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Seat Belt Investigation In Automobile Accidents

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Abstract

Field investigation of seat belt condition after an accident is often intended to answer two fundamental questions: (1) was the seat belt in use during the accident, and (2) did the seat belt function as intended by the designer? The authors present practical observations based on investigations of hundreds of collisions where use and performance of seat belts was of importance. An approach is suggested to determine whether or not a seat belt was used, along with a discussion of some common problems found in seat belt investigations. References are presented on seat belt research and testing.

Evidence of Seat Belt Use – Belt Inspection

When a restraint system is worn by an occupant during a collision, high tensile forces are developed in the belt webbing. These forces can result in physical changes to the webbing, hardware, and anchor points. For example, in a frontal collision of vehicles traveling 30 mph, forces of several thousand pounds can be developed in the webbing. In the presence of these forces, the webbing can stretch as well as leave evidence of loading on belt hardware and anchor points. An understanding of seat belt design and features is helpful in understanding evidence found on the belt.[1]

The most commonly found indicator of restraint system use is heat. Where the webbing material is in contact with plastic hardware, forces occurring during a collision develop friction resulting in heat and local melting of the hardware and belt material. The result is a distinctive fabric pattern often found in plastic covered hardware as seen in Figures 1 and 2.

Friction can also cause the webbing material to become puckered and locally streaked with a light color as seen in Figure 3. The cloth label near the end of the belt may become puckered when the underlying belt is stretched. This assumes that the label was drawn tight when originally sewn to the belt. Many belt labels are sewn loosely, so puckering does not occur. In addition, webbing subjected to high loads may feel stiff, similar to newly starched laundry. This stiffness is subtle, and may be relaxed by handling of the belt.

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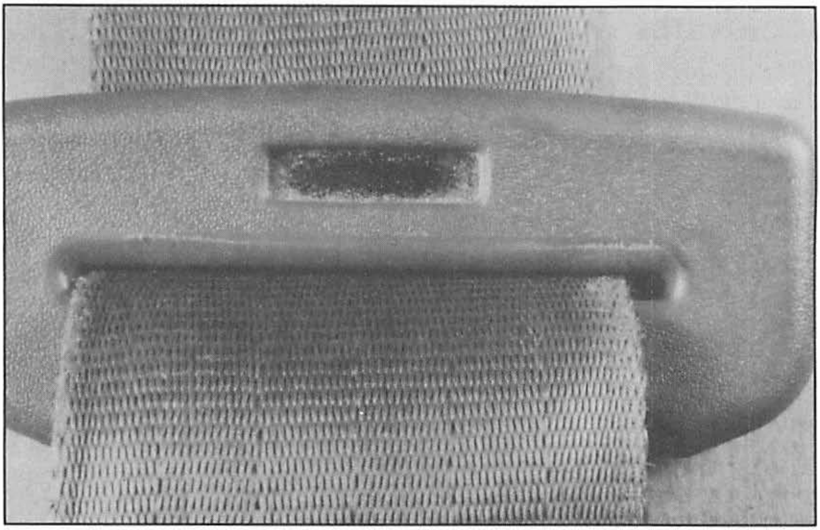
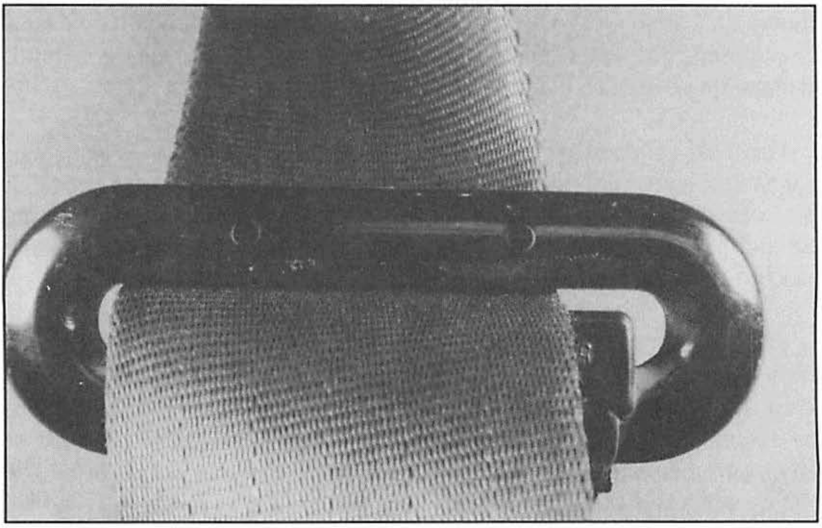
Figure 1



