What Applied Research Has Learned From Industry About Tire Aging

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Meetings With Industry

- From October 2002 through January 2003, NHTSA had meetings to discuss tire aging with:
  - Continental
  - Ford
  - General Motors
  - Goodyear
  - Michelin
  - ASTM F09.30 Committee
  - SAE Highway Tire Committee
  - Akron Rubber Development Lab
  - Smithers Scientific Services
  - Standards Testing Laboratory
- Also have had numerous informal contacts with industry

In-Use Tire Failures

Failures of Tires In the Field

- Industry has told NHTSA that common tire failure modes seen in the field are:
  - Belt Edge Cracking
    - May lead to tread separation
    - Known safety problem!
  - Bead Failure
    - Results in more rapid air loss
    - Generally not safety problem!

Failures of Tires In The Field

- Infrequently seen tire failure modes:
  - Tread Chunking
    - Usually due to manufacturing/quality control problems
    - Not generally a safety problem
  - Sidewall Failure (Blowout)
    - Occurs after tire sidewall damaged
    - Known safety problem!

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General Agreement: Older tires are more likely to suffer one of these failures than are new tires

→ Tire Aging Matters

Types of Tire Aging

- Industry has told NHTSA that while there are many aging mechanisms acting on a tire, only two really matter:
  - Chemical Aging
    - Changes in tire rubber due to heat and oxygen interactions
    - Oxygen permeation into area around end of top belt (Belt #2) is what really matters
  - Mechanical Aging
    - Changes in rubber due to mechanical stress/strain
    - Area around end of Belt #2 has highest stress/strain
    - Mechanical aging effects are greatest in this area

