Atlas Application Guide 110

Durability Testing of Wearables

Guidelines for environmental testing including radiation, heat, and moisture

Atlas Material Testing Technology

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Understanding materials and final product durability will allow you to meet customer expectations and avoid premature product failures. Typical failures are related to appearance, performance, and functionality. In times of vast, easily available similar wearable products, unexpected or premature failure often gives the end user a reason to choose a different brand next time.

1. *Introduction*

Wearables have shown large growth over past years with Sales projected to reach an estimated $16.9 billion by 2021 [1]. The market is mainly driven by smart watches and fitness trackers, however wearables used in care and medicine (blood sugar, blood pressure, emergency call, hearing aids, and others) recently become more popular. As a result, we see a high product diversification as shown in the graphic at right and most likely more innovations will be coming.

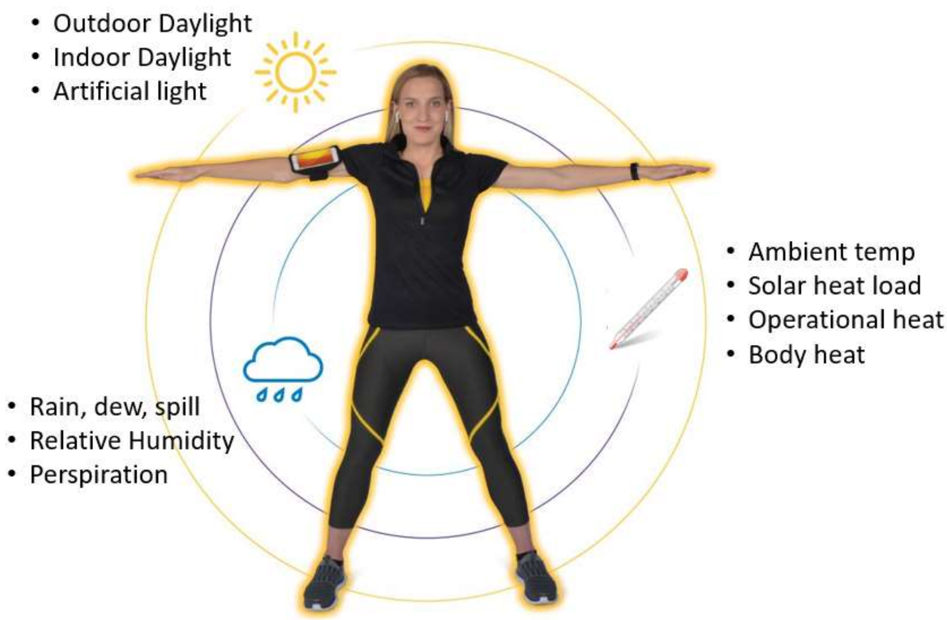
Four segments of wearables. (Image Source: original product manufacturer's website)

Most wearables undergo numerous quality and performance tests ranging from temperature cycling, humidity, corrosion, power cycling, mechanical bending, and many others. Designers of wearables are aware of the harmful effects of UV, however often unsure about which instrument to choose and what would be a good test. Wearables are made of different materials such as colored thermoplastics or rubber materials, sealants, and joints, displays, cameras, and protective films. They all tend to be sensitive to UV radiation, partially visible, heat and moisture. Further, their intended use can be outdoor and/or indoor, but worldwide climates can vary significantly with respect to radiant energy, temperature and moisture depending on their location. Therefore, Atlas created a set of four accelerated outdoor and indoor tests for wearables, which can be used as starting points. With additional information, Atlas can support which test to choose based on a best match to the intended end-use conditions. Further, the test duration reflecting targeted service lifetime.

By applying weathering and lightfastness testing, you will receive answers to questions like "What are the right materials for each part of my wearable?" or "Will my wearable product last as long as expected?" or "Will it look good as long as expected?". Those question and others should be answered to maximize commercial success.

