Can reinforced rubber technology applied for blast resistance of structures?

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Sept 24, 2004
What are the engineering functions of tires?

- Support 2000 – 5000 lbs of vehicle weight with a tire weight of 20-30 lbs.
  - Pneumatic design.
- Run days and nights at high speed of 60-75 mph on the road for 50,000 miles
- Damp out shock and vibration due to rubber hysteresis
  - Dissipate mechanical vibration → heat/damage
- Last 4 to 6 years
  - Truck tire carcass can ideally last to 1 million miles
Tire Manufacturing Process, Technology and Predictive Testing

Manufacturing Analysis

- **Safety**
  - Lost Time Rate
  - OSHA Reportable Rate

- **Quality**
  - Uniformity:
    - Process and components
    - Product: force and balance
  - Appearance

- **Productivity**
  - Tires/Day, Tons/Day, FPV/Day
  - Waste % FVP,
  - Output per associate hour
Tire Manufacturing Process

- Component preparation
  - Bead, ply, chafer/sidewall, belt, overlay, tread
  - Banbury, extruder, calender, steelastic

- Tire Assembly
  - Single stage
  - Two-stage: R1 and R2

- Curing:
  - Presses: radial versus bias, platen versus dome
  - Molds: 2-piece, segmented, 3-piece, ventless
Building A Tire

- Start innermost layer (liner) from a circular drum
- Lock beads on the drum
- Apply Apex, sidewall, …, Tread

From Green Tire to Cured Tire

Inspect Green Tires

Send Tires for Curing, Testing, Sorting and Shipping
Tire Assembly

- 2-Stage: Separate carcass building (stage 1) from green tire shaping (stage 2)
  - Advantage:
    - Two stage-1 machines feed one stage-2 machine
  - Disadvantage:
    - Bead unlocking, machine nesting.
Tire Assembly Machine
Tire Assembly Machine

- Green tire shaped at the 2nd stage
Tire curing: Presses and molds

- Molds: final tire shape
  - Mold rings, sidewall plate and tread ring
- Presses: house the molds
  - Bladder curing
  - Pressurized molding
  - Heat supply: steam and gas
Safety

- Corporate safety standards applied globally
- Reports of OSHA incidents in the same format
  - from paper, fax, to electronic update
- Safety benchmarking across all factories equally
- “Target hiring” of associates
- Push for same SOP: upgrade machines worldwide to have the same versions/standards
- Increase of frequency of safety awareness training
  - Safety talk at the beginning each shift
- Extend same safety requirements to contractors and casual labor.
Quality Check: Tire Force Uniformity

- Every radial tires are forced
  - Radial Force Variation
  - Lateral Force Variation
  - Conicity
  - Ply Steer
Quality Check:
Tire Dynamic Balance

- Every radial tires are balanced
  - Static vs couple
  - Exact 2 weights to balance a tire
  - Imbalances can be corrected on the wheel assembly
Tire Uniformity

- **Source:**
  - Component variation, splices, drum runout, mold runout, off-center laid
Tire Spotting

Inboard

Outboard

RSC(2)
O’lay

RSC(1)
O’lay

Viewing from IB to the OB

Tread

Ply 1

Ply 2

Beads

Apex

RSC Olay

1
2
3
4
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12
Tire Spotting : Vector Analysis
A Process Improvement

- **Spotting:**
  - positions of component splices in a tire
  - tire versus mold

- **Why?**
  - To make a tire as “round”/”balanced” as possible for:
    - better force uniformity
    - better dynamic balance

- **Spotting are subject to change**
  - As confirmed by in-situ trials and data analysis after process change

- **Optimal spotting may be different from code to code**
  - Continuous improvement
Trend: Uniformity focused

- Larger tires get more popular
  - SUVs, Vans, High-Performance
- Same Force limits applied regardless of tire size
  - More challenging to meet OE demands
- Dynamic Balance
  - Getting more conscientious in North America
    - although correctable by lead weights on the rim
  - Becoming an image of quality
    - viewable by customers
  - A quick assessment of factory uniformity level
Trend: Total Uniformity System

- National --> International --> Global Standards
- Production -> People -> Cross-Functional
Process Trend: Components

- Single Extrudate to Duplex --> Triplex --> Quadruplex
  - Cycle time reduction on the machine.
- Hot feed to cold feed
  - Compound mixing uniformity
- Apexer to chapex construction
- Double-pass to single-pass on calender
  - Electro-magnetic gauge control - Measurex
- Steelastic to wire calender
- 2 ply to 1 ply carcass
- Nylon --> Polyester --> wire carcass
Process Trend: Tire Machine