What We've Learned from Firestone Tire Failures

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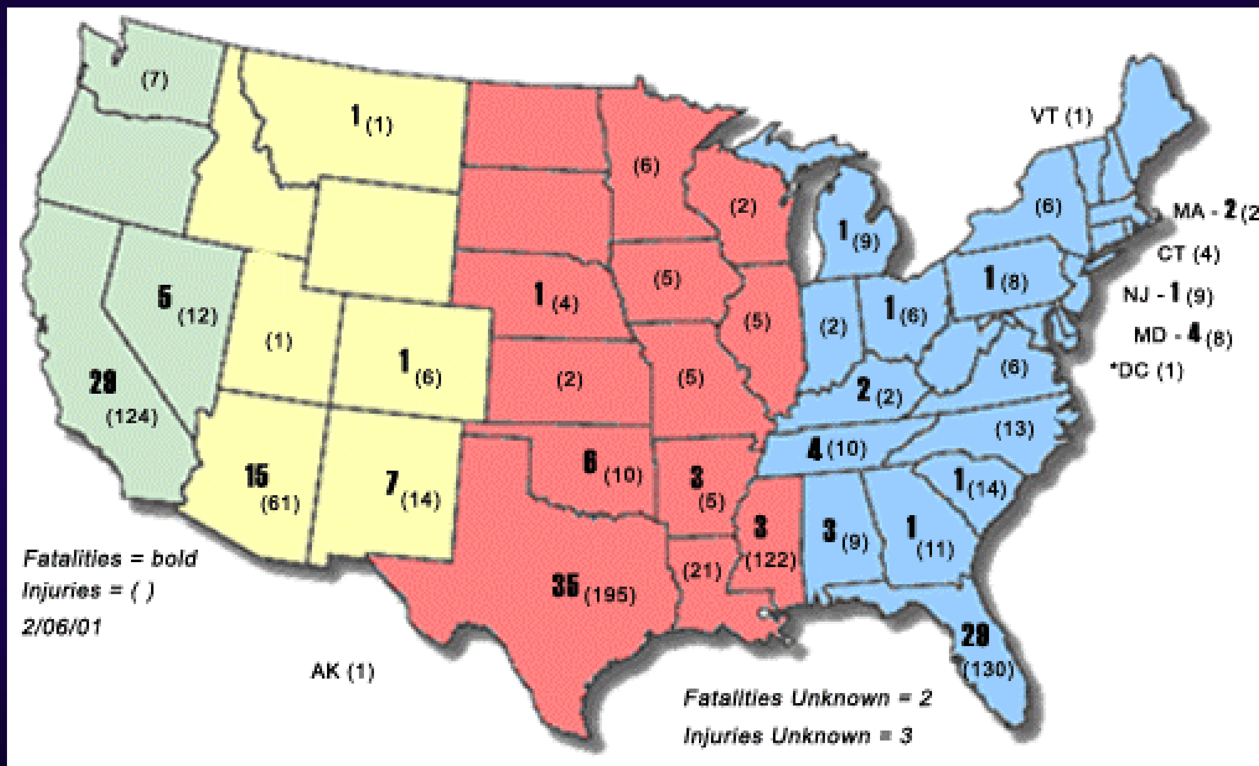
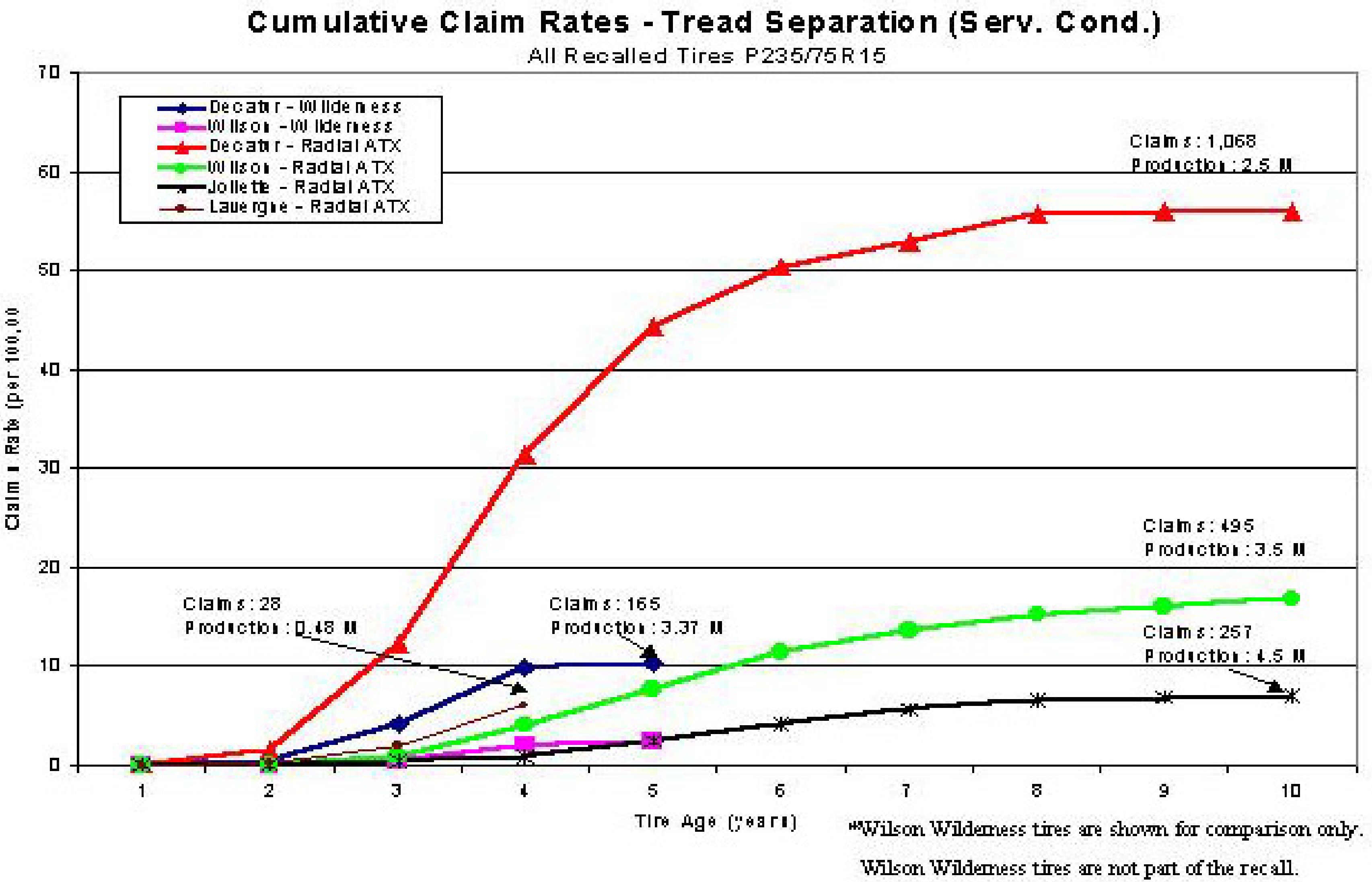
Fatalities and Injuries Resulting from Firestone Tire Failures by State



