PERFORMANCE TESTING FOR AUTOMOTIVE WIRE HARNESS TAPES

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Abstract

Wire Harnesses are the communication network in every vehicle; providing the lifeblood to components like brakes, steering, engine control, passenger safety and comfort features. Wire harnesses act on the idea of safety in numbers for the wires, connectors, terminals and clamps that carry and complete important automotive operational messaging. Wrapping wire harnesses in tape provides essential protection while performing many additional functions. Tapes reduce automotive buzz, squeak and rattle, shield with heat reflective properties, aid in trouble shooting and organization with critical color coding and fortify the wire harness against abrasion. Durability of the tape can determine driver safety and reduce ownership costs with less maintenance. Tape is a crucial line of defense for the expansive wiring that totals over a mile in modern vehicles.

Wire Harness tapes are tested to OEM performance specifications during design and annually thereafter. Validation covers the magnitude of environmental and operational stresses that a harness tape will experience in a ten or more, year lifespan. Understanding real world applications is essential to appreciating the role each required testing criteria plays. With expanding electrical system designs and the need for increased product life expectancy, the stakes are raised. Assessments in a performance specification include, amongst others, resistance against automotive fluids, aging at specified operating temperatures, abrasion resistance, noise damping and flame retardant properties.

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1.0 Introduction

The modern vehicle is a marvel; a product of sophisticated systems and components working in harmony to get from point A to point B. Consumers depend on vehicle manufacturers to provide safe and reliable products to transport cherished family and friends. Consequently, vehicles are subjected to rigorous impact testing by both government entities and insurance groups. The National Highway Traffic Safety Administration (NHTSA) began testing and rating vehicles with the use of crash test dummies in 1978[1]. These violent images can shock us into wearing our seat belts and scare us into changing dangerous behaviors like texting while driving. Ratings are published and are required on all new vehicle window labels. Equally as important as crash testing, though less emotion inducing, is the testing required for the materials building our vehicles and the components and systems within them.

2.0 Systems, Components and Performance Specifications

Automobiles are complicated machines made of smaller subsystems. In recent years, the intricacies and expansions of one such system, the electrical and electronics system is upping the ante on component performance and protection requirements. Automotive electrical systems distribute information to other critical systems and components like brakes, steering, engine control as well as passenger safety and comfort features. Cars are coming off the lots with rear video imaging, lane departure warning, forward collision warning and even automatic emergency braking which the NHTSA now recommends as driver assistance technologies[2]. These important tools rely upon the translation and transportation of input signals from the environment into vehicle system alerts and adjustments. Whether a safety accessory or a comfort feature, these components and many others, rely on the distribution of important electrical information. The system communicating this critical data must be protected during its tenure. Designed under the premise of safety in numbers, automotive electrical systems are made up of wire harnesses; where these harnesses group and protect the wires, connectors, terminals and clamps that carry and complete the important electrical messaging.

Harness covering solutions include pressure sensitive adhesive (PSA) tapes, heat-shrink tubing, split loom and nylon braids[3]. Specifically, PSA tapes play a key role in protecting the wires and other parts making up the electrical system while performing additional functions. PSA tapes used in the automotive industry are subject to required design and validation testing set forth by original equipment manufacturers (OEMs) to test these key elements. Cars experience the daily grind and OEM performance specifications aim to validate against the magnitude of environmental and operational stressors a harness tape will endure in an automobile's average 10 year, or greater, lifespan[4].

