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1.0 EXECUTIVE SUMMARY

The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) of 2005 directed the Secretary of Transportation to transmit a report to Congress by August 2007 on research conducted to address tire aging, and a summary of findings and recommendations. The U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) conducted a multi-year research program on the aging of tires used on light vehicles (passenger cars, light trucks, and vans), which evaluated several accelerated tire aging methods to determine their relative effectiveness in replicating the characteristics of tires undergoing aging in the field. This report documents the findings from that research.

Tire Aging refers to the reduction or loss in a tire's material properties, which over time leads to a reduction of its performance capabilities. Heat and oxygen are two environmental conditions that tires are exposed to during their use, which can adversely influence their material properties, and eventually their durability in service.

From 1994 to 2004, NHTSA estimates that about 400 fatalities, annually, may be attributed to tire failures of all types. [1] Tire failures can be caused by a number of factors such as under- or over-inflation of tires, overloading of vehicles, road hazards, improper maintenance, structural defects, and improper installation in addition to tire aging, so it is difficult to estimate, based on crash statistics currently available, how many crashes are caused specifically by tire aging. However, we do know that tire aging is a significant factor in tire related safety.

One commonly held belief is that tire failures are mainly due to poor maintenance. Proper tire maintenance is important for good wear and safety performance of tires. However, aging is a phenomenon that is affected by the heat generated in tires and the degradation that occurs due to the chemical reaction within the rubber components due to oxidation. This is a distinctly different phenomenon from tire inflation and maintenance related issues. Some tire and vehicle manufacturers recommend that consumers replace their tires after a specified number of years, (e.g., 6 years) because aging can affect the safe performance of tires even if they have adequate tread and proper inflation.

NHTSA determined from field reports that in Ford Explorer crashes involving Firestone tires prior to February 2001, about 85 percent of the injuries and about 90 percent of the fatalities occurred in the southern states, with 68 percent of the fatalities occurring in California, Arizona, Texas, and Florida.[2]

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[1] Based on analysis of NASS-CDS data, from 1994 through 2004 NHTSA estimates that tire-related problems may have contributed to about 400 fatalities annually. Crash investigators determined that tire related problems probably had some influence on these crashes. However, data limitations make it difficult to conclude that tire related problems are the *exclusive* cause of these crashes. In addition, an estimate of the number of fatalities directly related to tire aging cannot be determined from these cases.

2 In fact, the Ford Explorer/Firestone tire collisions in 2000-2001 brought considerable public attention to the broad area of tire safety, but, as directed by Congress, this research report focuses on just one aspect, tire aging.

This trend was observed in NHTSA’s analysis of data provided by a large insurance company that shared its insured tire claims reported to its hotline from 2002 through 2006 with NHTSA. It reported that 27 percent of its policy holders are from Texas, California, Louisiana, Florida, and Arizona, but 77 percent of the tire claims came from these states and 84 percent of these were for tires over 6 years old. While tire insurance claims are not necessarily an absolute measure of the failures due to aging, it is reasonable to assume that an inordinate number of insurance claims for tire adjustments in the four states listed combined with NHTSA’s fatality data given above is an indication that a large number of tire failures are likely occurring because of the affect of sustained high temperature on tires.

The trend was also observed again in the Rubber Manufacturers Association (RMA) scrap tire study (Docket No. NHTSA-2005-21276), in which scrap tires in Arizona, California, Florida, Pennsylvania, Massachusetts, Oregon, and Illinois were examined. The study showed that after 4 years, the rate of tire damage was significantly greater in Arizona, and that in every case, tires from those states with higher average ambient temperatures had higher rates than states with lower average ambient temperatures.

Thus, the research findings suggest that tires age faster in regions with higher ambient temperatures, and that low tire pressure was not the only failure mechanism at work. Since the highest failure rates were in the State of Arizona, and Phoenix has the highest maximum daily temperature of any large city in the continental U.S., NHTSA performed a field study there. The agency gathered used tires from light vehicles, which included vehicles under 10,000 pounds gross vehicle weight rating (GVWR), and compared the test results to those of the new tires. Later studies showed this aging phenomenon to be a thermo-oxidative degradation process (i.e., degradation due to their heat and oxygen exposure over time). The agency determined that this thermo-oxidative degradation is accelerated with higher temperatures and is a contributing factor for tire failures, such as tread separations.

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During its field study, NHTSA collected a total of 493 tires from tire dealerships. The tires were from privately-owned vehicles in normal service in the Phoenix, Arizona, metropolitan area. The tires selected were representative of the commonly used tire brands and sizes found in the U.S. fleet, and the selection was based on the 2001 market share of the major U.S. tire manufacturers.

Within the sample obtained, 181 tires were compared to 222 new tires of identical make and model to evaluate the rate of change in the tires’ material properties and roadwheel performance. Then 316 new tires of identical makes and models were artificially aged and compared to the results from Phoenix used tires. The goal of this work was to develop an accelerated tire aging test protocol that would simulate several years of service in regions of the U.S. with high average ambient temperatures, thus providing a test that could predict how a new tire will perform after several years in service. Two of the accelerated tire aging methods subjected new tires to an indoor roadwheel for long durations to accelerate the tire aging process, structurally degrade the tires, and evaluate the tires' performance. The third tire aging method was the Oven Aging Method, which subjected new tires, inflated with an oxygen-enriched gas, to elevated temperatures in an oven for an extended period. The oven-aged tires were then subjected to one of the available roadwheel tests. Technical reports on tire aging research and test procedures development are expected to be published beginning in December 2007.

In a much larger tire aging field study, the Ford Motor Company collected 18 different tire models from six geographic locales in the U.S. (including Phoenix) and observed identical trends in tire material property degradation.

Of the three aging methods studied, oven aging was the only method that successfully duplicated the change in material properties of 4- to 6-year-old Phoenix tires. Oven aging produced consistent results; however, different classes of tires may have to have different test parameters in order to match the desired aging targets. Research to refine the oven aging method included using roadwheel tests to evaluate the tire's ability to retain durability after the accelerated aging process in the oven was completed. The research findings for the tire models studied indicate that following oven aging, passenger car tires maintained their material properties and roadwheel performance better than light truck tires. In addition, based on the limited sample that NHTSA has tested to date, original equipment tires maintained their material properties and roadwheel performance better than replacement tires.

NHTSA's research has found that artificially aging a tire in a laboratory oven is a scientifically valid method to accelerate the tire aging process and to simulate a naturally aged tire in service on a vehicle. Enhancements to the test, such as a pre-oven roadwheel break-in and regular replenishment of the oxygen-rich inflation gas during oven aging, can reduce the time of the test and possibly increase its fidelity. Further, research has shown that testing an artificially aged tire on a roadwheel at specified laboratory conditions of speed, load, inflation pressure, and duration, may be a valid method to predict a tire's performance in the field. NHTSA has completed validation testing of the oven aging test procedure using a wide variety of light vehicle tires that are representative of the current market distribution of tire brands, sizes, and market segments.

> ***NHTSA's research has found that artificially aging a tire in a laboratory oven is a scientifically valid method to accelerate the tire aging process and to simulate a naturally aged tire in service on a vehicle.***

> ***The agency is currently investigating the feasibility of a potential regulation related to tire aging by analyzing the safety problem, tire aging as a causal factor in crashes, and potential benefits and costs of a requirement for minimum performance based on an aging method.***

The agency is currently investigating the feasibility of a regulation related to tire aging by analyzing the safety problem, tire aging as a casual factor in crashes, and potential benefits and costs of a requirement for minimum performance based on an aging method. NHTSA has initiated the following steps to estimate the effectiveness of a potential tire aging requirement. First, the data from the validation testing are currently being analyzed to determine the test parameters that would be most appropriate for an oven-aging test protocol. Second, a cost study has been initiated to determine the estimated cost of upgrading light vehicle tires to comply with a potential accelerated aging performance requirement. Third, a benefits study has been initiated to estimate the potential safety benefits that could be derived if all light vehicle tires are required to meet a specified minimum performance requirement for tire aging. NHTSA believes this work is needed in order to decide what further steps, if any, should be taken to address safety issues related to tire aging.

2.0 INTRODUCTION

2.1. PURPOSE

The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) of 2005 (Sec. 10303, Pub. L. No. 109-59) directed the Secretary of Transportation to transmit a report to the Senate Committee on Commerce, Science, and Transportation and the House Committee on Energy and Commerce on research conducted to address tire aging. The report was to include any Federal agency findings, activities, conclusions, and recommendations concerning tire aging and recommendations for potential rulemaking regarding tire aging. [1]

2.2. BACKGROUND

The Transportation Recall, Enhancement, Accountability, and Documentation (TREAD) Act (Pub. L. No. 106-414) was enacted on November 1, 2000, and included a mandate to update the passenger car and light truck tire safety standards. Members of Congress suggested that the agency consider the feasibility of including an aging test that could evaluate the risk of tire failure at a period later in the life of a tire than the current regulation, which only evaluates new tires. [2]

In response to the TREAD Act, NHTSA conducted tire safety research as part of the development of a new light vehicle tire standard, Federal Motor Vehicle Safety Standard (FMVSS) 139, *New Pneumatic Radial Tires for Light Vehicles*. [3] During this time, the agency conducted a comprehensive literature review and had numerous consultations with industry regarding the impact of tire aging on tire durability. Although a single industry-wide method for the accelerated aging of tires did not exist at the time, there were some methods that warranted further consideration. The agency conducted a preliminary evaluation of the effects of multiple accelerated "tire aging" methods on tire durability. [4] In the March 5, 2002 Notice of Proposed Rulemaking (NPRM) section related to tire aging for FMVSS 139 (67 FR 10050), [5] the agency proposed three alternative tests to evaluate a tire's long-term durability. These alternatives included a peel strength test, an extended duration roadwheel endurance test, and an oven-aging test followed by a roadwheel endurance test.

However, based on the results of this initial evaluation, as well as comments and data from industry, which did not have a uniform approach for tire aging, the agency decided to defer action on the proposal to add an aging test to the new FMVSS 139 (June 26, 2003; 68 FR 38116) until further research was conducted. The stated goal of this new research effort was to find an accelerated, laboratory-based tire-aging test that simulates real-world tire aging, and then develop the test with appropriate criteria to make it suitable for regulatory purposes. Subsequently, in the 2005 SAFETEA-LU legislation, Congress required submission of this report to address that research.

The goal of the research was to find a laboratory-based tire-aging test that simulates real-world tire aging, and then develop the test with appropriate criteria to make it suitable for regulatory purposes.

2.3. LONG TERM DURABILITY TRENDS

In 1973, the average tread life of a passenger car tire was approximately 24,000 miles, which increased to approximately 44,700 miles in 2004 [6]. The average passenger car traveled 9,992 miles in 1973 [7] and 12,497 miles in 2004 [8]. Thus, the average tire service life for a vehicle operated in 1973 was 2.4 years as compared with 3.6 years for 2004, a 49-percent increase. Tread life has increased such that some tires are currently being offered with limited warranties of up to 100,000 miles. [9] As average tread life increased, so has the concern about age-related degradation of tire materials and resulting effects on tire durability. The Federal motor vehicle safety standard for light vehicle radial tires established acceptable minimum performance requirements for new tires but provided no means by which to evaluate a tire's performance throughout its service life. However, the agency noticed in the data from the Firestone tire defect investigation, as well as other investigations, that tire designs that eventually proved defective generally performed well in the first couple of years of service and only began to degrade in performance after that time. [10]

The agency noticed in the data from the Firestone tire investigation, and from many similar cases, that tire designs that eventually proved defective generally performed well in the first couple of years of service and only began to degrade in performance after that time.

