TIRE AGING:

A Summary of NHTSA's Work

U.S. Department of Transportation

National Highway Traffic Safety Administration

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I. EXECUTIVE SUMMARY

Tire aging is a phenomenon involving the degradation of the material properties of a tire which overtime can compromise its structural integrity and jeopardize its performance. Tire aging takes place whether a tire is driven or not and for this reason is a concern for spare tires and tires that are not regularly driven. The effect of aging may not be visibly detectable on these tires and their integrity may be compromised even though they could be showing a great deal of remaining tread.

The current light vehicle tire standard, Federal Motor Vehicle Safety Standard (FMVSS) No.139; *"New pneumatic radial tires for light vehicles"* does not include a test to evaluate the risk of tire failure due to aging during a tire's service life.[1]

Before FMVSS No.139 became effective, the agency conducted several phases of research leading the development of the agency's tire aging protocol[2], including a field study, aging methods evaluation, tire aging method refinement and validation testing on pre-FMVSS No. 139 tires. FMVSS No. 139-compliant tires were evaluated in the last phase of research to the tire aging test protocol developed in the previous phases.

The last phase of research showed that the group of FMVSS No.139-complaint tires oven-aged following our current aging protocol presented an improved performance in the roadwheel durability test when compared with the group of pre-FMVSS No. 139 tires that were previously tested following the same protocol. Pre-FMVSS No. 139 tires developed more severe failure

[1] The National Highway Traffic Safety Administration (NHTSA) was asked by members of Congress to consider the feasibility of requiring a tire aging test during the hearings that preceded the enactment of the Transportation Recall, Enhancement, Accountability, and Documentation (TREAD) Act (H.R. 5164, Pub. L. No. 106-414, Nov. 1, 2000). Congress suggested this test to evaluate the risk of failure at a period later in the life of a tire than the current regulation, which only evaluates new tires.

[2] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0029

modes[3] when subjected to the endurance and low pressure test than FMVSS No.139-compliant tires did, with the latter developing mostly cracks.

NHTSA research also found that especially in the warmer parts of the United States, including Arizona, Florida, Texas and Southern California, there appears to be a relationship between the age of the tire and the propensity of the tire to fail.

Our most recent analysis on NASS-CDS[4] tire-related crash[5] data from 2007 through 2010 shows a 35 percent reduction in tire crashes (17,019 to 11,047), a 50 percent reduction in fatalities (386 to 195) and a 42 percent reduction in injuries (11,005 to 6,361) when compared with annual averages from 1995 through 2006. The overall fatalities decreased by 20 percent between 2007 and 2010 (dropping from 41,059 to 32,885 fatalities), and overall police reported crashes decreased by 10 percent between 2007 and 2010 (dropping from 6,024,000 to 5,419,000).

The agency believes that the more stringent FMVSS No. 139 has helped create better-quality and safer tires. This change in light vehicle tire performance may be one of the reasons the percentage of tire-related crashes, injuries and fatalities, has decreased in the 2007-2010 time frame, since FMVSS No. 139 became effective on September 1, 2007. Another reason may be that the number of vehicle crashes due to tire failures from under-inflation has decreased since

[3] Failure modes that will result in non- compliance under FMVSS No.139 (visual evidence of tread, sidewall, ply, cord, inner liner, or bead separation, chunking, broken cords, cracking, or open splices, and the tire pressure is less than the initial test pressure). The agency has not provided pass/fail criteria for the oven aging protocol.
[4] The National Automotive Sampling System - Crashworthiness Data System
[5] The NASS-CDS contains on its General Vehicle Form the following information: a critical pre-crash event, vehicle loss of control due to a blowout or flat tire. In 2009, NHTSA changed its selection of crashes involving vehicles more than 10 years old. Adjustments were made in this analysis for older vehicles in 2009 and 2010 data so that we had comparable data from 2007 to 2010.

all new light vehicles were required to have tire pressure monitoring system (TPMS) starting September 1, 2007 (FMVSS No.138).

An improved roadwheel performance of oven-aged FMVSS No. 139-compliant tires when compared to oven-aged pre-FMVSS No. 139 tires and an overall reduction of tire-related crashes have lessened the tire aging concerns since the TREAD Act was enacted.

At this time, the agency does not believe it is necessary for motor vehicle safety to add a tire aging requirement to its light vehicle tire standard due to the following reasons: First, FMVSS No.139 has contributed to an increased robustness of oven-aged light vehicle tires. Our research has shown that oven-aged FMVSS No. 139-compliant tires are more resistant to degradation than oven-aged pre-FMVSS No. 139 tires. Second, light vehicle tires are performing better on the road as reflected in our most recent crash data. Third, a mandatory TPMS on light vehicle tires since 2007 has helped alert consumers to under-inflation that is also known to degrade tires faster.

Tire aging is still a concern in the more southern parts of the Sun Belt states[6], during the summer months when heat build-up can cause a failure. Spare tires remain a concern as well, since they are not replaced regularly and may still show enough tread, even though the structural integrity of the tire may be compromised by aging. Adding to this concern, spare tires are often rotated into use and are sold as used tires.

For the reasons stated above, the agency is coordinating a promotional and educational initiative to raise consumer awareness about tire aging issues and how to prevent these types of failures. Campaign initiatives and outreach efforts to consumers, partners and the automotive

[6] Southern California, Arizona, New Mexico, Texas, Louisiana, Mississippi, Alabama, Georgia, and Florida

service industry will include social media messages, fact sheets, infographics, and other web content.

II. INTRODUCTION

Tire aging is a phenomenon involving the degradation of the material properties of a tire which overtime can compromise its structural integrity and jeopardize its performance. When aging occurs, tires are more prone to failure, which could, at best cause an inconvenience, or at worst lead to a motor vehicle crash.