The following OEM engineering and performance specifications[5,6,7] are extensive industry examples to which PSA tape manufacturers commonly design and validate wire harness tapes:

Table 1: Performance Specifications of Major US Manufacturers

OEM	Specification Number	Title
Ford Engineering Specification	ES-AC3T-1A303-AA	Harness Tape Performance Specification
Fiat Chrysler Automobiles	MS.90111	Tape with Adhesive or without Adhesive for Electrical Wiring
GM Worldwide Engineering Standards	GMW 16740	General Specification - Harness Tape

OEM performance specifications are vast and include many required elements as well as optional levels of performance in specialty categories. When reading one of these performance specifications, it is motivating to correlate real-life situations or even the applied purpose of the tape to the actual nuts and bolts of the test method. Why is this testing required? How does this test translate into a real-life scenario? Where do the results of these tests tie into what is truly important to the overall safety or comfort of the automotive consumer? Some interesting tests can be grouped and discussed in the following categories:

Durability and Safety
- Heat Aging
- Abrasion Resistance
- Flame Retardant Properties
- Automotive Fluid Resistance
- Heat Reflectivity/Thermal Effectiveness

Comfort and Driver Experience
- Fogging Levels
- Noise Damping

Weather and Environmental Impacts
- Environmental Cycling
- Cold Flex
- Thermal Overload

With an understanding of each test and how the results translate into performance during operation, products can be designed to meet different levels within performance categories. Additionally, product data sheets referencing certain overall specifications or key specialty tests can aid an engineer in choosing the proper tape for a specific harness design or lead a consumer to aptly choose a tape during maintenance and servicing.

Tapes are tested fully during development and annually. Some tests are chosen as regular checks utilized during each production run for QA purposes. At first glance, the logic for some testing is more obvious than others, but all of the testing either addresses a property that relates to tape performance indicating durability and safety, influence over driver comfort and overall user experience, or response and resistance to environmental factors.

3.0 Durability and Safety

3.1 Heat Aging

Durability of harness wrapping tape can determine driver safety and reduce ownership costs with less maintenance. Tape is a crucial line of defense for the expansive wiring that totals over a mile in modern vehicles[8]. Good performance after aging of the tape is an essential measure of the functionality of the tape. OEM specifications generally categorize tapes into performance groups by suggested operating temperatures. According to Ford's Performance Specification, operating temperatures are divided into 6 classes, defined as A through F. These classes can be correlated with their recommended application and location within an automobile, as proposed in the International Standard, ISO 16750, Part 4: Climatic Loads[9] and seen below.

Table 2: Temperature Rating according to Ford Specification ES-AC3T-1A303-AA

<table>
<tr><th>Temperature Rating</th><th>Class</th><th>General Application/Mounting Location Examples</th></tr>
<tr><td>- 40 to 85 °C</td><td>A</td><td>Passenger compartment out of radiation exposure
Inside luggage compartment
Inside doors, lids, exterior cavities (wheel housings)</td></tr>
<tr><td>- 40 to 100 °C</td><td>B</td><td>Engine compartment frame
Passenger compartment exposed to direct solar radiation
Passenger compartment exposed to radiated heat</td></tr>
<tr><td>- 40 to 125 °C</td><td>C</td><td>Engine compartment in/on plenum chamber
On engine/In engine
On engine compartment cover</td></tr>
<tr><td>- 40 to 150 °C</td><td>D</td><td rowspan="3">Engine compartment on or in transmission/retarder
Engine compartment to body</td></tr>
<tr><td>- 40 to 175 °C</td><td>E</td></tr>
<tr><td>- 40 to 200 °C (+)</td><td>F</td></tr>
</table>

Selection or design of a wire harness tape typically starts with its temperature class. With an average 10-year life span and the Federal Highways Administration (FHA) estimated 10,164 average annual miles per vehicle in 2017, vehicles likely see 101,640 miles, or more, in an average lifetime[10]. Under the Ford specification, all tapes are required to be heat aged for 3000 hours at their designed operating temperature. Ford and others require this long term 3000 hour aging, though test specimen preparations can differ between specifications.

Why 3000 hours? Using the FHA 2017 estimates of a 25 mph average commute[10] speed and a 10-year-old vehicle with 101,640 miles, a car operates 4,065 hours. If a car with 101,640 miles averages a commute speed of 50 mph, operating hours are 2,032. Coincidentally, if we project a vehicle with 150,000 miles travels an average of 50 mph during its lifetime, operating hours are 3,000; exactly the aging hours indicated in many performance specifications. A 3000-hour exposure to heat tests with the intent to ensure the life of performance parts use throughout a vehicle.

