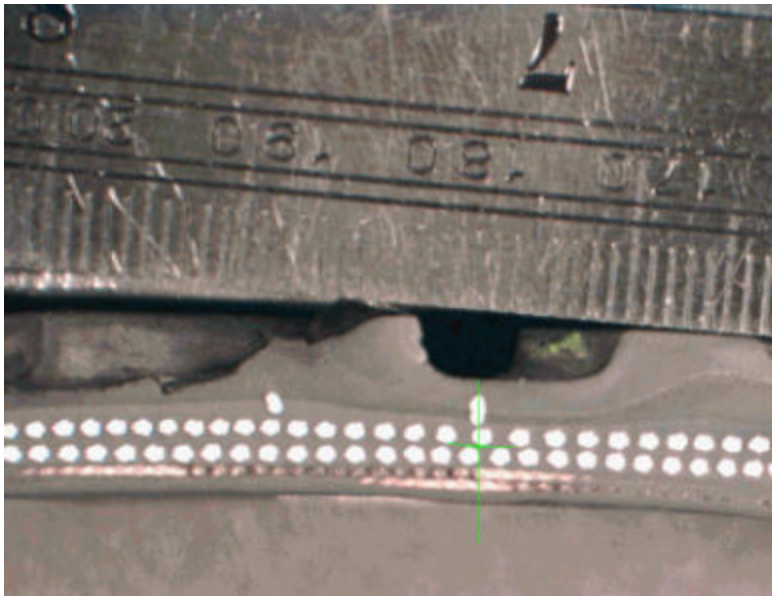


**Figure 28 – Pinched inter-belt gauge under tread groove,
Wilson P235/75R15 Wilderness AT tire,
manufactured in Nov 97 (W2 467).**

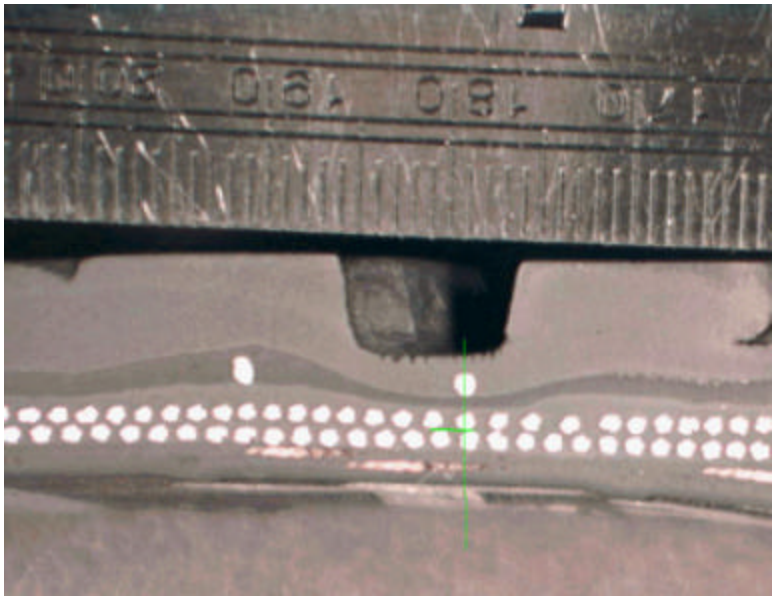


**Figure 29 – Pinched inter-belt gauge under tread groove,
Joliette P235/75R15 Wilderness AT tire,
manufactured in Nov 97 (VN 457).**

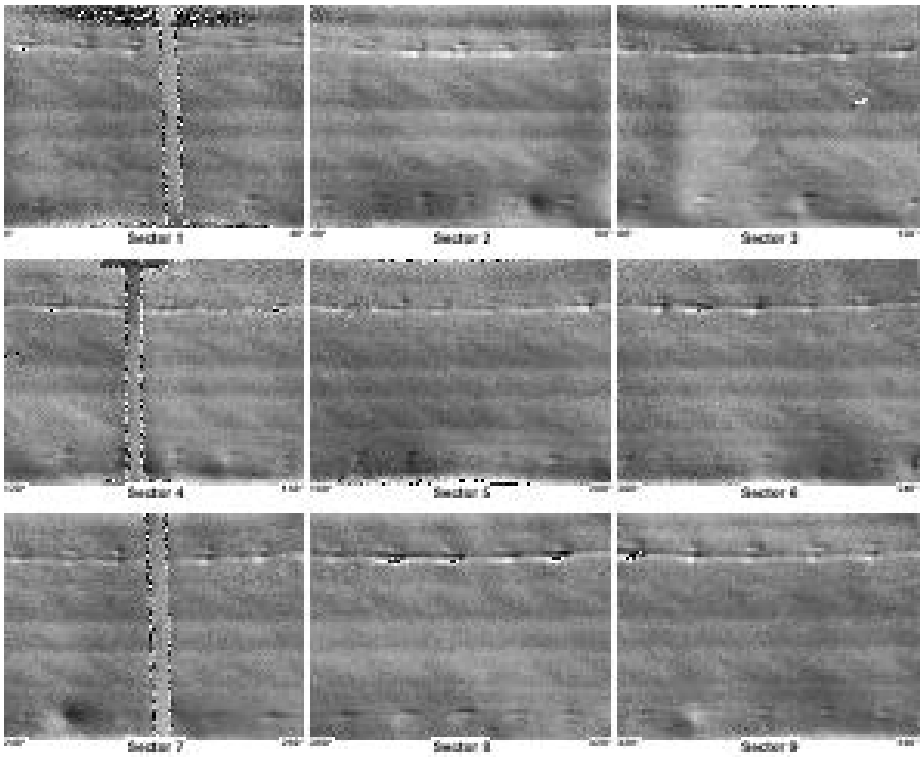


Figure 30 – Shearography showing localized incipient separations, Wilson P235/75R15 Wilderness AT tire, manufactured in Oct 97(W2 427).

Figure 31 – Localized separation pattern on tread pull of the same tire; "P" = pocket area, "L" = lug area.

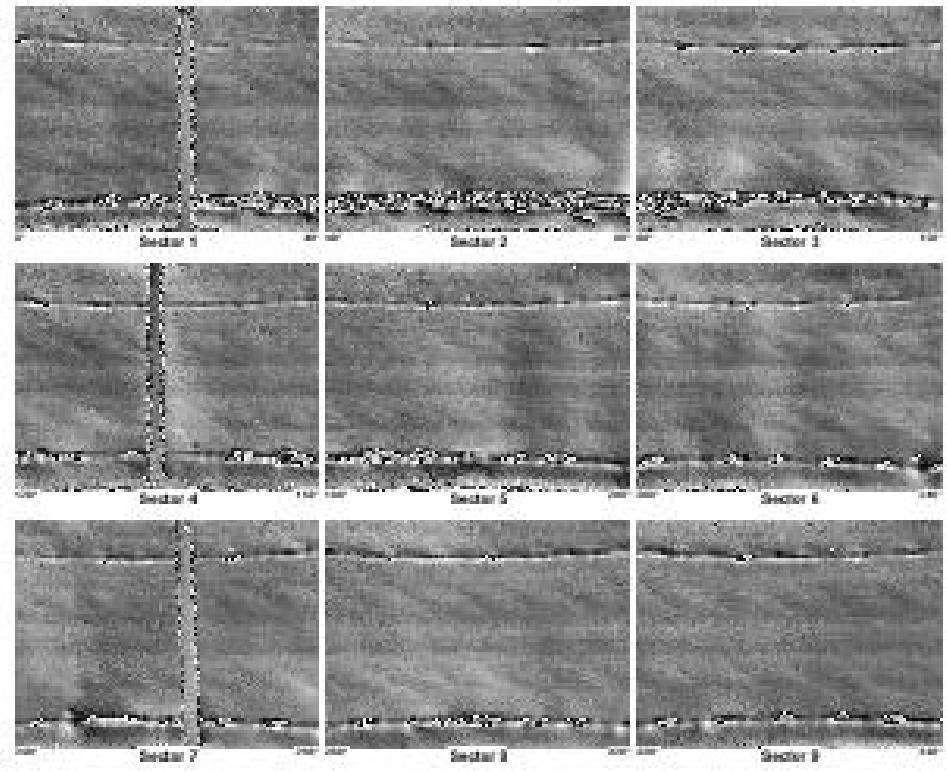


Figure 32 – Shearography showing more advanced belt-edge separations, Wilson P255/70R16 Wilderness AT tire, manufactured in Apr 98 (W2 148).

Figure 33 – Belt-edge separation pattern showing growth in pocket areas of the same tire; “P” = pocket area, “L” = lug area.