The effect of aging may not be visibly detectable. Tire aging takes place whether a tire is driven or not and its structural integrity may be compromised even though they could be showing a great deal of remaining tread. Traditionally, the consumer judges the end of service life of a tire to be independent of tire age and defined as the point when the tread wears down to the 2/32" tread wear indicator bar molded in the tread. Therefore, spare tires, and other tires that are not regularly used, seldom get replaced and their structural integrity may be weakened even though the tires show a great deal of remaining tread.

The aging mechanisms that are most likely to affect the relative safety of a tire are chemical and mechanical in nature. Chemical aging occurs due to the combined effect of heat and oxygen on the rubber compound and mechanical aging results from the stresses and strains that a tire incurs during its normal use.

Environmental conditions like heat and oxygen are known to deteriorate the material properties of the tires and affect their durability in service. NHTSA research shows that especially in the warmer parts of the United States, including Arizona, Florida, Texas and Southern California, there appears to be a relationship between the age of the tire and the propensity of the tire to fail[7]. These tire failures can result in motor vehicle crashes. From 1995 to 2006, NHTSA estimates that about 386 fatalities annually may be attributed to tire failures of all types[8]. Tire aging failures tend to appear in the high heat states, in the summer months, during the day, while the vehicle is being driven at highway speeds. All of these factors make it more difficult for the tire to dissipate heat, and heat build-up is the main factor in these types of failures.

Tire failures can be caused by a number of factors such as under- or over- inflation of the tire, overloading of vehicles, road hazards, improper maintenance, structural defects, improper installation and tire aging. One common belief is that tire failures are caused by poor maintenance. Proper tire maintenance is important for good wear and the safety performance of a tire, but tire aging is a degradation phenomenon that can occur due to the chemical reaction within the rubber components with oxygen and heat. This is different from inadequate inflation and maintenance problems. Some vehicle manufacturers recommend that tires be replaced every six years regardless of use and a number of tire manufacturers recommend 10 years as the maximum service life for a tire because aging can affect the performance of the tires even if they have adequate tread and proper inflation.

It is difficult to estimate how many crashes are caused specifically by tire aging. Based on analysis of data from 2005 to 2006, NHTSA estimates that with pre-FMVSS 139 tires, 90 fatalities and over 3,200 injuries occurred annually as the results of crashes that were probably caused by tire aging or where tire aging was possibly a significant factor[9].

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[7] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0055 Data has been collected in these four specific states, but we see no reason that other more southern sun belts states wouldn't have similar issues.
[8] NHTSA's NASS-CDS database
[9] Estimates are based on analysis of three different databases (NMVCCS, NASS-GES and NASS-CDS).

The current standard for light vehicle tires, FMVSS No.139, does not include a test that could evaluate the risk of tire failure at a period later in a tire's service life. NHTSA has developed an oven-aging test for light vehicle tires which simulates age-related tire degradation. The agency tested tires before FMVSS No. 139 was effective and after to this new protocol. The testing of FMVSS No.139-complaint tires showed an improvement in roadwheel performance after oven-aging.

This report summarizes the work and research the agency has done to address the safety problem of tire degradation due to age and the agency's plan to follow to bring awareness to consumers and the general public about this safety issue.

III. BACKGROUND

The U.S. House of Representatives' Committee on Energy and Commerce conducted hearings in late 2000, regarding the fatalities and injuries resulting from the tread separation failures of Firestone Radial ATX, Radial ATX II, and Wilderness AT tires on specific models of Ford, Mercury, and Mazda light trucks and SUVs. At the time, members of Congress expressed concern that the then-current light vehicle tire standard only tested new tires and did not evaluate how well tires perform at a period later in their life and asked the agency to consider the feasibility of including an aging test. It was believed at the time that if such an aging method was successful, then the light vehicle tires could eventually be required to meet a standard that would make them more resistant to operational degradation and possibly reduce their failure rate during normal highway service.

The TREAD Act[10] was enacted on November 1, 2000, as a consequence of the Committee's actions and Congress instituted two major tire related initiatives at NHTSA with the Act. One was an upgrade of the two Federal Motor Vehicle Safety Standards for light passenger vehicle tires to require increased performance requirements for new tires. The second was a requirement for a tire pressure monitoring system (TPMS) on all new light vehicles. These two initiatives strived to improve two somewhat related tire problems (in-service structural failures and under-inflation).

The first initiative required NHTSA to revise and update the passenger and light truck tire standards, FMVSS No. 109; *New pneumatic and certain specialty tires* and No.119; *New pneumatic tires for motor vehicles with GVWR of more than 4,536 kilograms (10,000 pounds)*

[10] H.R. 5164, Pub. L. No. 106-414

and motorcycles. The second initiative resulted in FMVSS No. 138; *Tire pressure monitoring systems.* The FMVSS No. 138 addresses under-inflation and became effective September 1, 2007.

To address Congress' tire aging concerns, the agency introduced three alternative tests for evaluating passenger vehicle tires' long term durability or aging tests on the March 5, 2002 NPRM for the new light vehicle tire standard. These alternatives included a peel strength test, an extended duration roadwheel endurance test, and an oven-aging test followed by a roadwheel endurance test.

Based on the agency's initial evaluation, as well as comments and data received from industry after the NPRM was published, the agency decided to defer action on the proposal of adding an aging test to the new standard. The FMVSS No. 139, the current and more stringent passenger vehicle tire standard was published on June 26, 2003 and does not include a tire aging test requirement. This new standard unifies regulation for passenger and light truck tires that were previously regulated under FMVSS No. 109 and FMVSS No. 119, respectively.

The lack of industry uniform approach to tire aging and the need to develop a laboratory-based accelerated service life test as well as having a better understanding of service-related tire degradation prompted the agency to start its own tire aging research.

On August 10, 2005, the president signed into law the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The SAFETEA-LU directed the Secretary of Transportation to submit a report to Congress by August 2007 on research conducted to address tire aging, and a summary of findings and recommendations.

