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ASTM Equivalent Severity Roadwheel
(Document presented by RMA)

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Creating Equivalent Test Severity for Light Vehicle Tires

by Tim Robinson

As a result of the Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act, passed by the United States Congress in November of 2000, the tire standards published in Title 49 Code of Federal Regulations Part 571 were revised and updated. This update included Part 571.139, "New pneumatic radial tires for light vehicles," also known as Federal Motor Vehicle Safety Standard 139 (or FMVSS 139). The perceived focus of FMVSS 139 was to update the federal tire safety standards to more closely represent real world worst-case conditions on a flat highway surface. These worst-case real world highway (flat surface) conditions resulted in FMVSS 139 compliance endurance testing conditions to be established as follows:

- Speed: 120 kph (75 mph)
- Load: 100 percent of Tire and Rim Association (T&RA) maximum sidewall load
- Inflation Pressure: 75 percent and 58 percent of T&RA maximum
- Ambient Temperature: 38 °C (100 °F)

Laboratory roadwheels are commonly used in the tire industry to facilitate testing of the final product to determine various performance attributes. The curved surface of the 1.7-metre diameter roadwheel may result in significantly different tire behavior than that observed on a highway, or flat surface. The curved surface of the 1.7-m roadwheel when compared to the flat surface results in:

1. Smaller contact area for the same load resulting in higher contact pressure.
2. Higher deflection and more localized bending of the tread region.
3. Items 1 and 2 result in higher cyclic stress-strain amplitudes as the tire rotates through the contact area.
4. Higher stress-strain amplitudes combined with the fact that there is typically less cooling airflow on the indoor roadwheel results in significantly higher tire internal temperatures, which can lead to parasitic losses and removal conditions, such as tread chunking, which are not prevalent in the field.

The purpose of any test is to predict a behavior that would occur in actual practice. If the test misrepresents the actual behavior, it can result in product design decisions that yield inferior performance and could remove commercialized products that are superior in the targeted performance. Roadwheel curved surfaces generate boundary conditions that are different than real-world (highway) operating conditions. ASTM Committee F09 on Tires formed a task group in April 2005 to establish a scientifically based severity adjustment for evaluating light vehicle tires on a 1.7-m roadwheel to enhance tire endurance performance assessments so that the test results would more accurately reflect actual performance under customer usage conditions on the highway (flat surface). The task group believes that a severity adjustment is required for all passenger car tires and light truck tires which:

1. Is scientifically based;
2. Provides equivalent test severity between a roadwheel and the real world highway field service conditions; and
3. Provides an accurate prediction of real-world highway field service condition performance.

Objective

The objective of the task group is to develop a technical standard for light vehicle tires that provides equivalent test severity on a curved surface vs. a flat (real-world) surface.

• Light vehicle tires: Tires for application to vehicles < 10,000 lb GVW (4545 Kg)
• Test severity: Determined by stress-strain amplitude as measured by tire internal temperatures (belt edge, tread lugs, bead, etc.)
• Curved surface: 1.7-m diameter roadwheel (laboratory)
• Flat surface: Real-world outdoor operating temperatures on highway and flat track

Strategy

1. Determine real world tire operating temperatures utilizing a flat surface design of experiment (DOE).
2. Determine curved surface tire operating temperatures utilizing a lab 1.7-meter roadwheel DOE.
3. Develop resultant response surface models that will facilitate matching real-world tire operating temperatures with roadwheel tire temperatures.
4. Develop a technical standard for light vehicle tires that provides equivalent test severity on a curved surface vs. a flat surface.

Data Acquisition Approach

Phase 1 (Outdoor real-world flat surface) and Phase 2 (Indoor 1.7-meter roadwheel) were conducted using two different size tires with two different types of tires within each size (four tires total). From experience and engineering logic it was evident that surface curvature, load, speed and inflation pressure were the biggest contributors to tire running temperatures. Ambient and surface temperatures could also have an effect. The DOE consisted of varying the following three parameters:

• Load: 85 to 115 percent of T&RA SW maximum.
• Inflation Pressure: 50 to 100 percent of T&RA maximum.
• Speed: 80 to 136 km/h (50 to 85 mph)

The DOE included all practical ranges of highway usage load, speed, and inflation pressure.

Temperatures Recorded

Tire internal temperatures were recorded by embedding thermocouples at the belt edges, the center of the tread shoulder elements at the top of the outermost belt, the center of the tread shoulder elements halfway between the outermost belt and the tread surface, and at the center of the bead filler at the top of the rim flange.