2. *Stress Factors*

The major stress factors for wearables are primarily light (UV and Visible), heat, and moisture.

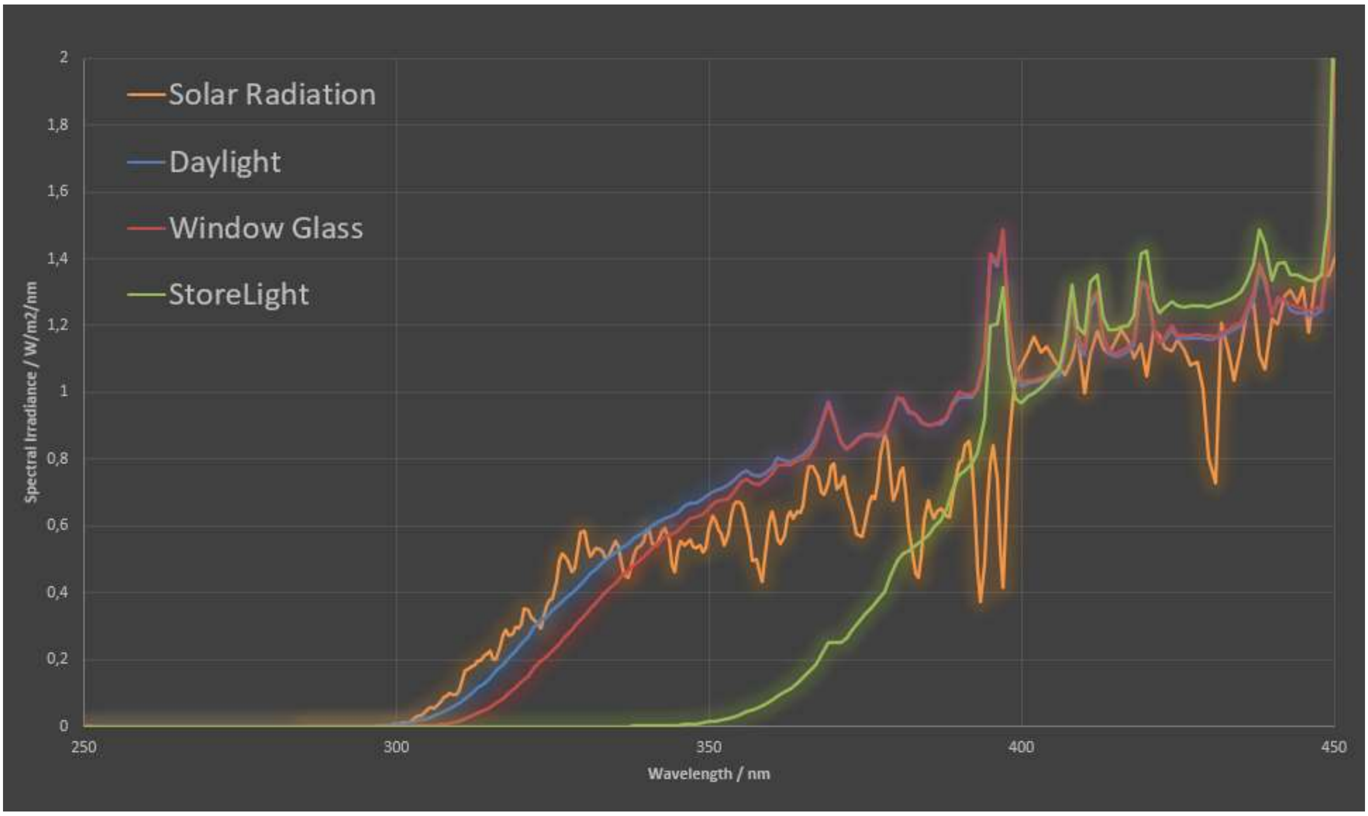


Radiation and product temperature are the two major drivers for the degradation of polymer materials via photo-oxidation reaction. For radiation, the ultraviolet range (between 295-380 nm for natural sunlight) is known as the most critical for the initiation of the degradation reactions via formation of radicals. The critical part of visible light is often limited to energy rich violet and blue light at wavelength ranges approx. 380-420 nm. However, each color will absorb respective portions of the complete visible light spectrum, contributing to its fading. Further, increasing intensities of radiation (up to a certain limit) lead to an increased amount of radical formation. This reaction is majorly independent of temperature. Finally, it is important to remember that all three stress factors do work synergistically, often causing a greater effect compared to separately applied individual stresses.

Radiation

The amount of radiation reaching the earth depends on the location and time of the year. Global weather stations maintain data bases providing annual average values for global radiation, temperature, and humidity. At Atlas, those measurements, including total UV measurements, are taken continuously at our benchmark natural weathering test sites in Miami (Florida), Phoenix (Arizona), Sanary (France), and Chennai (India).

Further to the radiant energy, the spectral power distribution is critical when speaking of outdoor or indoor solar radiation[2,3]. Outdoors, the amount of short wavelength UV-radiation shorter than 300 nm reaching the earth is small but the effect on the degradation of material can be significant. The natural UV cut-on wavelength lies at approximately 295 nm and a laboratory instrument should be able to accurately match that cut-on wavelength. Shorter wavelength energy below 295 nm can cause materials to fail unnecessarily (as not present in the natural exposure). In reverse, if your