Heat aging is completed by actually building bench size wire harnesses and exposing them to operating temperatures for the duration of 3,000 hours. Figure 1 below shows an example of the Ford specification wire harness. Tape is generally wound in a half-lapping style around a convolute, numerous wires, or even two inter-twined wires of a required type and size. Intermittently, and at total exposure, harness bundles are evaluated for performance indicators and manually wound around designated circumference mandrels. Winding of the harnesses around the mandrels stresses the half laps of the tape. Tape backings are evaluated for cracks and melting while the ends are checked for flagging, a term for the release of the open lap at the end of the bundle. Heat aging is a critical long term test meant to validate both the vigor of the backing and the stability of the adhesive in a tape as it operates throughout its life in a vehicle.

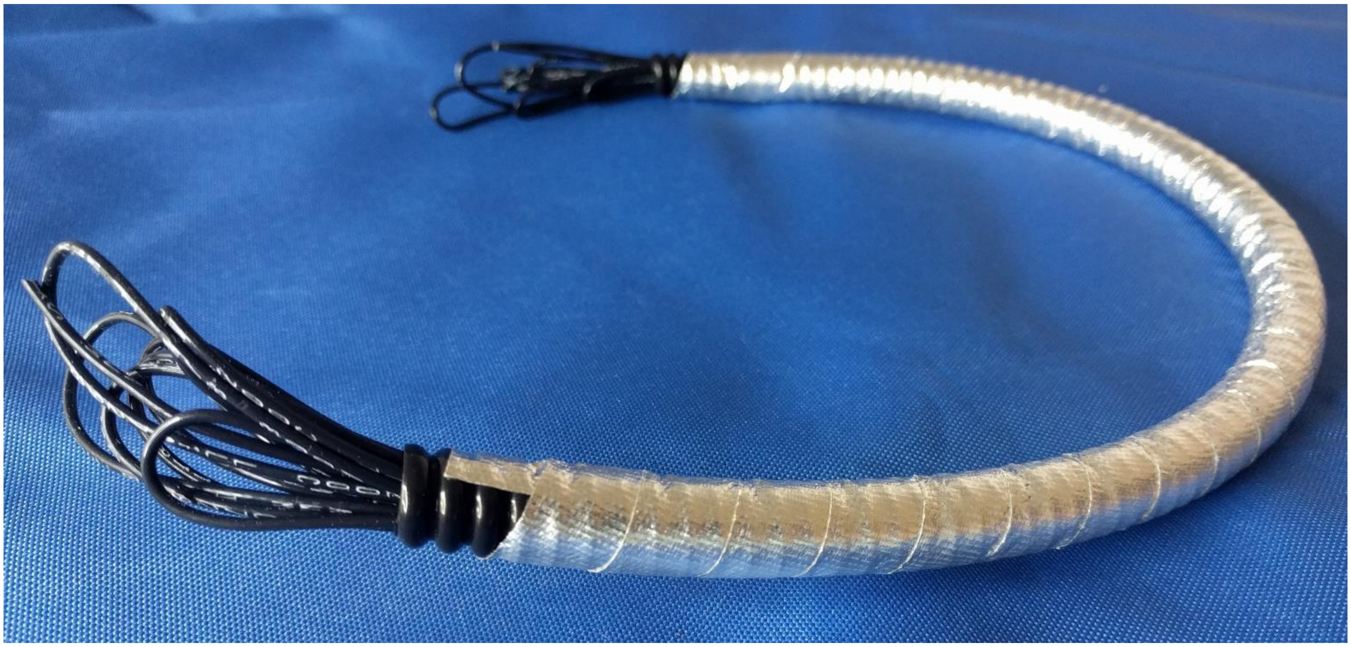

Figure 1: Ford Performance Specification Bench Scale Harness

3.2 Abrasion Resistance

Tapes see more than heat. Vehicles are designed to move. As vehicles travel along bumpy roads and highways, while moving parts create constant vibration, harnesses are exposed to tremendous abrasion risk. Tapes are often designed and selected for their performance against the abrasion a wire harness may experience. Imagine, if wires connecting the sensors of a vehicle's airbags and main controller were rubbing against engine parts just slightly during every mile driven; if left uncovered, a small continuous rub would ultimately result in the exposure of the wire's conducting core and leave the driver with a warning light and the need for expensive trouble shooting. In a worst case scenario, the air bag will not deploy when it should and an injury will occur during impact in an accident.

Abrasion resistance is evaluated using numerous methods. Ford requires needle style stroke abrasion and labels abrasion protection as a Wear Resistance category. The various levels of wear categories are as seen in Table 3.

