Accurate Testing of Flexible Hybrid Electronics Using Tension-Free™ Systems

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Flexible devices are coming. Early failures could be disastrous for a new product. It is imperative that the devices withstand the mechanical stresses induced by their use, i.e., being worn on a human body, vehicle displays, bendable components. etc. Various mechanical stresses (bending, torsion, tension, compression, folding, etc.) will occur on wearable devices because of human movement. Testing to determine the strength of the devices will be a necessary part of product design. We have found that Tension-Free™ testing is an excellent way to get consistent and accurate results. For more than five years, Tension-Free™ modular equipment has been developed by YUASA SYSTEM to allow testing that yields more accurate results than traditional methods. The Tension-Free™ method allows testing that meets the specifications of international standards. Some developers are thinking that endurance testing will be at the end of the development process, but the winners will be conducting their endurance tests in the early stages of development so that durability is designed into the product.

Introduction

The demand for mechanical stress endurance tests are suddenly increasing because flexible devices are coming. You can keep using current non-flexible devices if you use them carefully, but most flexible devices will break relatively early due to fatigue. Endurance tests can give you data about your products so you can assure your customers that your products will have good mechanical quality.

Wearable devices will be subjected to various mechanical stresses (bending, torsion, tension, compression, etc.) because of human movement, as illustrated in Figure 1. You should conduct every test that you think might represent stresses your device with be subjected to in the field, but it is difficult to choose among endurance testing methods. If you choose wrong methods, the device might break quickly. If you choose proper methods, the device should not break. You can find many endurance test methods at exhibitions or on web sites. You should compare not only cost but also specifications.

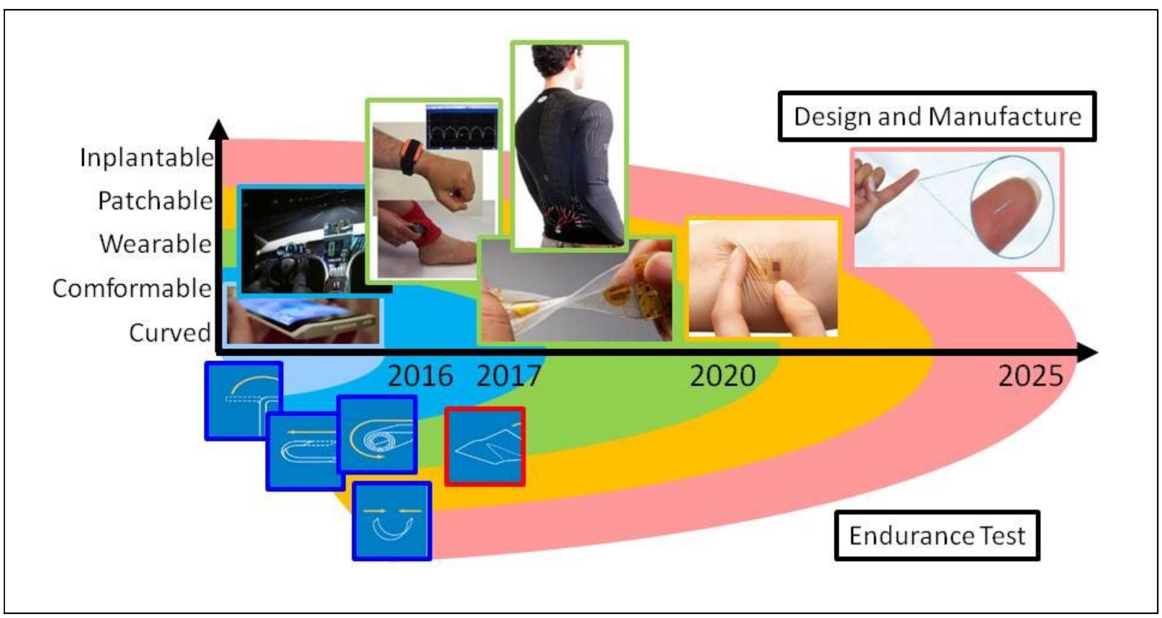


Figure 1 — Growing use of flexible hybrid electronics

Various flexible devices have been studied by numerous developers at different laboratories, but most devices or materials have some problems with durability. Some developers think that endurance testing is the last of their development processes, but the winners conduct their endurance tests in the early stages of product development so durability is designed into the product.

Background

The YUASA Group was founded in 1941. By 1992 the company was already designing and manufacturing factory automation systems and endurance testing systems for wires. YUASA SYSTEM Company Ltd. was formed in 1995 as a spin-off. The company has offices in Tokyo and Osaka, a factory in Kibitsu, and an office in Silicon Valley. YUASA SYSTEM maintains its own in-house expertise of mechanical engineering, electrical engineering, and software engineering.

In 2011, YUASA SYSTEM began developing Tension-Free™ endurance testing systems, and filed patents about Tension-Free™ technology. Also in 2011, they began applying Tension-Free™ technology to the tester for planar objects. Their third Tension-Free™ product was introduced in 2015, the Tension-Free™ Folding Tester, and it quickly became a best seller. Other Tension-Free™ products have been developed by YUASA SYSTEM, including the Tension-Free™ Torsion Tester for Planar Objects and the Tension-Free™ Bending Tester.

Tension-Free™ testing treats samples in an ideal manner, it is not necessary to apply tension that is needed only for the test machine to operate. For example, Figures 2 and 3 show the problem when the purpose of the endurance test is to determine the effects of bending a sample. Tension is applied to the sample to allow the bending jig to bend the sample, the tension comes from a weight attached to the sample.