laboratory instrument cuts on at longer wavelengths, testing becomes less severe and material that should fail may pass the test. Or, based on the test you expect your product to last for a certain amount of time may prematurely fail. This is entirely material dependent and correlation studies with natural exposures are critical. Indoor lighting must be separated into sunlight behind window glass and artificial lighting such as common fluorescent and LED lighting because of the significant difference in the spectrum. While sunlight behind window glass typically shifts the natural UV cut-on wavelength from 295 nm to approximately 315 nm, fluorescent lighting cuts on at approximately 350 nm and white LEDs typically at 390-400 nm.



Spectrum Comparison in the wavelength range 250-450 nm of natural solar radiation vs Atlas SUNTEST using Daylight / Window Glass / Store Light filters

Temperature

The natural range of outdoor exposed product temperatures heavily depends on their color[4]. Black product surfaces may reach up to 65°C outdoors and even up to more than 100 °C inside a car. White surfaces stay considerably cooler. Air temperatures during summer can reach up to 45 °C – very rarely higher. Wearables additionally get impacted through their operational energy and the wearer's body heat. The reaction rate increases with the temperature. This also applies to the photochemical degradation pathways of polymers.

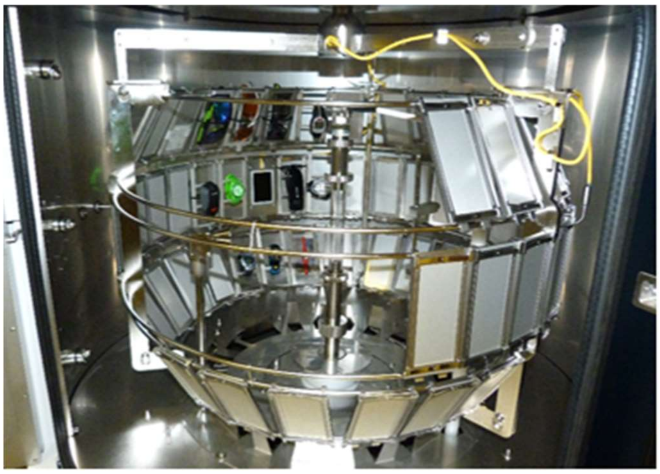
Water

Depending on their composition, polymers can swell when they absorb water. On the other hand, when water evaporates shrinking happens. This process can eventually cause mechanical stress most likely for thin film and coatings. As a rule, the effect of water is only important if water penetrates for a longer period over several hours. However, if a polymer absorbs water, the glass transition temperature drops significantly. Consequently, the oxygen diffusion rate is increased supporting photo-oxidation and hydrolysis reactions degrading the polymer matrix which ultimately results in loss of physical strength.