Tread surface temperatures at the center of the tread center and shoulder ribs and at the base of the outermost circumferential groove, and track and roadwheel surface temperatures, were measured using a hand held infrared scanner. Tire-contained air temperatures and pressures were measured using telemetry based sensors. Ambient temperatures were also recorded.

The flat outdoor DOE was conducted on a closed flat track in Texas in August 2005 when ambient temperatures ranged from 24 to 38 °C. The 1.7-m roadwheel DOE was conducted at 38 °C ambient temperature at an independent indoor tire test facility. Tires were tested on the flat highway conditions of the DOE and then tires from the same production run and specification were tested on the 1.7-meter roadwheel at the same DOE conditions. This facilitated matching real world tire operating temperatures with roadwheel tire temperatures so that resultant response surface models could be developed.

All of the tire temperatures recorded were higher on the indoor 1.7-m roadwheel when compared to the same conditions on the outdoor flat surface. The belt edge location measured the highest temperatures for every condition. On average the belt edge temperatures on the 1.7-m roadwheel were approximately 20 °C higher than the outdoor flat surface for all of the conditions tested with the range being approximately from 8 °C to 63 °C higher.

Preliminary Modeling Approach

The task group needed to determine how to treat and scale tire temperature measurements for differences in ambient and surface temperatures. The task group looked at various combinations of ambient and surface effects and determined that how they are weighted has marginal influence. The task group decided to adjust for ambient temperature because it provided the best fit.

Many surface response empirical models were examined looking at various tire measurement temperatures. The belt edge temperatures were chosen as the best indicator of stress-strain amplitude because they were the hottest measured temperature locations within the tire and would provide the best metric to use in determining equivalent test severity. It is also widely recognized within the tire industry that the belt edges provide the highest strain energy for passenger and light truck tires, a situation which is frequently validated using finite element modeling and thermocouple testing.

The mission of the task group is to develop the best technical prediction tool possible. When developing the belt edge temperature surface response model it was recognized that we needed to add logical terms into the model to reduce the amount of unexplained variation and increase the R-squared value and model quality. The task group added terms to account for tire tread depth and tire load capacity. When these terms were added, the R-squared values exceeded 0.94, which is excellent for an empirical model of this type. The most influential terms for the belt edge temperature regression model are as follows:

1. Curved (67-inch or 1.7-m roadwheel) or flat surface
2. Test load
3. Tire load capacity
4. Inflation percent
5. Speed
6. Tread depth
7. Ambient temperature

The preliminary application of our belt edge temperature model indicates that to obtain the equivalent BE temps on the flat highway, for the 1.7-m roadwheel you would typically need to reduce speed or load or increase inflation pressure while keeping the other variables constant.

Conclusions

• All recorded tire temperatures were higher on the indoor roadwheel when compared to the same conditions of the flat outdoor surface.
• The belt edge temperatures were the highest of any measured location for all conditions both on the indoor roadwheel and the flat outdoor highway surface.
• Equivalent flat highway stress-strain amplitude and, therefore, test severity can be achieved on the indoor 1.7-m roadwheel by matching belt edge temperatures.
• Equivalent flat surface belt edge temperatures can be achieved on the 1.7-m roadwheel by reducing load or speed or increasing inflation pressure.

Expected Standard

After we develop the best technical prediction tool possible, we need to apply the tool to develop a technically valid standard. One potential standard could be a simple look-up table. As we mentioned before, there are seven influential terms in our model. If we fix four of the conditions (curved surface, speed, inflation, ambient temperature) we can generate a table for the remaining three variables that provides a curved surface test load for a given tire load capacity and tread depth that provides the same belt edge temperature and therefore test severity as the flat surface under the same inflation, speed and ambient temperatures. For some tires our model indicates that to obtain the same BE temps on the flat highway surface, the loads on the 1.7-m drum may need to be reduced by as much as 28 percent (depending upon size and tread depth, keeping all other variables constant (speed, inflation, ambient temperature).

Next Steps

The task group decided that to provide the best technically valid model possible, the model range needs to be expanded to include a broader range of commercially available passenger and light

truck tire sizes that we will include in our Phase 3 testing. We will target testing on a 1.7-mroadwheel and an indoor flat surface belt machine (flat-trac) for better ambient temperature control. We also intend to repeat testing of some tires for validation purposes. When Phase 3 testing is completed, we plan to refine and tune our model by adding in all of the additional testing from Phase 3 with Phase 1 and 2.