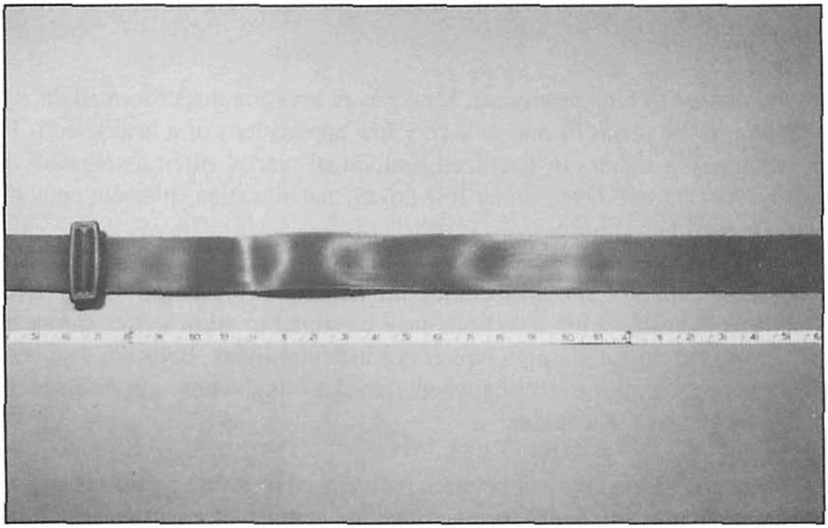
Heat Marks in Plastic Covered Hardware – Latch Plate

Figure 2



Heat Marks in Plastic Covered Hardware – D-Ring

Figure 3



Puckering from Friction and Load

The webbing is sewn to itself at the end attachments. Very high belt loads can begin to break the stitches. To improve occupant protection, some vehicles have a loop sewn into the webbing which is encased in a plastic sleeve. During a collision, loads in excess of 600 to 700 pounds will pull the stitches out of the loop. This lowers the peak force on the occupant, and pulls the webbing out of the sleeve to expose a label which advises, "Do Not Use" or "Replace Belt."

Both sides and both edges of the webbing should be examined over the entire belt length. Any abrasion marks should be matched to the corresponding surface which caused the mark in order to determine its cause and the position of the belt when the mark was made. The goal of this inspection is to differentiate evidence of collision related loading from marks made by normal wear.

In order to interpret evidence found on the belt webbing, an understanding of the webbing construction is important. Seat belt webbing is woven of threads called, "ends," which are made of fibers which in turn are composed of fine filaments twisted together. A typical seat belt is made of polyester or nylon, and may consist of 15,000 to 24,000 filaments.

During normal long term wear, relatively low belt forces are repeated many times. Scratches from long term wear are numerous and produce a uniform surface. This causes the webbing to lose its shiny appearance and become fuzzy.

Under low power magnification, this fuzziness will be seen to consist of uniform short filaments of about the same length exhibiting no signs of melting from heat.

In contrast to long term wear, scratches or abrasion marks formed during a collision are the result of one or a very few applications of a heavy load. This type of loading results in localized, individual marks, often associated with signs of friction and heat. Under low power magnification, filament ends may have a melted appearance.

The investigator should examine the belt for evidence of storage which would preclude the belt's use. Belts may be stored to allow easier entrance to rear seats or to defeat warning buzzers or indicator lights. Belts are also sometimes used to secure the steering wheel during towing, which can result in misleading marks on the webbing.

The signs of loading will be more pronounced in severe collisions and with heavier occupants. It should be noted that the absence of a particular belt indication may not mean that the belt was not worn. A lack of evidence on the belt must be carefully analyzed along with other available data such as crash speed, direction of force, interior damage, and details of occupant injuries. For example, in a side collision a driver may hit the driver's window even when wearing a properly adjusted three point restraint. This motion may not leave noticeable signs of belt loading.