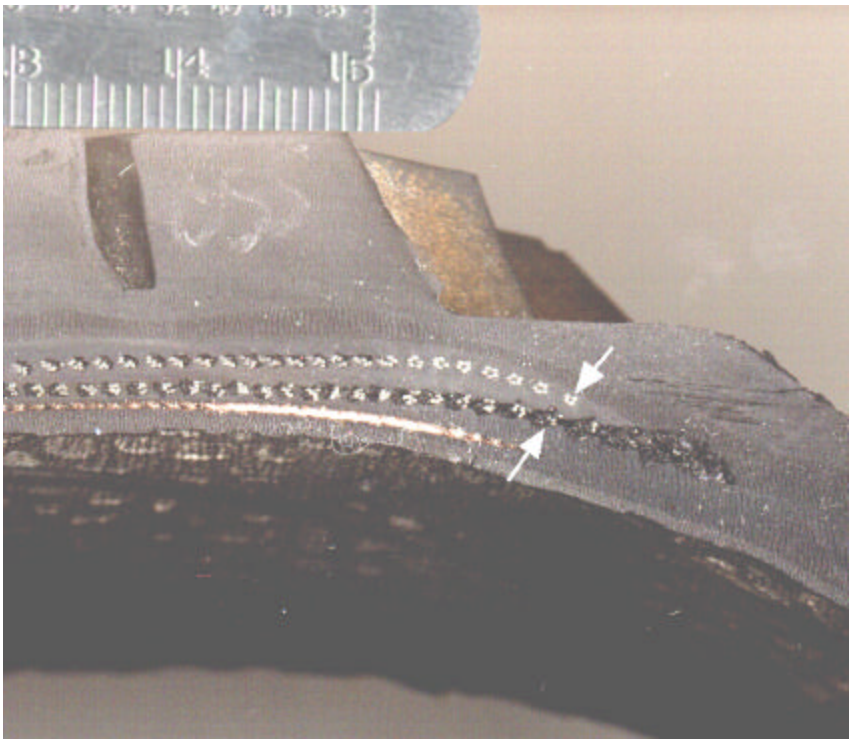


**Figure 34 – Wedge “pinching” under shoulder pocket,
Wilson P255/70R16 Wilderness AT tire,
manufactured in Nov 97 (W2 487).**

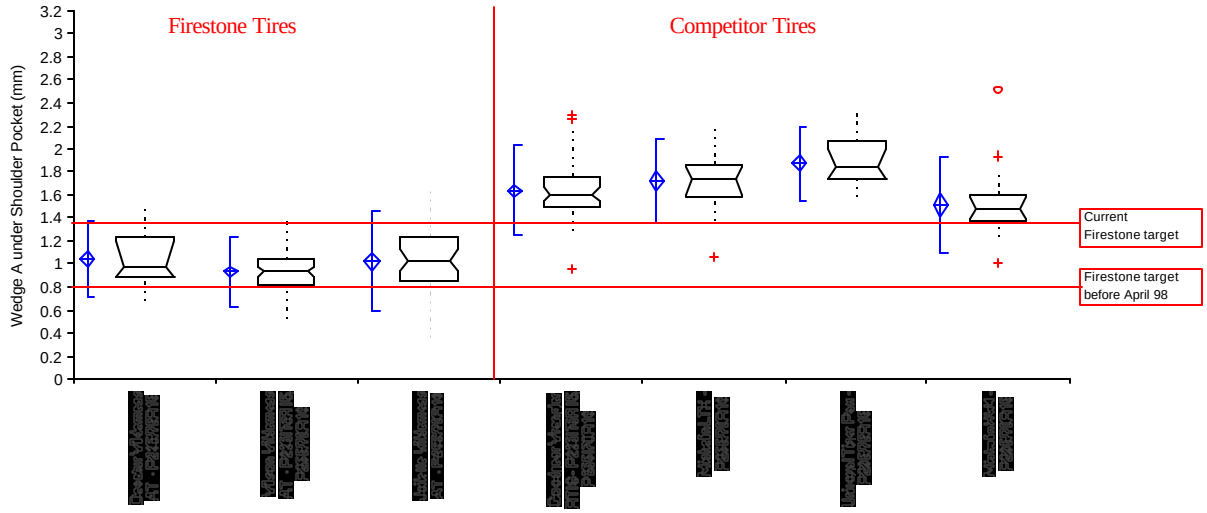


Figure 35 – Wedge gauge under shoulder pocket, Focus tires (prior to 1998 design change) vs peers.

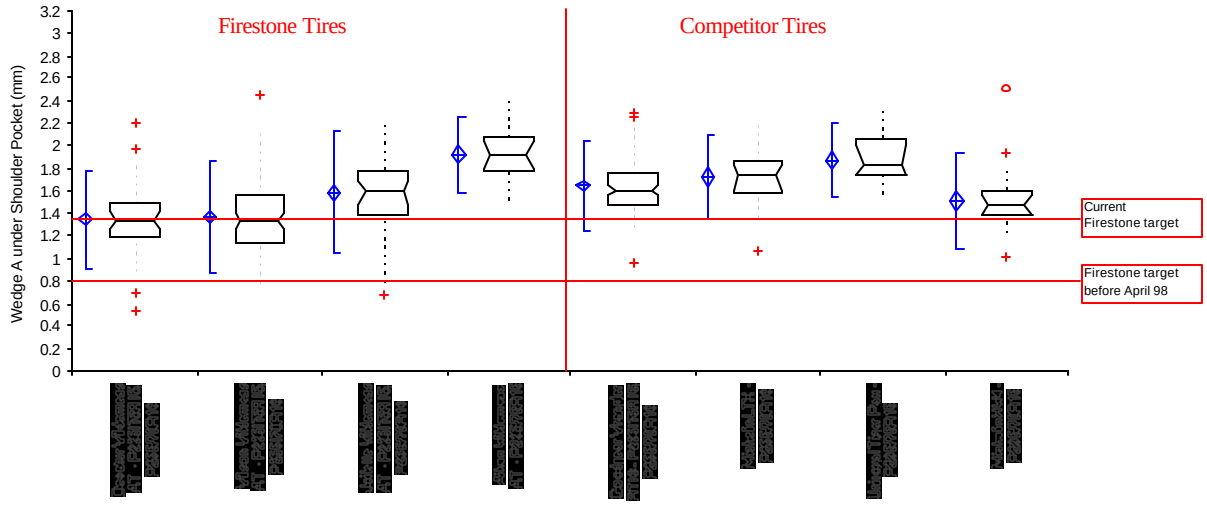


Figure 36 – Wedge gauge under shoulder pocket, Focus tires (after the 1998 design change) vs peers.

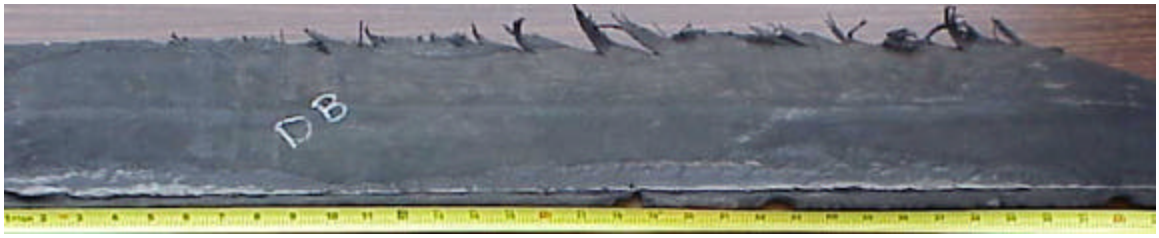


Figure 37 – Separation patterns on failed Wilderness AT tread
Wilson P235/75R15 Wilderness AT tire, manufactured in Sep 96 (W2 396).

Figure 38 – Tread-pull from test program tire with belt edge separation;
Wilson P255/70R16 Wilderness AT tire, manufactured Jun 97.

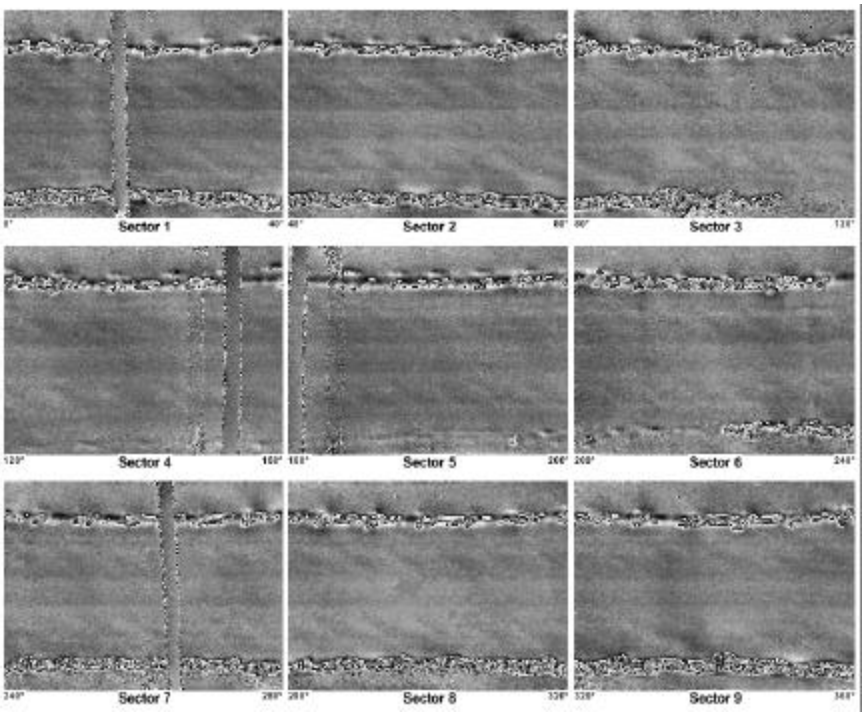


Figure 39 – Shearography of same tire.