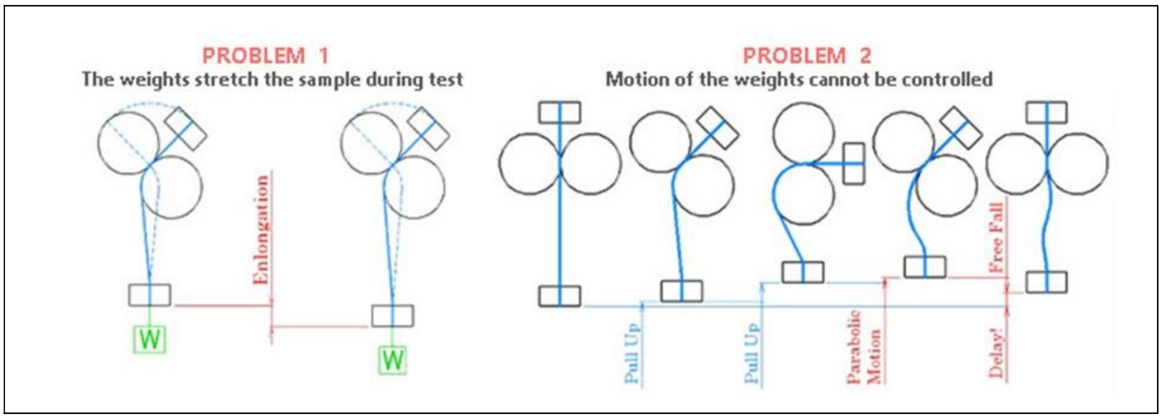


Figure 2 — Problems testing with weights

One problem, shown on the left in Figure 2, is that the weight can stretch the sample. If the endurance test is for bending, the tension can distort the testing results. The sample can break because of repeated stretching. A second problem, shown on the right in Figure 2, is that the weight can bounce around if the test is conducted rapidly. The test must be conducted slowly. The sample can break because of the bouncing weight. The Tension-Free™ test method, illustrated in Figure 3, never stretches the sample and it never shocks the sample.

The Tension-Free™ system consists of a controller (a fixed-length non-stretching string), a tension spring, and two clamps (a moving clamp and a following clamp). The following clamp can move quickly because it is pulled up by the controller and down by the tension spring, without using gravity. The sample is then attached to the moving clamp and to the following clamp. Tension is on the controller, not on the sample. The Tension-Free™ system treats the sample ideally, resulting in consistent and accurate data because the Tension-Free™ structure will not stretch the sample as long as the controller never gets longer

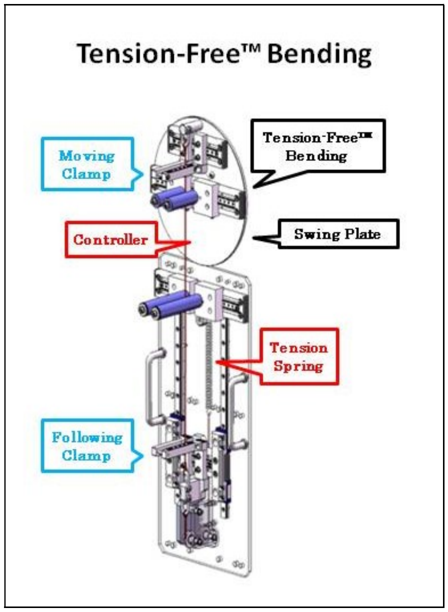


Figure 3 — Tension-Free™ testing

Torsion Testing

Of the various types of mechanical stress, torsion has been selected as the theme of this paper. You can expect wearable devices to be twisted by human movement. Some wearable devices will be twisted with tension if they are located on the outside of a joint. You can even imagine that some wearable devices will be washed and wrung out to dry. When you consider how to twist your samples in an endurance stress test, you must consider what situations the device might encounter in the future. You should understand how different test methods can give you different types of endurance data on the sample. You need to understand the differences, possibly subtle, of each test. To avoid mistakes, you need to know the purpose of each test, you must be able to answer the questions posed in Figure 4.

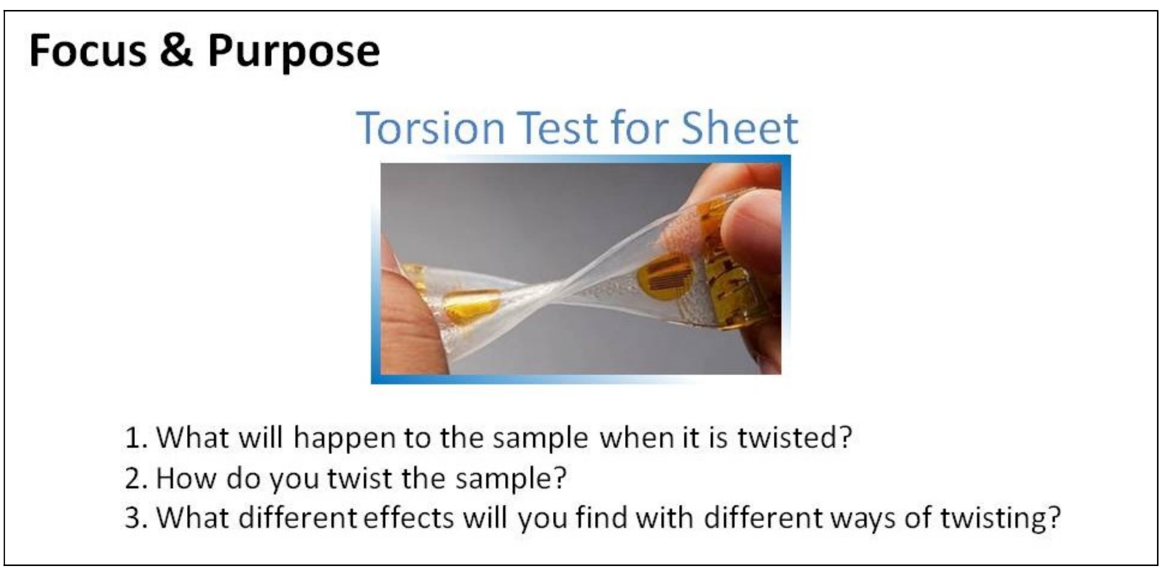


Figure 4 — Different tests give different results

You will discover that the stresses are more complex than you thought when you simply observe torsion. If you model the ideally transformed sample in two dimensions, you can represent variations of length and width by the formulas in Figure 5. The equations are complicated enough that they cannot be solved with a simple calculator.