Tires differ in both new tire performance characteristics and their degradation rates of these performance characteristics during service, making it difficult to predict long-term durability based on testing of a new tire. Also, one challenge associated with assuring long-term durability is in defining the beginning of a tire's service life, which could be defined as either the date of manufacture as shown in the DOT Tire Identification Number (TIN) on the sidewall of the tire or the date it is placed in service, which could range from weeks to years after the tire is manufactured.

Tires differ in both new tire performance characteristics and their retention rates of these performance characteristics during service, making it difficult to predict long-term durability based on testing of a new tire.

Equally challenging is defining the end of a tire's service life. Traditionally, the end of service life is independent of tire age and defined as the point when the tread wears down to the 2/32-inch tread wear indicator bars molded into the tread. [11] However, tires on some vehicles can be in service for many years and yet accumulate very few miles resulting in little or, in the case of full-size spare tires, no treadwear. NHTSA estimates that 50 percent of light trucks will still be in service after 14 years of age, and 25 percent after 20 years of age. [12] This prompts concerns about the use of full-size spare tires in these vehicles as few owners replace their full-size spare when replacing the in-service tires. Currently, some vehicle or tire manufacturers recommend that tires over a certain age be inspected by a qualified technician or replaced. Appendix A shows the tire inspection and maximum service recommendations given by various entities, and Appendix B provides examples of tire service life recommendations for vehicle and tire manufacturers.

2.4. TIRE AGING SAFETY PROBLEM

From 1994 to 2004, NHTSA estimates that about 400 fatalities, annually, may be attributed to tire failures of all types. [13] The estimate is based on an analysis of the NASS-CDS data, where crash investigators determined that a tire problem probably had some influence on the crash. However, since tire failures can be caused by a number of factors such as under- or over-inflation of tires, overloading of vehicles, road hazards, structural defects, and improper installation in addition to tire aging, we are unable to quantify the number of fatalities attributable to tire aging. In general, the effects of service life duration on long-term durability and how it relates to crash causation have not yet been quantified.

Keeping tires properly inflated is perhaps the most significant action a driver can take to prevent tire failure. Driving a vehicle with a significantly under inflated tire can damage the tire's structure. Moreover, any damage to the tire's structure is permanent and often invisible to the naked eye. If a failure occurs, it is most often a blowout or a separation, both of which can be potential safety concerns. The agency studied the problem and found that on average 26 percent of passenger cars and 29 percent of light trucks have at least one tire significantly under inflated by 25 percent or more. [14]

Average ambient air temperature also apparently plays an important role in the likelihood of tire failure. From field reports, the agency determined that in Ford Explorer crashes involving Firestone tires prior to February 6, 2001, about 85 percent of the injuries and about 90 percent of the fatalities occurred in the southern states, with 68 percent of the fatalities occurring in California, Arizona, Texas, and Florida (see Appendix C). During the Ford investigation, a trend was identified in fatality and injury rates. The highest fatality and injury rates in descending order were: light trucks in southern states in summer, light trucks in northern states in summer, and passenger cars in southern states in summer.

This trend was also observed in NHTSA's analysis of data provided by a large insurance company that shared its insured tire-related claims reported to its hotline from 2002 through 2006 with NHTSA. It reported that 27 percent of its United States policy holders were from Texas, California, Louisiana, Florida, and Arizona, but 77 percent of the tire-related claims reported to its hotline came from these states and 84 percent of these were for tires over 6 years old. The trend was observed again in the Rubber Manufacturers Association (RMA) scrap tire study (NHTSA-2005-21276), in which scrap tires in Arizona, California, Florida, Pennsylvania, Massachusetts, Oregon, and Illinois were examined. The study showed that after 4 years, the rate of tire damage was significantly greater in Arizona, and that in every case, tires from those states with higher average ambient temperatures had higher tire damage rates than states with lower average ambient temperatures.

The agency determined that tire properties degrade as tires age and this degradation is a contributing factor for the tire failures, such as tread separations.

These trends suggest that tires age faster in regions with higher ambient temperatures, and that low tire pressure was not the only failure mechanism at work. Since the highest failure rates were in the Phoenix area, the metropolitan area of the U.S. with the highest average ambient temperature, NHTSA performed a field study there, gathering used tires from light vehicles and comparing them to new tires. Later studies showed this aging phenomenon to be a thermo-oxidative degradation process (i.e., degradation due to their heat and oxygen exposure over time). The agency determined that this thermo-oxidative degradation is accelerated with higher temperatures and is a contributing factor for tire failures, such as tread separations.

As a result of the crashes of Ford Explorers equipped with Firestone Wilderness tires, NHTSA instituted a number of major tire related initiatives. The first was a rulemaking requiring the addition of a tire pressure monitoring system (TPMS) to new vehicles to address significant underinflation of tires, which NHTSA estimated would prevent 37 fatalities annually. The second was a rulemaking upgrading the existing tire safety standards, Federal Motor Vehicle Safety Standard No. 139, which NHTSA estimated could reduce fatalities by one to four, annually. These standards are estimated to reduce fatalities attributed to tire failures by about 10 percent. Tire aging may be a factor in a subset of the remaining cases, but NHTSA has been unable to isolate such crashes because tire age is not coded in most crash databases. NHTSA considered various databases that include tire information to learn more about the effect of older tires in crashes, but most of the searched databases did not record the Tire Identification Number (TIN). TIN is a federally mandated tire identification code, a part of which is the manufacturing date code. The databases NHTSA has considered include the National Automotive Sampling System (NASS), the Fatality Analysis Reporting System (FARS), and the National Motor Vehicle Crash Causation Study (NMVCCS). Each database is being reviewed to determine the feasibility of adding TINs in it in the future.

The Early Warning Reporting (EWR) program does require manufacturers to report the TIN, if available; however, manufacturers are only required to report on tires that are less than 5 years old, and thus EWR is of limited use for examining the tire aging issue. Generally, however, EWR data support the conclusion that ambient air temperature plays a significant role in the rate of tire failures. The number of deaths and injuries reported by manufacturers through EWR alleging a tire failure were higher in the hottest states, both in total, and in rate, when adjusted for state populations.

2.5. TIRE AGING RESEARCH AND TESTING OBJECTIVES

After the 2002 NPRM and decision to defer action on incorporating a tire aging test into FMVSS No. 139, NHTSA began intensive research into tire aging. This tire aging research consisted of a field study to retrieve and analyze the properties and performance of light vehicle tires currently in service, a tire aging methods evaluation, and a refinement of the method that most closely replicated the aging characteristics of tires in the field. The objectives of NHTSA's tire aging research were as follows:

The tire aging research consisted of a field study to retrieve and analyze the properties and performance of light vehicle tires currently in service, a tire aging methods evaluation, and a refinement of the method that most closely replicated the aging characteristics of tires in the field.

- Gain a better understanding of the material degradation processes and their effects on tires in service in the United States.
- Evaluate existing tire aging methods to determine their relative effectiveness in replicating the characteristics of tires that age in the field.

- Select or develop an accelerated, laboratory-based tire aging method and test for new tires suitable for regulatory purposes that simulates real world tire aging in states with high average ambient temperatures and evaluate the tire's safety performance (i.e., its critical durability properties).
- Evaluate various regulatory options taking into account minimum performance based on tire age.
- Provide research findings to support future agency activities related to tire aging.

3.0 TIRE AGING FIELD STUDY

3.1. FIELD STUDY OVERVIEW AND METHODOLOGY

In the spring of 2003, NHTSA began its research by conducting a tire aging field study to:

- Gain a better understanding of service-related tire degradation (tire aging).
- Determine if tire aging was quantifiable and if so, which parameters were good indicators of a tire's aged state.
- Establish a "real-world" aged tire profile for use in the development of a laboratory-based accelerated service life test for tires ("tire aging test").
- Determine if there was a correlation between the static rate of loss of inflation pressure of new tires and tire degradation (aging) rates.

During the field study, NHTSA collected tires from privately owned vehicles in the Phoenix, Arizona area. Phoenix was selected as the collection location because it is a high-population metropolitan area and has high average and maximum temperatures, which have previously shown a strong correlation with higher tire failure rates. Further details on the selection of Phoenix as the tire collection site can be found in Appendix E.

With the assistance of tire manufacturers, NHTSA chose 12 tire models that were available for purchase in Arizona that were in production from 1998 to 2003 and had had no 'significant' design changes during that period. In total, 493 in-service tires were collected off of local residents' vehicles from local tire retailers and dealers based on a set of specific selection criteria. Appendix F presents a detailed breakdown of the models and tires collected. The tires collected were inspected and a detailed list of vehicle and tire information, such as tire age, was recorded. In-service tires of up to 7 years old and/or 85,488 kilometers (53,120 miles) and full-size spares of up to 10 years old were collected. To prevent tires that may have been in service in other lower-temperature regions of the country from biasing the field study results, about 10 percent of the tires were eliminated because the vehicle was not registered in Arizona for the entire service life of the tire. Of the 12 tire models collected in Phoenix, only 181 tires from the 6 tire models shown in the table below had an acceptable distribution of age and mileage for field study testing.

Tire Models Selected for Testing

Tire Brand	Tire Model	Tire Size	Load Range	Speed Rating	Original Equipment Fitment
BFGoodrich	Touring T/A SR4	P195/65R15	89	S	Yes
Goodyear	Eagle GA	P205/65R15	92	V	Yes
Michelin	LTX M/S	P235/75R15XL	108	S	Yes
Firestone	Wilderness AT	P265/75R16	114	S	Yes
Pathfinder*	ATR A/S	LT245/75R16	120/116E	Q	No
General	Grabber ST	255/65R16	109	H	Yes

* Manufactured for the Discount Tire Company by the Kelly-Springfield Tire & Rubber Company, a subsidiary of the Goodyear Tire & Rubber Company

Within the set of 6 tire models tested, a total of 172 in-service tires and 9 full-size spare tires of varied ages and mileages were compared to 82 new, unused tires of the same makes and models to determine overall rates of degradation in whole-tire performance and component material properties. Another 140 new tires of the same makes and models were used to study either whole tire static air loss rate, intra-carcass pressure rates, or innerliner permeation rates. Both the new and Phoenix-retrieved (herein referred to as “used”) tires were subjected to one or more tests, which included tests to evaluate the whole-tire performance limits and the material properties of critical components within the tires.

The performance limit tests included stepped-up speed and stepped-up load tests, both of which were performed on a 1.7-m (67-inch) diameter indoor laboratory roadwheel.

- The stepped-up speed test measured the tire’s retention of its maximum speed capability under normal loading conditions. The initial phase followed the parameters of the FMVSS No. 139 High Speed test, and the speed was then increased incrementally until the rated speed of the tire was achieved, at which time the test continued until tire failure. [15]

- The stepped-up load test measured the tire’s retention of its endurance capability under overloaded and/or underinflated conditions. The initial phase followed the parameters of the FMVSS No. 139 Endurance test, and the load was then increased incrementally until the tire failed. The test loads and increments in the test are proportional to the maximum load rating of the tire. [16]

Several other tests were performed to evaluate the material properties critical components within the tires and to measure the degradation of those properties with increased mileage and/or age. Material property tests, such as peel strength and tensile strength, are destructive tests where the tire is cut into sections and multiple samples removed for laboratory testing. Peel strength is a measure of the level of force per inch or millimeter needed to separate the tire between the steel belts and tensile strength is a measure of the amount of force necessary to fail the sample as it is stretched to its ultimate breaking point.

After the tires were tested, the results were correlated with the absolute age and mileage (if original equipment) of the tires. The results of the field study testing were then used to guide test development of a tire aging test for new tires in subsequent phases of the project.