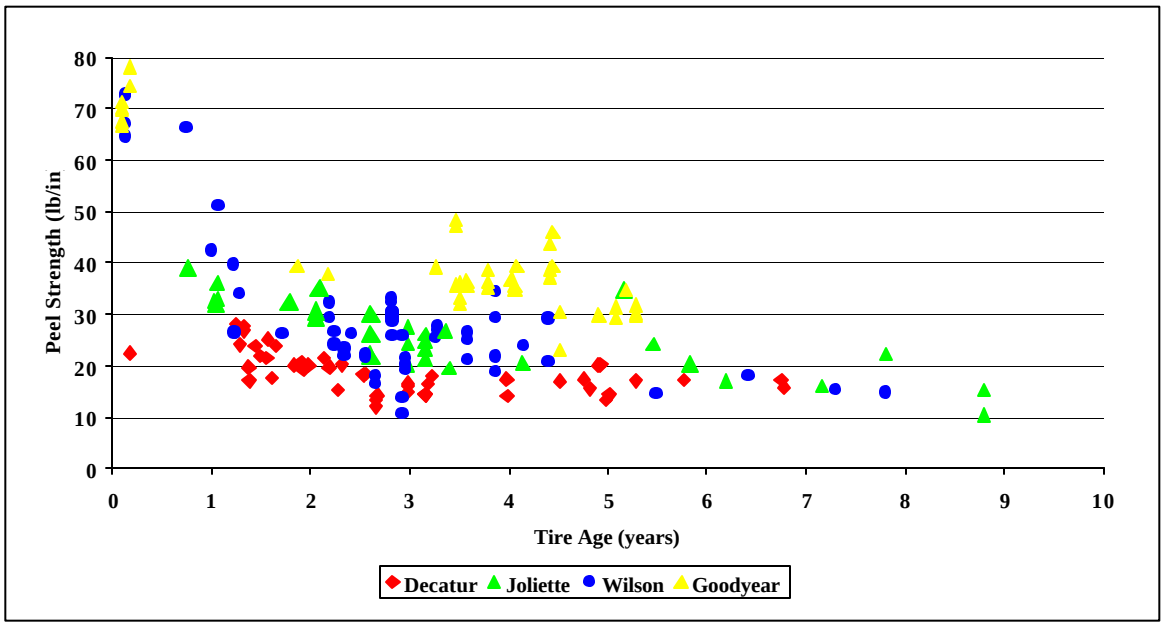


Figure 40 – Hot state peel adhesion vs. age; Firestone tires (recalled and focus tires, ATX and Wilderness AT by plant) and Goodyear Wrangler RT/S.

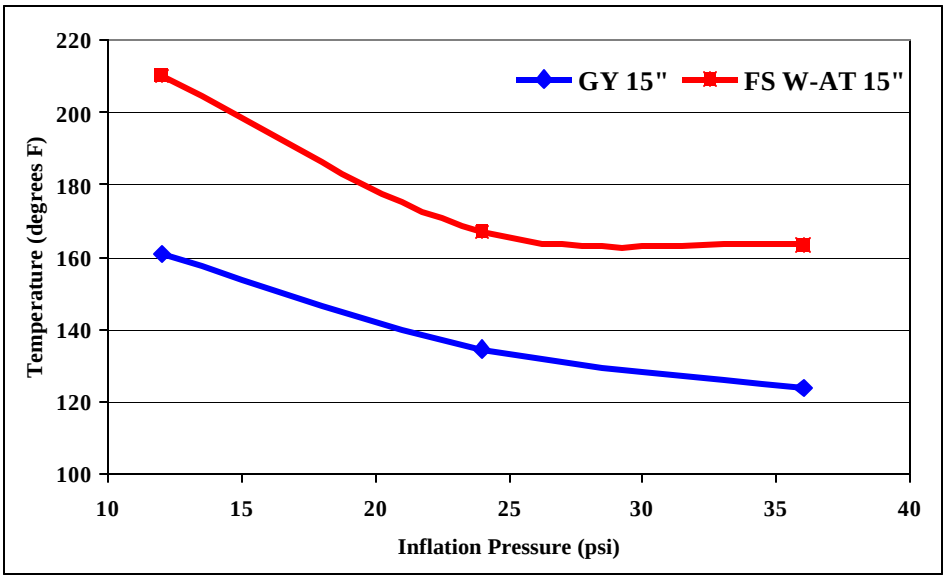


Figure 41 - Tire operating temperature, P235/75R15 tires Firestone Focus vs. Goodyear Wrangler RT/S (Ford probe testing).

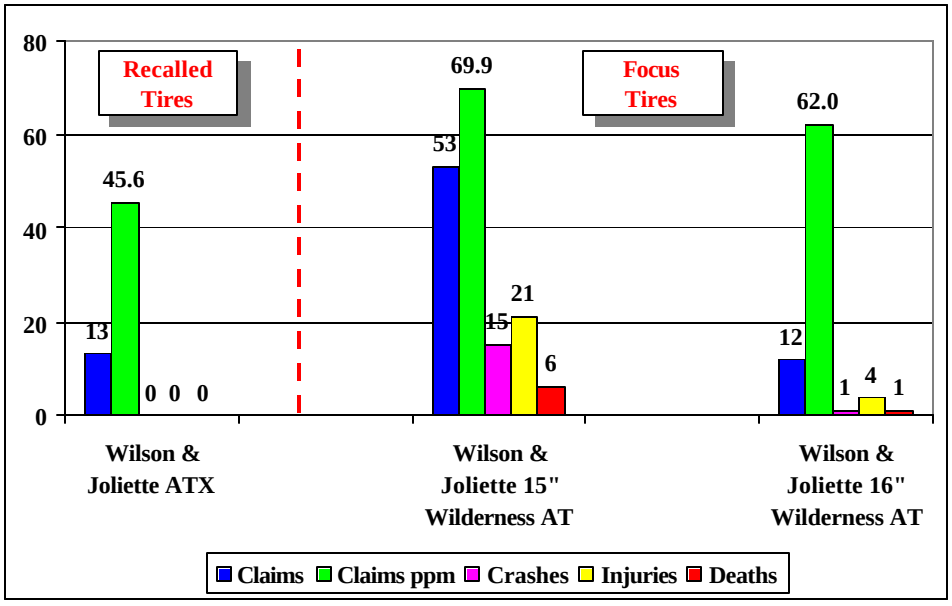
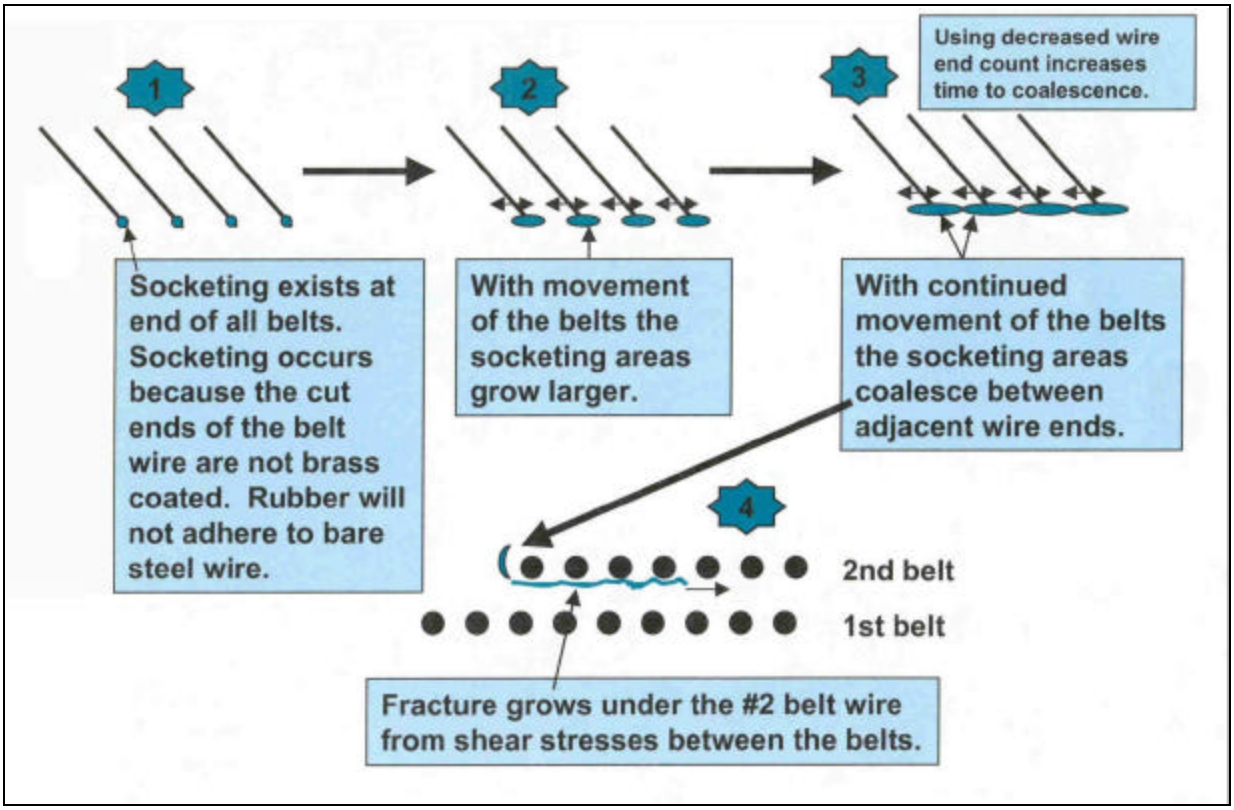


Figure 42 – Failure experience of ATX and Wilderness AT tires Produced in 1996 at the Wilson and Joliette plants.