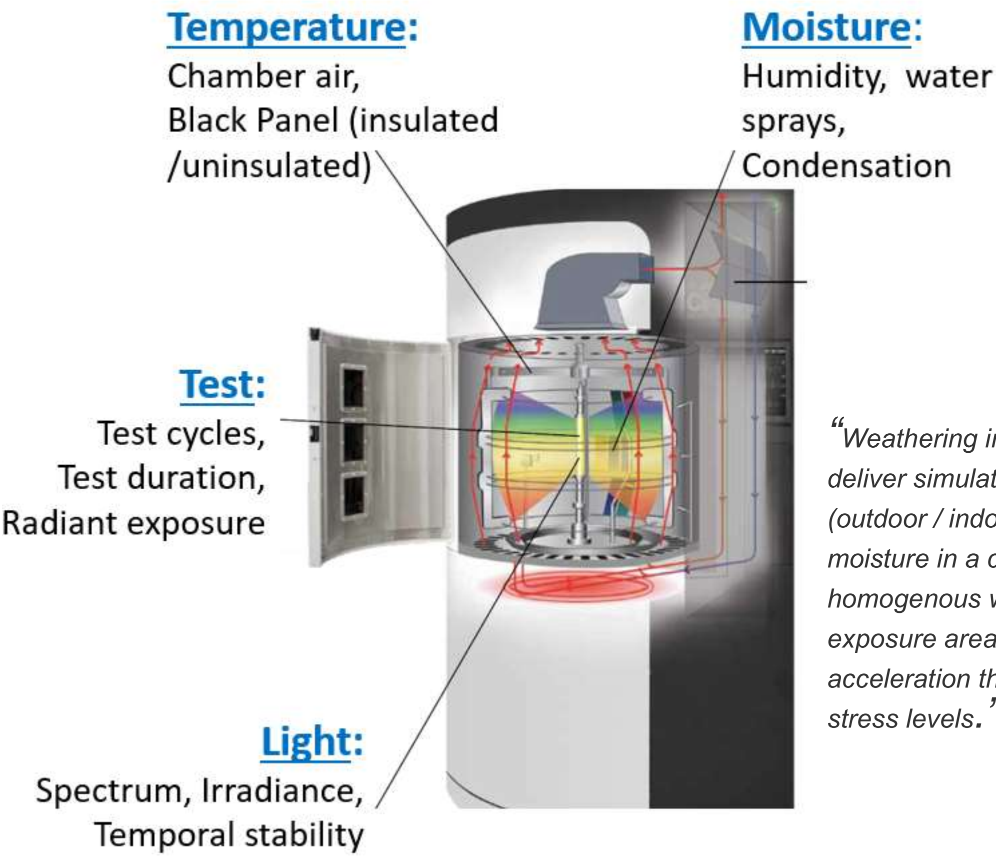
Weathering instruments

The intention of any accelerated weathering instrument is to deliver the same factors of weathering to which products are exposed in outdoor/indoor conditions. This means radiation, heat, and moisture. Regarding outdoor/indoor solar simulation, properly filtered long arc xenon lamps have shown for many years best spectral match to natural sunlight, as well as high temporal and spectral stability. Regarding moisture, this can be either through humidity, water spray, or water condensation. Furthermore, the instrument must be able to control each stress factor independently, at least at realistic maximum high level – better even beyond, to be able to further exploit the highest acceleration of the product degradation processes compared to natural static exposures without causing unnatural reactions.

