Forensic analysis in tire tread separations

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Tire forensic analysis requires the use of many pieces of information gleaned from a visual and tactile inspection of the tire pieces to determine the most probable cause of a tire’s failure. Discussions of the fractography of surfaces involved in tire tread separations can be found in several references.

Several classes of marks can usually be found on the skim rubber where the tire tread and outer steel belt have peeled away from the casing and inner steel. Typically, these are: beach marks, stop-start marks and yaw scratches. These forensic marks, and their significance to the forensic analyst, will be discussed in detail.

Beach marks

Traditional beach marks are always associated with some sort of fatigue process. In tires, the most common fatigue process that occurs in the field is that of tread separation. In this process, cracks originate at the ends of the outer belt wires as the tire rolls under load. This cyclic stress can cause microcracks at the edges of the outer steel belts to grow in a radial direction (i.e., along the body ply cords) toward the center of the tread.

Beach marks indicate crack progressions occurring over time. The sharpness of the marks gives some indication as to the amount of time the cracks were developing. Stop-start marks occur during the actual tread peel and are caused by the tread peel stopping and starting as the tire rotates. Stop-start marks are typically found near the ends of the outer steel belts. Such marks can be used to determine the duration of the tread peel and whether or not the casing was inflated at the time. Yaw scratches result from road abrasions occurring after the tread peel is complete. These can result in uniformly distributed abrasions or, in the case of locked-wheel braking, a single spot pattern.

Proper interpretation of these forensic marks is essential to the understanding of the progression of tread separation as a tire failure event. These patterns also shed light on the cause of the tire failure as well as the effect on the vehicle.

Fig. 1. Beach marks produced during a laboratory-created tread separation.

Fig. 2. Photomicrograph of the beach marks shown in Fig. 1.

Fig. 3. Beach mark region from a tread separation occurring in a field tire. Note the polished appearance and lack of distinct ridge patterns.

Fig. 4. Model relating instantaneous relative tread wear rate over tread separations to the size of the underlying separation.
Tread

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The majority of these cracks in an essentially parallel orientation. As these cracks progress more deeply into the skim rubber between the steel belts, the same external tire forces produce much higher levels of shear stress and therefore much faster crack growth.

This is especially true when the cracks move from the wedge material at the edge of the outer steel belt into the thinner base skim rubber. This fact produces characteristic failure regions in tires that are semicircular or parabolic in shape, with the crack ridges becoming more perpendicular to the belt wires themselves. The failure regions are sometimes called fatigue thumbnails, and they represent a region where the outer steel belt was not bonded to the inner steel belt for some period of time prior to the tread separation. In other words, the outer steel belt was “loose” over the inner steel belt.

The features shown in Figs. 1 and 2 are sharp and clearly defined. These cracks developed during the laboratory tread separation over a period of 30 seconds or less as previously noted. There was very little, if any, opportunity for the two surfaces to rub together as the crack progressed. Contrast Figs. 1 and 2 with the edge cracks shown in Fig. 3. The fatigue cracking shown in Fig. 3 occurred on a tire being operated in the field. Note that the beach marks and crack ridges have been “polished” smooth as a result of the crack surfaces having had the opportunity to rub together over a period of time. The looseness of the outer steel belt over the inner steel belt allows a slip of the belts relative to one another, which gives rise to the polishing effect. The same thing happens between the tread and the road surface, which can result in a region of more rapid wear on the tread.

While there is no clear answer to the question of the relationship between miles of service and level of polishing, it is clear that polishing denotes a crack area that has been present over some period of time, while sharply defined beach mark and ridge features are consistent with very rapid and recent crack development. Typical estimates of duration are thousands of miles for heavy polishing, versus merely several tens of miles for regions showing little or no polishing.

Pure fatigue failures are normally those that produce high levels of polishing. In these cases, the fatigue process in a properly designed and manufactured tire has been accelerated from the norm by any of a number of environmental or use inputs. Chronic overloading or underinflation, other abuse, puncture-related damage, and other phenomena of this sort are normally the culprits in these cases. Field sampling has shown that tire failure becomes more probable as tread depth is reduced, reinforcing the fact that as the tire is used, environmental issues like those listed above, especially if extreme, can gradually break down any tire.

In rare cases, some manufacturing anomalies can give rise to fatigue-related processes that will have similar appearances to environmentally driven ones. These include both snaked belts, which can couple with environmental drivers to produce tire failure. However, tires with manufacturing-related drivers alone will generally fail in the first third of their wear life, while those with environmentally related drivers typically last well into the final third of their wear life. The most notable exception to this is the case of a very old, but unused full-size spare tire, where extreme oxidation has rendered the rubber incompressible resisting crack growth while the tire generates high temperatures during operation because of its full tread depth. Road hazard impact damage has been shown to produce damage ranging in severity from skin rubber cracks between the steel belts to rupture of the inner liner and fracture of the wires in the steel belts themselves. Any sort of damage in the steel belt area represents a stress riser from which fatigue cracks will grow over time. While it is possible that a small impact damage area will produce slowly growing cracks and highly polished surfaces, it is more usual to find fatigue cracks with more sharply defined features, consistent with the cracks having developed very shortly before the tire failure itself. This is consistent with impact damage occurring away from the belt edge in areas of the tire where the strain energy density is much higher for a given level of tire deformation. Fig. 5 shows a fatigue crack region emanating from localized impact damage in the tire.