3.2. FIELD STUDY RESULTS SUMMARY

The results from the six tire models tested in the field study are summarized below:

- Of the new and used tires subjected to the stepped-up speed (SUS) roadwheel test:
  - All of the new tires and 95 percent of the used tires exceeded the 2-hour break-in and 90-minute duration of the FMVSS No. 139 High Speed test portion of the SUS test.
  - About half of the six models of used tires exhibited a trend of decreasing time-to-failure in the roadwheel test with increasing service life when compared to new versions of the same tires.
  - The SUS test results indicated a strong correlation with the speed rating of the tire, with higher speed-rated tires losing the least capability with increasing service life.
- Of the new and used tires subjected to the stepped-up load (SUL) roadwheel test:
  - All of the new tires, but only 59 percent of the used tires exceeded the 34-hour duration of the FMVSS No. 139 Endurance test portion of the SUL test.
  - As service life increased, all six models of used tires exhibited a trend of decreasing time-to-failure in the roadwheel test when compared to new versions of the same tires.
  - As was experienced in the SUS test, the SUL test results indicate a strong correlation with the speed rating of the tire, with higher speed rated tires losing the least capability with increasing service life.
- An evaluation of the tire and rubber material properties in different areas of the tires confirmed that the tire rubber compounds and the materials that bond them experienced thermo-oxidative degradation during service due to their heat and oxygen exposure over time as well as from service-related fatigue. The tires experienced a reduction in peel (adhesion) strength between the steel belts, an increase in hardness of most rubber components, a loss of the rubber components' ability to stretch, increased crack growth rates, and a reduction in cycles to failure in fatigue tests.
- The loss of inflation pressure was measured for new tires of all six tire models at both room temperature, 21^{o}C (70^{o}F), and at a temperature of 70^{o}C (158^{o}F) to examine the effects of heat on the relationship between the amount of oxygen permeating through the tire and the rate of thermo-oxidative degradation (tire aging). The results indicate that the rate of loss of inflation for new tires in the oven at 70^{o}C (158^{o}F) increased as much as 20

times more than tires at room temperature; however, the differences in the design of the six tire models prevented a meaningful comparison of air permeation rates to aging rates.

- Of the 453 on-road tires collected from vehicles in Phoenix for which tire pressure was available:
  - Approximately 11 percent of the in-service *passenger car tires* had inflation pressures below 180 kPa (26 psi), which is the minimum pressure recommended by the tire industry.
  - Approximately 14 percent of the in-service *light truck tires* had inflation pressures below 250 kPa (35 psi), which is the minimum pressure recommended by the tire industry.
- For the 29 full-size spare tires collected from the spare tire location, over 30 percent of passenger car and light truck spare tires had inflation pressures below the recommended minimum values. This is a safety concern since the test results suggest that older full-size spare tires, like in-service tires, are likely to have degraded material properties, which could lead to tire failure if the spare tire is placed in service in a severely underinflated condition.

3.3. FIELD STUDY FINDINGS

The objective of the tire tests in the field study was to gain a better understanding of how tires aged while in service on vehicles by testing tires retrieved from the Phoenix, Arizona area. A variety of tire performance and material properties' evaluations were conducted on these tires. It must be noted that the study was not designed to be a definitive study of tire aging in the field (Ford has completed that study), but only a response to a congressional request to report on what the agency had found from its research on tire aging. The goal of the research program was to obtain real world baseline information on an accelerated service life test for tires. While the agency is unable to specify individual tire design and construction features that help long-term tire durability, an effective laboratory aging test was developed that could drive more robust overall tire designs for safety. It is also noted that the tire maintenance issue is totally independent of the oxidative degradation of tire materials. The agency concluded the following from the field study:

The laboratory roadwheel test results for used tires often exhibited a trend of decreasing time-to-failure (i.e. decreasing mileage-to failure/cycles to failure) with increasing mileage and/or age.

- The laboratory roadwheel test results for used tires often exhibited a trend of decreasing time-to-failure (i.e. decreasing mileage-to failure/cycles to failure) with increasing mileage and/or age.
- With increased mileage and/or age, there was a quantifiable degradation in the material properties of critical components and interfaces within the tire.
- The limited amount of field study results on full size spare tires support the position that the material properties and roadwheel performance of full-size spare tires degrade over time while they are in storage in the vehicle and not used on the vehicle.

- The rate of static tire inflation pressure loss increased considerably with increasing temperature.

- At least 11 percent of in-service tires and 30 percent of spare tires retrieved from the field were observed to be significantly underinflated, which may increase the risk of degraded performance capabilities and tire failure if put into service before being reinflated.

4.0 TIRE AGING METHODS EVALUATION

4.1. AGING METHODS EVALUATION OVERVIEW

To evaluate how aging affects tire durability, it is necessary to develop a method to artificially age new tires in a way that is representative of real-world conditions. The field study results provided the agency with a "real-world" aged tire profile. This data could be used to validate test methods for artificially aging tires in the laboratory with real-world results.

With the assistance of tire and vehicle manufacturers, testing laboratories, consultants, and standards organizations, the agency reviewed the various accelerated tire aging methods in use and found that no industry-wide aging standard or practice existed. The agency evaluated the effectiveness of two laboratory road-wheel aging methods provided by the tire industry and an oven aging method provided by an automaker.

4.2. AGING METHODS TESTED

During the evaluation, 316 new tires of the six tire models studied in the field study were subjected to one of following three aging protocols submitted by industry for agency consideration:

- **Long Term Durability Endurance Test**: Michelin offered a 97 km/h (60 mph) Long Term Durability Endurance (LTDE) Test as a combined tire aging and durability test. In this test, the tire is inflated using an oxygen-enriched air mixture and run on an indoor roadwheel for up to 500 hours at elevated loads and pressures to fatigue the tire structure and induce heat, which in conjunction with the oxygen-enriched inflation mixture accelerated the aging process. The oxygen-enriched air mixture consisted of 50 percent oxygen and 50 percent nitrogen, topped-off every 24 hours. Regular compressed air contains only about 21 percent oxygen.

- **Passenger Endurance (P-END) Test**: Continental submitted a version of its Passenger Endurance (P-END) Test under the confidential submission process. As with the LTDE test, the P-END test is a combined aging and durability test in which the tire is inflated and run on an indoor roadwheel for up to 240 hours. Although this test was designed to be used for passenger cars, the tire manufacturer provided special light truck tire conditions under which light truck tires could be tested.

- **Oven-Aging Method**: Ford, in the course of its own tire aging research, had sufficient data to recommend that the agency use a method in which the tire is inflated using the same oxygen-enriched air mixture previously mentioned, and heated in an oven for a period of time to accelerate the aging process by speeding up chemical reactions and material property changes. This oven-aging method was not finalized at the time of

- submission; and, thus, NHTSA (and Ford independently) structured its test development to evaluate a wide variety of oven aging test conditions.

In each case, the companies provided information or data to the agency to support the merits of their accelerated aging test.

4.3. AGING METHODS EVALUATION RESULTS

The results from the roadwheel durability and oven-aging methods are summarized below:

4.3.1. Roadwheel Durability Aging Methods (LTDE and P-END) Results

Although the two roadwheel aging test methods evaluated, LTDE and P-END, were effective in some respects, such as creating certain observed physical properties like internal cracks and separations as observed in on-road tires, neither method could consistently replicate the material properties of used tires. These two aging test methods tended to age the tire non-uniformly, such as "over-aging" (i.e., overly degrading) some parts of the tire, which was not consistent with the Phoenix field study results.

Also, the two roadwheel aging test methods tended to structurally fail a considerable percentage of tires prematurely before reaching the material properties' targets of the used tires. Twenty-seven percent of the tires tested in the LTDE and 45 percent of the P-END tires failed before reaching the end of their test (i.e., before reaching desired material property states). The tires that prematurely failed tended to have removal conditions, such as tread chunking, rather than the targeted partial or full tread separation condition, which consists of the partial or full detachment of the tread and top steel belt from the remainder of the tire. Since tread separation is the relevant failure mode sought in these tests, the roadwheel aging tests turned out not to be well suited for agency purposes. Of the 36 new tires that failed the LTDE roadwheel aging method prematurely, there were no tread separations. Of the 41 new tires that failed prematurely during the P-END test, there were no full tread separations and only two partial tread separations, both of which occurred on light truck tires.

Twenty-seven percent of the tires tested in the LTDE and 45 percent of the P-END tires failed before reaching the end of their test.

4.3.2. Oven Aging Results

The oven aging protocol was the only method successful at replicating the overall material properties of the used tires. Under certain oven-aging conditions, it was also possible to replicate the stepped-up load roadwheel results of the used tires. Oven aging at 70°C (158°F) with an initial capped tire inflation pressure, where the tire inflation gas was set to an initial pressure but the gas was not replaced as the tire lost pressure, sometimes bordered on being too hot as it produced material properties in the tire

The oven aging protocol was the only method successful at replicating the overall material properties of the used tires.

that were not consistent with the used tires. However, oven aging tires at 55^{o} to 65^{o}C (131^{o} to 149^{o}F) for 3 to 12 weeks produced material properties results that were consistent with the used tires. During this testing, the agency also found that different categories of tires aged at different rates.

By using an oxygen-enriched inflation mixture, the tires aged at a faster rate than by using compressed air; however, the results also showed that tires with an initial capped tire inflation pressure showed a significant and continuing depletion of pressure and oxygen throughout the duration of the test. Since oven aging is a thermo-oxidative process, this depletion of pressure and oxygen could diminish the aging rate and slow down the aging process in oven tests of sufficient duration.

A number of roadwheel "break-in" protocols were evaluated in an attempt to induce mechanical softening of the rubber compounds prior to oven aging, relieve residual stresses in new tires, enhance gas circulation within the tire, and to initiate crack sites that could be embrittled during oven aging and propagated during post-oven roadwheel durability testing. While the post-test analysis indicated that none of the short duration (24 hour or less) break-in protocols generated any measurable tire belt-edge cracking or internal separation in new tires (properties seen in used on-road tires), the research suggested benefits to using a short duration, low severity pre-oven aging roadwheel break-in. While the benefits of a break-in remain to be validated in future testing, the rationale for using a break-in is detailed in Appendix J.

4.4. AGING METHODS EVALUATION CONCLUSIONS

During the Aging Methods Evaluation, 316 new tires of the six tire models studied in the field study were subject to one of three aging protocols submitted by industry. After the post-test analysis was completed, the following conclusions were made:

- Tire aging in the field is a thermo-oxidative process, whereby tire material properties degrade over time and the speed of the degradation increases with heat; however, there is a limited range of temperatures at which accelerated aging can be conducted and still replicate field-like tire properties. Beyond this range, results become non-representative.

- The Oven-Aging Protocol was the only method successful at replicating the overall material properties and stepped-up load roadwheel results of the used tires.

- Aging tires in the oven at 55^{o} to 65^{o}C (131^{o} to 149^{o}F) for 3 to 12 weeks produced artificially aged tires with the material properties consistent with the used tires. Using the highest temperature possible in the acceptable range will minimize the testing time and costs.

- The tire inflation gas, which consisted of an oxygen-enriched air mixture, needs to be replaced or replenished during oven aging to maintain the rate of oxidation and facilitate more consistent results from one tire model to another.

- Approximately one-fourth of the oven aging tires were subjected to an initial structural break-in prior to oven aging that consisted of running the tires on a roadwheel for 24 hours at 120 km/h (75 mph), 100 percent maximum load rating, 100 percent maximum sidewall pressure, with 50/50 N_2/O_2 inflation gas. These break-in conditions were not sufficient to initiate cracks and separations in the tire structure as seen in used on-road tires of the identical models. While certain material properties of on-road tires could only be matched by a combined roadwheel break-in and oven aging procedure, the 24-hour break-in was deemed too severe in terms of stressing the material properties and roadwheel performance beyond desired targets. Therefore, the benefits of a lower severity break-in were evaluated in subsequent test phases, and the test conditions specified in the FMVSS No. 139 high speed test break-in (2 hours at 50 mph) were used.