The Report to Congress[11] defined the safety problem, included a summary of the tire aging research and a list of items the agency needed to complete before deciding whether to pursue rulemaking. The agency reported that three aging protocols submitted by industry were considered. 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 oven-aging, which subjected new tires, inflated with an oxygen-enriched gas, to elevated temperatures in an oven for an extended period of time. The oven-aged tires were then subjected to roadwheel tests. The report also stated that NHTSA research 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 continued its research after the Report to Congress was released, finalizing an oven-aging test procedure[12] and publishing a report that summarizes the performance of FMVSS No. 139-compliant tires to the agency's oven-aging test protocol[13].

[11] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0042
[12] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0029
[13] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0070

IV. SAFETY PROBLEM

A. Agency's tire-related crash data

The agency examined its crash data files to gather available information on tire-related problems causing passenger vehicle crashes. The National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) uses trained investigators to collect data on a sample of tow-away light vehicle crashes around the country. These data can be extrapolated to national estimates. NASS-CDS data from 1995 through 2006 (see table below) shows an estimated 17, 019 tow away crashes caused per year by "blowouts or flat tires", 386 fatalities and 11,005 non-fatal injuries were found in these tow-away crashes.

Table 1: Light Vehicle Tire-related Crashes, Fatalities and Injuries
(Annual Averages)

NASS-CDS	1995-2006	2007-2010
Crashes	17,019	11,047
Fatalities	386	195
Injuries	11,005	6,361

NHTSA's most recent study on tire-related crash data since the Report to Congress was issued was an analysis on NASS-CDS data from 2007 through 2010. This analysis shows a 35 percent reduction in tire crashes (17,019 to 11,047), a 50 percent reduction in fatalities (386 to 195) and a 42 percent reduction in injuries (11,005 to 6,361). The overall fatalities decreased by 20 percent between 2007 and 2010 (dropping from 41,059 to 32,885 fatalities), and overall police reported crashes decreased by 10 percent between 2007 and 2010 (dropping from 6,024,000 to 5,419,000). It is important to note that the new, more stringent, tire standard for light vehicles tires FMVSS No. 139 became fully effective on September 1, 2007 and also all new light vehicles were required to have TPMS starting September 1, 2007.

B. Agency's tire aging-related crash data

NHTSA turned to its National Motor Vehicle Crash Causation Study (NMVCCS) database to determine the number of tire aging cases occurring annually. These are crashes examined by our trained crash investigators that were collected from July 2005 to July 2007. Our investigators learned about these crashes when emergency medical services (EMS) were dispatched. They arrived on the scene and tried to determine the causal factors leading up to the crash. During this process they took pictures of the tires, measured tread depth, took inflation pressures, made a scene diagram, and noted those cases in which the tires were considered the critical reason for the crash and the last causal factor leading up to the crash.

From these NMVCCS cases, all tread separations and sidewall separations (the way that tires might potentially fail due to factors related to tire aging) were examined. A total of 50 cases in NMVCCS were found with tread separations or sidewall separations. These 50 cases were examined by a team of NHTSA tire and crash causation experts trying to determine whether tire aging was not a factor at all in the case, an unlikely cause of the crash, possible cause of the crash, or probable cause of the crash. The factors we examined, included the age of the tire (when a TIN was available), the age of the vehicle, what the tire looked like in the crash scene photographs (to determine how it failed), tire pressure (could be too high or too low) in that tire or other tires of the vehicle (in some cases of tread separation, the tire retained pressure), whether all the tires on the vehicle were the same, or different brand / size, the mileage of the vehicle, the tread depth, whether the tire appeared to have been properly maintained, if, in the driver interview, the tire had recently been a spare tire, and was the tire recalled for a defect, etc. The team found that 16 cases could potentially be tire aging related. From these analyses the team determined that tire aging was the “probable” cause of 3 crashes, tire aging was a possible cause of 12 crashes and in 1 case the team could not determine if it was “possible or probable”.

In determining the possibility that tire aging was a factor in the crash, we did not use the area of the country the crash occurred in or the area of the country the vehicle was from. However, in the 16 cases we decided were potentially or possibly related to tire aging, there were 5 from the southwestern Arizona area (which included some vehicles registered in California), 5 from Florida, 4 from Southern California, 1 from Texas and 1 from North Carolina. So, 15 out of 16 were from high heat states. NMVCCS did not collect data in all 50 states, but from a representative sample of locations. Appendix D provides the NMVCCS cases examined.

The agency also looked at the available 2005 and 2006 data in NASS-CDS and NASS-GES[14] databases where blowout/flat tires was a causal factor (all three data sources have the same definition for blowout/flat tires and causal factors) and applied the same percentage found in weighted NMVCCS (23.2%) to be tire aging related to the NASS counts to estimate national figures for tow-away crashes and police reported crashes. Using this method, we can estimate how many possible or probable tire aging cases would have occurred if we had the same reporting in those NASS files as in NMVCSS.

[14] National Automotive Sampling System – General Estimated System

Based on analyses of data from 2005-2006 (all of these tires were manufacturer before FMVSS 139 took effect), the agency estimates that 90 fatalities and over 3,200 injuries occurred annually as the result of crashes that were probably caused by tire aging or where tire aging was possibly a significant factor[15].

Table 2: Light Vehicle Tire-related Crashes, Fatalities and Injuries Possibly Caused by Tire Aging – Pre-FMVSS 139 Tires
(Annual Averages)

NMVCCS – NASS	2005-2006
Fatalities	90
Injuries	3,200

C. Weather effect on tire performance

Average ambient air temperature also plays an important role in the likelihood of tire failures. The agency 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 Sun Belt states, with 68 percent of the fatalities occurring in California, Arizona, Texas, and Florida.