There are basically two types of xenon instruments – rotating rack and flatbed. The different chamber geometries primarily affect irradiance and temperature. This means, how well they reach each location inside the test chamber exposure area. This is often referred to as test chamber uniformity. Test standards typically address this uniformity within maximum allowed variations for irradiance and temperature ± 10% [4]. Atlas rotating rack instruments typically perform in the range ± 2-4 %, while flatbed range ± 7-10% which can be decisive for reliable differentiation between two similar materials.



Left: Ci4400 Weather-Ometer® (rot. rack, 7300 cm² exposure area. Right: SUNTEST® XXL+ (flatbed, 3000 cm² exposure area)



"Weathering instruments should deliver simulated solar radiation (outdoor / indoor), heat and moisture in a controlled, homogenous way over the entire exposure area and provide test acceleration through increased stress levels."

3. Guidelines for Accelerated Laboratory Testing: Outdoor Conditions

Wearables durability testing involves testing for the longer-term degradation of materials, much of which is environmentally influenced. The type of accelerated testing targets the effects of accumulated radiation, heat, and moisture to reflect a certain service lifetime. Although wearables have been on the market for many years, there are no specific testing standards. Traditional materials such as polymers and coatings can be tested using existing ISO, ASTM, and other standards, but may not be ideal for every type of wearable.

In our experience, test settings and test duration often need to be customized for certain types of products and the individual client expectations. Therefore, Atlas modified the international polymer test methods towards a better fit for wearables – and at least suit as practical starting points for beginners. Each test reflects a specific exposure a wearable eventually experiences. Atlas suggests testing wearables intended for major outdoor usage according to the outdoor weathering test protocol applying water spray cycles. For specific water tightness applications, you may also want to consider a benchtop instrument combined with an immersion unit (e.g., SUNTEST XLS+). Here specimens up to a height level of 30 mm can be fully immersed in water and simultaneously irradiated.

3.1 Test conditions for outdoor wearables

Application: Designed for wearables which are used permanently or frequently outdoors under the full exposure to the environment in combination with a "close-to-the-human-body" microclimate.

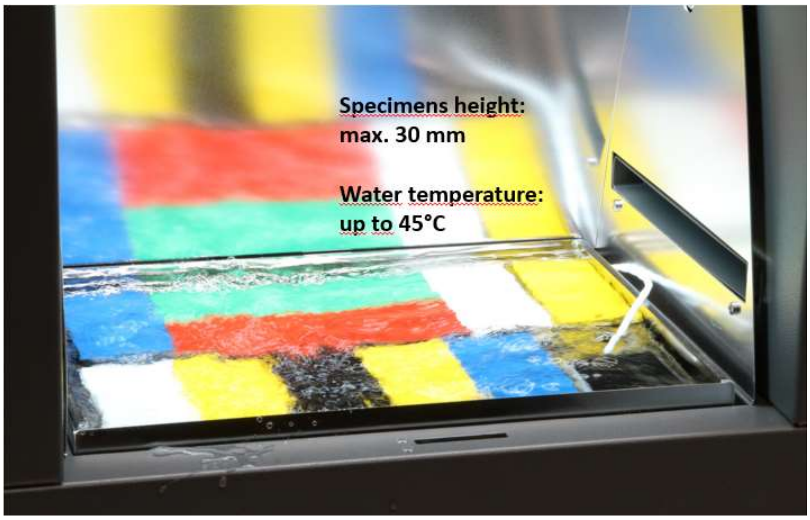
Parameters: Outdoor solar simulation based on ISO 4892-2 "Xenon-arc weathering of plastics: Cycle 1: Weathering; adjusted temperatures; high RH addressing sweat effects.