Firestone claims database as of March 2001

Appendix A: Failure Mode



Failure Mechanism

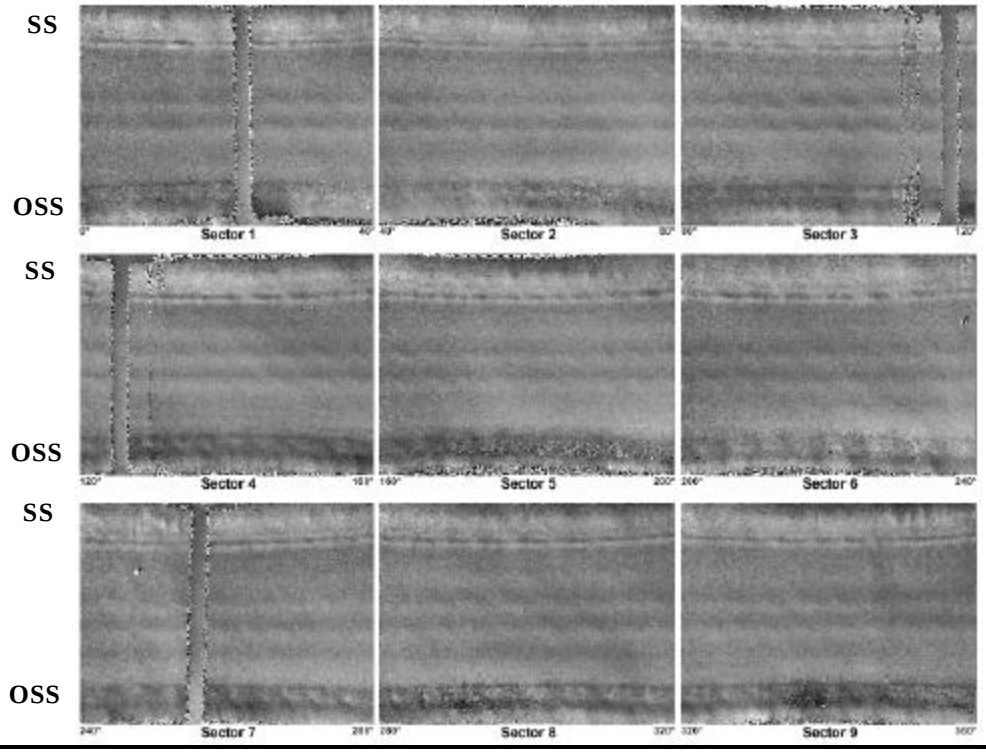
The following pages show representative samples of shearography results corresponding to the separation progression described in the figure above. These patterns were used by ODI in the analyses shown in Figures 21 - 24. It should be noted that there may be some overlap between categories and that some tires exhibit more than one level of separation. Also, the pattern of separation in the focus tires is slightly different from this figure because of the pocket area effect.

Clean – Level 0

Tire	G204
Tire Model	Wrangler RT/S
Tire Size	P235/75R15
Tire DOT	M6 046
Tire Plant	Lawton, OK
Tread Wear (%)	78
State	TX
Shearography Rating	OK
Crack Length (mm)	N/A
Wedge Gauge (mm)	N/A
Avg. Peel Strength (lb/in)	37

Not all radial tires develop belt edge separation during their service life, even when used in the most extreme climates (e.g., Arizona, Texas). Forty-four percent of the peer tires tested by ODI with at least 30 percent tread wear had shearography results similar to the one shown here.

Shearography



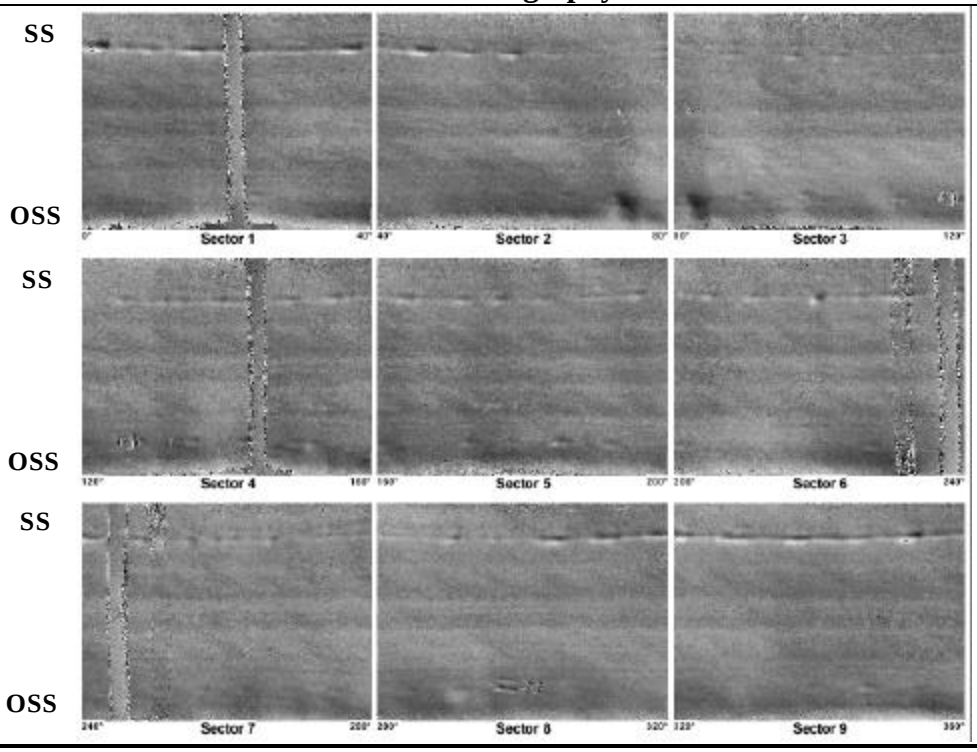
DOT Number is at +20°

Single Cord End – Level 1

Tire	V113
Tire Model	Wilderness AT
Tire Size	P235/75R15
Tire DOT	W2 338
Tire Plant	Wilson, NC
Tread Wear (%)	44
State	AZ
Shearography Rating	NR1
Crack Length (mm)	5.5
Wedge Gauge (mm)	1.36
Avg. Peel Strength (lb/in)	24

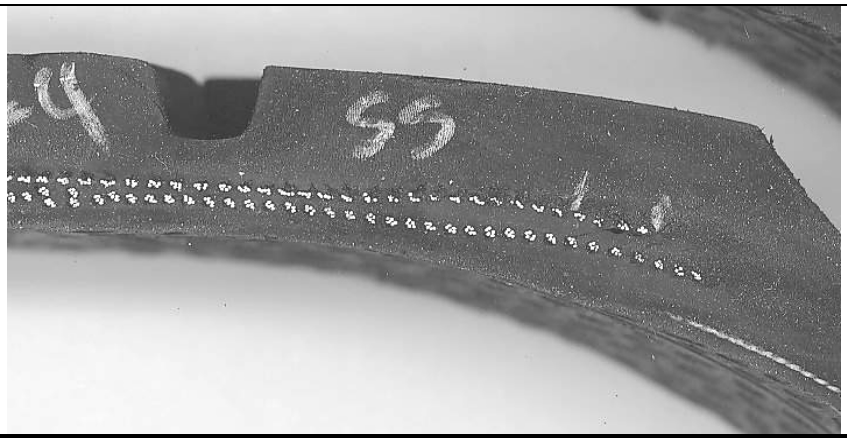
Looseness develops at the ends of cords where steel is exposed to rubber. Focus tires exhibit pattern of preferential initiation in pocket areas.