Needle Abrasion is performed by adhering one layer of the tape to a steel rod with a diameter of 10 mm. The test is an altered version of ISO 6722 to accommodate testing tape instead of the insulation on a single strand of wire[11]. The diameter of the horizontal scraping needle is 0.45 mm. The needle is changed at each test. The scrape test occurs down the center of the tape. The needle is weighted from above. The scrape abrasion stops when electrical contact is made between the steel rod and the abrading needle; when a hole in the protecting tape surface has been worn. Figures 2 shows the needle and tape set up for testing.

Table 3: Wear Resistance Categories

Wear Category	Requirement (Double Strokes)
0 – No wear protection	< 100
1 – Little wear protection	100 – 499
2 – Medium wear protection	500 – 999
3 – High wear protection	1000 – 4999
4 – Very high wear protection	5000 – 14999
5 – Ultra high wear protection	15000 – 29999
6 – Super high wear protection	> 29999
N – Not tested	N/A

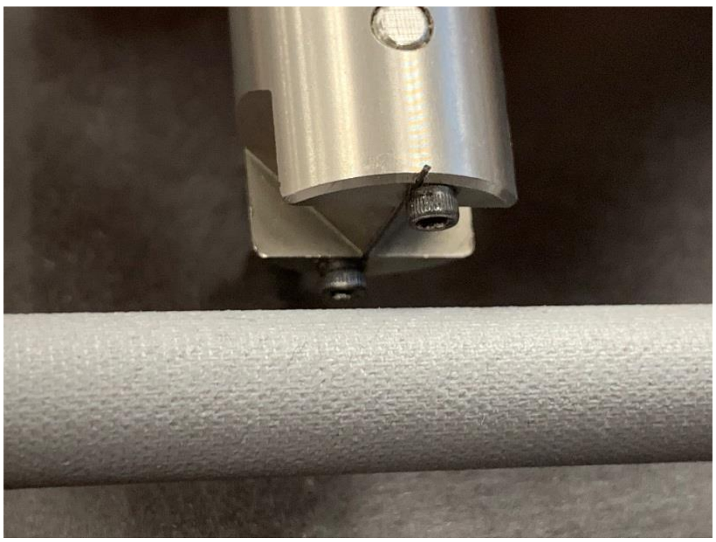

Figure 2: Needle Abrasion Testing

The final number of double strokes by which a tape is rated, across and back equaling a double stroke, is determined by the mean of ten iterations of the test. It should be noted that most harnesses are half-lap wrapped resulting in a double layer of tape along the entire harness covering, while the test merely examines the durability of a single layer.

Abrasion results help harness design engineers choose tapes with a protection level required for wires traveling through potentially wearing transitions between the body and engine compartment, running along tight locations in doors and bending around curves and corners throughout the vehicle.

3.3 Flame Retardant Properties

Tapes applied to protect the wires and components of harnesses are also tested for flame retardant properties. Heat aging performance and abrasion resistance indicate how a tape will age over a lifetime and handle repeated stress. Flammability testing informs a design engineer how a tape will help protect the components within the harness system, the vehicle, and in turn, the driver, against the worst – the spread of fire.