This trend was also 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[16]. 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

[15] This method resulted in an estimated 90 fatalities and 2,550 injuries on average in 2005 and 2006. In addition we considered unreported crashes, which added 660 injuries.
[16] Report to Congress: http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0042

these involved tires over six years old. While tire insurance claims are not necessarily an absolute measure of the failures[17] due to aging, it is reasonable to assume that a considerable number of insurance claims for tire adjustments in the four states listed combined with NHTSA's fatality data and NMVCCS data given above is an indication that a large number of tire failures are likely occurring because of the effect of sustained high temperature on tires.

The trend was observed again in a study by the Rubber Manufacturers Association (RMA)[18], in which scrap tires in Arizona, California, Florida, Pennsylvania, Massachusetts, Oregon, and Illinois were examined. The results of the RMA study were somewhat obscured in that structural failures of the tires and road hazard damage were not separately coded. For instance, a tire with a full tread separation and a tire with a nail in the tread were both coded as having "tread damage". Therefore, trends for tire structural failures, which are infrequent events, are lost in the vast numbers of road hazard incidents. Additionally, vehicles involved in a tire-related traffic crash serious enough to cause injury or death were not likely to be taken to a tire retailer post-crash for new tires. The failed tire(s) usually are retained by the insurance company or legal counsel rather than returning to the retailer for an adjustment or replacement. Therefore it is very unlikely that tires causing serious crashes would be found in the scrap tire stream examined by the RMA. Nonetheless, the study showed that after four years, the rate of "tire damage" was significantly greater in Arizona, than in the other states and that in almost every case, tires from those states with higher average ambient temperatures had higher rates than states with lower average ambient temperatures.

[17] With a sufficiently high applied stress or strain, every material is subject to failure. In use, tire materials are subjected to the effects of fatigue, wear, heat, corrosion, and other external damage. The magnitude and frequency of externally applied forces and moments can ultimately cause rubber to fatigue and tear or cause steel and polyester cords to rupture. The process of tire structural failure can progress slowly, or be essentially immediate; it depends upon the structure itself, the magnitude and rate of imparted energy, and external conditions such as temperature. Taken from http://www.nhtsa.gov/staticfiles/safercar/pdf/PneumaticTire_HS-810-561.pdf

[18] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0015

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. This is supported by the fact that NHTSA's tire pressure surveys of over 11,500 vehicles[19] did not show increased numbers of underinflated tires in Texas, Oklahoma, Louisiana, and Florida, relative to the rest of the country. Nor is the agency aware of any evidence that these states possess harsher roads, or have more road debris than other states.

[19] http://www-nrd.nhtsa.dot.gov/Pubs/811086.pdf

V. AGENCY'S RESEARCH

NHTSA started its tire aging research in 2002 when the agency decided to defer action on the proposed addition of an aging test to the new FMVSS No.139[20]. The main goals of the research were to develop an accelerated, laboratory-based tire aging test for new tires suitable for regulatory purposes and to evaluate tire safety performance after aging. Before FMVSS No.139 became effective, several phases of research were conducted, including a field study, aging methods evaluation, tire aging method refinement and validation testing on pre-139 tires. After FMVSS No.139 became effective, 139-compliant tires were evaluated to the tire aging test protocol developed in the previous phases.

A. Research before FMVSS No.139

Field Study[21]

The first objective of the research was to develop a better understanding of service-related tire degradation over time. In order to do so, the agency studied how tires change during actual service as measured by changes in their roadwheel performance levels and quantitative material properties when compared to new versions of each tire. Since the rate of degradation of tire rubber components increases with temperature, NHTSA expected that the "worst case" tires in service in the United States would be found in the relatively hotter Sun Belt States. It was thought that designing a tire aging test to simulate service in a severe environment that has high relative tire failure rates would offer the best margin of safety nationwide. Per this approach, Phoenix, Arizona, was selected as the location for the collection of tires for analysis and six different tire models were collected from service on privately owned vehicles. Within the set of

[20] 49 CFR 56166, (October 30, 2009)
[21] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0055

six tire models, a total of 172 in-service tires and nine 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. Both the new and Phoenix-retrieved tires were subjected to stepped-up speed (SUS)[22] and stepped-up load (SUL)[23] tests until tire failure[24], both of which were performed on a 1.7-m (67-inch) diameter indoor laboratory roadwheel (See Figure 1).

Figure 1: Roadwheel test

The results of this research indicated that there are two mechanisms operating to produce changes in tire properties. First is degradation of the rubber compound and material interfaces due to the effects of heat and reaction with oxygen (thermo-oxidative aging). The second is the effect of cyclic fatigue during tire deformation, which can initiate and propagate cracks and separations.

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[22] The Stepped-Up Speed (SUS) roadwheel tire test is based on FMVSS No. 139 High Speed tire test and follows the procedures of that test for the first 210 minutes. Per the High Speed test conditions, the tire is subjected to a two hour break-in on the roadwheel at 80 km/h (50 mph), then run continuously and uninterrupted for 90 minutes through three 30-minute test stages at the following speeds: 140, 150, and 160 km/h (87, 93, and 99 mph).

[23] The Stepped-Up Load (SUL) roadwheel test is based on FMVSS No. 139 Endurance tire test and follows the procedures of that test for the first 34 hours. The tire is inflated, stabilized at the laboratory temperature, then run continuously and uninterrupted at 120 km/h (75 mph) for 4 hours at 85% maximum load, 6 hours at 90% maximum load, and then 24 hours at 100% maximum load.

[24] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0059

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

Aging methods evaluation[25]

This phase focused on developing an accelerated, laboratory-based tire test that simulates real world tire aging. The six tire models that had previously been evaluated after long-term service on vehicles in Phoenix, AZ were evaluated using three candidate methods of laboratory aging: two long term endurance tests proposed by Michelin and Continental and an oven-aging test proposed by Ford. Although the two long term endurance tests were effective in creating internal cracks and separations as observed in on-road tires, neither could consistently replicate the material properties of used tires. The most successful method at replicating the overall material properties of used tires was the one provided by Ford, who recommended that the agency use a method in which the tire is inflated using the 50% nitrogen and 50% oxygen (50 % N_2 / 50 % O_2) mixture, and heated in an oven for a period of time to accelerate the aging process by speeding up chemical reactions, and thus material property changes. Research showed that increased time in service in Phoenix or increased time of laboratory aging produced changes consistent with the mechanism of thermo-oxidative aging[26]. The oven-aged tires were also tested using a SUL test until the tire failed, intended to compare the structural integrity of the tire after aging to that of a new tire. Oven-aging tires for six to eight weeks at 60°C to 70°C decreased the

[25] Phase 2 report
[26] Chemical aging due to the combined effect of heat and oxygen.

running time on the SUL test to that of a tire with approximately two to five years of service in Phoenix.