Shearography



DOT Number is at +20°

Cut Section



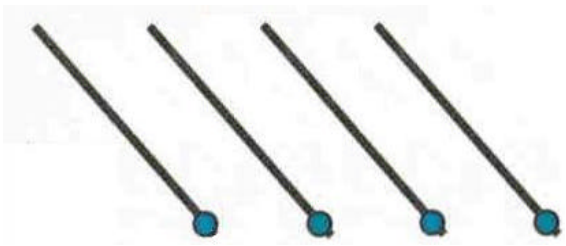
Serial Side

Section at 208°

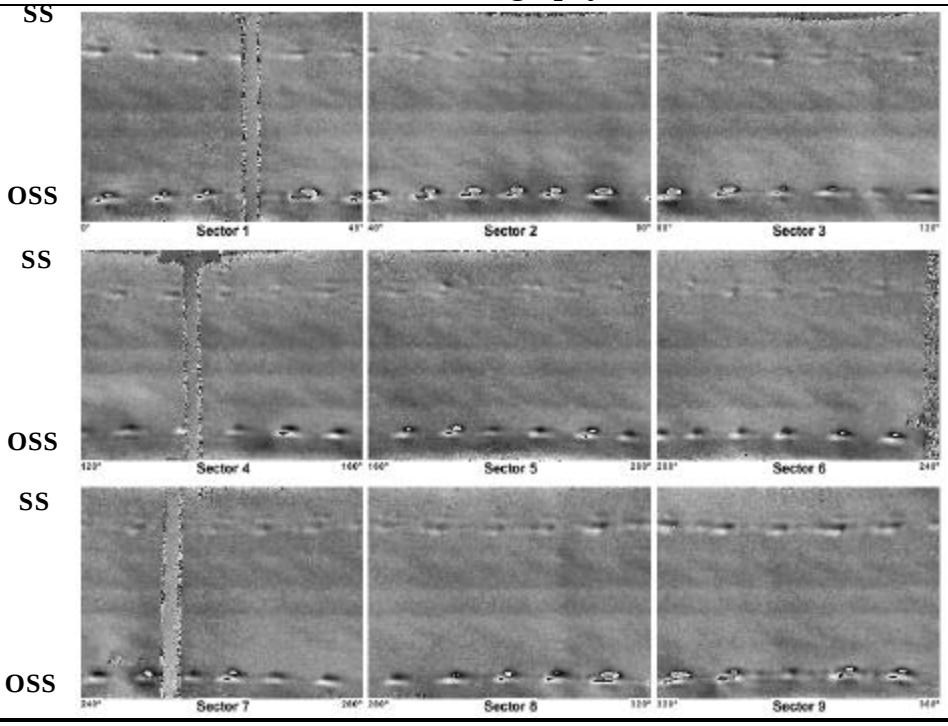
Multiple Cord Ends – Level 2

Tire	V102
Tire Model	Wilderness AT
Tire Size	P235/75R15
Tire DOT	W2 238
Tire Plant	Wilson, NC
Tread Wear (%)	65
State	AZ
Shearography Rating	MR3
Crack Length (mm)	14.2
Wedge Gauge (mm)	1.33
Avg. Peel Strength (lb/in)	22

Separation spreads to adjacent cord ends within pocket areas. Separation spreads along cords (socketing) and as circumferential cracks.

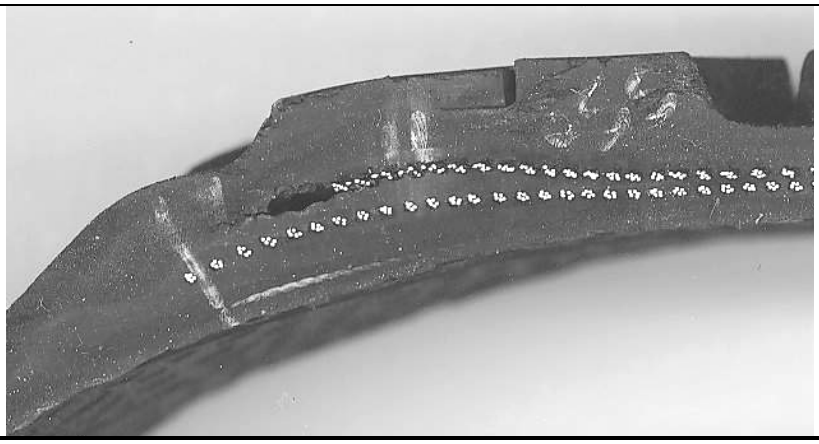


Shearography



DOT Number is at +20°

Cut Section



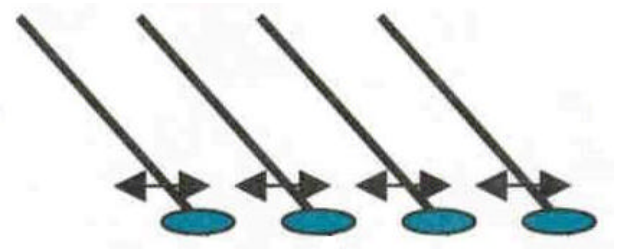
Opposite Serial Side

Section at 90°

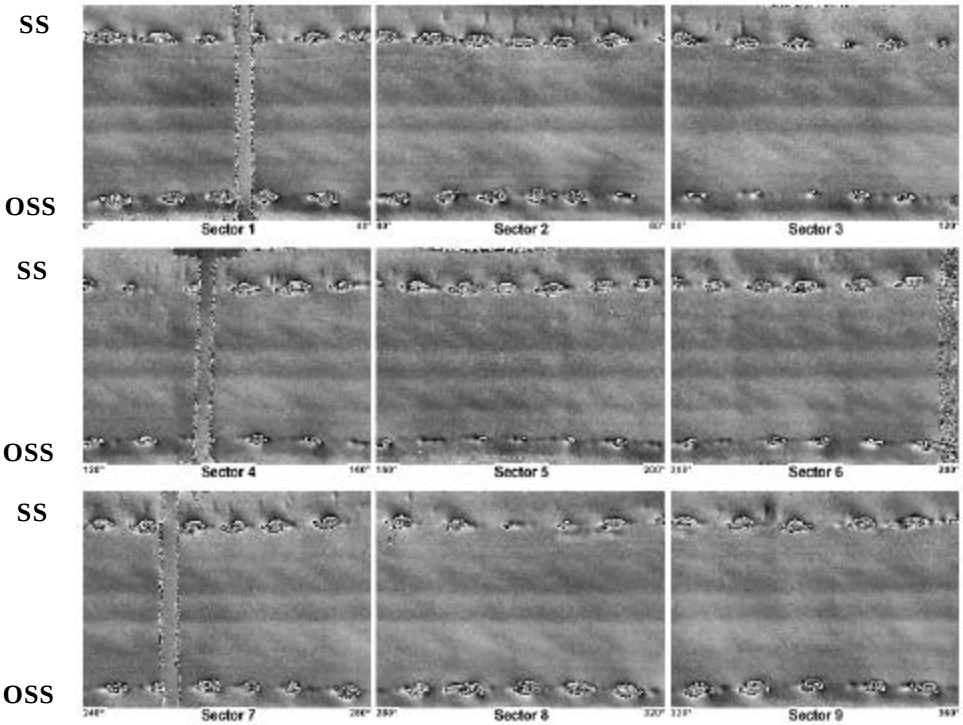
Incipient Separation ("Socketing") – Level 3

Tire	D4131
Tire Model	Wilderness AT
Tire Size	P235/75R15
Tire DOT	W2 417
Tire Plant	Wilson, NC
Tread Wear (%)	56
State	TX
Shearography Rating	160LHMR5
Crack Length (mm)	9.2
Wedge Gauge (mm)	1.14
Avg. Peel Strength (lb/in)	29

Socketing spreads along cords and edge separations continue to grow circumferentially from pockets into neighboring lug areas.