OEM performance specifications typically require flammability to be evaluated according to the horizontal method described in ISO 3795-1989[12]. This International Standard outlines the determination of burning characteristics for materials utilized in vehicles interiors.

Flammability testing per ISO 3795-1989 utilizes a rectangular combustion chamber with a gas burner at one end and a hole for introduction of the sample and a holder in the other end. The sample holder exposes one end of a tape strip horizontally to a 1.5-inch-high flame for 15 seconds. Tapes are generally tested with the backing side down to the flame; indicating their purpose as a line of defense against exterior flames.

Burning distance (D) is measured in millimeters by observing the front of the flame as it propagates from one marker point to another or where the flame burns out; whichever is first. A timer is started and stopped at the first and final markers, giving a burn time (T) in seconds. The overall characteristic determines, Burning Rate (B), which is given in millimeters per minute and calculated using Equation 1 as shown below.

$$B = \frac{D}{T} \ x \ 60 \qquad \text{(Equation 1)}$$

The Ford specification requires harness tapes have a burn rate of no more than 100 millimeters per minute; less than 4 inches per minute. Ensuring that tapes meet or exceed this Ford requirement and others, helps reduce the proliferation of a fire within a vehicle, protects the electrical system, and buys precious time for drivers and passengers in an emergency situation.

3.4 Automotive Fluid Resistance

Tapes wrap wire harnesses to ultimately help protect a driver from electronic failure. Coincidentally, drivers have the potential to influence the longevity and performance of certain harnesses throughout the engine compartment every time they top off their engine oil, refill the windshield wiper fluid, add coolant, and more. Most drivers can relate to spilling some fluid while refilling and helplessly watching the spill trickle onto the visible engine parts and flow or drip down into the dark spaces hands cannot easily fit to wipe and clean up the mess.

As a car ages, fluids can also seep from leaking hoses and connections throughout engine, batteries can potentially leak acid and degreasers used around the engine during servicing can drip or over-spray onto adjacent harnesses; all of these possibilities posing a threat of destroying tape protecting wire harnesses and causing corrosive damage. Even salt spread across roads during the winter months can influence longevity of a wire harness if the tape is not designed and tested to resist salt corrosion. Given the high likelihood of harnesses being exposed to all of these potentially damaging fluids, OEM specifications require thorough examination of a wire harness tape's resistance against a multitude of automotive fluids at room temperature and at elevated temperatures over an extended period of time.

The Ford specification requires tapes to be immersed or saturated in the following fluids for 5 minutes before being drained and conditioned for 72 hours and aged prior to evaluation.

Table 4: Automotive Fluids for Resistance Testing

Test Fluid	Test Exposure Temperature
Battery Acid	Room Temperature: 23 ± 3 °C
Windshield Washer	
Engine Cleaner	
Salt Spray (5% NaCl)	
Brake Fluid	
Gasoline	
Diesel Fuel	
E85 Ethanol	
Transmission Fluid	Elevated Temperature: 80 ± 3 °C or 90 ± 3 °C
Power Steering Fluid	
Engine Oil	
Engine Coolant	

Samples are prepared similarly to the Heat Aging tests. Bench versions of wrapped wire harnesses are built and vary slightly between different specifications. In Ford's specification, after wrapped wire harness specimens are exposed and conditioned, evaluations of performance are made by wrapping the harnesses around a 40 mm diameter mandrel.

Any signs of cracks, tears, melting, incompatibility between fluid and tape or reduction or loss of adhesive capacity results in a tape's failure to meet the Ford specification requirements. Fluid Resistance testing is a thorough evaluation of the tape's resistance to seemingly unavoidable corrosive materials.

3.5 Heat Reflectivity/Thermal Effectiveness

Some specialty tapes not only resist aging in heat but are designed and tested for their ability to reflect heat and significantly reduce the temperature experienced by the wires and components beneath them. Heat reflecting engine compartment tapes generally consist of an aluminum-type backing and are rated for 150 °C, 175 °C or 200 °C operating temperatures. Tapes applied to the wire harnesses to protect against external heat sources are tested utilizing test method SAE J2302[13], a method originally designed for sleeves, measuring the effectiveness of the tape to insulate against heat.