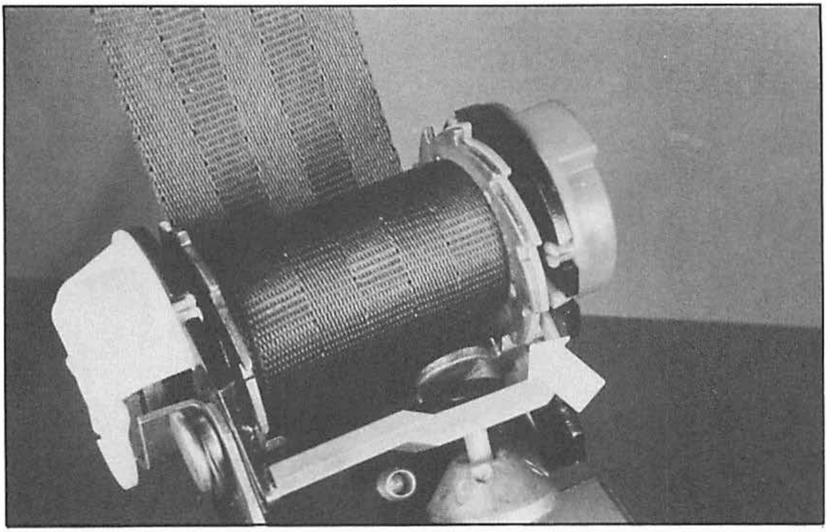
Evidence of Seat Belt Use – Hardware Inspection

In addition to belt webbing inspection, the investigator should look for signs of heavy loading on belt hardware and anchor points. Belt hardware includes the locking retractor, latch plate and mechanism, and the shoulder guide loop, often called the "D-ring."

The most commonly found indication of belt use is melting from friction and heat. Where the webbing passes through plastic coated hardware, such as the latch plate or shoulder guide loop, a distinctive fabric pattern is imprinted on the plastic, and evidence of melting may be found, see Figures 1 and 2. This heat evidence indicates that the belt was worn during the collision, but it does not indicate whether or not the belt performed properly. After determining that the belt was worn, the question of proper restraint operation must be addressed separately.

In a typical locking retractor, there are one or two wheels with teeth as shown in Figure 4. When the retractor locks, the toothed wheel is engaged by the locking bar to prevent rotation. Under heavy load, this sometimes causes

Figure 4



Retractor Locking Bar Engagement on Toothed Wheels

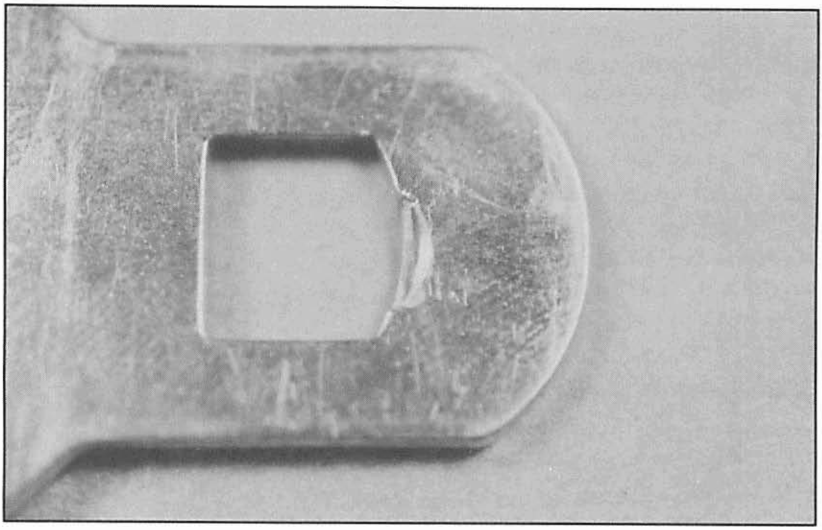
local deformation of the bar or teeth. This is a relatively insensitive indicator of belt use, and will normally be accompanied by other indications of use, such as heat marks on plastic hardware. If locking bar evidence is found, it can be used to determine the length of webbing extended at the time of impact.