- Oven aging coupled with a pre-oven roadwheel break-in and followed by a stepped-up load roadwheel test provided the desired test focus on the target belt edge area and tread separation failures.

- Further test development on a wider selection of tires was needed to address the air loss mechanism during oven aging and to further evaluate the utility of a pre-oven aging break-in of the tires.

Tire aging in the field is a thermo-oxidative process, whereby tire material properties degrade over time and the speed of the degradation increases with heat; however, there is a limited range of temperatures at which accelerated aging can be conducted and still replicate field-like tire properties. Beyond this range, results become non-representative.

5.0 TIRE AGING METHOD REFINEMENT

5.1. TIRE AGING METHOD REFINEMENT

The objective of the Tire Aging Method Refinement phase was to develop the oven aging method evaluated in the Aging Methods Evaluation phase into a usable test method using a larger, more representative sample of 18 new tire models shown in Appendix G. When compared to the previous phase, Aging Method Refinement had the following distinctions:

- The tire inflation gas was vented and refilled weekly to better maintain original levels of inflation pressure and oxygen.

- The pre-test roadwheel break-in conditions used for one-third of the tests were reduced to 23 hours at 80 km/h (50 mph), 100 percent maximum load rating and corresponding inflation pressure, with normal air inflation.

- Tires were aged at the maximum inflation pressure required to carry the maximum load rating for the tire, rather than at the maximum inflation pressure labeled on the sidewall

The test methodology was designed such that a total of 145 new tires were tested in one of the following three oven aging conditions using a weekly replacement of the same oxygen-enriched air mixture used in the previous phases:

- Ten weeks in the oven at 60°C (140°F) with no roadwheel break-in

- Eight weeks in the oven at 65°C (149°F) with no roadwheel break-in

- Eight weeks in the oven at 65°C (149°F) with a 23-hour roadwheel break-in at 80 km/h (50 mph)

After oven aging, the tires were subjected to either the stepped-up load test used in the previous phases or a tire section analysis of the material properties. Since field results from Phoenix did not exist for the 18 new tire models being tested, aging targets were established in terms of the average percent change in material properties (from new) for a roughly 4- to 6-year-old tire in Phoenix; based on research conducted at Ford, this can represent the equivalent of tires twice as old in the northernmost states.

5.2. TIRE AGING REFINEMENT RESULTS AND CONCLUSIONS

The oven aging method proven effective in the Aging Methods Evaluation underwent further refinement and evaluation on an additional 18 tire models. After the post-test analysis was completed, the following results and conclusions were found:

- The second, less severe 23-hour break-in at 80 km/h (50 mph) on the road wheel failed to generate any measurable belt-edge cracking or internal separation in new tires (properties seen in used on-road tires). As with the first (24 hours at 75 mph) break-in evaluated, certain material properties of on-road tires could only be matched by a combined roadwheel break-in and oven aging procedure. The second (23 hours at 50 mph) break-in evaluated was deemed too severe in terms of stressing the material properties and roadwheel performance beyond desired targets. Therefore, the benefits of a lower severity break-in were evaluated in subsequent test phases, and the test conditions specified in the FMVSS No. 139 high speed test break-in (2 hours at 50 mph) were used.

- The weekly replacement of the oxygen-rich inflation gas during oven aging maintained a consistent and rapid aging rate that had fallen off in the Aging Methods Evaluation testing, which used a capped inflation pressure. This resulted in significantly reducing the oven time required to reach targets.

- After approximately 25 percent of tires were tested, material properties testing showed that oven aging tires for 8 weeks at 65°C (149°F) with weekly replacement of the oxygen-enriched gas was too severe and overshot the 4- to 6-year-old used tire targets.

- By reducing the oven time to 5 weeks at 65°C (149°F) or 7 weeks at 60°C (140°F), the test results more closely matched the overall material properties and stepped-up load roadwheel test results of the 4- to 6-year-old used tire retrieved from Phoenix.

- Although both of the reduced time conditions provided valid results in matching material properties, a final test procedure of approximately 5 weeks in the oven at 65°C (149°F), with weekly maintenance of the oxygen-rich inflation gas, and a short, low severity pre-oven roadwheel break-in was selected as the final test method to best replicate 4- to 6-year-old used tires in Phoenix.

During oven aging, inflation gas built up in interior layers of some of the light truck tires and resulted in a separation, blister, or sidewall rupture during the test. A pressure manifold is strongly recommended to maintain tire pressure during oven aging.

- A problem was detected in about 19 percent of the oven aging tests of load range D and E light truck tires. During oven aging, inflation gas built up in interior layers of some of the light truck tires and resulted in a separation, blister, or sidewall rupture during the test. This occurred in both tires with a pre-oven roadwheel break-in and without. This prompted safety concerns, and the resulting conclusion was that a pressure manifold is strongly recommended to maintain tire pressure during oven aging. In addition, special test conditions for light truck tires may have to be considered.

6.0 NON-NHTSA RESEARCH

In addition to NHTSA's tire aging research, other tire aging research was conducted outside the agency. Below is a summary of the tire aging research conducted by Ford and the American Society for Testing and Materials (ASTM). Appendix H presents some additional tire aging related studies and commentary that was submitted to the aging docket.

6.1. FORD MOTOR COMPANY

Ford determined that critical properties of an oven-aged tire duplicate equivalent properties in a naturally aged tire ,that the aging rate varies for different tire types and brands, and that spare tires age at only a slightly slower rate than on-road tires.

After the TREAD Act, Ford Motor Company (Ford) began an independent research project to develop a tire aging test protocol and test method for use in all of its original equipment (OE) tire fitments with a goal to reduce tire aging as a causal factor in tire-related disablements. Ford concluded a 5-year, multi-phase, independent research project of testing and evaluating approximately 2,500 tires from six U.S. cities (Detroit, Hartford, Phoenix, Miami, Denver, and Los Angeles), to determine the best method to artificially age a new tire. Significant positive correlations were obtained between naturally aged field tires and tires aged with Ford's artificial protocol, and data showed that tires from hotter climates, such as Phoenix, age faster than tires from cooler climates, such as Detroit. Ford determined that critical properties of an oven-aged tire duplicate equivalent properties in a naturally aged tire, that the aging rate varies for different tire types and brands, and that spare tires age at only a slightly slower rate than on-road tires.

Ford believes thermo-oxidative aging protocol will simulate critical characteristics of a new tire that was naturally aged for six years in Phoenix.

As a result of its research, Ford decided that all of its OE tire fitments must pass a stepped-up-load test at 120 km/h (75 mph) for 34 hours using a new tire that has been artificially aged for 8 weeks in an oven at 65^{o}C (149^{o}F), inflated with a oxygen-enriched air mixture of 50-percent oxygen and 50-percent nitrogen that is refilled biweekly. Ford believes this thermo-oxidative aging protocol will simulate critical characteristics of a new tire that was naturally aged for 6 years in Phoenix. Further, once a tire is approved for a Ford OE fitment, the tire will have a 6-year service life limitation regardless of tread depth. This limitation also applies to full-size spare tires despite their lack of on-road use. (Docket No. NHTSA-2005-21276)

6.2. AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM)

Since 2002, the ASTM F09 Committee, with members from 20 organizations of the tire and automotive industries, has been developing an accelerated tire-aging protocol for light vehicle radial tires utilizing a peer review process. Through an increasingly rigorous research, test, and evaluation process, ASTM determined that statically aging a tire in the oven between 55 to 65°C (131° to 149°F) is the most effective method of replicating actual field properties and that there is a relationship between the length of time in the oven and the amount of equivalent aging in the field.

Through rigorous research, test, and evaluation process, ASTM determined that statically aging a tire in the oven between 55 to 65°C (131° to 149F) is the most effective method of replicating actual field properties and that there is a relationship between the length of time in the oven and the amount of equivalent aging in the field.

The task group then focused on finding a method for testing an aged tire to predict its performance at various ages in the field. A stepped-up load (SUL) roadwheel test (similar to the FMVSS No. 139 Endurance Test) [17] and a steady state load roadwheel test have produced the most promising results. Currently, the group is validating the aged tire durability test protocol across a wider range of tire model types, including light truck and passenger car tires as well as OE and replacement tires. The group plans to begin the balloting process for a standard on aged tire durability in late 2007. (Docket No. NHTSA-2005-21276)

7.0 FINDINGS AND CONCLUSIONS

The NHTSA Field Study concluded that tires continue to degrade throughout their service lives, whether used on the road or in the full-size spare position. Results showed that thermo-oxidative degradation of the tires during service in Phoenix led to reduced material properties. The field study also showed structural degradation of the tires in terms of internal cracks and separations resulting from the tires being used in service. This internal degradation and damage was nearly all internal to the tire and likely impossible to detect from a visual inspection alone. The effects of material property degradation and structural degradation together reduced the performance of tires in laboratory roadwheel tests with increasing age and mileage of the tire.

The NHTSA field study concluded that tires continue to degrade throughout their service lives, whether used on the road or as a full-size spare tire in a stored position. Results showed that thermo-oxidative degradation of the tires during service in Phoenix led to reduced material properties.

The tire aging field study showed that the material properties of the tires in service in Phoenix degraded due to thermo-oxidative degradation. The field study also showed that the in-service tires structurally degraded as a result of cyclic fatigue, resulting in internal cracks and separations.

The Aging Methods Evaluation phase attempted to replicate the degradation of tire material properties, structure, and roadwheel performance measured on the used tires from the field study using three accelerated aging methods commonly used by industry. Of the three aging methods evaluated, only the oven-aging method was found to be effective at matching the material properties of the used tires. The capped-inflation oven aging evaluated in this phase was observed to diminish in effectiveness as the internal oxygen-rich inflation gas permeated through the tires at high rates during oven aging. Also, oven aging alone did not fully match the structural properties and roadwheel performance of the used field study tires. It was concluded that further development of the oven-aging method was needed to address the inflation gas permeation and structural issues.

Research showed that the material properties of the tires in service in Phoenix degraded due to the thermo-oxidative process. The field study also showed that the in-service structurally degraded as a result of cyclic fatigue, resulting in internal cracks and separations.

The Aging Method Refinement phase focused on further development of the oven-aging method and expanded the testing to many more tire models. Since no Phoenix field data existed on the tires considered in this phase, aging targets developed from the field study data were used. In this phase, weekly replacement of the oxygen-rich inflation gas was used during oven aging to address the permeation issues observed in the Aging Methods Evaluation phase. Also, an addition of a short pre-oven roadwheel break-in was performed to initiate structural degradation and better match physical material properties. Using a weekly replacement of the inflation gas protocol during oven aging rather than the capped inflation protocol maintained a more consistent and rapid tire aging rate, and subsequently shortened the test. With no discernible difference in results between aging at 65^{o}C (149^{o}F) for 5 weeks and 60^{o}C (140^{o}F) for 7 weeks, the shorter of the two tests (65^{o}C (149^{o}F) for 5 weeks) was chosen as the final test method. This test ages new tires to the equivalent of roughly 4 to 6 years of on-road use in Phoenix, or, based on research at Ford, to approximately the equivalent of twice that use in the northernmost states.

Oven aging alone did not fully match the structural properties and roadwheel performance of the field study tires. It was concluded that further development of the oven-aging method was needed to address the inflation gas permeation and structural issues.

In addition to NHTSA's research findings, both Ford's and ASTM's independent research found that using oven aging followed by a roadwheel endurance test was the best method available to artificially age a tire and assess its tire durability performance. They concluded, as did NHTSA, that this was the best method available in terms of accuracy of results obtained and cost-effectiveness of conducting the test. It is also concluded that the results of the limited Phoenix field study are highly consistent with the results of the much larger

In addition to NHTSA's research findings, both Ford and ASTM's independent research found that using oven aging followed by a roadwheel endurance test was the best method available to artificially age a tire and assess its tire durability performance.

study completed by Ford Motor Company, which also tested tires collected from Phoenix. The raw data have been peer reviewed by industry for over 2 years and are currently being used by a large cross-industry task group (tire manufacturers, vehicle manufacturers, suppliers, test laboratories) in a tire aging test development effort.
(See http://dmses.dot.gov/docimages/pdf99/432846_web.pdf.)