Stop-start marks

Stop-start marks are essentially small surface ridges of rubber that are created when a rapidly-moving crack front momentarily changes directions. These marks are created during the peel of tread and outer steel belt from casing and inner steel belt (tread skin surface).

Fig. 5. Cracking around an impact damage point. Note the sharpness of the ridge lines.

Fig. 6. Stop-start mark created during the peel of tread and outer steel belt from casing and inner steel belt (tread skin surface).

Fig. 7. Stop-start marks on the underside of a separated tread and outer steel belt. There are two stop-start marks in the photograph.

Fig. 8. Schematic of peeling tread showing the origin of the curvature of the crack front in the skim rubber.
cars when the crack front stops moving. There will be a slight relaxation in the stress state of the crack tip, and the crack will reorient itself. When the movement of the crack begins again, the crack resumes its original heading.

The stop-start motion results in the creation of a small ridge (or groove, depending upon the surface being inspected) of rubber perpendicular to the direction of motion of the crack all along the crack front.

**Fig. 6** shows an example of a stop-start mark in the skin rubber between the two steel belts of a tire that experienced a tread separation. This particular view shows the skin rubber on the underside of the tread and outer steel belt. In this photograph, the tread peel moves from left to right.

There is also a tear between two steel wires near the center of tread, which is not to be confused with the stop-start mark. Measured tearing rates on tread separations done under precise laboratory conditions are generally in the order of 1 m/sec or higher in the region of rapid tearing. **Fig. 7** shows another photograph of stop-start marking, also from a section of tread, which has two of these marks in the frame. The tread peel motions are from left to right as in the previous example. The stop-start marks are about one-third and two-thirds the width across the photograph, respectively.

In addition, the lower the combination of peel strength and bend of the rubber to the steel cord of the skin rubber at the tire temperature when the separation occurred, the higher the tear rate that likely will be observed on a given separation event, and the further apart the stop-start marks will be. However, as NHTSA has found, lower peel strength is usually related to better crack and fatigue resistance, so there is no accepted standard for peel strength.

Peel strength also varies with tire oxidation and other factors. Since a tread separation is a rather random event in terms of exactly where the forces being developed in the tread flap, the distance between stop-start marks cannot, by themselves, be used as an indicator of the acceptability of the materials used in the tire's construction. For example, the lower the vehicle speed at the onset of the separation, the lower the forces generated on the tire tread and the longer the tread peel duration, all other things being equal.

The marks shown in Figs. 6 and 7 are curved lines from one side of the steel belt to the other. This represents a mark that has particular significance to the forensic analyst. This type of mark is found in conjunction with the peeling of the tread and outer steel belt from a casing that has radial and circumferential curvature. This will always be the case if the tire retains air at the time of the tread separation. The direction of travel of the crack front is from the back of the “C” shape to the front, or from left to right in both Figs. 6 and 7.

**Fig. 8** shows a schematic of a peeling tread explaining the orientation of the crack front and the resulting stop-start mark. Obviously, the more rounded the tire design, the more pronounced the curvature of the crack front. If the tread and outer steel belt are not peeling in the plane of the tire, the “C” shape will be skewed to one side or the other of the tire, as seen in Fig. 6. Conversely, if the tire is not inflated, the opportunity for the casing surface to have double curvature is extremely limited, so absence of the curvature of the stop-start marks generally indicates that the tire lost a significant amount of air prior to the tread peeling off.

Static tread peels done under laboratory conditions on uninflated tires tend to produce stop-start marks having curvature because the casing tends to be pulled into a shape that is very similar to an inflated tire. In tread separation events on vehicles, however, the casing shape when the tire is uninflated is random, and will be extremely distorted in the area of the contact patch where the curvature of the stop-start marks lies in their spacing, or rather in the number of these marks found on the tire after the tread separation. For a rolling tire, the speed of the tread at the center of the contact patch is zero. For a tire undergoing a tread separation, the speed of the peeling tread at the center of the contact patch must be zero, as shown in Fig. 10 for the rolling tire with a leading edge tread flap.

Therefore, one of these stop-start marks will be created on each of the leading and trailing edge flaps for every revolution of the tire during the tread peel. This means that, if the speed of the vehicle is known, the duration of the tread separation can be defined by counting the number of stop-start marks found on either the leading or trailing edge flap (but not both). The duration of the tread separation has been shown to be related to the amount of force exerted on the vehicle, and consequently the yaw angle likely to be experienced by the vehicle, independent of the driver's inputs (steering and/or braking).