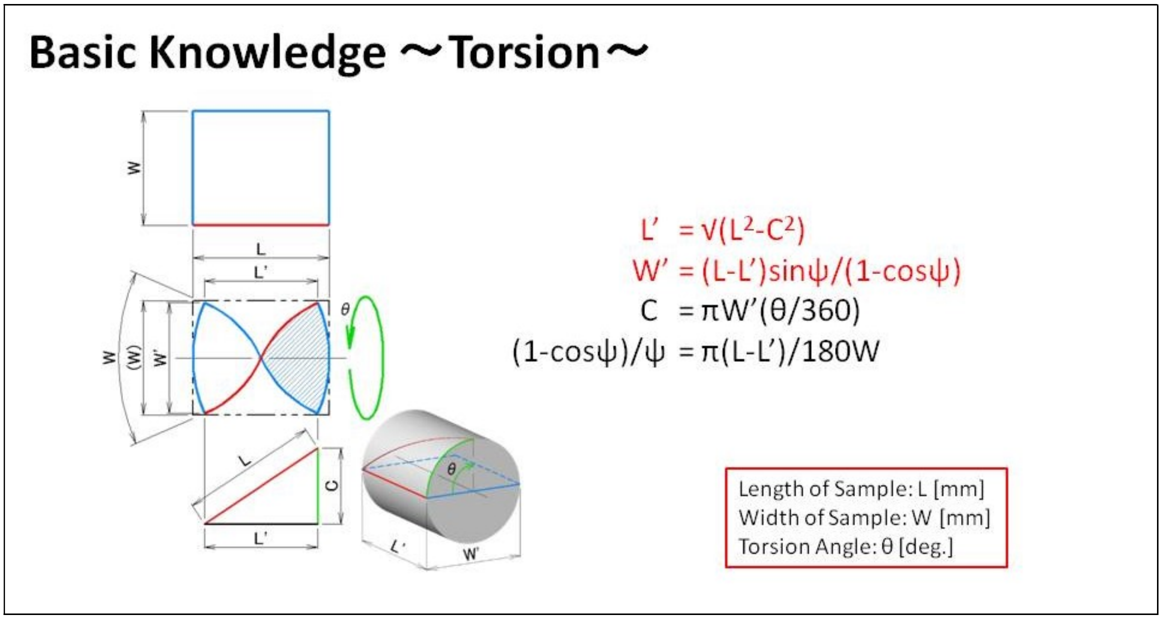


Figure 5 — Sample dimensions change under torsion

We will consider four methods that twist the sample between the turning clamp and the non-turning clamp. Those methods are: Sagged, Tension-Free™, Adjustable Tension, and Stretching. In Figure 6, solid lines represent the twisted sample and the broken lines represent the sample prior to twisting.

Basic Knowledge ～Torsion～

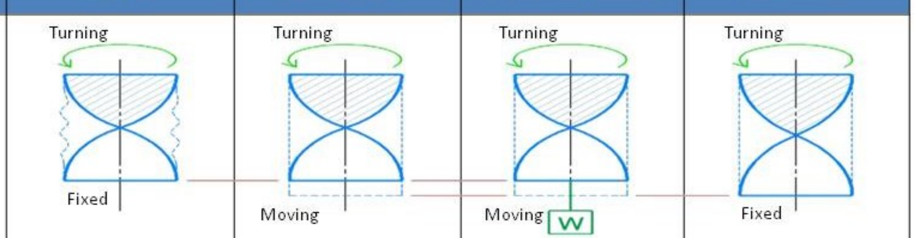
Name	Sagged	Tension-Free™	Adjustable Tension	Stretching
Image				
Initial Tension	Non	Non	Adjustable (more heavy than zero)	Non
Tension to stretch	Non	Non	Adjustable (equal to the initial)	Own Course (Heavy)

Figure 6 — Different test methods for torsion

In the Sagged method, the clamps are fixed at a distance closer together than the length of the sample such that the sample will continue to sag a small amount even when the maximum amount of twisting is applied.

In the Stretching method, the clamps are fixed but in this case the sample is flat when the clamps are fixed. The Stretching method is the traditional method for destructive testing. The tension will increase as the torsion angle increases.

In the Adjustable Tension method, the non-turning clamp moves to follow the change in the length of the sample. Tension is applied to the sample, using weights, to pull back the non-turning clamp as the twisting is removed.

The Tension-Free™ method, the subject of this paper, is an attractive way to twist the sample because weights can be an obstacle, they can stretch and break the sample.

The Tension-Free™ method is a new breakthrough technique. You do not have to load weights on the sample to pull it back when the twisting is removed, as in the Adjustable Tension method. The non-turning clamp moves back and forth, automatically, with the torsion. No tension is applied to the sample. The solution is very simple. The turning clamp has only a turning motion, the non-turning clamp only moves in linear motion. Figure 7 gives the equation for the sliding distance of the non-turning clamp.