Closing

When Phase 3 testing is completed, we plan to refine our model to make it the best technically valid tool possible. We will then pursue the development of an ASTM technical standard that will complete our mission by providing a standard adjustment on the 1.7-m roadwheel to provide equivalent test severity to the highway, which would more accurately reflect actual performance under customer field use conditions. Our plan within ASTM is to develop, ballot and adopt our standard in the second quarter of 2007.

Figure 1

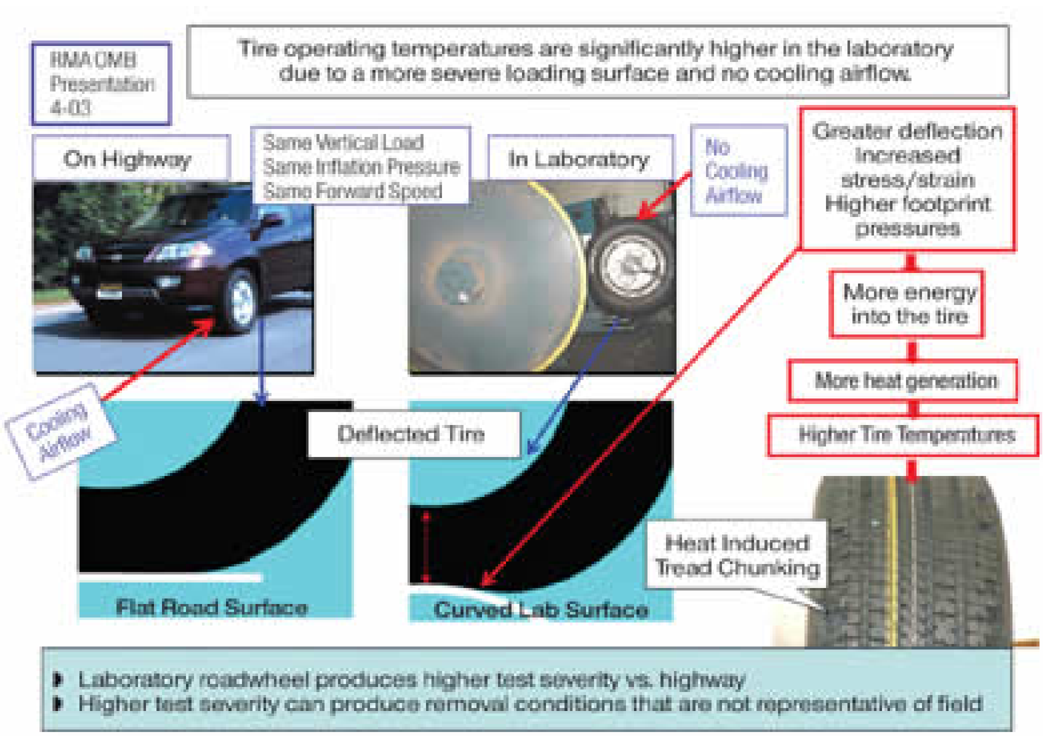

Figure 2

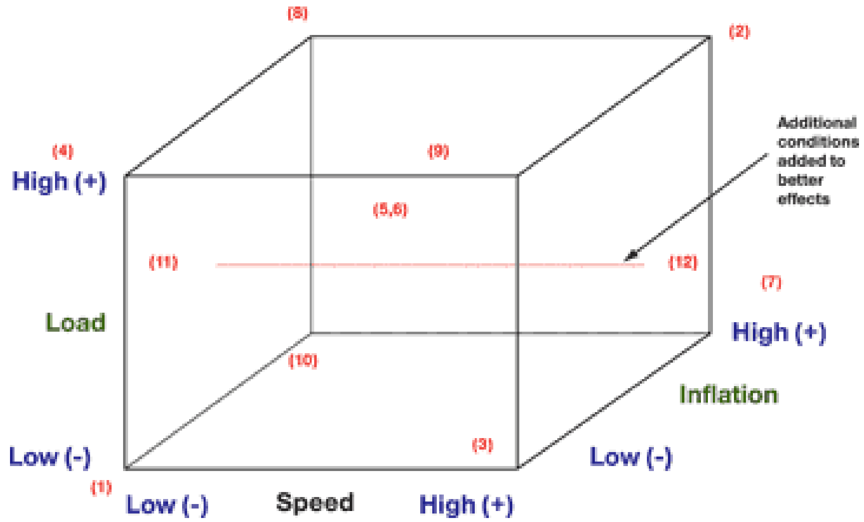

Figure 3