It is because the tearing of the tread and outer steel belt from the casing and inner steel belt produces a relatively constant impulse level at constant speed in the fore-aft vehicle direction on each tire rotation. The more of these impulses that occur before the tread completely separates from the tire (or breaks off, leaving some tread remaining attached), the larger the change in the vehicle's momentum will become. In the case of a partial tread separation where a flap of tread remains attached to the tire casing, tread peeling ceases when the vehicle speed becomes low enough that the forces being generated can no longer peel the tread back.

For example, suppose the forensic analyst locates five stop-start marks on the peeling surface of the leading edge flap of a tread separation that reportedly occurred at 96 kph (60 mph). At that speed, the typical sports utility vehicle

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**Fig. 9** shows another example of the stop-start marks, but instead in the area where the tread peel is just beginning. Because the stop-start mark is not bounded by one of the steel belt wires, it is triangular in shape. The stop-start marks are curved, as before, but only go from the belt edge to the separation line.

This sort of pattern, along with other indications discussed by Davis, is often helpful in defining the origin of the tread separation on the tire.

**Fig. 10** shows an example of stop-start marking, independent of the vehicle's inputs (steering and/or braking). This is because the tearing of the tread and outer steel belt from the casing and inner steel belt produces a relatively constant impulse level at constant speed in the fore-aft vehicle direction on each tire rotation. The more of these impulses that occur before the tread completely separates from the tire (or breaks off, leaving some tread remaining attached), the larger the change in the vehicle's momentum will become. In the case of a partial tread separation where a flap of tread remains attached to the tire casing, tread peeling ceases when the vehicle speed becomes low enough that the forces being generated can no longer peel the tread back.

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Stop-start marks cannot be found in the skid mark web that was undetected during the tread attachment. In such cases, the Hinged door of Hammer Mill Model 141 from Munson Machinery Co. provides rapid access for changing of hammers, hammer pins and screens.

Wayne Machine & Die Co.’s medium-sized “Yellow Jacket” Cast Film Takeoff System features orientation capability suited for existing extruders, as drop-in replacements for existing take-off or as part of a complete cast film system including extruder, die, take-off and winding. Anti-stick matte finishes are available for polyurethane films. For information, contact Janice Lischak at 973-256-7374 or visit www.waynemachine.com.

ExxonMobil Chemical made available a new finite element analysis database for Santoprene specialty products for semi-dynamic applications. It also has updated its database for static applications. Both sets of data can help predict behavior of non-linear elastomer materials when modeling Santoprene specialty elastomers, the company said. Visit www.santoprene.com for more information.

Dow Corning Corp. introduced its Sylastic LC-45-2004, a 45 shore hardness abrasion resistant silicone rubber designed to provide high clarity, superior mechanical properties and short cycle time for semi-dynamic applications. It also has a base for Santoprene specialty products. For more information, contact the firm. Dow said it is well-suited for applications such as diving goggles and baby bottle nipples, where a durable, clear, unblemished surface matters.

The Series 1700 Flush Grid Nub Top Abrasion Resistant system from Intralox L.L.C. features a new belt/hinge rod design.

The Series 1700 Flush Grid Nub Top Abrasion Resistant System from Intralox L.L.C. boasts minimal contact between the rubber and belt in dip tanks. The belt features a new belt/hinge rod design, new plastic material and new production process where the company said the system eliminates 90 percent of all maintenance costs and unscheduled downtime.

Munson hammer mill reduces material sizes

A new Hammer Mill Model 141 from Munson Machinery Co. Inc. reduces flammable, friable and fibrous materials into uniform particle sizes ranging from 20 to 300 mesh, according to the company. The mill can separate rubber from cord fiber and reduce the size of other chemical, plastic, rubber and agricultural products. For more details, contact 800-944-6644, e-mail info@munsonmachinery.com or visit www.munsonmachinery.com.

In brief

Sunnex Inc. has a free catalog detailing its line of durable, high-performance anti-vibration mounts, leveling mounts and specialty products. The products are manufactured using materials such as stainless steel, high-grade nylon polymer and nitrile rubber. For a catalog, visit www.sunnexonline.com/literature/mounts-literature-request.htm or call 1-800-445-7869.

Sartomer Co. Inc. has released CN9014, a new urethane acrylate photoinitiator that functions as plastic and rubber additive ingredients. The information has been gathered from more than 1,500 worldwide manufacturers, then supplied to the company said.

The "Handbook of Plastic and Rubber Additives" from Research and Markets Ltd. describes more than 16,000 trade name and generic chemicals that function as plastic and rubber additive ingredients. The information has been gathered from more than 1,500 worldwide manufacturers, then supplied to the company said.