Additional details regarding the results of all NHTSA's tire aging research will be forthcoming in full technical reports issued by the agency.

At this time, NHTSA's research supports the conclusion that the age of a tire, along with factors such as average air temperature and inflation, plays some role in the likelihood of its failure, and that a refined oven aging method can realistically approximate the effects of aging. However, the agency must take additional steps before it can have a sufficient understanding of the aging phenomenon to support any possible safety standard or consumer recommendations on the issue. Additionally, necessary cost and benefit analyses have to be performed before making any regulatory decisions.

NHTSA's research supports the conclusion that the age of a tire, along with factors such as average air temperature and inflation, plays some role in the likelihood of its failure. A refined oven aging method can realistically approximate the effects of aging.

8.0 NHTSA'S NEXT STEPS

NHTSA is currently evaluating the feasibility of a regulation related to tire aging by analyzing the safety problem (tire aging as a significant causal factor in crashes) and potential benefits and costs of a requirement for minimum performance based on an aging method taking into consideration the implementation of NHTSA's recent major tire related initiatives such as the requirement for TPMS in new vehicles and upgrade of the existing tire safety standards. NHTSA has initiated the following steps to estimate the effectiveness and costs of a potential tire aging requirement.

First, the agency is currently analyzing data from the validation testing to determine the test parameters that would be most appropriate for an oven-aging test protocol. NHTSA has conducted validation testing using the 20 tire models shown in Appendix I. The models tested were specifically chosen to gather data to supplement previous tire testing by more closely matching current market distributions of tires in terms of brands, sizes, and market segments. The objectives of validation testing were: 1) to determine the optimal artificial oven-aging test parameters; 2) to validate the oven-aging test procedure over a wide range of new tires; 3) to evaluate the effectiveness of the FMVSS No. 139 Endurance and Low Pressure test [18] sequence as a post-oven-aging durability test; and 4) to gather and evaluate data for quantifying and determining the need for any additional agency actions. This analysis is scheduled to be completed in early 2008.

Second, NHTSA has initiated a cost study to determine the estimated cost of upgrading light vehicle tires to comply with a potential accelerated aging performance requirement. The agency is conducting testing, which is expected to provide estimates of the cost, weight, and lead time needed for different potential levels of aged performance.

Third, the agency has initiated a benefits study to estimate the potential safety benefits that could be derived if all light vehicle tires are required to meet a specified minimum performance requirement for tire aging. In addition to the various NHTSA databases that include tire information, the agency is continuing to pursue other sources of data on tire age-related crashes, which could help the agency quantify the impact of tire aging on motor vehicle safety.

NHTSA believes that after this work is completed, the agency will have the necessary information to decide what further steps, if any, should be taken to address safety issues related to tire aging.

ABBREVIATIONS AND GLOSSARY

Accelerated Service Life: Artificially simulating the effects of service life (age and mileage) on new tires.

Air permeation rates (of a tire): The rate of static inflation pressure loss in a tire over a specified time.

Bead (of a tire): A ring of steel wires or cable that anchors the tire carcass plies to the rim.

Belt: Rubber encased cords located directly under the tread in the crown of the tire to resist deformation in the footprint.

Belt edge: The place where the cords terminate in the shoulder region of the tire. The cords are not fully encased by rubber in this area.

Blowout (of a tire): Any tire failure that occurs while a tire is in service resulting in rapid air loss deflation.

Break-in period: The period of time a tire is subjected to a set of conditions on a roadwheel prior to oven aging the tire or subjecting the tire to a more stringent set of conditions in a roadwheel test.

Capped tire inflation pressure: The initial pressure inside a tire resulting from filling the tire with air or another gas that is not replaced as the tire loses pressure.

Carcass: The internal tire structure, excluding the tread and sidewall rubber, which bears the load when the tire is inflated.

Degradation (of a tire): Any reduction or loss of the material properties or performance of a tire as a result of being driven on the road, subjected to a roadwheel, or subjected to environmental conditions, such as heat or oxygen.

Durability: The ability of a tire to retain physical integrity and sufficient material properties to perform safely in normal service.

Full size spare tire: A tire of the same size or approximately the same size as an in-service tire that has been mounted on a rim, pressurized, and stored on the vehicle in case of a failure of an in-service tire.

Inner liner (of a tire): The innermost layer(s) in a tubeless tire that limit(s) the diffusion of the inflation gas into other areas of the tire.

In-service /On-road tires: Tires mounted on rims which are inflated and being driven on a vehicle.

Laboratory roadwheel: A motorized steel test wheel of a certain diameter that a tire mounted on a free spinning axle is pushed against to simulate on the road speed and load of an in-service tire.

Light truck (LT) tire: A tire constructed for loads and rough terrain that is usually used on medium light-duty trucks. These tires contain the prefix LT before the size designation molded on the tire sidewall.

Load (on a tire): The amount of force being applied to a tire in-service or a tire being tested.

Load Rating (of a tire): The maximum load a tire is rated to carry for a given usage at a specified cold inflation pressure.

Material property: A measure of a tire component's chemical or physical state.

Maximum load rating (of a tire): The load rating at the maximum permissible cold inflation pressure for that tire.

Original equipment (OE) tire: A tire that is installed on a vehicle by the manfactuer at the time of its manufacture.

Passenger car tire: A tire that is constructed and approved for use on passenger vehicles and usually contains the prefix 'P' before the size designation on the tire sidewall.

Peel strength (of a tire): A laboratory test on a sample removed from the tire that measures the level of force per inch or millimeter needed to separate the tire between the steel belts..

Performance (of a tire): The ability of a tire to continuously translate tractive, braking, and steering forces to the road surface while maintaining its physical integrity.

Ply (of a tire): A layer of rubber-coated parallel tire cords that are placed in a tire..

Replacement tire: A tire purchased in the aftermarket to replace an original equipment tire.

Separation: A detachment of some portion of the tire or between some components of the tire that occurs during service or testing.

Service life: The length of time an inflated tire is mounted on a vehicle and used or stored for emergency use.

Shoulder (of a tire): The upper portion of the sidewall just below the tread edge

Sidewall (of a tire): The portions of a tire between the tread and the beads. The tire's name, safety codes, and size designation are molded on the sidewall.

Speed rating: A letter assigned to a tire denoting the maximum speed for which the use of a tire is rated (e.g., S = 112 mph, H = 130 mph). The speed rating is contained in the tire size designation molded on the sidewall.

Stepped-up Load (SUL) Test: A laboratory roadwheel test where the tire is subjected to increasing loads for certain periods of time while being run at a constant speed.

Stepped-up Speed (SUS) Test: A laboratory roadwheel test where the tire is subjected to increasing speeds for certain periods of time while being run at a constant load.

Tensile strength: A laboratory test on a sample removed from the tire that measures the amount of force necessary to fail the sample as it is stretched to its ultimate breaking point.

Thermo-oxidative degradation (in tires): The degradation of the material properties or performance of a tire as a result of being subjected to heat and oxygen.

TIN (Tire identification number): The tire identification number located on the sidewall of the tire, which contains the manufacturer's or retreader's identification code, the tire size code, the manufacturer's optional code, and the date code (the week and year the tire was manufactured).

Tire Aging: Any reduction or loss in a tire's material properties, which leads to a reduction of its performance capability over time, as a result of being driven on the road and/or when subjected to environmental conditions, such as heat or oxygen.

Tread (of a tire): The peripheral portion of the tire designed to contact the road surface.

Tread life: The length of service in miles anticipated (often warranted) by the tire's manufacturer before the tread depth will be so low that the tire needs to be replaced. A "40,000 mile tire" is expected to be able to travel approximately 40,000 miles before its tread is worn out (i.e. worn to 2/32 inch).

Tread Separation: A failure mode of the tire where the tread region of the tire delaminates and partially or fully detaches from the rest of the tire, usually at the interface between the two steel belts while the tire is in service or testing.

REFERENCES

[1] SAFETEA-LU, "Within 2 years after the date of enactment of this Act, the Secretary shall transmit a report to the Senate Committee on Commerce, Science, and Transportation and the House of Representatives Committee on Energy and Commerce on research conducted to address tire aging. The report shall include a summary of any Federal agency findings, activities, conclusions, and recommendations concerning tire aging and recommendations for potential rulemaking regarding tire aging." [Sec. 10303, Pub. L. No. 109-59]

[1] FMVSS No. 139 Final Rule, http://www.nhtsa.dot.gov/cars/rules/rulings/UpgradeTire/Final/Index.html, Chapter VI. Agency Decision regarding Final Rule, Section C. Performance Requirements, Subsection 6. Aging: "The agency acknowledges that, during the Firestone hearings, members of Congress suggested that an aging test could evaluate the risk of tire failure at a period later in the life of a tire than the period tested by the current endurance test. Additionally, reports (Clark, Govindjee) resulting from the Ford-Firestone investigation recommended that the agency should consider instituting an aging test in its revised regulation because of the known degradation of peel strength with time and temperature."

[1] FMVSS No. 139 will unify regulation of most passenger and light truck tire designs for vehicles with a gross vehicle weight rating of 10,000 pounds or less. These tires were previously regulated under the separate FMVSS 109 ("passenger car tires") and less stringent FMVSS 119 ("tires for vehicles other than passenger car"). This new standard becomes effective September 1, 2007 for non-snow tire designs and September 1, 2008 for designated snow tire designs. Optional compliance is permitted before those dates.

[1] Results contained in Docket NHTSA-2000-8011-27.

[1] Docket Submission NHTSA-2000-8011-19

[1] "Tire Service Life", February 2005, Tire Business Databook, Source Goodyear, http://www.tirebusiness.com/subscriber/databook/piecharts.html?chart=33

[1] Highway Statistics, 1973," Annual publication of the Federal Highway Administration, 1974.

[1] Highway Statistics 2004, FHWA, Table VM-1, http://www.fhwa.dot.gov/policy/ohim/hs04/htm/vm1.htm

[1] Hankook Optimo H727:

http://www.hankooktireusa.com/product/tire_detail.asp?pid=43

[1] Example: In ODI's engineering analysis of the recalled Firestone ATX and Wilderness AT tires, they noted that: "…tread separations failures rarely occur in the focus tires (ATX / Wilderness AT) until at least three years of use…". Engineering Analysis Report and Initial Decision Regarding EA00-023: Firestone Wilderness AT Tires, Oct. 2001, page 6.

[1] Forty two U.S. states require a minimum tread depth of 2/32", two states use 1/32", and six states have no minimum tread depth. Source: THE IMPORTANCE OF TIRE TREAD DEPTH AND PLACEMENT FOR WET TRACTION, William Blythe, Ph.D., International Tire Exhibition and Conference (ITEC), 2006.

[1] Page VIII-15, Table VIII-2 *"Vehicle Miles Traveled and Survival Rates By Age for Light Trucks (Based on 2001 data)"*

http://www.nhtsa.gov/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/2006_FRIAPublic.pdf

[1] National Automotive Sampling System – Crashworthiness Data System (1995 – 2005)

[1] NHTSA Final Economic Assessment Tire Pressure Monitoring System, FMVSS No. 138, March 2002 NHTSA-00-8572-216

[1] During the stepped-up speed test, the tire was first run through the FMVSS No. 139 High Speed test where the tire was subjected to a two-hour break-in on an indoor roadwheel at 80 km/h (50 mph)and then run continuously for 90 minutes through three 30-minute test stages at the following speeds: 140, 150, and 160 km/h (87, 93, and 99 mph). If the tire completed the FMVSS No. 139 High Speed test intact (i.e. no catastrophic structural failures or significant loss of inflation pressure), the tire was stopped for a one-hour cool down period and inspected. Tires that passed inspection were then run through additional speed steps that increased 10 km/h (6 mph) every 30 minutes until the speed rating of the tire was reached, at which time the tire was run at that speed uninterrupted until a catastrophic failure occurred.