In reflectivity testing, a ceramic cylindrical rod is half-lap wrapped in tape. Thermocouples are applied to the ceramic rod before taping as well as attached to the exterior of the tape. A heat source is seated below the wrapped rod at a given distance and set to radiate a specified temperature. Tapes are subjected to heat-source settings of 121°C, 260 °C, 482 °C and even 550 °C. The test is completed in an open-top heat resistant box. Temperatures on the exterior and interior (TI) of the tape are measured after the heat source has reached equilibrium. To determine the thermal effectiveness of the tape, tape wrapped rod measurements are compared to that of a bare rod (TB) reading completed prior to tape application for each temperature tested. A tape's thermal effectiveness (TE) at each temperature setting is calculated by Equation 2.

$$TE\ (°C) = Average\ TB - Average\ TI \qquad \text{(Equation 2)}$$

Essentially, the higher the Thermal Effectiveness (TE) value at a given test temperature, the more effective the tape is at reflecting heat from the wires and components it protects. Engineers designing wiring harnesses traveling through a hot engine compartment can use these ratings to best select the protection level needed for the route required.

4.0 Comfort and Driver Experience

Safety and performance are not the only factors addressed in automotive specification testing. Harness tapes used inside or near the passenger compartment are also designed to ensure and enhance a positive driver experience. Wire harnesses run through tight spaces inside doors, throughout the dashboard, along beams, and sometimes even overhead. Tapes can protect wire harness, but if used in the wrong space or designed incorrectly, they can inhibit the driver experience.

4.1 Fogging

With the driver in mind, a tape is designed and tested for a characteristic called fogging. Fogging addresses, a unique problem. If a tape under heat exposure releases particulates, oils, water vapor or plasticizers; this will ultimately condense on surfaces inside the vehicle as the temperature cools. The resulting condensation can produce a fog on windows or a film on vehicle interior surfaces, neither of which being favorable.

Tapes tested to the Ford specification are required to produce a fogging number of 20 or less. This value is a measure of initial (R_i) and final (R_f) optical gloss values on glass panels. Glass panels are placed atop 400 mL tall form 80 mm circumference beakers. At the bottom of the beaker lies a tape sample applied to aluminum. The beakers are lowered into a 100 °C heating bath while the glass panels are topped with cooling blocks, chilling the panels to 21 °C. The environment created facilitates condensation and is maintained at those conditions for 3 hours.

At the end of exposure, the cooling blocks are removed and the panels are placed flat on a black surface with the condensation catching side up. Gloss readings are taken at 1 hour after conditioning at room temperature and 16 hours later. Extensive cleaning of the glass reference panels and beakers ensues to make sure that the readings are truly reflecting only materials released by the heated tape specimen. Fogging numbers are determined by Equation 3 as seen below.