The operation of a vehicle sensitive retractor can be demonstrated without disassembly by slapping with a fist near the retractor location while slowly reeling out the webbing. The pendulum may swing due to impact load and lock the retractor. This is a simple technique but if the retractor does not lock it can not be concluded that the retractor is defective.

A more definitive test is to remove the retractor from the vehicle and tip it while pulling the belt out. A vehicle sensitive retractor should lock before it reaches an angle of 45 degrees.

The latch consists of a male "tongue" and a buckle body containing the latch mechanism. The tongue typically has a hole which is square or "D" shaped. When in use, latching is accomplished by insertion of a metal piece into the hole. This piece bears on the side of the "D" shaped hole. In a very severe crash, loads on the belt can create an impression on the side of the hole, see Figure 5. This is an insensitive indication of belt use, and would be accompanied by other evidence of loading. Light scratches on the surface of the tongue between the hole and the male end indicate frequent belt use.

Figure 5



Impression on Latch Plate Due to High Load

Evidence of belt use can also be found near anchor points. The force from belt tension can deform the sheet metal. A slight bulge may occur which is perpendicular to the sheet metal surface, or the mounting hole may be deformed in the direction of load. A simple way to check for this deformation is to remove the anchor bolt and thread a longer bolt into the hole. Misalignment can be seen by the angle of the bolt. It is helpful to compare mounting point geometry to a similar point on the opposite side or to an undamaged exemplar vehicle.

Evidence of Seat Belt Use – Occupant Motion

In determining whether or not a seat belt was used during a collision, it is useful to visualize the likely occupant motion and then look for evidence of whether or not that motion was restrained. This process begins with an external inspection of the vehicle to determine the magnitude and direction of the forces applied during a collision. Computer software based on the CRASH and SMAC programs is useful in estimating forces.[2]

In a frontal collision, an unbelted occupant will move forward while remaining nearly vertical to impact the steering wheel, dashboard, or windshield. Lower extremities will impact below the dashboard. An occupant restrained only by a lap belt will rotate forward about the restrained pelvis. This rotational motion is also experienced when excessive shoulder belt slack is present. If information on specific injuries is available, it can be correlated with impact evidence inside the vehicle to determine occupant motion.

A properly restrained occupant typically will not impact the interior of the vehicle at frontal barrier collision speeds below 20 to 25 mph. Slamming into a concrete barrier at 20 mph is equivalent to a head on collision between identical vehicles traveling 20 mph. It is unlikely that a restrained occupant will cause excessive bending of the steering wheel or compression of the energy absorbing steering column, except in the most severe collisions.

In a side collision, a lap belt will restrain the lower torso, but a shoulder belt is of little value in restraining upper body sideways motion. Forces on the shoulder belt webbing are lower, and may not result in detectable evidence of belt use. The lap belt may or may not have evidence of load, depending on occupant motion before interior impact. Again, visualize occupant motion and correlate specific injuries with impact evidence.

In a near side collision, which is an impact to the side near the occupant, the occupant's body will move sideways to impact the door or window. The distance to interior impact is small, particularly if significant door intrusion into the passenger compartment occurs. The shoulder belt is not loaded significantly during this sideways motion, and the lap belt may not show signs of load.

In a far side collision, the unrestrained occupant will remain nearly vertical and move sideways until impact with other occupants or the vehicle interior. Legs may become tangled below the dash board, resulting in injuries to the lower extremities and rotation of the body. In contrast, a restrained occupant will move out of the shoulder belt while rotating about a restrained pelvis. In this case, the lap belt may be loaded while the shoulder belt does not exhibit signs of loading.

In a rear end collision, the occupant will initially move rearward with reference to the vehicle and impact the seat back. A seat belt will have no effect on this motion. Back and neck injuries will often result from the rearward motion and seat impact regardless of seat belt use. After initial impact with the seat back, the occupant will rebound from the seat toward the front of the vehicle. Seat belts are effective in limiting this rebound motion and preventing impact with the dashboard or steering wheel. The forward rebound motion may have as much as 30 percent of the energy of the initial rearward motion.

Many collisions involve combinations of frontal, side, and rear impacts. Rollovers apply a different set of forces to the occupant and belt. The total vehicle motion should be considered in terms of each of the component motions.