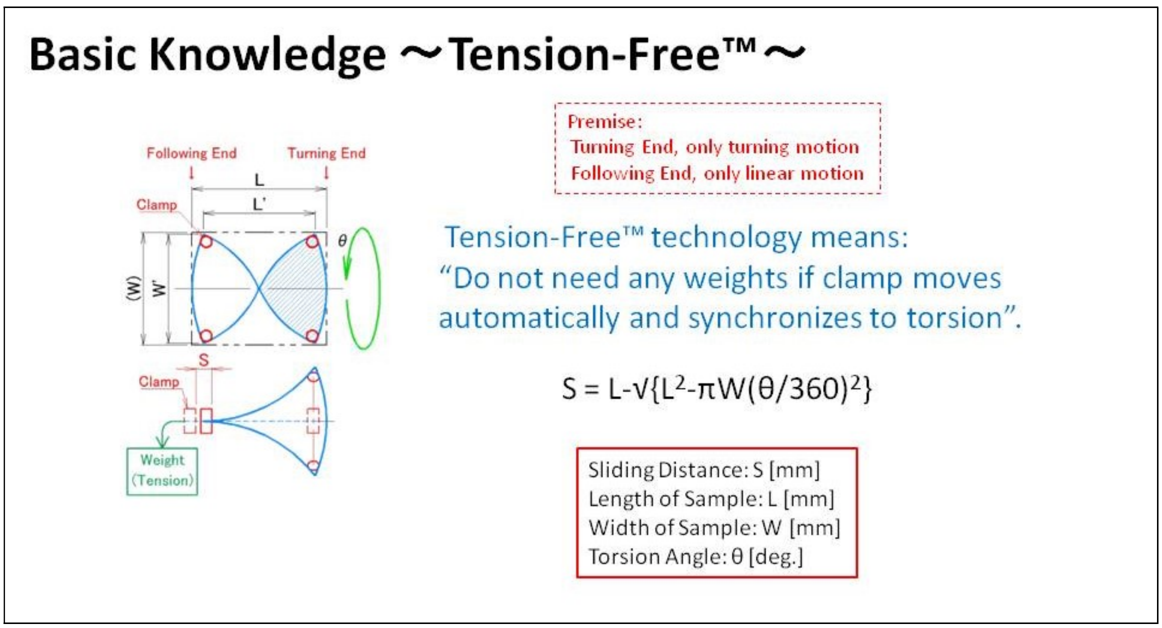


Figure 7 — Tension-Free™ clamp sliding distance

Experiments were run to compare results using the five different test methods. Two types of samples were prepared as shown in Figure 8, one sample was metallic foil, the second sample was stretchable wire sheet. The metallic foil was not something used for flexible hybrid electronics, it was selected because characteristics of wear would show in a short period of time. The stretchable wire sheet was fabricated by AIST for wearable devices.

Torsion was categorized to be one of five kinds, sagged, Tension-Free™, the right weight, a heavy weight and the stretching-method. Five samples per method were twisted. See Figure 9. Two different endurance tests were conducted. In Test 1, the samples were twisted five times in slow speed to observe any phenomenon. In Test 2, the samples were twisted 1,000 times at 60 reciprocations per minute (rec/min), to break the sample. Only one endurance testing system was used, YUASA

SYSTEM's, Tension-Free™ Torsion Tester for Planar Objects, model TCDMLH-FT. This testing system could be used for all of the test methods in this experiment.

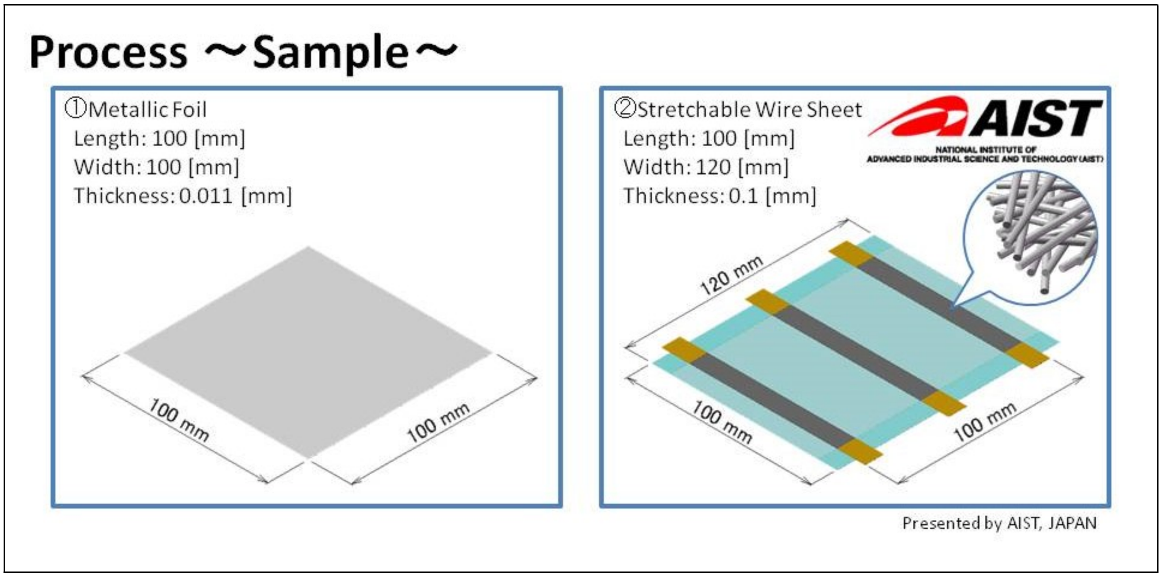


Figure 8 — Samples used for the tests

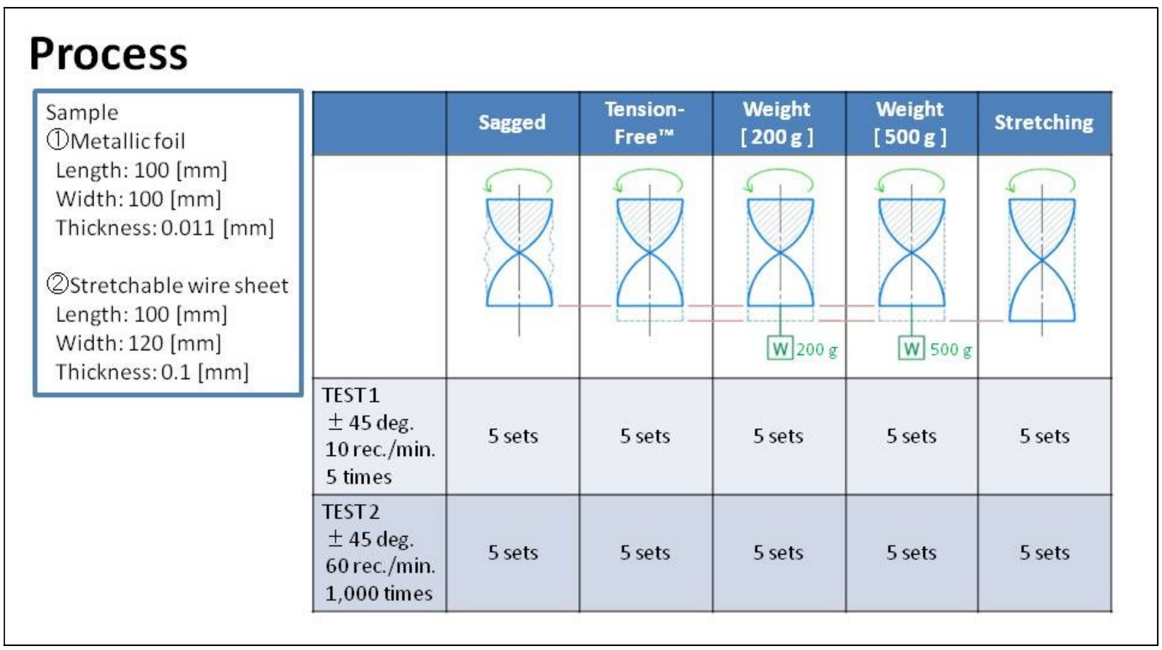


Figure 9 — Five test methods, two different sets of tests

In Test 1, differences were observed resulting from each test method. See Figure 10. There were differences in the shapes of edges after the tests. In the sagged test method and the Tension-Free™ test method, edges were a shaped curve. In each adjustable tension method, the edges were straight. The stretching method did not work for the metallic foil, every sample was torn.