$$Fogging\ Number = \frac{Rf}{Ri} \times 100 \quad \text{(Equation 3)}$$

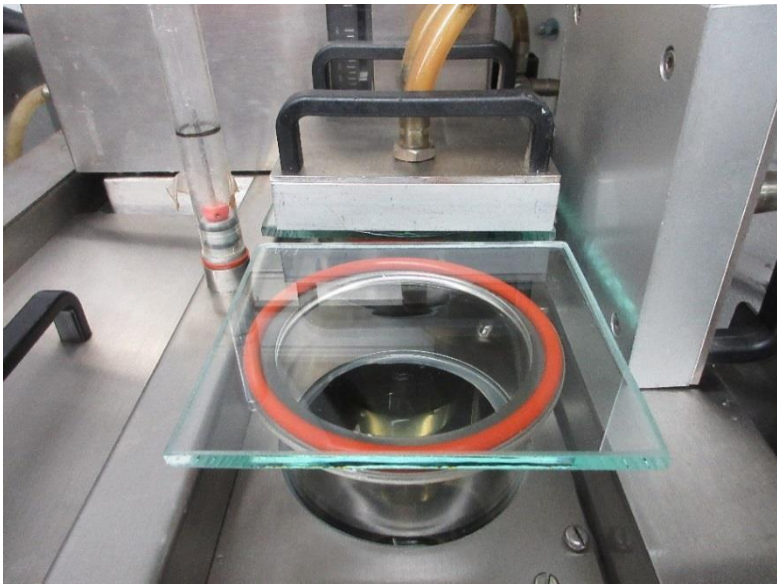

Figure 3: Fogging Heating Bath with beakers, glass panels and cooling plates

4.2 Noise damping

Noise prevention in automobiles includes Buzz, Squeak, and Rattle (BSR) tapes and other Noise, Vibration, and Harshness (NVH) products[14]. BSR tapes prevent or minimize noise to enhance driving experience. These tapes are generally soft and fluffy; designed to cushion the impact between components. NVH products also work to reduce driver experienced noise by absorption of sound energy, but are not common as harness wrapping materials.

As cars age, parts within age as well. Clips break and harnesses begin moving more within the space available. Conversely, as electrical system intricacies increase, new vehicle harnesses can become crowded. Harnesses can be in closer proximity to other components or even more compressed between vehicle frames and interior enclosures. In all of these situations, the likelihood of rattles and squeaks is high. Parts or frames and harnesses bumping and tapping routinely can create an annoying orchestra behind the dashboard or within a doorframe.

Harnesses routed through tight or cramped areas are prime candidates for BSR tapes. The Ford specification breaks tapes into the following noise damping categories:

Table 5: Noise Reduction Categories

Noise Damping Category	**Requirement [dB(a)]**
0 – No noise dampening	0 to ≤2
1 – Little noise dampening	<2 to ≤5
2 – Medium noise dampening	<5 to ≤10
3 – High noise dampening	<10 to ≤15
4 – Very high noise dampening	<15
N – Not tested	N/A

Noise reduction of a tape is measured by covering an 8 mm steel bar with one wrap of tape. A lever is pulled to release the steel bar, dropping it from a height of 20 mm onto an arched aluminum plate with a force of 0.16 N. The test procedure is a standardized set-up and Figure 4 is a schematic of the test fixture:

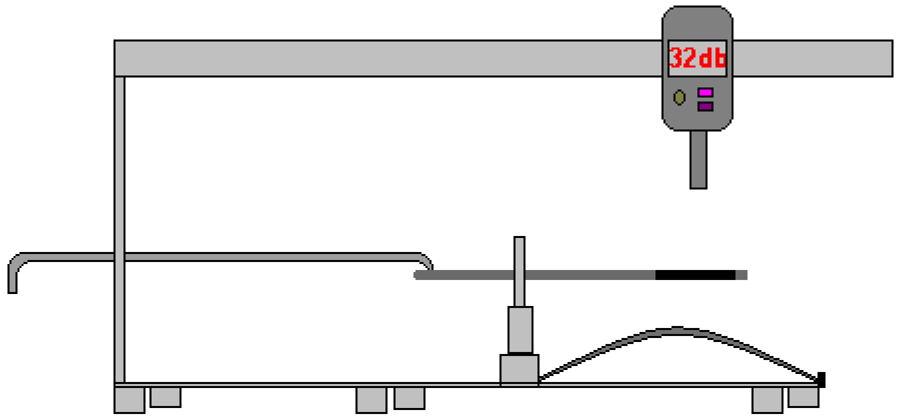

Figure 4: Noise Testing Fixture

Above the steel rod is a sound meter which measures resulting decibels from the rod and plate collision. Readings are taken 10 times at the same point of impact. Values are recorded for the bare steel rod and the difference in decibels, dB (A) or noise reduction from bare to covered rod determines a tape's noise reduction performance category.