A common misconception is that the lack of occupant bruising from seat belts indicates the belt was not used. In fact, although bruising is often found, seat belts do not always result in bruises. Thus, the absence of bruising does not necessarily mean the belt was not used or that it failed to properly restrain the occupant.

Seat Belt Webbing Failure

Occasionally, belt webbing is found to be separated. The belt may have failed due to cutting or overload. If the belt was cut, it must be determined whether the cut was intentional, such as during rescue operations, or was a result of contact with an exposed sharp edge during the collision.

In tests where seat belt webbing is loaded to failure using its own hardware, it displays distinctive features visible to the naked eye. The failure will either be from fractured hardware, broken stitching, or cut webbing where the belt contacts the hardware. Webbing is never observed to break in tension away from the hardware in these tests.

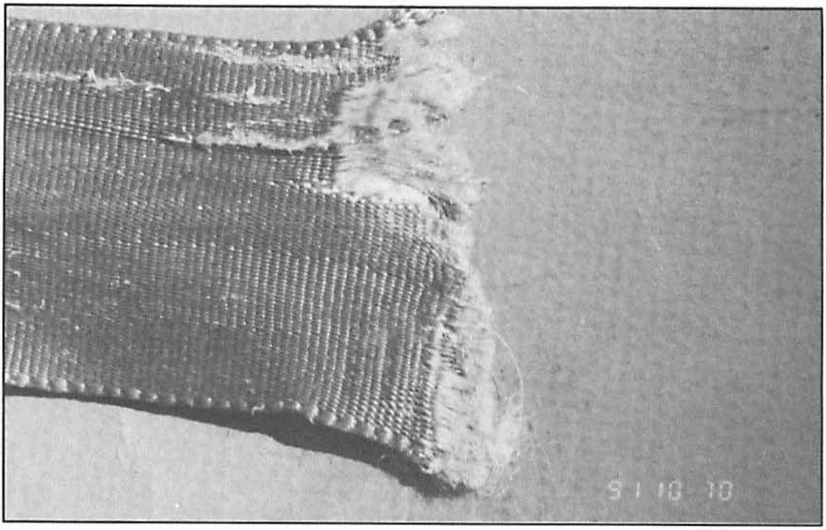
Figure 6 shows the typical appearance of webbing which has been cut at the latch plate during a collision. Figure 7 shows belt webbing which has been overloaded and pulled apart in tension during a collision. In these overload failures, the fibers separate in a random pattern, leading to non-uniform ends. In nylon, this effect is called "horse-tailing." In polyester, the effect is less pronounced.

Microscopic examination of individual filaments may be used to determine the failure mechanism. A filament stretched to breaking has a large amount of stored energy which is suddenly released, causing melting of the filament end. The filament may also neck down near the failure, and snap back when the filament breaks. These effects combine to produce a "mushroom" at the tip, as shown in Figure 8, and a hooking or sagging from weight.

FMVSS 209 requires a minimum webbing tensile strength of 5,000 pounds for lap belts and 4,000 pounds for shoulder belts.[3] Typical failure loads are well over 6,000 pounds, with an average elongation of 17% for nylon and 7% for polyester.

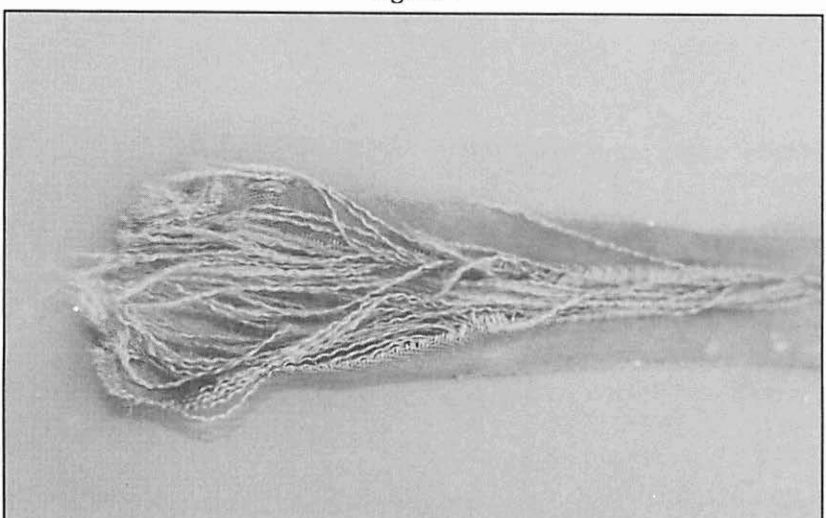
Webbing may be cut during a collision by pulling against an interior surface in the vehicle, such as intruding metal structures. Two findings typically identify a belt cut by an interior surface. First, the location of the cut will match the cutting structure, and belt fibers may be present on the surface. It is important to visualize the interaction between the belt and the cutting surface in the dynamically deformed position, which is normally different from the post-crash static position. Second, unless the belt has been pulled across a straight edge, the cut will have an uneven appearance across its width.