Tire aging method refinement[27]

This phase of research evaluated the prototype laboratory oven-aging and roadwheel test sequence created in the first two phases on tire models previously not tested and further refined the process. The effect of a 23-hour break-in cycle on a roadwheel prior to oven-aging was also investigated. A final test procedure of approximately five weeks in the oven at 65°C with weekly maintenance of the oxygen enriched inflation gas, and a short, low severity pre-oven roadwheel break-in was selected as the final test method to best replicate four- to six- year old used tires in Phoenix.

The physical properties and the roadwheel durability of twenty additional passenger and light truck tires which had been oven aged at 60°C to 70°C, were compared to those of new tires of the same model. The properties of the rubber compound of all tires changed in a manner consistent with thermo-oxidative aging. It was also shown that aging for five to eight weeks at temperatures of 60°C to 70°C, while inflated with the 50 % N_2 / 50 % O_2 mixture, produced percentage changes within the range of the results in the previous phases of research. The tires were tested using the SUL test and the time to failure for all models decreased after oven-aging to levels that were consistent with the tire models used in the previous phases of research.

The initial 34 hours of the SUL test are identical to the endurance portion of the updated FMVSS No. 139 test for light vehicle tires. While the new tires ran significantly beyond the 34 hour portion of the SUL test, nearly one-half of the tires aged for five weeks at 65°C or seven

[27] Phase 3 report

weeks at 70°C presented failure modes prior to 34 hours. There was no significant correlation between initial running time and the reduction of running time due to oven-aging.

Validation testing[28]

Validation testing was conducted to determine the test parameters that would be most appropriate for an oven-aging test protocol; the final protocol can be found in NHTSA's tire aging docket[29]. Testing was performed on pre-FMVSS No. 139 passenger and light truck tires, including original equipment (OE) and replacement tires. The results show that OE tires maintained their material properties and roadwheel performance better than replacement tires[30] and passenger car tires maintained their material properties and roadwheel performance better than the light truck tires.

Twenty tire models were aged and tested to determine if the FMVSS No. 139 Endurance and Low Pressure test was an appropriate test to determine the durability of aged tires. Tires were oven aged for 3, 4, or 5 weeks at 65°C while inflated with the 50 % N_2 / 50 % O_2 mixture and then tested according to the FMVSS No. 139 Endurance and Low Pressure test. Aging three weeks at 65°C is approximately equivalent to 2.4 years of service and aging five weeks at 65°C approximates the aging experienced by a tire with 4.0 years of service in Phoenix. All new tires completed the Endurance and Low Pressure test and 46 percent (6/13) of passenger tire models and 43 percent (3/7) models of light truck tires exhibited no failures after oven-aging up to 5 weeks at 65°C.

[28] Phase 4 report
[29] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0029
[30] All OE passenger tires and 67 percent of OE light truck tires completed the test without failure.

Figure 2: Components of a radial tire[31]

Approximately 70 percent of the failures[32] for passenger car tires took place in the critical belt edge and shoulder region of the tire (see Figure 2 for tire components). The light truck tires failures were predominantly separations between components in the innerliner and sidewall region of the tire, including two tires that separated in the oven during aging. Inspection of the failures indicated that the separations were likely initiated by a buildup of air pressure between the components. Some of the failure modes observed were the following: belt edge separation, separation between belts, loss of tread and belt, tread element tear/chunk out, innerliner detachment, sidewall split and rupture, white sidewall separation, tread and belt separation, black sidewall separation. Appendix B contains pictures of some of the failure modes observed and Appendix E includes a list of failure modes for all tires after five weeks of oven aging.

Seven of 13 models (54 percent) of passenger tires and two of seven models (29 percent) of the light truck models completed the Endurance and Low Pressure test after all of the aging conditions. For the six models of passenger tires that failed, very few failures were observed

[31] Taken from: http://www.nhtsa.gov/staticfiles/safercar/pdf/PneumaticTire_HS-810-561.pdf
[32] Failures in this context mean failure modes that will result in no compliance under FMVSS No. 139.

prior to five weeks of oven-aging. The failure times for light truck tires were, on-average, less than those for passenger car tires.

Nine of the tire models had no failures even after being oven-aged for five weeks, tires from two models failed after three weeks of oven-aging, three additional models did not complete the test after four weeks of oven-aging and a total of 11 models did not complete the test after five weeks of oven-aging.

B. Research after FMVSS No.139[33]

The purpose of the last phase of research was to evaluate the performance of selected FMVSS No. 139-compliant light vehicle tires to the oven-aging protocol developed by the agency (See Appendix A for the test sequence). Twenty models of three tires each were selected, only replacement tires were tested this time since pre-FMVSS No.139 original equipment tires performed well after oven-aging in the previous phase of research. The tires were a mix of passenger and light truck tires. Purchased tires were less than one-year old, based on the date of manufacture stamped on the tire. Tires were artificially aged for five weeks in an oven while being exposed to high concentrations of oxygen. The aged tires were then tested in accordance with FMVSS No.139 to determine the effect of aging on tire performance. The results indicate that some tires exhibit reduced performance in endurance testing after aging. The majority of tires that did not perform well in the endurance tests had cracks at the shoulder. In extreme cases, the cracks in the shoulder propagated to partial or full tread separation at the shoulder.