- Single-stage to two-stage
  - Increase of production over investment
  - Loss of quality
- Smart Technology: Machine innovation
  - Benefits of single and 2-stage m/c
- Solid (positive) drum to BRC drum
- O-Bell for belt pick-up to Transfer Ring
- Beam light marker to laser beams
- Visual alignment to BETS
- Booked/spooled to extrusion at the m/c
Process Trend: Tire Machine (con’t)

- Manual steps to PLC auto-cycles.
- Tire bar-coding - defect, quality trouble shooting
- Manual component cut to machine cut and splicing
  - Male builder/operator to mixed work force
- More tire-machine centered operation unit
  - prepare the customized components at the tire machine
  - merging the components to reduce cycle times and splicing.
  - Stand-alone tire building manufacturing unit.

Michelin C3M: built on a mandrel, no green inflation
Process Trend: Curing

- Dome curing --> Platen curing
- Steam Curing --> Steam/Gas curing  
  ◆ Energy cost reduction
- PCI (post-cure inflation) --> No PCI  
  ◆ Nylon to polyester
- Manual/mechanical --> PLC control
- Manual tire loading --> Full automation  
  ◆ from lining cement to a complete curing cycle
- Bladderless cure!
- Levels of curing : stepwise improvement goals
Tire Smart Technology

- RF / Telemetry to monitor tire parameters
  - SmarTire, Inc., Schrader Bridgeport, ...
    - Inflation
    - Temp
    - Tire Ids.

- Goodyear Extended Mobility Tire (run-flat) and Michelin PAX
  - Beef-up sidewall and rubber block insert

- Silica tread for low rolling resistance and long wear.
Goodyear Aquatread - Aqua-channels for wet traction

Electric charge to increase traction

Short fiber composite tread: snow and wear

Injection-molded tire components

Tire and vehicle suspension integrated system design

Bullet proof tire - Kevlar carcass: Concord jet

Revisit of urethane tires - solid tires

RSAT - Residual Self Alignment Torque - Tuning
  ◆ Optimizing ply steer, conicity and tread steer
Quality Assurance
Consumer’s Point of View

Oxygen-Enriched Tire Endurance Test

Predictive
Principle and Hypothesis

- A **TRUE** tire endurance test lasts for years
  - A multi-year test program for manufacturers to release a new tire is costly and impractical
- All tire endurance tests accepted as a standard of practice are **ACCELERATED** tests
  - Methods to accelerate an endurance test
    - Higher load
    - Higher speed
    - Lower Inflation
    - Cleated roadwheel (higher magnitude of cyclic loads)
    - Oxygen-enriched?
Rubber Aging - Oxidation

- Real-life tire operation is subject to oxidation
  - Rubber surface in contact of air
    - Exterior
    - Interior
  - Rubber is an insulator of air, including oxygen
    - Oxygen permeation rates differ in types of rubbers
  - Issues of oxidation in fatigue life
    - Question: If the air were of no oxygen, would a tire have a higher endurance life, i.e., longer service mileage/life, given all other parameters equal?
Oxygen-enriched inflation

- Inflate the tire with 50% oxygen air
  ◆ Selected 3 passenger tires, 205/60R15
  ◆ Inflate the tire to 50 psi
  ◆ Regulate the inflation to reach 50% Oxygen
    ◆ As checked with an oxygen concentration analyzer (A portable measuring device)
    ◆ Plastic bag the inflated tires
    ◆ Draw vacuum to insulate the tire exterior surface
  ◆ Store the tires in an elevated-temperature room
    ◆ At 75 degrees C (167F) for 3 weeks
Result of Oxygen-Enriched Inflation

- Measured the tire pressure at the end of 3 weeks
- Inflation pressure was of little change
- Concentration of the oxygen was of little change

Butyl liner
- Rubber of poor crack resistance
- For the purpose of air retention
- A good insulator of oxygen
Issues in Oxygen-Enriched Test

- Safety caution
  - Not favored by the test facilities
    - At least at Goodyear – Strong resistance due to extra safety requirement for an oxygen-enriched room.
  - Inflation capped or maintained test
    - Capped tests was currently used.
    - Maintained test was not available at Goodyear facility without capital investment on an controlled oxygen line
Innovation in Oxygen-Enriched Test

- Perforated liner
  - Provide oxygen passage
  - Little tire structural change
  - Test verification
  - Concept verification

- Potentials?
  - Controlled failure!
  - Minimize from-tire-to-tire test variation
Needs of tire predictive testing

- From manufacturer’s point of view:
  - Validating design improvement
  - Advancing tire technology