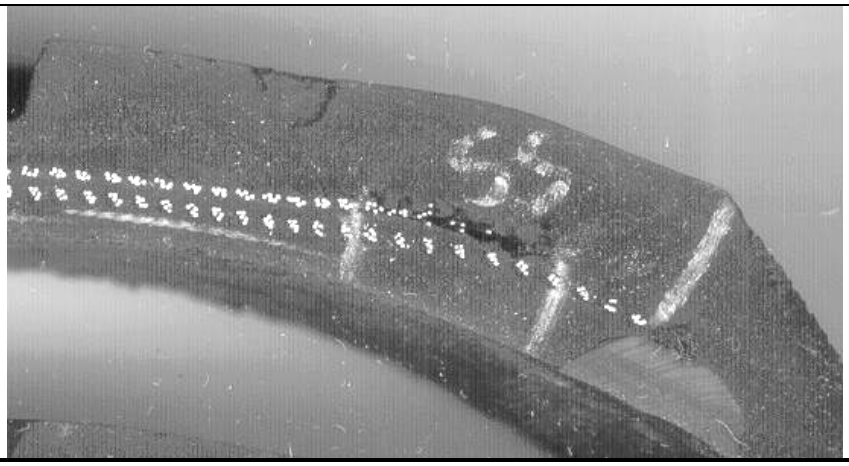


Shearography



DOT Number is at +20°

Cut Section



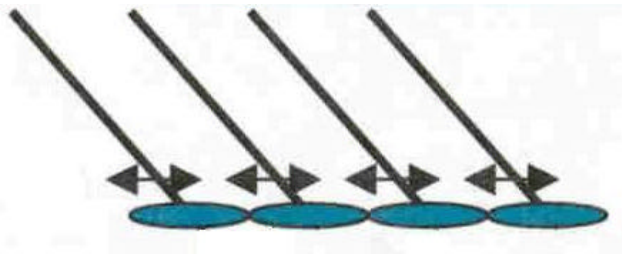
Serial Side

Section at 50°

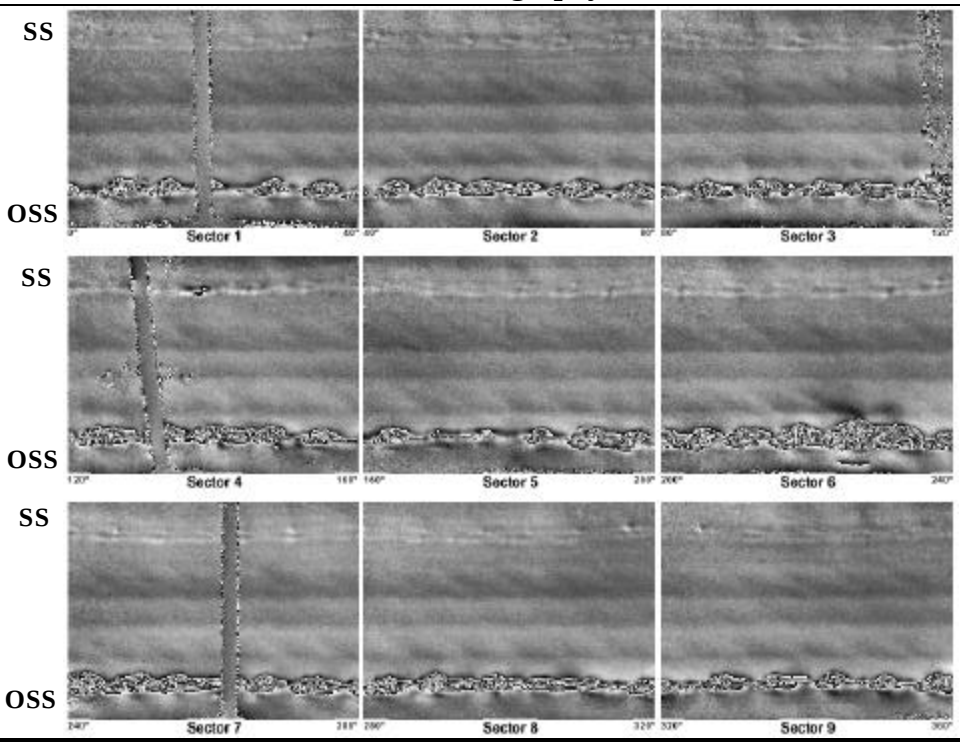
Coalescence – Level 4

Tire	D3684
Tire Model	Wilderness AT
Tire Size	P235/75R15
Tire DOT	W2 127
Tire Plant	Wilson, NC
Tread Wear (%)	47
State	AL
Shearography Rating	70LHMR6
Crack Length (mm)	24.3
Wedge Gauge (mm)	1.48
Avg. Peel Strength (lb/in)	29

Adjacent areas of pocket separation begin to coalesce across lug areas as cord sockets join to form crack growing between belts. Cracks grow faster in areas with greater localized strain.

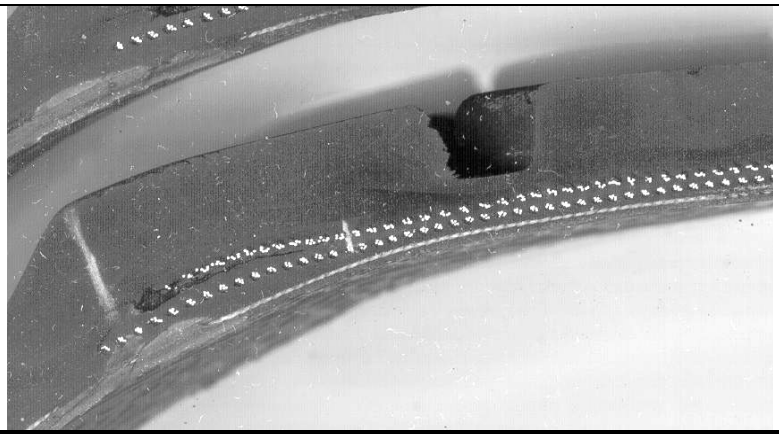


Shearography



DOT Number is at +20°

Cut Section



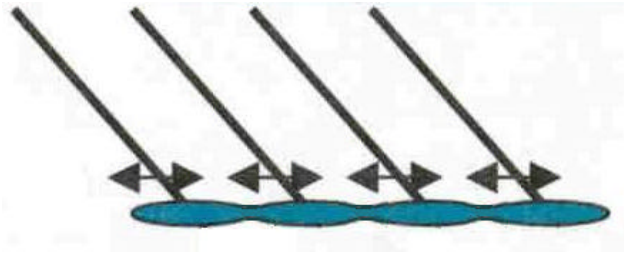
Opposite Serial Side

Section at 230°

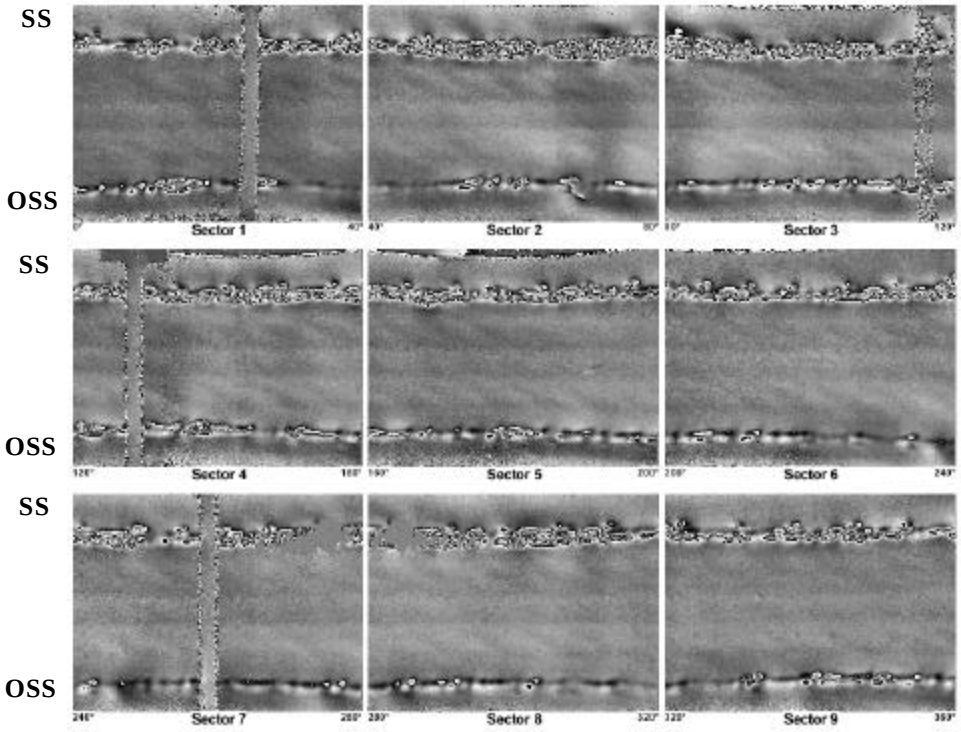
Lateral Crack Growth – Level 5

Tire	D3486
Tire Model	Wilderness AT
Tire Size	P235/75R15
Tire DOT	VN 397
Tire Plant	Joliette, CAN
Tread Wear (%)	74
State	AL
Shearography Rating	160LHMR5
Crack Length (mm)	14.8
Wedge Gauge (mm)	1.16
Avg. Peel Strength (lb/in)	27

Separation has coalesced around circumference of shoulder(s). Crack grows at constant rate per cycle up to about 10-15 mm.