[1] During the stepped-up load test, the tire was first run through the FMVSS No. 139 Endurance test where the tire was run, while significantly underinflated, on an indoor roadwheel continuously at a speed of 120 km/h (75 mph) for four hours at 85 percent of its maximum load rating, six hours at 90 percent of its maximum load rating, and then 24 hours at 100 percent of its maximum load rating. If the tire completed the FMVSS No. 139 Endurance test intact (i.e. no catastrophic structural failures or significant loss of inflation pressure), the tire was stopped for a one-hour cool down period and inspected. Tires that passed inspection were then run through additional load steps that increase by 10 percent of maximum its load every four hours until catastrophic failure occurred.

[1] The FMVSS No. 139 Endurance test consists of running the tire on an indoor roadwheel continuously at a speed of 120 km/h (75 mph) while significantly underinflated for four hours at 85 percent of its maximum load rating, six hours at 90 percent of its maximum load rating, and then 24 hours at 100 percent of its maximum load rating.

[1] The FMVSS No. 139 Low Pressure Test is conducted following the completion of the FMVSS No. 139 Endurance Test and consists of running the tire on an indoor roadwheel at a constant speed of 120 km/h (75 mph) in a significantly under-inflated condition.

[1] The Arrhenius Equation ($k = Ae^{-E/RT}$), where k is the reaction rate constant, predicts the chemical reaction rate for the thermo-oxidative degradation of tire rubber increases as an exponential function as temperature increases.

[1] http://www.ncdc.noaa.gov/oa/climate/online/ccd/nrmavg.txt and http://www.ncdc.noaa.gov/oa/climate/online/ccd/mxge90.txt

[1] "Correlation Of Rubber Properties Between Field Aged Tires And Laboratory Aged Tires", Rubber Chemistry And Technology, Vol. 78, David R. Bauer, John M. Baldwin, Kevin R. Ellwood, Ford Motor Company, http://dmses.dot.gov/docimages/pdf95/388794_web.pdf

[1] Maricopa County, Phoenix population: 3,072,149 (2000 U.S. Census), http://www.census.gov/

APPENDICES

APPENDIX A: TIRE INSPECTION AND MAXIMUM SERVICE LIFE RECOMMENDATIONS

Some tire standards organizations, automakers, and tire companies currently give recommendations regarding tire aging. NHTSA has examined tire age advisory excerpts from about 70 different owners' manuals and company advisory bulletins. Several auto manufacturers suggest or present warnings in the owner's manual either that the vehicle's tires be inspected or replaced at 6 years.

Tire manufacturers customarily warrantee tires for a specified mileage period but also do impose varying time restrictions that can be as long as 72 months. Some tire manufacturers have specified a maximum service life of up to 10 years. The type of information and content available to consumers vary among the organizations and much of it is available on corporate Web sites. A summary of publicly available information on the Internet is presented below.

Organization or Corporate Entity	Tire Warranty or Inspection	Max Service Life (Yrs)*	Web Site
Japan Automobile Tire Manufacturers Assoc. 2005	Professional Inspection at 5 Years	10	http://www.jatma.or.jp/
Tyre Industry Council UK	Tire Storage Expiration at 6 Years	10	http://www.tyresafety.co.uk/
Gulf Standard SASO	Tire Storage Expiration at 2 Years	--	http://www.saso.org.sa/openshare/SASO/en/ index.htm
DaimlerChrysler	--	6	http://www.daimlerchrysler.com/
Ford	--	6	http://www.ford.com/
VW/Audi	--	6	http://www.volkswagen.com
BMW AG	--	6	http://www.bmw.com
Toyota	Professional Inspection at 6 Years	--	http://www.toyota.com
Opel, Vauxhall GM Europe	Spare Tires Greater Than 6 Years Old For Use Only in Emergencies or at slow speeds	--	http://www.gmeurope.com/brands/opel_vauxhall.html
BFGoodrich	Warranty 72 Months* or Original Tread Life	--	http://www.bfgoodrichtires.com/
Bridgestone-Firestone	Warranty 60 Months+ or 72 Months* ; Professional Inspection at 5 Years	10	http://www.bridgestonetire.com/
Continental	Warranty 72 Months+ Professional Inspection at 5 Years	10	http://www.conti-online.com/
Cooper	Warranty Original Tread Life	--	http://www.coopertires.com/
Falken	Warranty Original Tread Life	--	http://www.falkentire.com/
Goodyear	--	--	http://www.goodyear.com/
Hankook	Warranty Original Tread Life	--	http://www.hankooktireusa.com/
Kumho Tires	Warranty NLT 6 Years+	6	http://www.kumhousa.com/
Michelin	Warranty 72 Months* or Original Tread Life; Professional Inspection at 5 Years	10	http://www.michelin-us.com/
Pirelli	Warranty Original Tread Life	--	http://www.us.pirelli.com/
Yokohama	Warranty 60 Months+ or 72 Months*	--	http://www.yokohamatire.com/

*From date of manufacture +From date of purchase

APPENDIX B: EXAMPLES OF VEHICLE AND TIRE MANUFACTURERS' TIRE SEVICE LIFE RECOMMENDATIONS

Vehicle Manufacturers		
Entity	**Tire Service Life Recommendations Excerpts**	**Source**
BMW AG	"The manufacturer of your vehicle recommends replacing all tires after six years at the latest, even if a tire service life of ten years is possible."	2005 MiniCooper Owners Manual, page 99, 07/04 BMW AG
DaimlerChrysler Co.	"WARNING! Tires and spare tire should be replaced after six years, regardless of the remaining tread. Failure to follow this warning can result in sudden tire failure. You could lose control and have an accident resulting in serious injury."	2006 Jeep Grand Cherokee Owner's Manual, Page 293
Ford Motor Co.	"Tires degrade over time depending on many factors such as weather, storage conditions, and conditions of use (load, speed, inflation pressure, etc.) the tires experience throughout their lives. In general, tires should be replaced after six years regardless of tread wear. However, heat caused by hot climates or frequent high loading conditions can accelerate the aging process and may require tires to be replaced more frequently. You should replace your spare tire when you replace the road tires or after six years due to aging even if it has not been used."	2007 Ford Explorer Owner's Manual, Page 191
Porsche (Dr. Ing. h.c. F. Porsche AG)	"The perception that tire durability and performance are immune to the effects of storage and age is unfounded. Chemical additives, which make the rubber elastic, lose their effectiveness in the course of time and the rubber becomes brittle and cracks. Therefore, the tires should be inspected from time to time. Note: Under no circumstances should tires older than 6 years be used on your Porsche."	2006 Porsche 997 Owners Manual, page 237, WKD 997 021 06 5/05
Toyota Motor North America, Inc.	"Any tires which are over 6 years old must be checked by a qualified technician even if damage is not obvious. Tires deteriorate with age even if they have never or seldom been used. This also applies to the spare tire and tires stored for future use."	2003 Toyota 4Runner Owner's Manual, page 329
Vauxhall (GM UK)	"Tyres age, even if they are used only very little or not at all. A spare wheel which has not been used for 6 years should be used only in emergencies; drive slowly when using such tyres."	2005 VAUXHALL Corsa & Combo Owners Manual, page 165

APPENDIX B: EXAMPLES OF TIRE SERVICE LIFE RECOMMENDATIONS (CONTINUED)

Tire Manufacturers		
Entity	**Tire Service Life Recommendation Excerpts**	**Source**
Bridgestone Firestone North American Tire, LLC ("BFNT")	"JATMA (Japan Automotive Tyre Manufacturers Associated) has announced a new recommendation for passenger and light truck tires that have been in use for more than five (5) years. They recommend that, in addition to regular tire inspections, customers have their tires inspected by a qualified tire service person after five (5) years of use to determine if the tires can continue in service. It is recommended that spate tires be inspected at the same time. Further, even when tires appear to be usable from their external appearance or the tread depth may have not reached the minimum wear out depth, it is recommended that all tires (including spare tires) that were manufactured more than ten (10) years previous be replaced with new tires. BFNT had elected to follow the JATMA recommendation. Although BFNT is not aware of technical data that supports a specific tire service life, we believe it is appropriate to follow the JATMA recommendation in the interest of further encouraging consumers to focus on the importance of maintaining and properly replacing their tires. The replacement of tires ten (10) years after the date of production is an important consideration; however, it is not an indicator of actual service life for any individual tire. Some tires will need to be replaced before ten (10) years due to operational conditions such as punctures, impact damage, improper inflation, overloading, or other conditions resulting from user or misuse of the tire. Also, while some tires many have been operated in a manner which would give them a service life beyond ten (10) years, BFNT believes that it is good practice and recommends that tires be removed from service ten (10) years after the date of manufacture. Note: The vehicle manufacturer's recommendations found in the owner's manual may have instructions on the need for tire inspection and replacement intervals. The vehicle owner and driver should follow the recommendations in the owner's manual."	Bridgestone Firestone Technical Bulletin, Oct. 2005, Ref. No. P-05-10, Tire Inspection Guidelines
Continental Tire North America	"Continental is unaware of any technical data that supports a specific tire age for removal from service. However, as with other members of the tire and automotive industries, Continental recommends that all tires (including spare tires) that were manufactured more than ten (10) years previous be removed from service and be replaced with new tires, even when tires appear to be usable from their external appearance and if the tread depth may have not reached the minimum wear out depth. Vehicle manufacturers may recommend a different chronological age at which a tire should be replaced based on their understanding of the specific vehicle application; Continental recommends that any such instruction be followed. Consumers should note that most tires would have to be removed for tread wear-out or other causes before any proscribed removal period. A stated removal period in no way reduces the consumer's responsibility to replace tires as needed."	Product Service Information Bulletin PSIB 06-02, "*Tire Maximum Service Life for Passenger Car and Light Truck Tires*", February 13, 2006

APPENDIX B: EXAMPLES OF TIRE SERVICE LIFE RECOMMENDATIONS (CONTINUED)

<table>
<tr><th colspan="3">Tire Manufacturers</th></tr>
<tr><th>Entity</th><th>Tire Service Life Recommendation Excerpts</th><th>Source</th></tr>
<tr><td>Michelin North America, Inc.</td><td>“The following recommendation applies to passenger car and light truck tires. Tires are composed of various types of material and rubber compounds, having performance properties essential to the proper functioning of the tire itself. These component properties evolve over time. For each tire, this evolution depends upon many factors such as weather, storage conditions, and conditions of use (load, speed, inflation pressure, maintenance etc.) to which the tire is subjected throughout its life. This service-related evolution varies widely so that accurately predicting the serviceable life of any specific tire in advance is not possible.

That it is why, in addition to regular inspections and inflation pressure maintenance by consumers, it is recommended to have passenger car and light truck tires, including spare tires, inspected regularly by a qualified tire specialist, such as a tire dealer, who will assess the tire's suitability for continued service. Tires which have been in use for five years or more should continue to be inspected by a specialist at least annually.