- From consumer’s point of view
  - Screening tires for safety and performance
  - Establishing general guidelines in tire service life projection

  Tire removal regulation
Issues in tire predictive testing

- Test acceleration
- Test tires have the same failure mode and mechanism as the tires from the field
- Failure standards
  - Significant variation of remaining endurance life from the point of detectable internal or external damage
  - Damage assessment
  - Uniform standards in tire removal
- Statistical meaning in tire fail/pass rate
  - Develop bogey → QA bogey → DOT bogey
Traditional Setup of Resiliometer

- Tires against wall of cylindrical road wheel
  - Artificial Effects:
    - **Outside**: positive crown
    - **Inside**: negative crown

Fig. 1A

Fig. 1B
Testing MRT on a Roadwheel

- **Outside:**
  - A more severe crown deformation
    - Difference in footprint and belt edge than on a flat road surface

- **Inside:**
  - Less severe crown deformation
  - Favored for bead endurance validation
  - More affected by heat dissipation.
Resiliometers

- Goodyear ODR machines
  - Of smaller diameter (40-60” dia)
  - Outdoors
  - Can have fixed slip

- Goodyear indoor resiliometers
  - Programmable controls in
    - Load
    - Inflation
    - Slip
    - Camber

50,000 mi = 35-day continuous run at 60 mph
How to make a radial tire?
1 Radial tire manufacturing starts with many kinds of raw materials: pigments, chemicals, 30 different kinds of rubber, cord fabrics, bead wire, etc. The process begins with the mixing of basic rubbers with process oils, carbon, black pigments, antioxidants, accelerators and other additives, each of which contributes certain properties to the compound. These ingredients are mixed in giant blenders called Banbury machines operating under tremendous heat and pressure. They blend the many ingredients together into a hot, black gummy compound that will be milled again and again.
2 The cooled rubber takes several forms. Most often it is processed into carefully identified slabs that will be transported to breakdown mills. These mills feed the rubber between massive pairs of rollers, over and over, feeding, mixing and blending to prepare the different compounds for the feed mills, where they are slit into strips and carried by conveyor belts to become sidewalls, treads or other parts of the tire.

Still another kind of rubber coats the fabric that will be used to make up the tire's body. The fabrics come in huge rolls, and they are as specialized and critical as the rubber blends. Many kinds of fabric are used: polyester, rayon or nylon. Most of today's passenger tires have polyester cord bodies.
Another component, shaped like a hoop, is called a bead. It has high-tensile steel wire forming its backbone, which will fit against the vehicle's wheel rim. The strands are aligned into a ribbon coated with rubber for adhesion, then wound into loops that are then wrapped together to secure them until they are assembled with the rest of the tire. Radial tires are built on one or two tire machines. The tire starts with a double layer of synthetic gum rubber called an innerliner that will seal in air and make the tire tubeless.
How to make a radial tire? (4)

4 Next come two layers of ply fabric, the cords. Two strips called apexes stiffen the area just above the bead. Next, a pair of chafer strips is added, so called because they resist chafing from the wheel rim when mounted on a car. The tire building machine pre-shapes radial tires into a form very close to their final dimension to make sure the many components are in proper position before the tire goes into the mold.
5 Now the tire builder adds the **steel belts** that resist punctures and hold the tread firmly against the road. The *tread* is the last part to go on the tire. After automatic rollers press all the parts firmly together, the radial tire, now called a **green tire**, is ready for inspection and curing.
How to make a radial tire? (6)

- **6** The **curing press** is where tires get their final shape and tread pattern. Hot molds like giant waffle irons shape and **vulcanize** the tire. The molds are engraved with the tread pattern, the sidewall markings of the manufacturer and those required by law.

- Tires are cured at over **300 degrees for 12 to 25 minutes**, depending on their size. As the press swings open, the tires are popped from their molds onto a long conveyor that carries them to **final finish and inspection**.
If anything is wrong with the tire – if anything even seems to be wrong with the tire, even the slightest blemish – it is rejected. Some flaws are caught by an inspector's trained eyes and hands; others are found by specialized machines. Inspection doesn't stop at the surface. Some tires are pulled from the production line and X-rayed to detect any hidden weaknesses or internal failures. In addition, quality control engineers regularly cut apart randomly chosen tires and study every detail of their construction that affects performance, ride or safety.
How to make a radial tire? (8)

- This is how all the parts come together: the tread and sidewall, supported by the body, and held to the wheel by the rubber-coated steel bead. But whatever the details, the basics are fundamentally the same: steel, fabric, rubber, and lots of work and care, design and engineering.