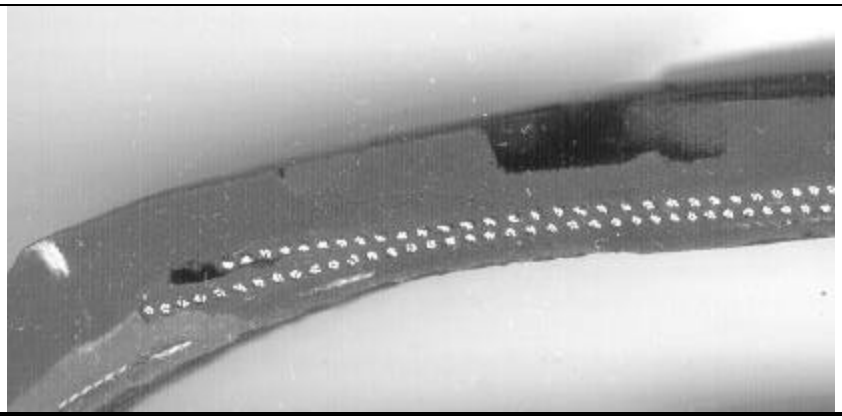


Shearography



DOT Number is at +20°

Cut Section



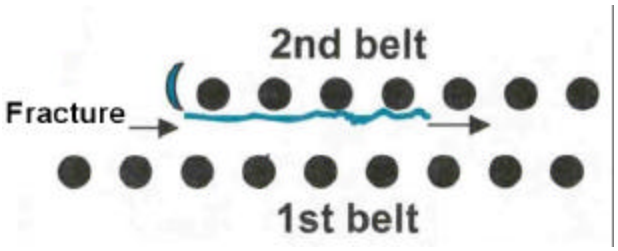
Serial Side

Section at 60°

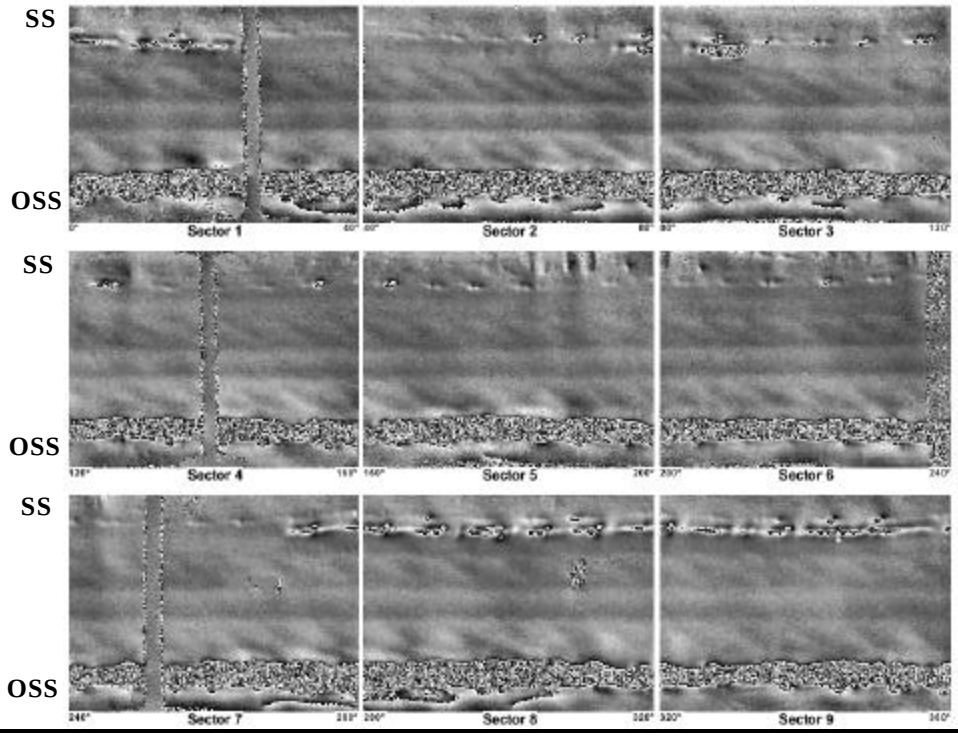
Progressive Lateral Crack Growth – Level 6

Tire	V138
Tire Model	Wilderness AT
Tire Size	P235/75R15
Tire DOT	W2 117
Tire Plant	Wilson, NC
Tread Wear (%)	75
State	TX
Shearography Rating	100LHMR8
Crack Length (mm)	19.5
Wedge Gauge (mm)	0.86
Avg. Peel Strength (lb/in)	21

Lateral crack growth between the belts reaches sizes where strain energy release rates will begin to increase with crack size.

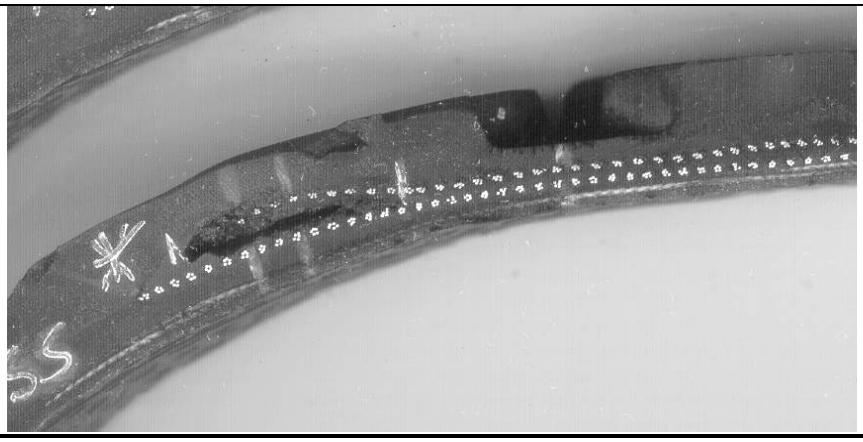


Shearography



DOT Number is at +20°

Cut Section



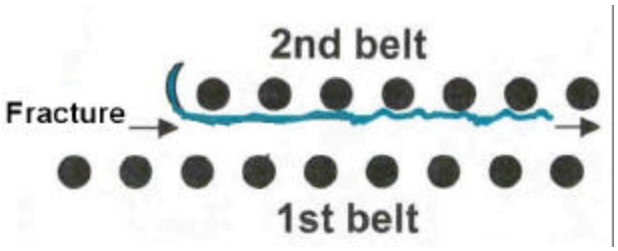
Serial Side

Section at 300°

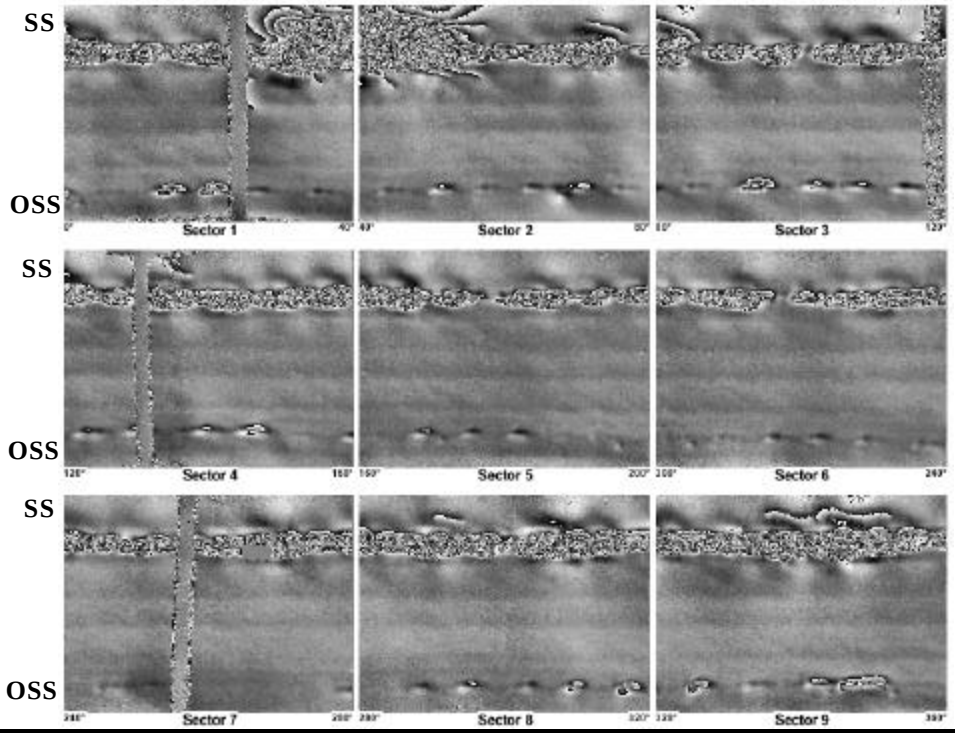
Accelerated Crack Growth ("Pockets") – Level 7

Tire	D3464
Tire Model	Wilderness AT
Tire Size	P235/75R15
Tire DOT	VN 196
Tire Plant	Joliette, CAN
Tread Wear (%)	44
State	TX
Shearography Rating	90LHR8+8LHR**10**
Crack Length (mm)	26.3
Wedge Gauge (mm)	1.49
Avg. Peel Strength (lb/in)	20

Local pockets of accelerated crack growth begin to develop. Pockets grow more rapidly as crack size increases. Largest pocket tends to be precipitator of tread detachment.