[33] http://www.regulations.gov/#!documentDetail;D=NHTSA-2005-21276-0070

After five weeks in the oven, the tires were removed and inspected for signs of oxidation damage. All three tires from one model exhibited tread shoulder cracks and exposed belt edges after oven-aging. One of these tires experienced total air loss in the oven.

A total of three tires representing two different tire models did not complete the 34-hour endurance test. Two of these tires of the same model exhibited tread separation at the shoulder. The third tire from a different model had sidewall delamination. The remaining two tires of this model completed the endurance test without failure.

All of the remaining 54 tires from the 20 tire models completed the endurance testing. Twenty-five of the tires exhibited visual evidence of failure at the completion of the tire endurance testing. Only seven models of tires completed the oven-aging and tire endurance test without failure modes noted in any tires in the set.

The most frequently occurring failure was cracking in the shoulder (55.6 percent), other failure modes observed were: cracking in tread groove (22.2 percent), cracking in base of tread at shoulder (18.5 percent), tread separation at shoulder (18.5 percent). Smaller percentages of tread shoulder blister, tread chunking, cracking in sidewall, sidewall delamination, sidewall bubbles, sidewall deformation at splice. See Appendix C for some pictures of the failure modes observed and Appendix F for a list of the failure modes for all the tires tested.

VI. OBSERVATIONS

The agency's last phase of research showed that the group of FMVSS No.139-complaint tires oven-aged following our current aging protocol presented an improved performance in the roadwheel durability test when compared with the group of pre-FMVSS No.139 tires that were previously tested following the same protocol. Pre-FMVSS No.139 tires developed more severe failure modes[34] when subjected to the endurance and low pressure test than FMVSS No.139-compliant tires did, with the latter developing mostly cracks.

During validation testing of pre-FMVSS No.139 tires, the passenger car tires tested maintained material properties and roadwheel performance better than light truck tires. This was due to the fact that before FMVSS No.139 became effective, passenger tires were regulated under the FMVSS No. 109 ("Passenger car tires") and light truck tires under the separate FMVSS No. 119 ("Tires for vehicles other than passenger car"). FMVSS No. 119 had less stringent endurance test conditions (lower speeds and higher inflation pressures) than FMVSS No. 109 and did not include a high speed test for tires. FMVSS No. 139 expanded the scope of the passenger car tire standard by adding light truck tires with load ranges C, D, and E, and now covers tires used on vehicles with a gross vehicle weight rating of 10,000 pounds or less.

We believe that the more stringent FMVSS No. 139 has helped create better-quality and safer tires. This change in light vehicle tire performance may be one of the reasons the percentage of tire-related crashes, injuries and fatalities, has decreased in the 2007-2010 time frame, since FMVSS No. 139 became effective on September 1, 2007. Another reason may be that the

[34] Per 139 performance requirements, a tire fails when there is visual evidence of tread, sidewall, ply, cord, innerliner, or bead separation, chunking, broken cords, cracking, or open splices, and the tire pressure is less than the initial test pressure.

number of vehicle crashes due to tire failures from under-inflation has decreased since all new light vehicles were required to have TPMS (FMVSS No.138) starting September 1, 2007.

Our current aging protocol simulates the aging of tires with four years of service in Phoenix, Arizona, a metropolitan area with some of the highest average ambient temperatures in the US. Some vehicle manufacturers recommend that tires be replaced every six years regardless of use and a number of tire manufacturers recommend 10 years. Tires in service in the northern states are generally replaced before tire aging becomes an issue, but aging is still a concern in the Sun Belt states for light vehicle tires, in the summer months, during the day, when they are driven at highway speeds. For this reason, the agency encourages tire manufacturers to continue oven-aging testing and consider using the agency's oven-aging protocol to evaluate tire degradation due to heat.

In summary, NHTSA's main findings with regard to tire aging can be listed as follows:

- The aging mechanisms that are most likely to affect the relative safety of a tire are chemical and mechanical in nature. Chemical aging occurs due to the combined effect of heat and oxygen on the rubber compound and mechanical aging results from the stresses and strains that a tire incurs during its normal use.
- In the warmer parts of the United States where we have data, including Arizona, Florida, Texas and Southern California, there appears to be a relationship between the age of the tire and the propensity of the tire to fail.
- Tire aging failures tend to appear in the high heat states, in the summer months, during the day, while the vehicle is being driven at highway speeds. All of these factors make it more difficult for the tire to dissipate heat, and heat build-up is the main factor in these types of failures.

- 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.
- Our current oven-aging protocol approximates the aging experienced by a tire with four years of service in Phoenix, Arizona.
- Oven-aged FMVSS No.139-compliant tires developed less severe failure modes (mostly cracks) than oven-aged pre-FMVSS No.139 tires after endurance and low pressure test.

VII. CONCLUSIONS

When Congress suggested the idea of a tire aging test requirement, passenger car tires and light truck tires were regulated under FMVSS No. 109 and FMVSS No. 119 respectively. It was believed at the time that a tire aging standard would make tires more resistant to degradation. The agency believes that an improved roadwheel performance of oven-aged FMVSS No. 139-compliant tires when compared to oven-aged pre-FMVSS No. 139 tires and an overall reduction of tire-related crashes have lessened the tire aging concerns since the TREAD Act was enacted.

At this time, the agency does not believe it is necessary for motor vehicle safety to add a tire aging requirement to its light vehicle tire standard due to the following reasons: First, FMVSS No.139 has contributed to an increased robustness of oven-aged light vehicle tires. Our research has shown that oven-aged FMVSS No. 139-compliant tires are more resistant to degradation than oven-aged pre-FMVSS No. 139 tires. Second, light vehicle tires are performing better on the road as reflected in our most recent crash data. Third, a mandatory TPMS on light vehicle tires since 2007 has helped alert consumers to under-inflation, which is also known to degrade tires faster.