Most tread separations occurred in warm climate states: CA, AZ, TX, MS, FL

Tread Separation Rate (service condition): Recalled Tires Only*



Summary Firestone Data

- High ambient temperatures result in an increase in tire failures (southern states)
- High ambient temperatures accelerate the rate of chemical aging in tires
- Tire failures don’t begin to manifest until about 2-3 years of use
- Most importantly: Testing new tires from the factory may not identify defective designs

Possible Tire Aging Tests

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Possible Aging Test Protocols

- **Five possible aging test protocols were advanced during NHTSA's discussions with industry:**
  - Air Permeability Test (ASTM F1112-00)
  - General Motors Accelerated Tire Endurance (ATE) Test
  - Michelin LTDE Test
  - Oven/Mechanical Aging Endurance Test
  - Roadwheel conditioning followed by Peel Force Test

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Air Permeability - Test Philosophy

- Chemical aging is due to oxygen diffusing through the tire composite and reacting with the internal components
- If the rate at which air diffuses through the tire is slowed, the rate of chemical aging will be similarly slowed
- Other tests in the proposed FMVSS 139 will hopefully ensure that mechanical aging effects are reasonably handled

Air Permeability - Test Philosophy

- **According to Tire Manufacturers**
  - Tires with more expensive, halogenated-butyl inner liners lose air at a rate of 2.0 - 2.5 percent per month
  - Tires with cheaper, non-halogenated-butyl inner liners lose air at a rate 4.0 - 5.0 percent per month
  - For the same inner liner compound, a thicker inner liner will lower the air loss rate
  - A reduction in air loss rate, by a factor of 2, may be achievable for some tires

Air Permeability Test

- **Test Procedure:**
  - Place inflated tire in climate controlled room
    - Inflated with air
    - Maximum permitted inflation pressure
  - No data taken for first month
  - Measure percent air lost per month for next five months
  - Industry standard procedure for doing this - ASTM F1112-00 “Standard Test Method for Static Testing of Tubeless Pneumatic Tires for Rate of Loss of Inflation Pressure”

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Air Permeability Test

- Good Points:
  - Well established, mature test procedure
  - Easy to perform
  - Inexpensive
    - Cost expected to be well below that of other proposed tests
- Issues/Problems:
  - Does not deal with mechanical aging
  - Only permits one countermeasure to chemical aging

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General Motors Accelerated Tire Endurance (ATE) Test

- **Test Procedure:**
  - Test tires on an actual vehicle
    - Tires inflated with air
    - Front tires - 26 psi inflation pressure

      - T&RA rated load for 26 psi
    - Rear tires - minimum inflation pressure required to carry T&RA maximum rated load
    - Different values used for LT tires
    - Align suspension to minimize tire wear

General Motors Accelerated Tire Endurance (ATE) Test

- **Test Procedure:**
  - Drive vehicle 45,000 miles on public roads in Texas and Mexico
    - Speeds range from 70 to 25 mph
    - Paved and gravel surfaces
  - Test takes approximately 11 weeks to perform