Figure 6



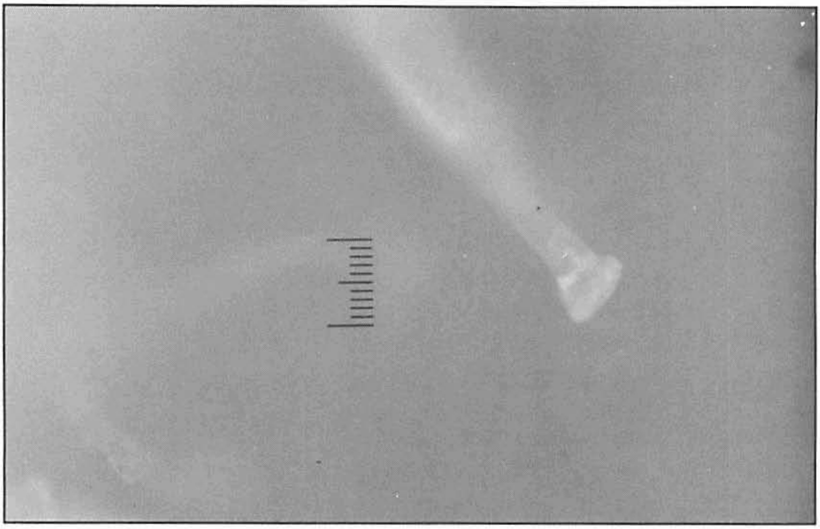
Webbing Which Failed at the Latch Plate During a Collision

Figure 7



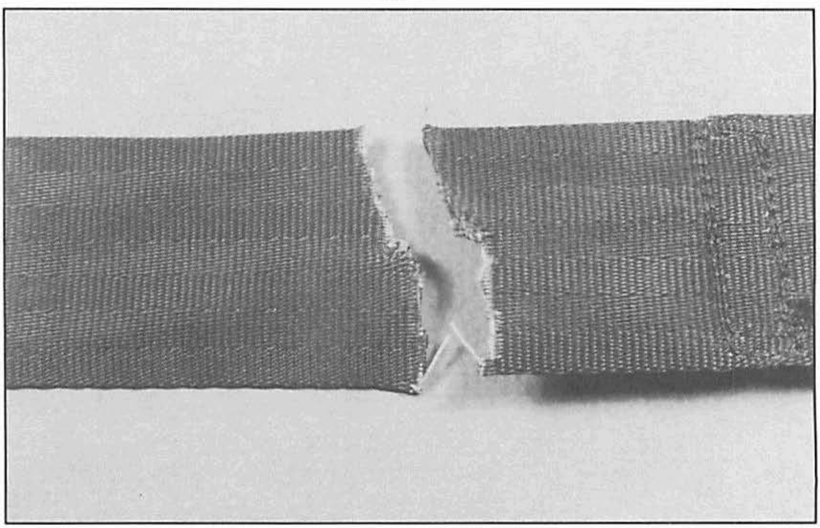
Webbing Pulled Apart due to Overload

Figure 8



Microscopic Photograph of Filament Which Failed

Figure 9



Webbing Cut With a Knife

Webbing cut intentionally with a knife or scissors results in uniform profiles with many fibers of the same length as seen in Figure 9. Such cuts may occur during rescue operations.

Intentionally cut filaments generally have a distinctive end appearance when examined microscopically, with a lack of the heat evidence found in tensile failures. Cut filaments often have serrations near the end, and the uniform length evident to the naked eye is seen clearly.