Differences were found in the shapes of creases. In the sagged test method, creases were found in the perpendicular, or somewhat perpendicular, direction to the turning axis. In the Tension-Free™ test method, creases were complex. In the adjustable tension test method, creases were found in a parallel, or somewhat parallel, direction to the turning axis. These phenomena were caused by tension. In the adjustable tension test method, some cracks happened on the sample because the sample was bent at the clamped point.

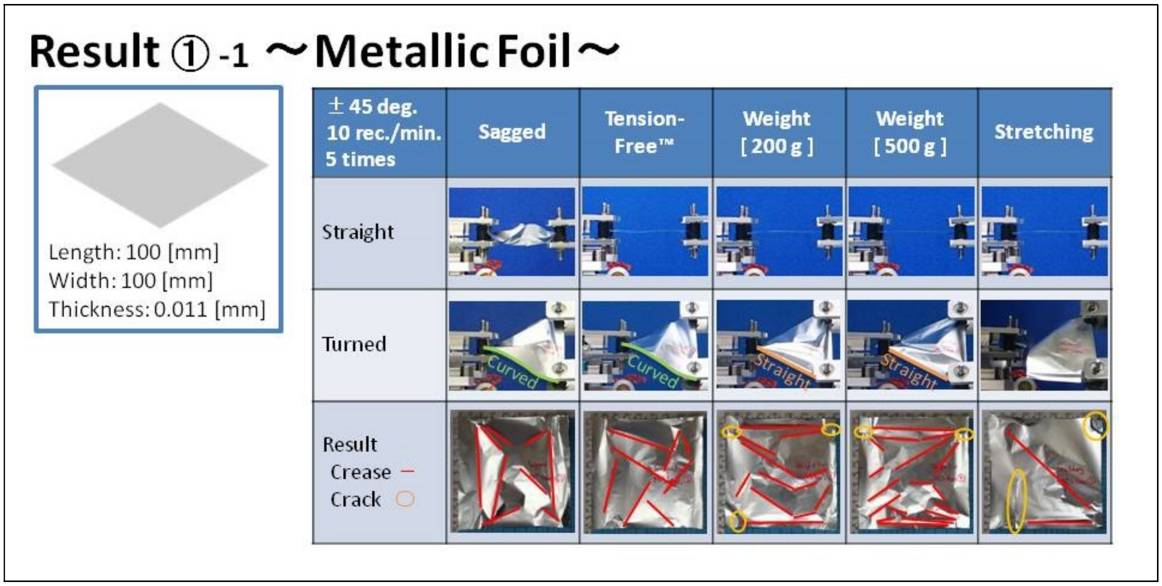


Figure 10 — Cracks observed in Test 1

The difference in the results of Test 1 became clear in Test 2. Adjustable tension methods did not work for the metallic foil in Test 1, every sample was torn before the reciprocating number reached the target level. Reciprocation numbers before breaking varied, the shortest one was 7 times and longest one was 93 times. The variation may have been because the metallic foil edges were not perfectly smooth -- during preparation the samples were cut from a large sheet. Because the metallic foil could not survive the 500 gram test and the stretching test, those two test methods were cancelled in Test 2.

An interesting phenomenon occurred on cracks. Cracks could be clearly found when lit from behind, as shown in Figure 11.

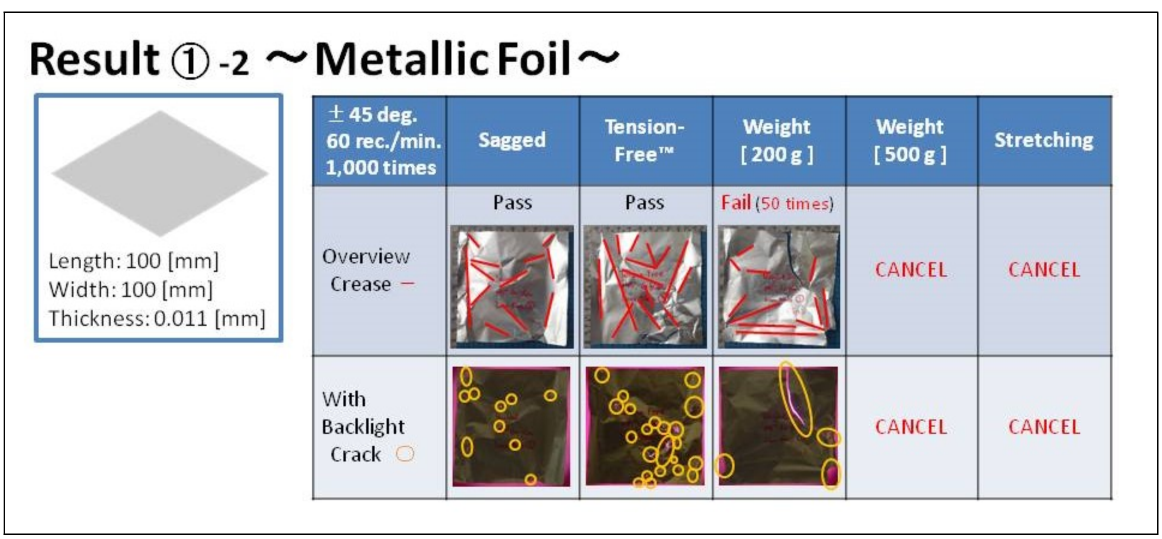


Figure 11 — Viewing cracks with backlight

The samples from the Tension-Free™ method exemplify the complexity of torsion. Cracks by the sagged and the Tension-Free™ method were not straight, having multiple curves, the edges of the cracks were jagged, and they lost their gloss. These are the typical phenomena of fatigue destruction. See Figures 12 and 13. The three samples shown in Figures 12 and 13 are the same samples that are shown in Figure 11. On the left is the Sagged test sample, the Tension-Free™ test sample is in the middle, and the 200 gram weight sample is on the right..