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General Motors Accelerated Tire Endurance (ATE) Test

- **Good Points:**
  - Appears to do good job of mechanically aging tire
  - Tests tire on a “real” road surface (flat road surface vs. a roadwheel with curved steel surface)
  - Well established, mature, test run by major vehicle manufacturer and multiple tire manufacturers for many years
  - GM vehicles have not had tire tread separation problems while using this test

General Motors Accelerated Tire Endurance (ATE) Test

- **Issues/Problems:**
  - ATE does not do good job of chemically aging tire
    - Experimental data show essentially no oxygen permeation into rubber around end of Belt #2 during test
  - Poor repeatability
    - Run outdoors on public roads
  - High cost
    - Typically, all four tires on vehicle are identical
      - Different front/rear loadings
    - Estimated $50,000 cost to perform by NHTSA

Michelin Long Term Durability Endurance (LTDE) Test

- **Test Procedure (Michelin submission, not NPRM version):**
  - Test performed on 67-inch roadwheel
  - P-metric standard load tires tested at 111% of maximum T&RA load, 40 psi pressure
    - Different load/pressure combinations used for Extra Load and LT tires
  - Inflation mixture of 50% oxygen, 50% nitrogen used

Michelin LTDE Test

- **Test Procedure:**
  - Ambient temperature of 38° C (100° F)
  - 60 mph speed
  - Michelin believes that 100 hours of LTDE testing simulates one year of actual tire service

Michelin LTDE Test

- **Good Points:**
  - Well established, mature, test run by a major tire manufacturer for many years
  - Test intended to predict and exceed tire performance requirements of General Motors ATE test
  - Pattern of tire failures in LTDE test matches pattern of field failures
    - Lots of belt edge cracking, bead failures
    - Infrequent chunking, sidewall failures

Michelin LTDE Test

- **Good Points:**
  - Test generates temperature distribution throughout tire that simulates normal operation
    - Conversely, oven aging heats tire uniformly
    - Actual tire has hot spots near edges of Belt #2 and at bead when vehicle is being driven
    - LTDE test mimics these hot spots
  - Cost well below that of General Motors ATE

Michelin LTDE Test

- **Issues/Problems:**
  - Not presented with data as to how test ages rubber around end of Belt #2
    - Concerned as to whether test long enough to obtain adequate oxygen permeation into end of Belt #2 rubber
      - GM ATE test takes five times longer than three years of aging with LTDE test and still doesn't have adequate oxygen permeation
  - No correction for effects of tire size due to testing on road wheel
  - Test does not accurately simulate aging of tires on stationary vehicle

Conditioning followed by Peel Force Test

- Test Procedure (from draft FMVSS 139 final rule)
  - Condition tire for 24 hours on 67-inch roadwheel
    - 75 mph
    - 40°C ambient temperature
    - 26 psi air inflation
    - 90%/100%/110% of maximum load rating labeled on tire with 8 hours at each load step
  - After conditioning, a test specimen is cut out of the tire
  - The force required to separate adjacent belts is measured using the ASTM D413-98 test procedure

Conditioning followed by Peel Force Test

- **Good Points:**
  - Peel force test is established, mature, test procedure
  - Peel force testing is quick, straightforward test to perform
  - Peel force test has been around for many years
  - Experimental data show that peel force decreases as a tire ages

Conditioning followed by Peel Force Test

- **Issues/Problems:**
  - Conditioning procedure is not well established or mature
    - Parameters recently developed by NHTSA
  - Not expected to substantially chemically age tire
    - 24 hours with air at lower than maximum pressure just isn't long enough

Conditioning followed by Peel Force Test

- **Issues/Problems:**
  - Peel force alone is insufficient to characterize tire durability
    - High initial peel force = lower resistance to crack initiation, better resistance to crack propagation
    - Low initial peel force = higher resistance to crack initiation, lower resistance to crack propagation
    - Which is better?
  - Some brands have a much higher peel strength for any age of tire than other brands. Yet both brands of tires have acceptable performance in field