Suitable Atlas instruments: Ci Weather-Ometer, Xenotest 440, Beta+, SUNTEST XXL+/XXL+FD

	Test-1
Parameter	**Outdoor Weathering Test**
Optical Filter	Daylight
Irradiance	60 W/m^2 (300-400 nm)
Black Standard Temperature	60 °C (55°C)*
Chamber Air Temperature	35 °C
Relative Humidity	70%
Front Spray	Intermitent
Cycle	Light: 102 min Light + front spray: 18 min

* 55°C BPT

Test duration of 24 hours delivers radiant energy of approximately 5.2 MJ/m^2 (300-400 nm).
Note: higher irradiance levels >60 W/m^2 are possible inside Ci and Xenotest to shorten test durations accordingly.
1-day direct sunlight depending on location and time of the year: ~ 0.5 - 1.0 MJ/m^2
(e.g.: Miami annual radiant exposure: ~350 MJ/m^2)



Alternative instruments equipped with immersion unit: Left: Atlas SUNTEST CPS+ with SunFlood immersion unit: exposure area ~27 cm x 20 cm. Alternative: Atlas SUNTEST XLS+ with SunFlood immersion unit: exposure area 38 cm x 30 cm.

4. Guidelines for Accelerated Laboratory Testing: Indoor Conditions

Wearables intended for major indoor usage should be tested according to an indoor test. Atlas suggests three different indoor test methods, each addressing a specific climate. All indoor tests are designed for high acceleration compared to real-time. At our homes, a realistic worst-case scenario is a high level of solar radiation through window glass, high temperatures and high humidity. Test-2 simulates such conditions, addressing the sometimes surprisingly high temperatures achievable on such locations like a windowsill. Test-3 has been originally designed back in the 1980ies especially for automotive interior parts and proven to work well. Shorter test durations for wearables certainly make sense, as automotive interior parts will be tested to withstand ~6-10 years continuous usage. Wearables on the other hand might experience such conditions only occasionally when taken off / forgotten inside a car. Test-4 reflects artificial lighting conditions typical for products at their point of sale. Think about which indoor conditions will be most important to you.

4.1 Test conditions for indoor wearables

Application: Designed for wearables, which are used mostly indoors with an “close-to-the-human-body” microclimate.

Parameters: Indoor solar simulation based on ISO 4892-2 “Xenon-arc weathering of plastics” Cycle 2: Lightfastness testing; adjusted temperatures; high RH addressing sweat effects.

Suitable instruments: Ci Weather-Ometer, Xenotest 440, Beta+, SUNTEST XXL+/XXL+FD

	Test-2
Parameter	Indoor Daylight Test
Optical Filter	Window Glass
Irradiance	50 W/m^2 (300-400 nm)
Black Standard Temperature	60 °C (55°C)*
Chamber Air Temperature	35 °C
Relative Humidity	60%
Front Spray	None
Cycle	Continuous Light

* 55°C BPT

Test duration of 24 hours delivers radiant energy of approximately 4.3 MJ/m^2 (300-400 nm).
1-day sunlight behind window glass: ~ 0.43 MJ/m^2;* Average irradiance: 10 W/m^2 (300-400 nm)*
Note: higher irradiance levels >60 W/m^2 are possible inside Ci and Xenotest to shorten test durations accordingly.

4.2 Test conditions for wearables occasionally left/used in cars

Application: Designed for wearables, which are not used permanently and may be left/used inside cars or similar. Represents extreme stress conditions.

Parameters: Indoor solar simulation based on ISO 105-B06 "Xenon-arc weathering of automotive interior materials" Condition 3

Suitable instruments: Ci Weather-Ometer, Xenotest 440, Beta+, SUNTEST XXL+/XXL+FD

	Test-3
Parameter	Automotive Interior Test
Optical Filter	Window Glass
Irradiance	60 W/m² (300-400 nm)
Black Standard Temperature	100 °C (90°C)*
Chamber Air Temperature	65 °C
Relative Humidity	30%
Front Spray	None
Cycle	Continuous Light

* 90°C BPT

Test duration of 24 hours delivers radiant energy of approximately 5.2 MJ/m² (300-400 nm).
1-day sunlight inside a car can vary greatly depending on location, type of automotive window glass, wearable location. Automotive parts are typically exposed to 10 – 13 MJ/m² (300-400 nm) ➔ ~ 48-60 h

4.3 Test conditions for wearables exhibited at point of sale

Application: Designed for wearables exhibited inside retail stores on tables or shelves illuminated by artificial lighting.