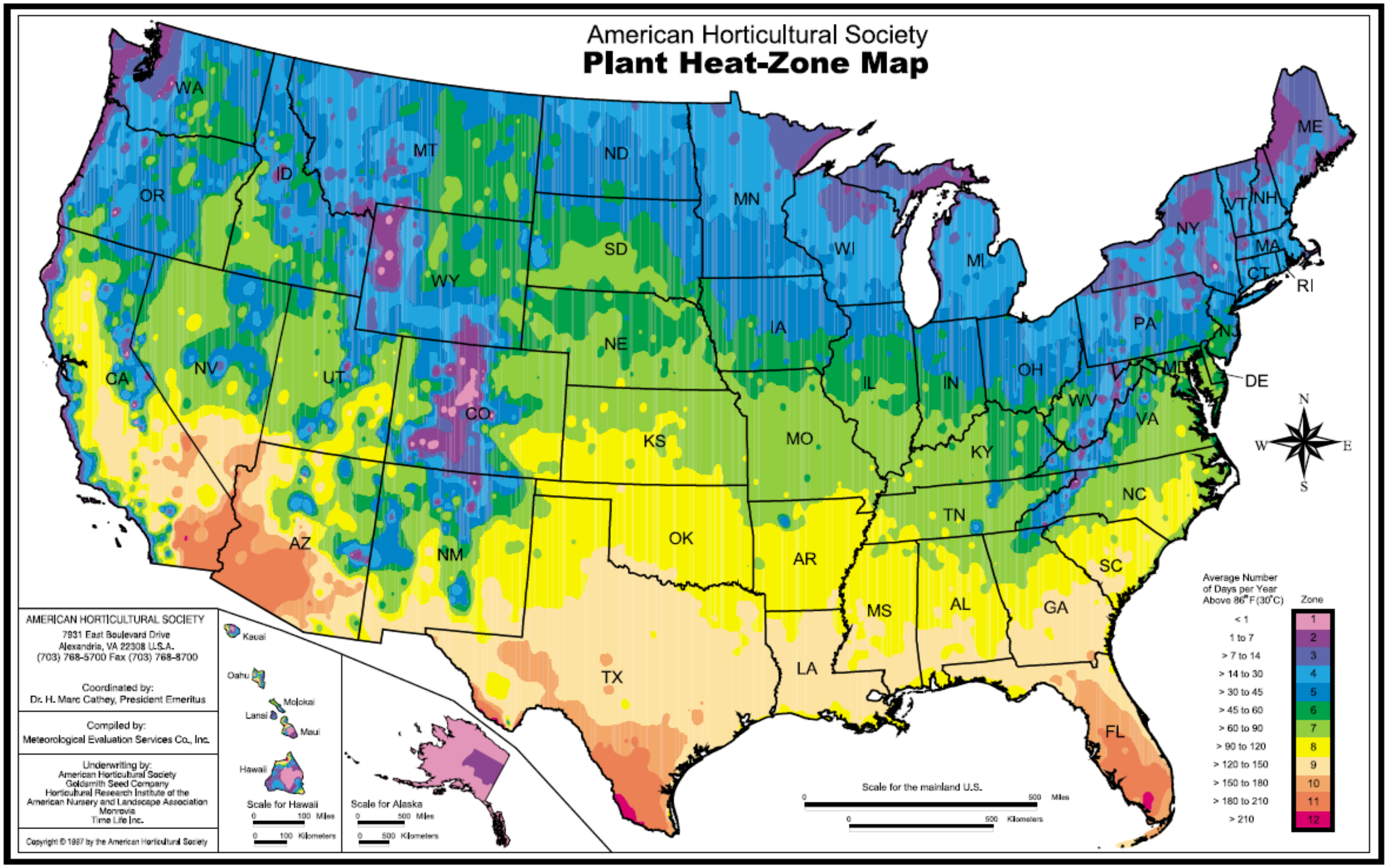
Consumers are strongly encouraged to be aware not only of their tires' visual condition and inflation pressure but also of any change in dynamic performance such as increased air loss, noise or vibration, which could be an indication that the tires need to be removed from service to prevent tire failure.

It is impossible to predict when tires should be replaced based on their calendar age alone. However the older a tire the greater the chance that it will need to be replaced due to the service-related evolution or other conditions found upon inspection or detected during use.

While most tires will need replacement before they achieve 10 years, it is recommended that any tires in service 10 years or more from the date of manufacture, including spare tires, be replaced with new tires as a simple precaution even if such tires appear serviceable and even if they have not reached the legal wear limit.”

For tires that were on an original equipment vehicle (i.e., acquired by the consumer on a new vehicle), follow the vehicle manufacturer’s tire replacement recommendations, when specified (but not to exceed 10 years).</td><td>Technical Service Bulletin PM-06-02, “Service Life for Passenger Car and Light Truck Tires including Spare Tires”, February 9, 2006</td></tr>
</table>

APPENDIX C: HEAT ZONE MAP FOR DAYS EXCEEDING 85 ^{O}F



Source: American Horticultural Society (For raw data, see http://www.ncdc.noaa.gov/oa/climate/online/ccd/mxge90.txt)

APPENDIX D: REASONS FOR SELECTION OF PHOENIX, ARIZONA AS THE TIRE COLLECTION SITE

During the field study, NHTSA collected tires through tire dealerships in the Phoenix, Arizona area. Phoenix was selected as the collection location for the following reasons:

- Agency data indicated that tire aging is exponentially related to a tire's heat exposure [19] and that states with high average ambient temperatures have much higher tire failure rates. Phoenix, Arizona had an average temperature of 23^{o}C (74^{o}F) and an average of 169 days with a maximum temperature of 32^{o}C (90^{o}F) or higher. [20]

- A study conducted by the Ford Motor Company indicated that Phoenix, Arizona had the highest tire material degradation rates of the six cities studied [21]. Since the rate of degradation is exponentially relative to temperature, the high relative rate of tire rubber degradation in the Phoenix area was attributed to both its high mean and maximum temperatures.

- Phoenix is a large population center with over three million residents [22] and possessed a suitable infrastructure of tire retail centers.

APPENDIX E: TWELVE TIRE MODELS COLLECTED IN PHOENIX, ARIZONA

Tire Manufacturer	Tire Model	Tire Size	Load Range	Speed Rating	Tires
Hankook	H406	P185/65R14	85	H	34
BFGoodrich	Touring T/A SR4	P195/65R15	89	S	70
Goodyear	Eagle GA	P205/65R15	92	V	31
Michelin	LTX M/S	P235/75R15XL	108	S	39
Firestone	Wilderness AT	P265/75R16	114	S	50
Goodyear	Wrangler HP	255/55R18	109	H	49
Kumho	ECSTA HP4	P205/60R15	90	H	29
Pathfinder	ATR A/S	LT245/75R16	120/116E	Q	49
Yokohama	Avid Touring	P205/70R15	95	S	22
Continental	Touring Contact A/S	P205/65R15	92	S	45
Pirelli	P6 4Seasons	P235/45R17	94	V	35
General	Grabber ST	255/65R16	109	H	40
				Total	**493**

APPENDIX F: TIRE MODELS USED IN THE AGING METHOD REFINEMENT (3) PHASE

Test Phase	PC/ LT*	MKT **	Tread ***	Tire Brand Name	Tire Model	Tire Manufacturer	Tire Size	Load Range	Spd Rating	Wheel Size
3	PC	Repl.	AS	Arizonian [Discount Tire]	Silver Edition	Goodyear Tire and Rubber Co., U.S.	P195/65R15	89	S	15x6J
3	PC	Repl.	AS	Big O [Big O Tire]	Aspen	Cooper Tire and Rubber Co., U.S.	P205/65R15	92	S	15x6J
3	LT	Repl.	AS	Big O [Big O Tire]	Bigfoot A/T (LT235)	Goodyear Tire and Rubber Co., U.S.	LT235/85R16	120 (E)	Q	16x6.5J
3	LT	Repl.	AS	Big O [Big O Tire]	Bigfoot A/T (LT235)	Goodyear Tire and Rubber Co., U.S.	LT265/75R16	123 (E)	Q	16x7.5J
3	PC	Repl.	AS	Big O [Big O Tire]	Merit Four Season Black	Cooper Tire and Rubber Co., U.S.	P195/65R15	89	S	15x6J
3	LT	Repl.	AS	Bridgestone	Dueler A/T 693	Bridgestone Corp., Japan	LT285/75R16	122 (D)	Q	16x8J
3	PC	OE	AS	Bridgestone	Dueler H/T 689	Bridgestone Corp., Japan	P245/70R16	106	S	16x7J
3	PC	OE	AS	Continental	Contitrac	Continental A.G., Germany	P235/70R16	104	T	16x7J
3	PC	OE	AS	Continental	TouringContact AS	Continental A.G., Germany	P205/65R15	92	T	15x6J
3	PC	Repl.	AS	Dominator [Discount Tire]	All Season	Cooper Tire and Rubber Co., U.S.	P205/65R15	92	S	15x6J
3	LT	Repl.	AS	Dominator [Discount Tire]	Durango Radial A/T	Cooper Tire and Rubber Co., U.S.	LT285/75R16	122 (D)	N	16x8J
3	LT	Repl.	AS	Dominator [Discount Tire]	Sport A/T	Cooper Tire and Rubber Co., U.S.	LT265/75R16	123 (E)	Q	16x7.5J
3	PC	OE	AS	Firestone	Wilderness AT I	Bridgestone Corp., Japan	P265/75R16	114	S	16x7.5J
3	PC	Repl.	AS	Futura [Pep Boys]	Dakota H/T	Cooper Tire and Rubber Co., U.S.	P265/75R16	114	S	16x7.5J
3	LT	Repl.	AS	Futura [Pep Boys]	Scrambler A/P (LT)	Cooper Tire and Rubber Co., U.S.	LT235/85R16	120 (E)	N	16x6.5J
3	PC	Repl.	AS	Futura [Pep Boys]	Scrambler A/P (P-XL)	Cooper Tire and Rubber Co., U.S.	P235/75R15XL	108	S	15x6.5J
3	LT	Repl.	AS	Goodyear	Wrangler Silent Armor	Goodyear Tire and Rubber Co., U.S.	LT235/85R16	120 (E)	R	16x6.5J
3	LT	OE	AS	Pirelli	Scorpion STR	Pirelli and C. S.p.A., Italy	LT265/75R16	123 (E)	R	16x7.5J

* PC/ LT: Passenger Car Tire (PC), Light Truck Tire (LT), or Non-Service (NS)
** Market (MKT): Original Equipment (OE), Replacement (Repl.), or Non-Service (NS)
*** Tread Design: All Season (AS) or Non-Service (NS)

APPENDIX G: OTHER TIRE AGING STUDIES AND DOCKET COMMENTARY

ExxonMobil Chemical

ExxonMobil Chemical conducted a tire test program to determine the relationship between the Inflation Pressure Retention (IPR) rates and the tires aging characteristics. ExxonMobil contracted for the production of one tire model with test samples having one of three different innerliner formulations, including a 100 percent halobutyl liner, and an 80/20 percent and a 60/40 percent halobutyl/natural rubber liner with each innerliner being uniform throughout the entire tire. Tires were subjected to ExxonMobil air retention and tread separation test protocols and to NHTSA FMVSS No. 139 (High Speed, Endurance, and Low Pressure tests) until tire failure. The test results revealed a strong correlation between the percentage of halobutyl in the innerliner and the resulting static IPR rate (i.e., static rate of loss of inflation pressure). Higher halobutyl content resulted in a lower inflation pressure loss rate, and the tires aged more slowly.

ExxonMobil also used nitrogen gas inflation in laboratory tests on tires aged through oven aging and roadwheel methods. They found that nitrogen, when used according to the ExxonMobil procedure (dry 99.9 percent nitrogen), can reduce the static air loss rate by 45 percent, correspondingly reduce the rate of aging, and result in improved tire performance; however, ExxonMobil cautions that these results are for ideal laboratory conditions only and that the results that could be potentially obtained by the average consumer in real-world conditions have not been studied. (Docket No. NHTSA-2005-21276)

Rubber Manufacturers Association (RMA)

The Rubber Manufacturers Association (RMA) submitted two entries into the NHTSA Tire Aging Docket (NHTSA-2005-21276). The first was a letter that addressed factors that affect tire service life. The fundamental question that RMA states must be addressed in tire aging is, "whether there is any scientifically valid data that demonstrates correlation between tire service life and real world tire safety performance and does such data, if available lead to a reasonably identifiable maximum service life."