Tire aging is still a concern for the Sun Belt states, during the summer months when heat build-up can cause a failure. Spare tires remain a concern as well, since they are not replaced regularly and may still show enough tread, even though the structural integrity of the tire may be compromised by aging. Adding to this concern, spare tires are often rotated into use and are sold as used tires.

For the reasons stated above, the agency is coordinating a promotional and educational campaign to raise consumer awareness about tire aging issues and how to prevent these types of failures. Campaign initiatives and outreach efforts to consumers, partners and the automotive service industry will include social media messages, fact sheets, infographics, and other web content.

Appendix A

The aging protocol followed in the last phase of research was as follows:

1. The tires were mounted on rims and inflated to the pressure recommended by FMVSS 139 with compressed air.
2. The tires were conditioned for three hours at 38° C +0°/-6° C at the pressure recommended by FMVSS 139.
3. The tire pressure was adjusted to the pressure recommended by FMVSS 139 and the tires ran a two-hour break-in in accordance with FMVSS-139 high speed (85 percent of rated load at 80 km/hour).
4. After break-in all tires were purged of air and re-inflated to maximum sidewall pressure with a mixture of 50% nitrogen / 50% oxygen.
5. Each tire / wheel assembly was placed in an aging oven at 65° C.
6. Tires were removed from the oven once per week for inspection and purge
    a. Remove tire from oven.
    b. Allow tire / wheel assembly to cool for two-hours.
    c. Measure oxygen content and tire pressure.
    d. Purge tire of 50/50 mix.
    e. Re-inflate with 50/50 mix to maximum sidewall pressure.
    f. Total time for each tire in oven was 840-hours (5 weeks).
7. At the end of five weeks, the tires were removed from the oven and inspected for signs of oxidation damage.
8. Tires were purged of 50/50 mix and re-inflated with compressed air to the pressure recommended by FMVSS 139.
9. The tires ran a 34-hour standard tire endurance cycle using the tire pressure recommended by FMVSS 139.
10. Immediately following the standard tire endurance test the pressure was reduced to the pressure recommended for the low pressure endurance test per FMVSS 139 and the 1.5-hour low pressure performance cycle was run in accordance with FMVSS-139.
11. Tires were inspected at the end of the 35.5 tire-endurance test for signs of failure modes to the sidewall or tread surfaces.

Appendix B Pre-FMVSS No. 139 Tire Testing Results

Figure B1: Belt edge separation

Figure B2: Loss of tread and belt

Figure B3: Tread and belt separation

Figure B4: Black sidewall separation

Figure B5: Innerliner detachment

Figure B6: Sidewall split and rupture

Appendix C FMVSS No. 139-compliant Tire Testing Results

Figure C1: Tread separation at shoulder

Figure C2: Cracking in shoulder

Figure C3: Tread shoulder cracking out of oven

Figure C4: Cracking in tread groove

Figure C5: Cracking at base of tread shoulder

Figure C6: Sidewall bubbles

Appendix D NMVCCS cases of tire blowouts/flats that are causal factors

CASE ID	Decision – tire aging related
2005041600322	Possible
2005076597981	Possible or Probable
2005078436546	Possible
2005079624441	Possible
2006041601822	Possible
2006041600586	Possible
2006041508831	Possible
2006049137713	Possible
2006078436729	Possible
2006079625365	Possible
2007078732571	Possible
2007078598651	Possible
2007041508056	Probable
2007043731551	Possible
2007079624348	Probable
2007079624588	Probable
2005002585502	
2005002585522	
2005009276241	
2005012695842	
2005012695962	
2005012696062	
2005041601002	Unlikely
2005043602021	

2005072603441	Unlikely
2005074433782	
2005075153621	
2005075585121	
2005078436041	
2005078598203	Unlikely
2005078436684	
2006012696787	
2006012695866	
2006012695907	Unlikely
2006012695087	
2006041600921	Unlikely
2006048103147	
2006049186275	Unlikely
2006078436969	Unlikely
2006078436011	
2006078598111	Unlikely
2006079624962	
2006079624102	Unlikely
2007041600690	
2007048102151	Unlikely
2007078436391	Unlikely
2007079624747	
2007012694714	
2007076597349	
2007078732711	

Appendix E **Pre-FMVSS No. 139 Tire Testing - Failure Modes**

Passenger Tires

Tire Manufacturer	Tire Name	Tire Size	Failure Mode
Futura [Pep Boys]	Scrambler A/P(P-XL)	P235/75R15XL	Sidewall Cracking
Futura [Pep Boys]	Scrambler A/P(P-XL)	P235/75R15XL	Complete Tread and Belt 2 Detachment
Goodyear	Ultra Grip	P235/75R15XL	Tread Shoulder Cracking + Belt Edge
Goodyear	Ultra Grip	P235/75R15XL	Tread Chunking
Firestone	Wilderness AT I	P265/75R16	No Visible Failure
Firestone	Wilderness AT I	P265/75R16	Sidewall Cracking
Bridgestone	Blizzak DM-Z3	235/70R16	No Visible Failure
Bridgestone	Blizzak DM-Z3	235/70R16	No Visible Failure
Mohave [Discount Tire]	RS	P205/65R15	Tread Shoulder Cracking + Belt Edge
Mohave [Discount Tire]	RS	P205/65R15	No Visible Failure
Michelin	Cross Terrain SUV	P265/75R16	No Visible Failure

Michelin	Cross Terrain SUV	P265/75R16	Sidewall Rupture + Delamination
Michelin	X-Ice	205/65R15	No Visible Failure
Michelin	X-Ice	205/65R15	No Visible Failure
Sumitomo	HTR+	225/60R16	Sidewall Separation
Sumitomo	HTR+	225/60R16	Belt Edge Exposed, Belt Edge
Toyo	800 Ultra	P235/60R16	No Visible Failure
Toyo	800 Ultra	P235/60R16	No Visible Failure