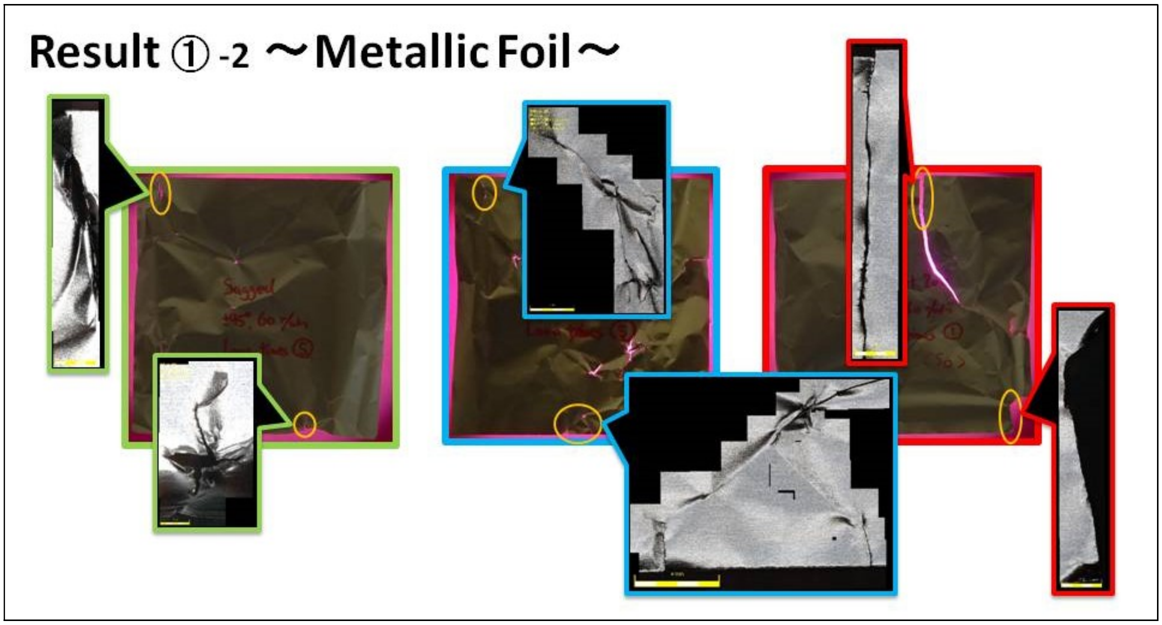


Figure 12 — Cracks from the tests

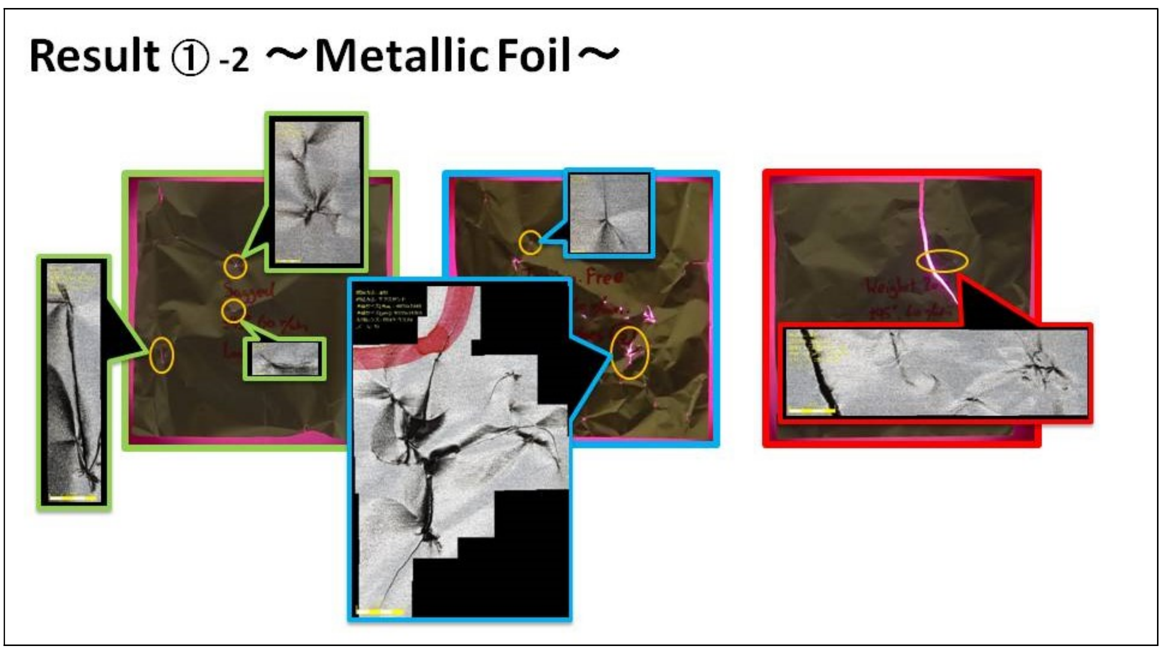


Figure 13 — Cracks from the tests

On the other hand, in the adjustable tension-methods, the cracks had sharp edges, almost straight lines, and were glossy. That shows that cracks grew in a short time. In other words, the samples were torn by the testing system. Figure 14. shows the causes of the cracks.