Conditioning followed by Peel Force Test

- **Issues/Problems:**
  - Peel force test data are noisy
    - Typical plot contains many peaks, valleys
    - Industry is not sure how to interpret
      - Use maximum?, average?, …

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Oven/Mechanical Aging Endurance Test

- **Test Procedure:**
  - Heat tires aging in oven interspersed with mechanical stressing on 67-inch roadwheel
  - Inflation mixture of 50% oxygen, 50% nitrogen used
  - Oven temperature of 70° C (158° F)
    - Industry has presented data that higher temperatures may cause rubber reversion problems
    - Two ASTM procedures use this temperature
  - Time in oven needs to be determined
  - Roadwheel testing parameters need to be determined

Oven Aging

- **Effect of Temperature**
  - Rate of chemical aging due to oxidation increases with temperature
    - However, cannot increase temperature above 70° C without having thermal reversion problems
  - In their comments to the FMVSS 139 NPRM, RMA stated that rate of chemical aging due to oxidation doubles for each 10° C increase in temperature
    - At 70° C, a tire chemically ages 32 times faster than at 20° C

Oven Aging

- **Effect of Temperature (continued)**
  - Industry experts have told us that doubling for each 10° C rule only works for thin sheets of rubber
    - For an actual tire, situation is more complicated. Oxygen diffusion is limited by:
      - Physical boundaries – diffusion rates changed by different layers of tire (cords, skim stock, belts, etc.)
      - Temperature – at higher temperatures, outer layers consume oxygen before can reach inner components
      - Oxide layers – which harden rubber from outside in and impede oxygen diffusion (slow down aging)
    - They recommended use of finite element models with limited diffusion to obtain a more accurate calculation

Oven Aging

- **Effect of Oxygen Partial Pressure**
  - Rate of chemical aging due to oxidation increases with difference in partial pressures of oxygen between inside and outside of tire
    - Can fill tire with 50% oxygen, 50% nitrogen inflation mixture to accelerate chemical aging
    - Cannot use more than 50% oxygen in inflation mix without causing safety problems
    - Over-inflating tire will also accelerate chemical aging but may cause non-realistic permanent stretching of tire

Oven Aging

- **Effect of Oxygen Partial Pressure (continued)**
  - In their comments to FMVSS 139 NPRM, the RMA stated that rate of chemical aging increases by 50% if a 50/50 oxygen/nitrogen mixture is used
  - Based on limited diffusion finite element tire models, industry experts have estimated a 72 to 84 % increase in chemical aging of rubber around end of Belt #2

Oven Aging

- **Combining Inflation Mixture and Temperature Effects**
  - Based on limited diffusion, finite element tire modeling combining these two effects, a tire at 70° C filled with a 50/50 oxygen/nitrogen mixture will chemically age a typical tire by one year in 35 days
    - Acceleration factor is approximately 10
  - Substantially slower than rate given to NHTSA by RMA

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Mechanical Aging

- Typical vehicle driven 12,000 to 15,000 miles per year
- This equates to approximately 10 million cycles (revolutions of the tire)
- Fatigue plots typically reach an asymptote for large numbers of cycles
  - Do not have to perform all 10 million cycles per year to adequately fatigue tire

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Oven/Mechanical Aging Endurance Test

- **Good Points:**
  - Can select oven, roadwheel parameters to accurately simulate actual, in-service, chemical and mechanical aging seen by tires
  - Costs of oven/mechanical aging well below that of on-road testing

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Oven/Mechanical Aging Endurance Test

- **Issues/Problems:**
  - Procedure not well established or mature
    - Parameters had to be developed by VRTC
    - Parameter setting process discussed below
  - No data as to how well procedure ages rubber around edge of Belt #2 either chemically or mechanically