Light Truck Tires

Tire Manufacturer	Tire Name	Tire Size	Failure Mode
Yokohama	Geolandar A/T+II	LT285/75R16	No Visible Failure
Yokohama	Geolandar A/T+II	LT285/75R16	No Visible Failure
Nokian	Hakkapeliitta 10LT	LT235/85R16	Complete Tread and Belt 2 Detachment
Nokian	Hakkapeliitta 10LT	LT235/85R16	Complete Tread and Belt 2 Detachment

Nokian	Hakkapeliitta LT	LT265/75R16	Plycoat Delamination - Interface
Nokian	Hakkapeliitta LT	LT265/75R16	Innerliner Separation
Big O [Big O Tire]	X/T BIG FOOT (356)	LT265/75R16	Failed During Oven Aging
Big O [Big O Tire]	X/T BIG FOOT (356)	LT265/75R16	Failed During Oven Aging

Appendix F FMVSS No. 139-compliant Tire Testing - Failure Modes

Passenger Tires

Tire Manufacturer	Tire Name	Tire Size	Failure Mode
Hankook	DYNAPRO AS	P265/70R17	Tread separation at shoulder (Inboard side)
Hankook	DYNAPRO AS	P265/70R17	Tread separation at shoulder
Hankook	DYNAPRO AS	P265/70R17	Tread shoulder blister; tread separation ; air loss
Goodyear	ASSURANCE	205/65R15	Cracking in tread groove, cracking in shoulder, sidewall deformation at splice
Goodyear	ASSURANCE	205/65R15	Cracking in tread groove, cracking in shoulder, sidewall deformation at splice
Goodyear	ASSURANCE	205/65R15	Cracking in tread groove, cracking in shoulder, sidewall deformation at splice

CONTINENTAL	ContiTrac TR	P265/70R17	Cracking in shoulder
CONTINENTAL	ContiTrac TR	P265/70R17	Cracking in shoulder
CONTINENTAL	ContiTrac TR	P265/70R17	Cracking in shoulder
PIRELLI	P6 FOUR SEASONS	P225/55R18	Cracking in shoulder
PIRELLI	P6 FOUR SEASONS	P225/55R18	Cracking in shoulder
PIRELLI	P6 FOUR SEASONS	P225/55R18	Cracking in shoulder
FUTURA -- Pep Boys	SCRAMBLER A/P	P235/75R15	Cracking at base of tread shoulder
FUTURA -- Pep Boys	SCRAMBLER A/P	P235/75R15	Cracking at base of tread shoulder
FUTURA -- Pep Boys	SCRAMBLER A/P	P235/75R15	Cracking at base of tread shoulder
UNIROYAL	TIGER PAW TOURING	205/60R16	Cracking at base of tread shoulder
UNIROYAL	TIGER PAW TOURING	205/60R16	Cracking at base of tread shoulder
UNIROYAL	TIGER PAW TOURING	205/60R16	Cracking in sidewall, cracking at base of tread shoulder
FUTURA	SCRAMBLER A/P	P235/75R15	No visible failure
FUTURA	SCRAMBLER A/P	P235/75R15	No visible failure
FUTURA	SCRAMBLER A/P	P235/75R15	Tread Chunking

NOKIAN	WR	205/55R16	No visible failure
NOKIAN	WR	205/55R16	No visible failure
NOKIAN	WR	205/55R16	No visible failure
KUMHO	ECSTA ASX	215/55R17	Oven Failure -- Tread shoulder cracking with belts exposed
KUMHO	ECSTA ASX	215/55R17	Oven Failure -- Tread shoulder cracking with belts exposed
KUMHO	ECSTA ASX	215/55R17	Oven Failure -- Tire failure in oven. Tread Shoulder cracking
SAILUN	ATREZZO SH402	P205/60R16	Sidewall Delamination
SAILUN	ATREZZO SH402	P205/60R16	No visible failure
SAILUN	ATREZZO SH402	P205/60R16	No visible failure
CONTINENTAL	Extreme Winter Contact 94T BW	205/55R16	No visible failure
CONTINENTAL	Extreme Winter Contact 94T BW	205/55R16	No visible failure
CONTINENTAL	Extreme Winter Contact 94T BW	205/55R16	No visible failure
Goodyear	INTEGRITY	P235/65R17	No visible failure
Goodyear	INTEGRITY	P235/65R17	No visible failure
Goodyear	INTEGRITY	P235/65R17	No visible failure

FIRESTONE	DESTINATION LE	P235/70R16	No visible failure
FIRESTONE	DESTINATION LE	P235/70R16	No visible failure
FIRESTONE	DESTINATION LE	P235/70R16	No visible failure
BRIDGESTONE	B450	P205/65R15	No visible failure
BRIDGESTONE	B450	P205/65R15	No visible failure
BRIDGESTONE	B450	P205/65R15	No visible failure

Light Truck Tires

Tire Manufacturer	Tire Name	Tire Size	Failure Mode
Hankook	DYNAPRO AS	LT245/75R16	Cracking in shoulder
Hankook	DYNAPRO AS	LT245/75R16	Cracking in shoulder
Hankook	DYNAPRO AS	LT245/75R16	Cracking in shoulder
Goodyear	WRANGLER	LT275/70R17	No visible failure
Goodyear	WRANGLER	LT275/70R17	Pre-existing cosmetic condition on tire shoulder

Goodyear	WRANGLER	LT275/70R17	Pre-existing cosmetic condition on tire shoulder
BRIDGESTONE	DURAVIS M773 II	LT265/75R16	No visible failure
BRIDGESTONE	DURAVIS M773 II	LT265/75R16	No visible failure
BRIDGESTONE	DURAVIS M773 II	LT265/75R16	No visible failure
Cooper	DISCOVERER ATR	LT275/65R18	No visible failure
Cooper	DISCOVERER ATR	LT275/65R18	Sidewall bubbles
Cooper	DISCOVERER ATR	LT275/65R18	No visible failure