Parameters: artificial light simulation based on the ATLAS Shelf-life Test; normal temperatures

Suitable instruments: SUNTEST XXL+FD

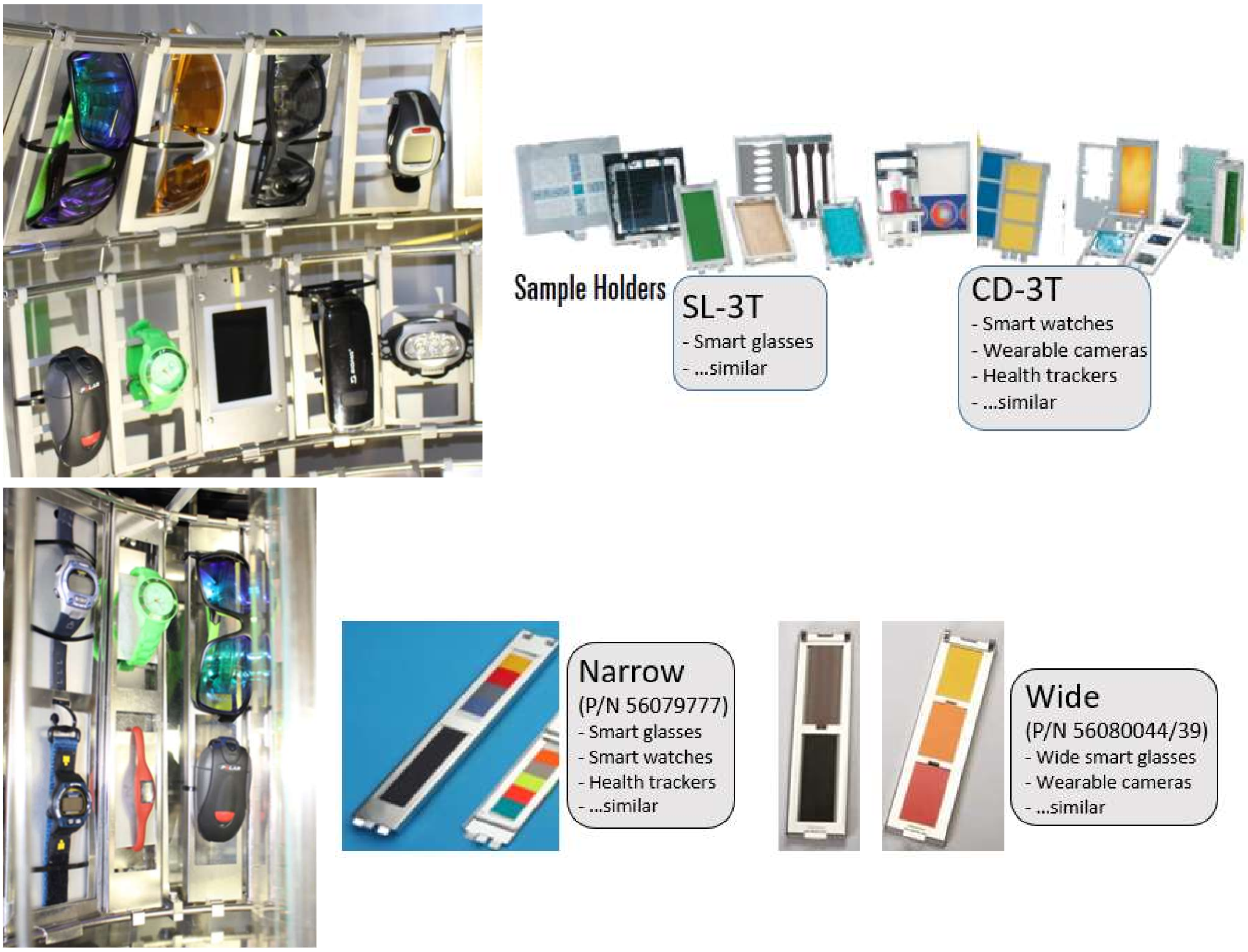
	Test-4
Parameter	Artificial Indoor Light Test
Optical Filter	StoreLight™
Irradiance	470 W/m² (300-800 nm)
Black Standard Temperature	35 °C (32°C)*
Chamber Air Temperature	21 °C
Relative Humidity	-
Front Spray	None
Cycle	Continuous Light