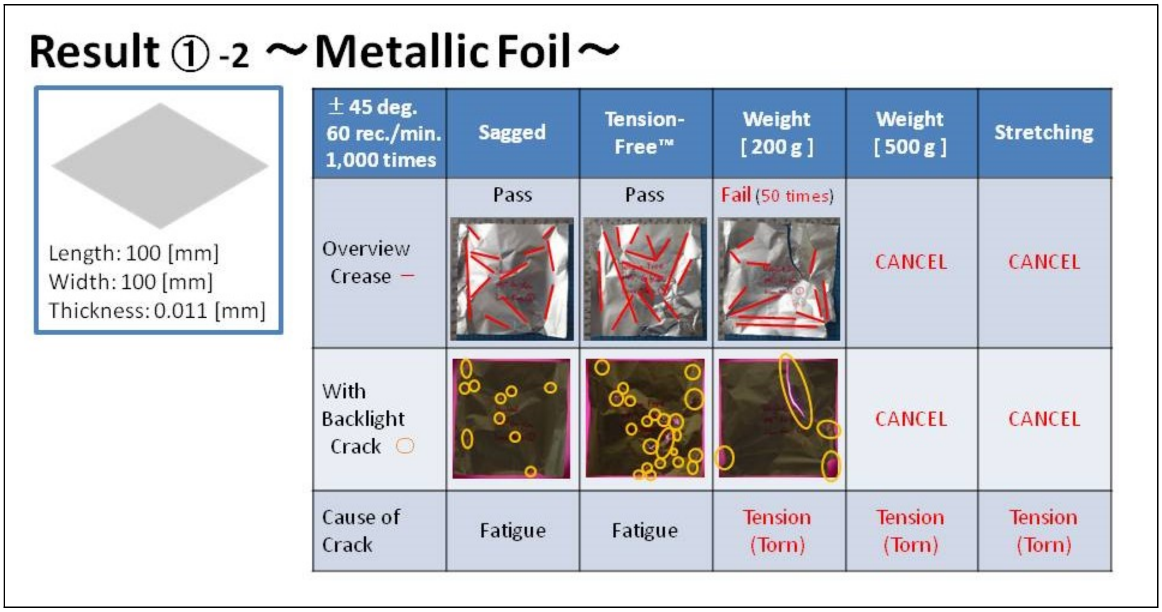


Figure 14 — Causes of cracks

When testing the stretchable wire sheets in the sagged test method and the Tension-Free™ test method, the edges were a shaped curve, the same as the metallic foils. And in each adjustable tension test method the edges were straight, the same as the metallic foils. The edges were straight also in the stretching test method, but they did not tear as was the case with the more fragile metallic foil. The stretchable wire sheets were permanently stretched by the weights, remaining longer after the adjustable tension testing was completed. Creases were different in every condition. See Figure 15.

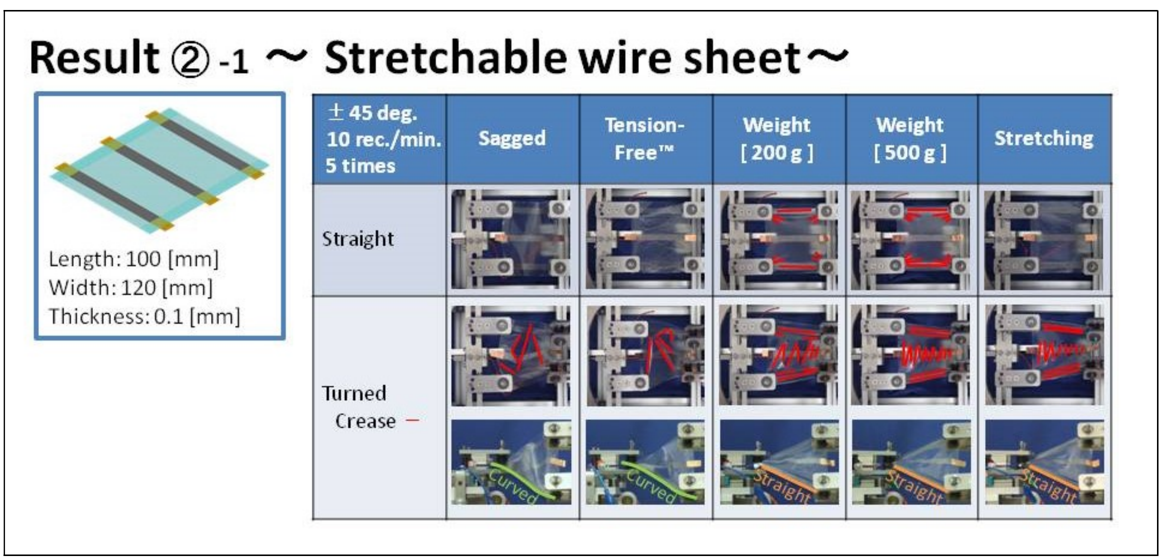


Figure 15 — Stretchable wire sheet creases

Electrical resistance was measured to assess the effects on the stretchable wire sheets because the electrical resistance will change according to the stretched length and the number of times stretched. The stretchable wire sheets consist of free silver plated nylon fibers. The contact pressure between fibers affects the total electrical resistance. Electrical resistance will decrease when the contact pressure is increased by tension or stretching. Electrical resistance will increase when contact pressure is decreased by compression or sagged effect.

The test results can be classified into two groups. One group consists of the sagged test method and the Tension-Free™ test method. In this group, the change in the electrical resistance of the different wires in the sheet was the same. In the other group, the electrical resistance of the center wires in the sheet changed a lot. This difference is because of tension.

There was a common characteristic of electrical resistance from all the test methods, though. The resistance decreased when the sample was twisted, and it increased when the sample was returned to its original straight position. This phenomenon is a typical effect of torsion, pressure occurs on every wire. See Figure 16.