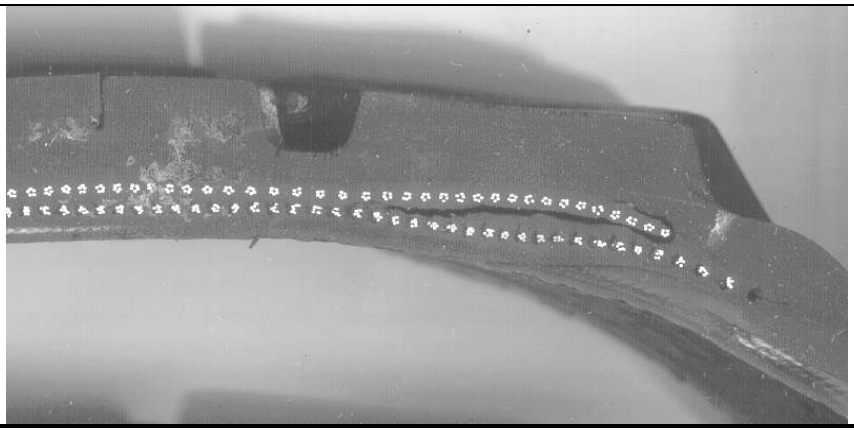


Shearography



DOT Number is at +20°

Cut Section



Serial Side

Section at 40°

Appendix B: Shoulder Pocket Designs

Figure 1 - Ford-Spec P235/75R15 ATX

Figure 2 - Ford-Spec P235/75R15 Wilderness AT

Figure 3 - Toyota-spec P225/75R15 Wilderness AT II

Figure 5 - Toyota-spec P265/75R15 Wilderness ATIII

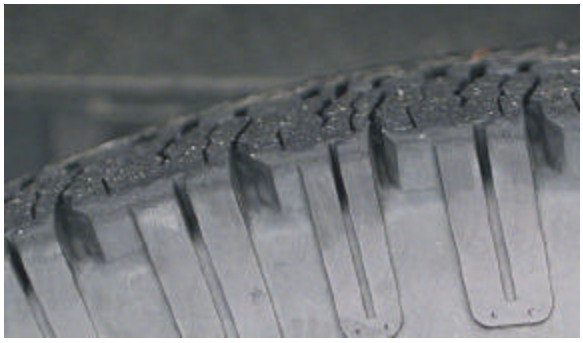


Figure 6 - GM-spec P265/75R16 Wilderness AT

Figure 1 - Ford-Spec P235/75R15 ATX

Figure 2 - Ford-Spec P235/75R15 Wilderness AT

Figure 7 - P225/75R15 Goodyear Wrangler RT/S

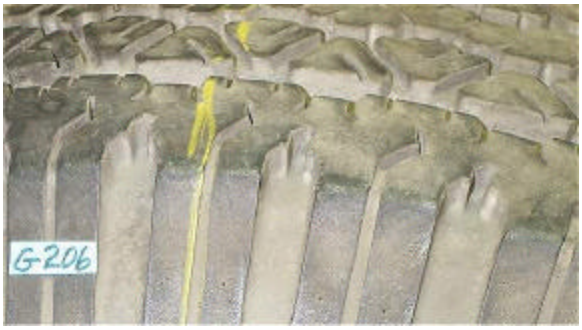


Figure 8 - P235/75R15 Goodyear Wrangler RT/S

Figure 9 - P235/70R15 Michelin XW4

Figure 10 - P235/70R15 Uniroyal Laredo

Figure 11 – P235/70R15 Uniroyal Tiger Paw

Figure 12 - Goodyear Wrangler GS-A P235/75R15

Figure 13 - General Grabber AP P235/75R15

Figure 14 - General Grabber AW P255/70R16

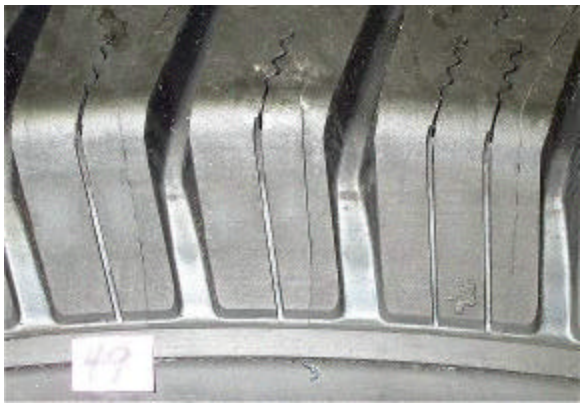


Figure 15 - Michelin LTX P255/70R16

Figure 16 - Goodyear Wrangler AP P255/70R16

Appendix C: A Tire's Tread Life Should Exceed Its Fatigue Life

The fundamental principle underlying NHTSA defect finding is that the fatigue life of the tire should exceed the tread life, by some design/safety margin, for all reasonably foreseeable service conditions where the tire is intended to be sold and used. This is the basic message from a paper by a Pirelli scientist, published by the Society of Automotive Engineers in 1989[3], which stresses the fundamental connection between tire fatigue life and vehicle safety:

> "In view of the importance of the tyre to vehicle safety, it is specifically designed so that it comes to the end of its life-cycle because of tread wear and not because one of its parts fails. In other words, the tyre is not a product which breaks and is thrown away, but rather one which is thrown away because it wears out; for this reason it must be highly durable in terms of its structural integrity.

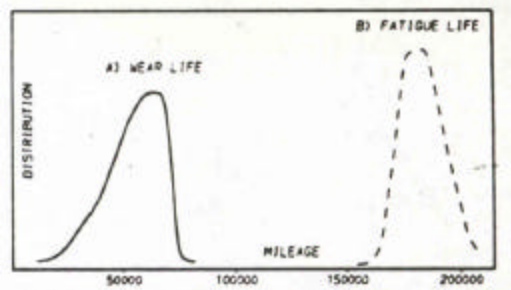


FIG.6 Comparison between a typical frequency distribution for tyres wear-life and that one for mechanical failure occuring in the hypotetical case where there is no tread wear.

> "Curve A represents the frequency distribution for the tyre's wear life in its various uses. Curve B represents product life distribution for mechanical failure occurring in the hypothetical case where there is no tread wear.
>
> "Tyre resistance to fatigue depends more on the selection of compounds and of reinforcing materials and their geometric distribution in such a way as to avoid stress concentration, than on mould geometry.
>
> "The development of a new tyre always involves rigorous testing of the mechanical reliability of its components to achieve higher performance with respect to existing products on the market.
>
> "This is also a two-level process:
>
> 1. Forecasting which involves calculating the distribution of stress and strains interpreted in the light of suitable resistance criteria to select the most critical tyre areas. Such techniques have recently reached a high development level, particularly using finite element methods.
> 2. Laboratory testing for mechanical fatigue of tyres on an indoor rig. By modifying the load, pressure and speed conditions as required, ad hoc tests can be created causing premature failure in the relevant tyre areas (belt, sidewalls, beads …) and therefore providing insight into how design intervention, carried out on structure and materials, can give the tyre higher fatigue margins."

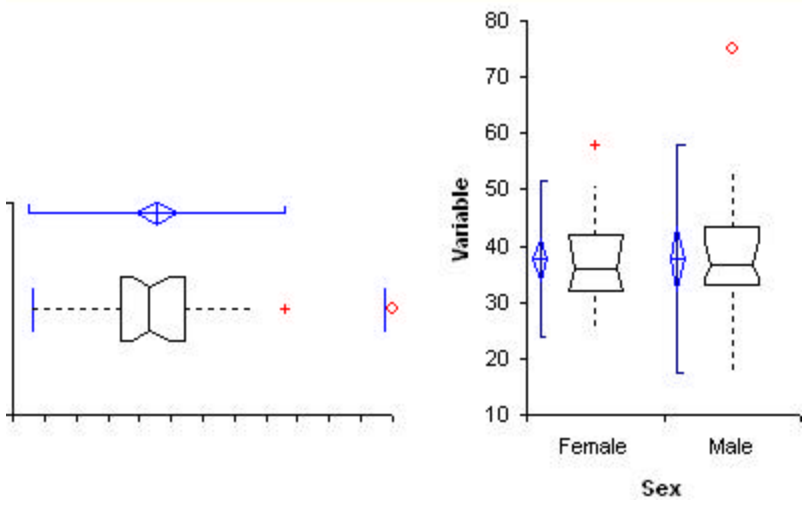
---

[3] G. Rimondi, Pirelli, "Basic Car Tyre Development Principles," Society of Automotive Engineers, Paper 890103, 1989.

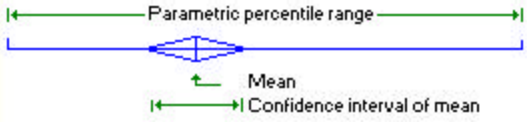
Appendix D: Box-Whisker Plot Explanation

BOX-WHISKER PLOTS

Box-plots graphically show the central location and scatter/dispersion of the observations of a sample(s). Single continuous descriptives shows a single horizontal box-plot for the sample. Comparative descriptives shows vertical box-plots for each sample, side-by-side for comparison.

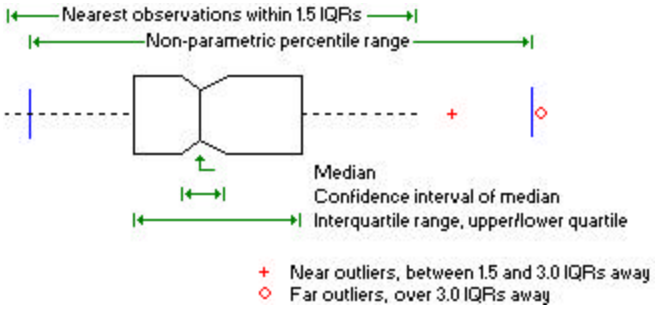


The blue line series shows **parametric statistics**:



- the blue diamond shows the mean and the requested confidence interval around the mean.
- the blue notched lines show the requested parametric percentile range.

The notched box and whiskers show **non-parametric statistics**:



- the notched box shows the median, lower and upper quartiles, and confidence interval around the median.
- the dotted-line connects the nearest observations within 1.5 IQRs (inter-quartile ranges) of the lower and upper quartiles.
- red crosses (+) and circles (o) indicate possible outliers - observations more than 1.5 IQRs (near outliers) and 3.0 IQRs (far outliers) from the quartiles.
- the blue vertical lines show the requested non-parametric percentile range.