In summary, RMA believes that the service life of a tire is determined by many issues, including tire storage conditions, driving habits and road conditions, tire maintenance (pressure, balancing, alignment, etc.) and road hazards. RMA believes that the consumer plays a key role in inspecting tires regularly, acting on any symptom of tire problems (bubble, noise, vibration, etc.) and removing damaged tires from service, regardless of age.

RMA also submitted results from their project titled "Tire Service Life Results from an RMA Study of Scrap Tires" which collected tire service life data from over 14,000 out of service tires at seven tire scrap facilities in seven states in the U.S. RMA concluded that chronological age alone does not determine the service life of a tire. Of the tires they examined, RMA found that approximately 43 percent had low or uneven tread wear, 25 percent had road hazard damage, and 17 percent had been repaired with 87.5 percent of those repairs done improperly. (Docket No. NHTSA-2005-21276)

Safety Research & Strategies, Inc. (SRS)

Safety Research & Strategies, Inc. (SRS), is a research, consulting and advocacy firm specializing in motor vehicle safety issues. SRS submitted four separate letters to the Docket, the major points of which are summarized herein.

SRS recommended the use of the NHTSA Phoenix field study tire data in future rulemaking actions. They stated that the RMA Scrap Tire Study is fundamentally flawed and reaches inappropriate conclusions about tire age and that tire property damage and injury claims would be a more appropriate source to make those determinations. SRS agreed with Ford that NHTSA should issue a consumer advisory regarding tire age as a risk factor. They recommend that the tire industry provide an expected service life of tires considering the differing characteristics of tires and their different rates of degradation. SRS recommended to NHTSA that Early Warning Reporting (EWR) requirements be expanded to include tires that are greater than 5 years old, and that the date of manufacture, instead of the current date code, be molded onto the tire sidewalls as an interim step to address tire aging. SRS also recommended that NHTSA examine international tire standards and trade associations from other countries and regions and recommendations and practices from tire technical and trade associations. (Docket No. NHTSA-2005-21276)

North Carolina State University

A North Carolina State University study, titled "People Do Not Identify Tire Aging as a Safety Hazard," was submitted to the docket (NHTSA-2005-21276-32). In this published study, a survey asked participants to list all factors they believed contributed to tire problems. In part, the authors found that the general public is not aware of tire aging as a potential hazard, and they recommended various types of consumer warnings labels and literature with tire aging information to be available at tire and automobile dealerships. (Docket No. NHTSA-2005-21276)

APPENDIX H: TIRE MODELS USED IN VALIDATION TESTING (4)

Test Phase	PC or LT*	Market **	Tread Design***	Tire Brand Name	Tire Model	Tire Manufacturer	Tire Size	Load Range	Speed Rating	Test Wheel Size
4	LT	Repl.	AS	Big O [Big O Tire]	X/T BIG FOOT (356)	Cooper Tire and Rubber Co., U.S.	LT265/75R16	123 (E)	N	16x7.5J
4	PC	OE	AS	Bridgestone	B450	Bridgestone Corp., Japan	P205/65R15	92	S	15x6J
4	PC	Repl.	Winter	Bridgestone	Blizzak DM-Z3	Bridgestone Corp., Japan	P235/70R16	105	Q	16x7J
4	LT	OE	AS	Bridgestone	Duravis M773 II	Bridgestone Corp., Japan	LT265/75R16	123 (E)	-	16x7.5J
4	PC	OE	AS	Continental	Contitrac TR	Continental A.G., Germany	P265/70R17	113	S	17x8J
4	PC	Repl.	RFT	Dunlop	SP Sport 4000 DSST (RFT)	Goodyear Tire and Rubber Co., U.S	P225/60R17	98	T	17x6.5J
4	PC	OE	AS	Firestone	Wilderness AT I	Bridgestone Corp., Japan	P265/75R16	114	S	16x7.5J
4	PC	Repl.	AS	Futura [Pep Boys]	Scrambler A/P (P-XL)	Cooper Tire and Rubber Co., U.S.	P235/75R15XL	108	S	15x6.5J
4	PC	OE	AS	General	Ameri G4S	Continental A.G., Germany	P205/65R15	92	T	15x6J
4	PC	Repl.	Winter	Goodyear	Ultra Grip	Goodyear Tire and Rubber Co., U.S	P235/75R15XL	108	S	15x6.5J
4	LT	OE	AS	Hankook	DynaPro AS	Hankook Tire Co. Ltd., So. Korea	LT245/75R16	120 (E)	-	16x7J
4	PC	Repl.	AS	Michelin	Cross Terrain SUV	Group Michelin, France	P265/75R16	114	S	16x7.5J
4	LT	OE	AS	Michelin	LTX A/S	Group Michelin, France	LT245/75R16	120 (E)	R	16x7J
4	PC	Repl.	Winter	Michelin	X-Ice	Group Michelin, France	205/65R15	94	Q	15x6J
4	PC	Repl.	AS	Mohave [Discount Tire]	RS	Goodyear Tire and Rubber Co., U.S	P205/65R15	92	R	15x6J
4	LT	Repl.	Winter	Nokian	Hakkapeliitta 10LT	Nokian Tyres P.L.C., Finland	LT235/85R16	120 (E)	-	16x6.5J
4	LT	Repl.	Winter	Nokian	Hakkapeliitta LT	Nokian Tyres P.L.C., Finland	LT265/75R16	119 (D)	-	16x7.5J
4	PC	Repl.	AS	Sumitomo	HTR+	Sumitomo Rubber Industries LTD., Japan	225/60R16	98	V	16x6.5J
4	PC	Repl.	AS	Toyo	800 Ultra	Toyo Tire & Rubber Group, Japan	P235/60R16	99	T	16x7J
4	LT	Repl.	AS	Yokohama	Geolandar A/T+II	Yokohama Rubber Co. Ltd., Japan	LT285/75R16	122 (D)	Q	16x8J
4	LT	Repl.	AS	Yokohama	Geolandar A/T+II	Yokohama Rubber Co. Ltd., Japan	LT285/75R16	122 (D)	Q	16x8J

Notes:
* PC or LT: Construction Type including Passenger Car (PC), Light Truck (LT), or Non-Service (NS)
** Market: Original Equipment (OE) or Replacement (Repl.)
*** Tread Design: All-Season (AS), Run-Flat (RFT), Winter

APPENDIX I: PERCEIVED BENEFITS TO PRE-OVEN AGING ROADWHEEL BREAK-IN

The property that makes elastomers unique is their ability to be deformed and return to their original conformation (e.g., stretching and releasing a rubber band). They are able to do this because the long chain molecules of the rubber are coiled around one another, often described as a "plate of spaghetti." Two constraints are needed to make simple rubber molecules work in a highly engineered composite such as a tire: Crosslinking and Reinforcement

Crosslinking, chemically bonding the rubber molecules together at various points along their length, is necessary to keep the rubber molecules from permanently slipping past one another and conforming to some new shape. Crosslinks are formed by sulfur containing compounds when two active sites, typically carbon-carbon double bonds, are at the proper distance, have the proper orientation and sufficient energy is available. As the number of sulfur atoms in the crosslink decreases, the bond decreases in flexibility and extensibility. Additionally, relatively inflexible carbon-carbon and sulfoxide bonds are formed especially during thermo-oxidative aging. During rubber processing and tire curing the forces on the rubber molecules are essentially uniaxial, causing the rubber molecules to adopt a physical conformation that has the minimum energy in that system. A tire in service is subjected to multi-axial strain and the rubber molecules will conform to a minimum energy configuration in this new system. This takes place on two levels: physical reconfiguration to achieve minimum energy in the new system, the Mullins effect, and breaking of some inflexible bonds to allow the chains to adopt a minimum energy conformation in the multi-axial system. If sufficient thermo-oxidative aging is allowed to take place before the molecules achieve a new conformation, the chains will be locked in place in a uniaxial conformation.

Reinforcement can be simplistically thought of as the ability of the rubber compound to be "rigid" at low strains and still stretch at higher strains. All tire compounds use very small particle size fillers that reinforce the compound by forming a rigid network of particles, and physically restricting the movement of the molecular chains past the small particles. These physical effects are essentially reversible; however, as the flexibility of the crosslinks is decreased, the magnitude of the effect is amplified. Thus, rubber compounds without a roadwheel break-in cycle will be subjected to non-representative strains during their initial load (such as during a roadwheel durability test) after thermo-oxidative aging. Some rubber compounds are also reinforced with a resin system, typically a 3-dimensional network formed from the reaction of resorcinol and an aldehyde derivative which is 'intertwined' with the polymer macromolecular system. This system tends to soften under strain as crosslinks are broken and harden in thermo-oxidative aging as new crosslinks are formed. Thus a resin containing compound subjected to thermo-oxidative aging alone will be much harder than the same compound in on-road service that has seen an equal amount of thermo-oxidative aging coupled with mechanical cycling. A roadwheel break-in cycle will tend to reduce this discrepancy, and also allow the resin system to reform around the polymer chains in the multi-axial minimum energy conformation. The direct implications to oven aging and a post-aging roadwheel durability test are:

APPENDIX I: PERCEIVED BENEFITS TO PRE-OVEN AGING ROADWHEEL BREAK-IN (CONTINUED)

1) If a new tire is statically oven aged (i.e., no mechanical cycling) to the point where the hardness levels of various rubber components match targets observed in used on-road tires, the mechanical cycling of the tires during post-oven roadwheel durability test will soften resin reinforced rubber in the tire such that it may no longer match used on-road tire targets. However, if the tire is broken in on a roadwheel to pre-soften the reinforced rubber components, and then oven aged to the desired hardness levels, the tire will be tested in a state more representative of a used on-road tire.

2) The goal of a laboratory roadwheel test, whether on new tires or post oven-aging, is to evaluate real world tire performance. As previously stated, new tires have residual stresses imparted from their manufacture that are quickly relieved during on-road service. Ideally, these residual stresses should be relieved before a high severity roadwheel test. For instance, the FMVSS No. 109 High Speed test for passenger vehicle tires specifies a 2-hour tire break-in at 50 mph (80 km/h) before the first speed step of 75 mph (120 km/h). This break-in was also retained in when the High Speed test was upgraded in FMVSS No. 139. The new FMVSS No. 139 Endurance and Low Pressure test sequence is also conducted 75 mph (120 km/h). The concern is that residual stresses in new could become "locked-in" during oven aging and produce failures not representative of real world performance during the post-oven roadwheel durability testing if not adequately relieved prior to aging.

Additionally, since a goal of the test development project was to develop the shortest test possible, efforts to improve uniform circulation of the oxygen-rich inflation gas within the tire structure are considered desirable. The Inflation Pressure Retention (IPR) testing indicated that it takes some period of time for the pressure trapped in the structure of a new tire (often referred to as intra-carcass pressure) and its air loss rate to equilibrate after mounting. (For this reason the first 30 days of air loss rate data are discarded when using the ASTM F-1112 procedure at room temperature.) A brief roadwheel break-in should open up the channels within the cords and uncover the non-brass coated steel belt edges to allow faster pressure equilibration and more effective wicking of the oxygen-rich inflation gas through the tire structure during oven aging. Breaking in the tires with the 50/50 O_2/N_2 inflation gas would theoretically be more effective than with air inflation (as done now) in that it would pre-fill the tire composite with a gas of higher oxygen content than air.