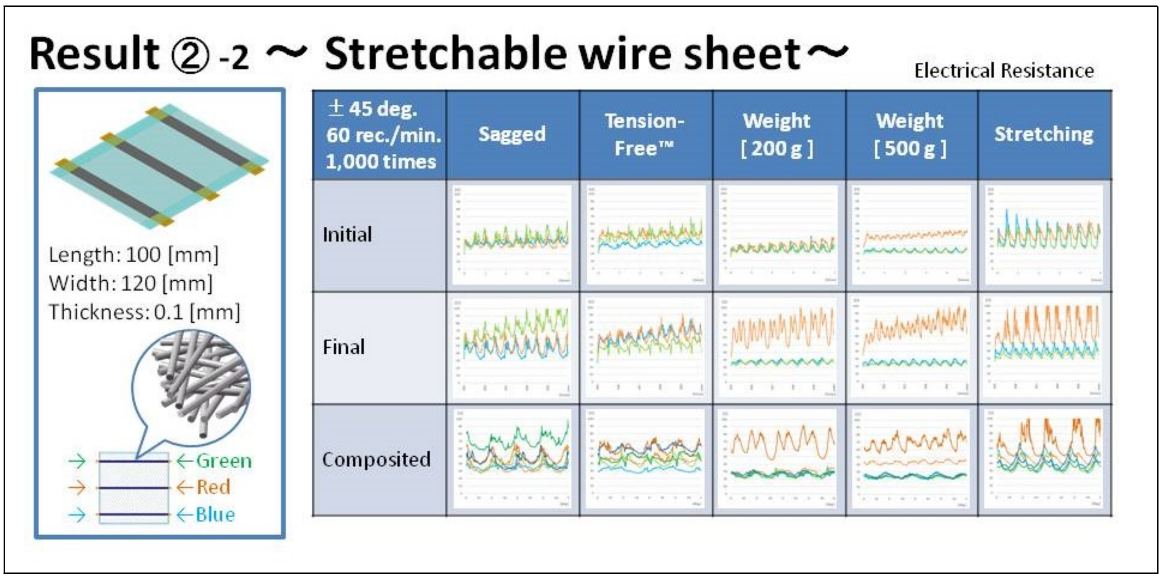


Figure 16 — Electrical resistance changes

With the sagged test method, the sample will be in an ideal state when the torsion angle is maximum and the sample is sagged. On the other hand, with the Tension-Free™ test method, the sample is always in an ideal state. These two test methods have similar electrical resistance characteristics. The difference is only the amount of the electrical resistance variation. The electrical resistance will change more with the sagged test method.

With the adjustable tension test method, the difference in tension on the center wire compared to the side wires gives a different characteristic to its electrical resistance. On both of the clamped side wires, the amount of electrical resistance variation is small because constant tension occurs on the side wires because of the weight — constant tension gives constant pressure to the fibers. The electrical resistance of the center wire decreased when the sample was flat because the tension was the same as the side wires. Because the amount of tension affects the amount of the electrical resistance variation, you can control the amount of the electrical resistance variation by changing the tension, or weight. The resistance will increase if the tension is low. The resistance will decrease if the tension is high.

With the stretching test method, all of the sample area will be stretched repeatedly. This is a special test method that is different from the other test methods. The electrical resistance of most of the wires was increasing during testing. But only with the stretching test method, the electrical resistance of the side wires was decreasing during testing because the sample could not be changed back to its initial form because pressure remained on the fibers. In the last phase, the sample stretched and sagged repeatedly, like the sagged test method. But this is a different phenomenon. With the sagged test method, the sample will twist in an ideal manner with no tension. With the stretching test method, there will be heavy tension on the sample. And, it was interesting that the electrical resistance of the center wire increased more than with the adjustable tension test methods. This phenomenon is similar to a minimum tension test method.

These tests clearly show that there are differences among the test methods. The test results will change if the test method changes.

Conclusions

Flexible hybrid electronics devices are coming, and quickly. Endurance testing should be done early in the design phase of products. Quality should be designed in, not be an afterthought. Your Quality Assurance and Quality Control programs will benefit from this decision. You should conduct tests using more than one test method and compare the results. That will help you to better understand your sample. It is important to know how to compare and analyze the results from endurance tests.

The Tension-Free™ test method was shown to have the clearest reproducible results in simple torsion tests. Test results are more consistent, more accurate, and more rapidly acquired. Treatment of the sample is more uniform, across the entire sample. And, tension test methods can damage the samples. It was noted that some of the results from the sagged or adjustable tension or stretching test methods can show similar results.

Endurance tests can give you a lot of data about your products. This will allow you to develop products, and upgrade them, at a rapid pace. YUASA SYSTEM, as well as other research institutions, will continue to develop this knowledge. We have to continue our R&D of new endurance testing systems to find phenomenon that is not reproduced by current endurance testing systems. We look forward to using numerous flexible devices in the near future.

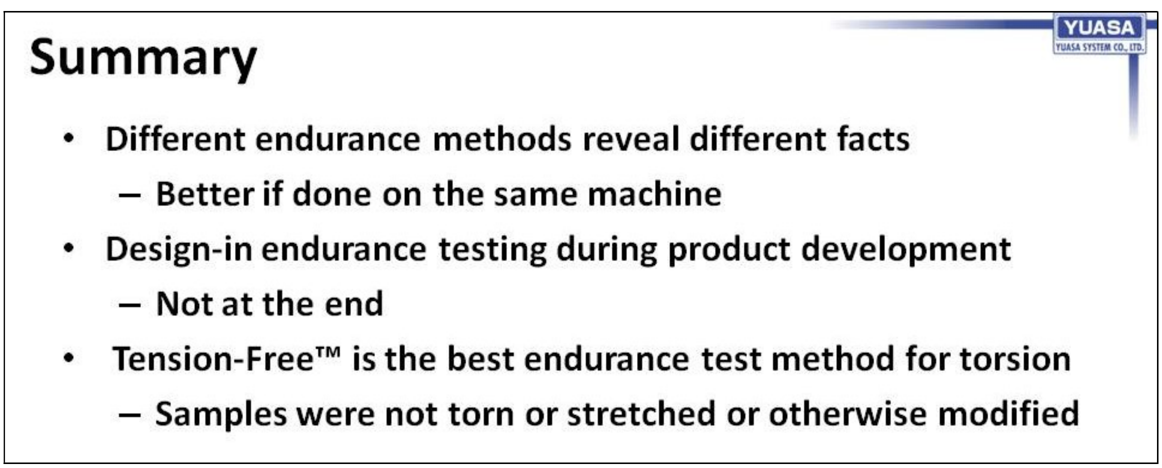


Figure 17 — Summary