5.0 Weather and Environmental Impacts

Automobiles are routinely subjected to extreme temperature variations due to the difference between ambient and operating temperatures. Ideally, all vehicles would be garage kept, keeping ambient temperatures warmer and reducing the temperature fluctuations harness tapes may experience as a vehicle warms up, operates and cools down; a cycle possibly experienced multiple times a day for much of its life time.

5.1 Environmental Cycling

Environmental Cycling requirements test and confirm that tapes can withstand the stresses that heating and cooling cycles exert on the electrical systems. In the Ford specification, bench size harnesses are built and tested to seven cycles in the following exposure sequence:

3 hours at service/operating temperature
2 hours at uniform cool down to - 40 ± 2 °C
3 hours at - 40 ± 2 °C
1 hour uniform heat up and humidification to 38 ± 2 °C and 95-98 % Relative Humidity
1 hour at 38 ± 2 °C and 95-98 % Relative Humidity
1 hour uniform heating and drying to service temperature

After the seven cycles and required reconditioning, exposed bundles are evaluated in a manner similar to Fluid Resistance bundles. Tapes pass this test if minimum flagging and no indications of deterioration of the backing or adhesive is exhibited after wrapping the bundle around a 40 mm mandrel.

5.2 Cold Flex

Similarly, tape behavior is evaluated in excessively cold environments. Per the Ford specification, bundles are prepared for Cold Flex testing and exposed to -40 °C for 4 hours while weighted with 0.5 kg and attached to a 20 mm mandrel. As seen below in Figure 5, samples are wrapped by turning the mandrel while still cold after 4 hours of exposure. Samples are brought to room temperature and reviewed for defects.

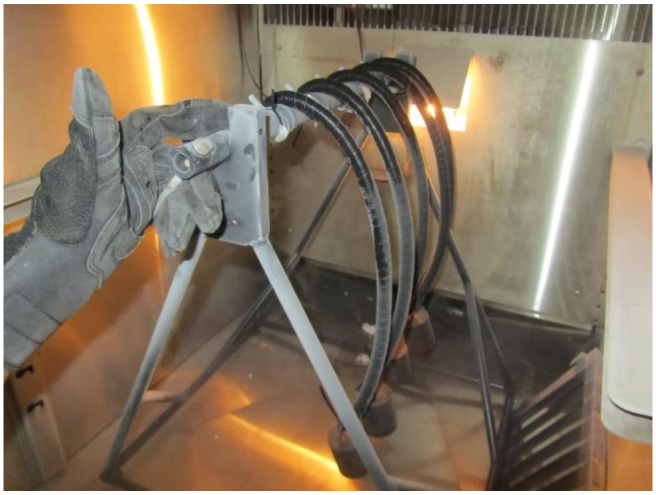

Figure 5: Cold Flex Testing

5.3 Thermal Overload

Conversely, samples are inspected for exposure to excessive heat as well. Temperatures within the engine compartment as well as in the passenger compartment can climb significantly in certain situations. Interior temperatures can escalate in hot summer heat and engines can overheat or maintain and build heat after a drive when parked in direct sunlight during the hot summer months. Thermal Overload requires bench bundles be exposed to 50 °C above a harness tape's operating temperature for 6 hours. As in the previously reviewed tests, fatigued bundles are wrapped around a 40 mm mandrel, stressing the heat exposed tape backing and adhesive. Thermal Overload testing strictly and ruthlessly evaluates performance and safety of protection providing harness wrapping tapes.

6.0 Conclusion - Tapes, Testing and Owner Confidence

Pressure sensitive adhesive tapes are used in many areas of automobile manufacturing and servicing. Specifically, wrapping wire harnesses in tape provides critical protection that ensures the safety, reliability and positive experience consumers expect and vehicle manufactures aim to deliver. Testing harness tapes to OEM performance specifications provides crucial information to design engineers and after-market service providers. A true understanding of real world application is beneficial to appreciating the role each required testing criteria plays in continuing consumer trust and OEM dependability.

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