* 32°C BPT

Test duration of 24 hours delivers radiant energy of approximately 40.6 MJ/m² (300-800 nm).
1-day artificial light inside store: ~ 0.86 MJ/m²*
**Average irradiance: 20 W/m² (300-800 nm)*

5. *Sample Preparation Inside Xenon Rotating Rack Instruments*

Though many sample holders are designed for preparation of rather flat specimens, some of them like SL-3T or CD-3T for use in Ci instruments can also hold wearables fastened with cable ties. Xenotest 440 and Beta+ provide narrow and wide type holders allowing for the same practical mounting procedures.



Above: Atlas Ci4400 with sample holders SL-3T and CD-3T.
Below: Xenotest Beta+ with sample holders narrow and wide

6. Summary

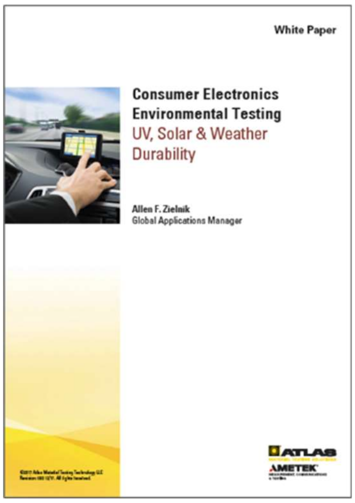
Early-stage environmental stress testing allows for screening and selection of candidate materials and components - typically polymers, colors, sealants, films, and display materials. Proven useful here are xenon weathering and lightfastness instruments which combine the synergistical stresses of light, temperature, and moisture in a realistic, compressed, and intensified way.
Since worldwide outdoor and indoor climates can vary much with respect to radiant energy, temperature and moisture, Atlas created a set of four accelerated outdoor and indoor tests for wearables. Sample preparation inside rotating-rack instruments can be done easily with specific sample holders and cable ties. Examples are given for Ci 4400 Weather-Ometer and Xenotest Beta+ instruments.
There are several xenon instrument types considered as suitable for the above mentioned four test methods. On the material level and small product level, we recommend xenon rotating rack type instruments, since they offer higher precision and wider testing ranges up to 120 W/m^2 (300-400 nm) irradiance. When it comes to larger types of wearables such as VR goggles or smart shoes, then exposure in flatbed xenon instruments such as SUNTEST XXL+ and XXL+FD is more practical.

7. Literature

1) CCS Insights, Market Forecast: Wearables, 2017.
2) ISO/TR 17801:2014 Plastics — Standard table for reference global solar spectral irradiance at sea level, relative air mass 1
3) CIE 241:2020 Recommended Reference Solar Spectra for Industrial Applications
4) W.D. Ketola, R.M. Fischer, "Surface Temperatures of Materials in Exterior Exposures and Artificial Accelerated Tests", Accelerated and Outdoor Durability Testing of Organic Materials, ASTM, STP 1202, 1994
5) ISO 4892-1:2016 Plastics — Methods of exposure to laboratory light sources — Part 1: General guidance

Further information: www.atlas-mts.com

- White Paper “Consumer Electronics Environmental Testing”
- Recorded seminars and free registration for coming online seminars on basics, advanced, and special topics (“Durability Testing of Wearables”)



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