Although filament ends exhibit characteristic shapes when cut or broken, it can be misleading to examine a small number of the 15,000 to 24,000 filaments to reach a conclusion about the entire webbing. In a given failure, some filaments may be found exhibiting both types of failures. For this reason, overall appearance of the separated belt must be considered first, and microscopic examination is used to provide more information about the mode of failure.

Proper Seat Belt Operation – Is the Belt Defective?

Once it has been determined that the belt was worn during a collision, the question of proper belt operation must be addressed. Two common operator complaints are that the retractor did not lock and the belt came unlatched. Evidence to address these questions has been presented above.

Excessive slack in seat belts is often overlooked as a cause of inadequate protection by the restraint system. With properly adjusted seat belts, dummies in 30 mph frontal barrier crash tests typically do contact the steering wheel, dashboard, and sometimes the windshield. Even a small amount of slack will increases the force of interior contact and create the potential for serious injury.

One source of belt slack is a restraint system designed to reduce belt tension on the upper body to increase comfort. For many years, some manufacturers offered a "window shade" feature in belt retractors. These retractors would lock the belt in a given position, and slack had to be removed by pulling out extra belt and releasing it quickly, similar to a spring loaded roll up type window shade. Problems arise when normal driver motion, such as adjusting the radio, leaves excess slack in the seat belt. In an accident, such slack may produce serious injury to the occupant even while wearing a seat belt.

Another source of belt slack is a retractor design which reduces belt tension when the door is closed. This feature is activated by a button in the door jamb connected to the retractor with a cable, sometimes called a "Bowden" cable.[4] The intent of this reduced belt tension is to improve operator comfort when the door is closed. When the door is opened, the belt tension increases to retract the belt into its stored position along the B pillar. If the cable and button become jammed, the result may be excessive belt slack, which has the potential to cause occupant injury during a collision.

The authors worked on a case where the belt did not retract properly due to a cable defect in the door of a new vehicle. The manufacturer's service representative erroneously explained that the reason the belt was designed to retract with greater force when the door was opened was to allow paramedics quick access to cut the belt after an accident. The low belt tension and excessive slack with the door closed were "normal" in his opinion.

In fact, this defect resulted in excessive belt slack with the potential to cause injury during a collision. This example highlights the importance of proper understanding of seat belt function, and demonstrates how popular mythologies can have disastrous consequences on proper restraint operation.

Another source of belt slack is a loop of belt webbing caught in the door when closing. This loop may allow the belt to feel snug, but in a collision the loop will pull out of the door and allow excessive occupant motion and injury.

Some belt latching mechanisms have been found to unlatch during laboratory testing under a specific loading. This mechanism of unlatching is known as "inertial unlatching" and occurs in some latch mechanisms which have the release button operating at 90 degrees to the direction of the latch plate engagement. The belt must be loaded with light tension while an impact force is applied to the back of the latch. This mode of unlatching has been duplicated by the authors during testing. The precise loading required to cause inertial unlatching might occur during a collision involving rollovers or side impacts under limited conditions. Such loading might not leave physical evidence for an investigator to determine whether or not a vehicle occupant was belted prior to the collision.

Some belts can become so firmly jammed in the latch plate or other hardware that they are not used by the occupant. In this case, failure to use the belt may be the result of defective design rather than operator error.

Conclusion

Investigation of seat belt performance must start with a basic understanding of seat belt function. Visualizing occupant motion during the collision will lead the investigator to look for evidence of belt use. Crash severity, direction of impact forces, and occupant size all play a part in the nature of the evidence which will exist.[12] Computer software based on the SMAC and CRASH programs will assist an investigator in understanding forces acting on the occupant during a collision.

The absence of indications of seat belt loading during a collision can mean that:

1) the belt was not worn,
2) the belt was worn but the magnitude or direction of the forces during the impact did not result in belt loading (for example low speed impacts or rear end collisions),
3) the belt was worn but slack existed preventing significant loading prior to occupant impact with the vehicle interior, or
4) the belt was worn but a total malfunction, such as the failure of a locking retractor, precluded significant belt loading.

After determining that a belt was worn during a collision, an evaluation of restraint performance should be conducted. In some instances, defects can cause the restraint system to provide less than the expected degree of protection even when seat belts are used.

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