Endurance testing of flexible displays and electronics

Eisuke Tsuyuzaki, founder of Bayflex Solutions (San Francisco, California), discusses reliability tests for various flexible devices – including flexible displays

Bayflex Solutions collaborates with the largest branded consumer electronics companies and is a private venture that has been developing reliability test (especially mechanical deforming stress) data specifically for various flexible devices, such as foldable displays, and components in partnership with Yuasa System of Okayama, Japan, originally an automobile parts and factory automation manufacturer, who has been building interchangeable mechanical deformation testing tools for over 25 years.

Reliability data and test protocols are critical to the product design process which are influenced by test levels, duration and various environmental acceleration factors. All flexible electronics components, but most prevalent in flexible display devices, require long-run repeatable mechanical deformation testing such as folding, flexing in hostile conditions to determine failure analysis used to assess new failure modes such as delamination, buckling and contact failures.

Previously, many pioneers in electronics hoped that additive manufacturing or printed flexible hybrid electronic components would find commercial applications in flexible and wearable electronics. At that time there were few devices in commercial use and knowledge of proper design and material selection were limiting factors for product design. Initially most tests were based upon universal testers which measured only the physical limits of material properties, e.g. until it broke; or used home-built tools which were not adequate for mechanical precision, long cycle runs nor scalability across different organisations.

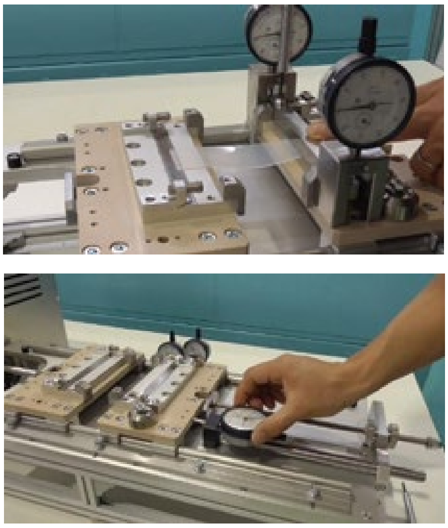

Fig. 1: Stretch testing with gauges for high precision: a) measuring pinching force b) measuring stretching force

Since 2016, Bayflex Solutions has worked with the flexible displays and electronics supply chains, as well as many other research institutions. This includes makers of films and other substrates, printed inks, conductors, adhesives and other materials, display manufacturers, developers and producers of flexible electronics (including printed and flexible-hybrid), and branded vendors and system interrogators in smartphones, tablets and PCs.

Flexible displays testing evolution

When we saw the emergence of flexible OLED in addition to mechanically rigid glass based OLED multi-layer designs, there was a need to supply unbreakable, lighter and thinner devices. In many cases conductive adhesives was not the primary challenge, but bonding components were, as traditional electrically conductive adhesives cannot survive flexing over small radii, between mismatched components or substrates.

After technical trials we determined that there were several basic mechanical motions which could be used to determine specific failures (see Table 1) and determined that a modular interchangeable method was most appropriate to accommodate various test scenarios, and now have a total of 120 configurations including mechanical tools folding, stretching, sliding, rolling, pushing,

Deformations	Fold	Flex	Twist	Roll	Stretch	Bend
Cracked	possible	possible	YES	Possible	YES	possible
Delaminated	YES	YES	YES	Possible	possible	possible
Bent Permanently	YES	YES		YES		possible
Stretched Permanently			possible		YES	possible
Torn			YES		possible	

Table 1

bending, flexing and twisting combined with different size, speed and powered motor drive units.

Butterfly motion folding test (FS)

While display manufacturers desired to understand the motion of rigid samples, the industry found and determined that an U-shape or "butterfly motion" folding method was most appropriate. An U-shape motion on the sample is generated by gentle warping , by a push rod movement. It is most suitable for semi-rigid, rigid and curved LCD i.e. static form factors, and is still very much in use today to determine edge deformation failures and in-mould or conformable applications (see Figure 2).

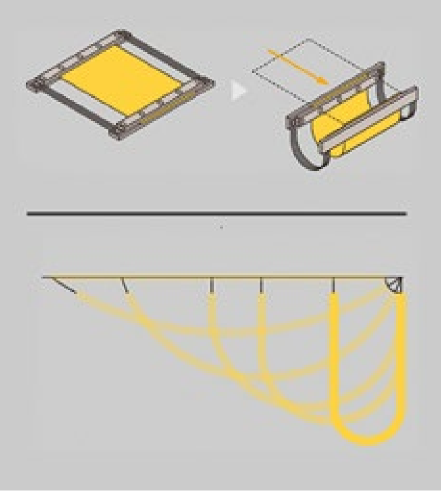

Fig. 2: U-shape or butterfly folding: a) moving mechanism b) deformation profile

The U-shape folding machine in Figure 2 uses "tilt controllers", or plate springs, on each side of the folding sample to control the folding and to bear the tension, keeping tension off the sample. The tilt clamp on the left moves back and forth under the control of a motor drive unit, the tilt clamp on the right remains stationary.

As the moving clamp approaches the fixed clamp, the tilt controllers cause the tilt clamps to rotate down, helping the sample begin U-shape folding, and eventually the tilt clamps become vertical. The entire length of the sample is being flexed initially, and as the folding increases, the amount of the sample in the fold becomes less.

This standard test is also the most diverse flexible electronics testing tool used today, such as in flexible batteries and medical patch sensors, and can be simply reconfigured to perform a 3-in-1 limited stretching and bumping function as well.

Rod folding motion test (BTFB)

When folding a sample around a rod, as shown in Figure 3, a large tension will occur on the sample when the test starts. Basically, the length of the sample is too short compared with the movement track of the clamp. Subsequently with larger screen sizes for e-readers, tablets and digital assistant devices, we developed folding around a mandrel without applying tension to the sample, our tension-free bending test machine, using a system of pulleys eliminating the need for counterweights and is now a regular feature of many mechanical testers.

Clamshell flexing motion test (CS)

More recently, wearables, smartphones, tablets and laptops have incorporated complicated multiple use designs leading to new dynamic material development. Specifically, larger size, in-fold, out-fold motions, rolling or sliding mechanisms appeared.

The critical testing requirement is to maintain continuous mechanical performance, ensure no burn-in and maintain various scratch and touch connectivity requiring even more stringent delamination, surface reliability and low impact energy testing needs.

For this generation of flex testing the industry requirement was to simulate flexing with a double hinge movement which in effect focused on single pivot point. To this end, we developed the "clamshell flexing motion" based upon tension-free flexing using a double hinge mechanism. Tolerances and more precision is required to flex from 0.01 to over 0.5mm radius at least over 200 000 cycles.

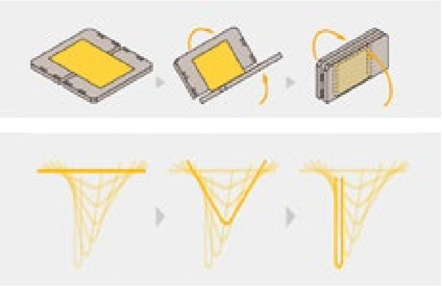

Fig. 4: Clamshell flexing: a) moving mechanism b) deformation profile

In fact, the clamshell has become the de-facto testing platform for all recent flexible display device testing as partners require more detailed and predictable analysis of delamination and to meet such a challenge we incorporated various optical systems and optional image software analysis to detect material deformation, delamination detection, especially around hinge mechanisms and edge deformation.

With regards to the motion itself, the sample is fastened to the holding plates. The holding plates fold together keeping the bottom

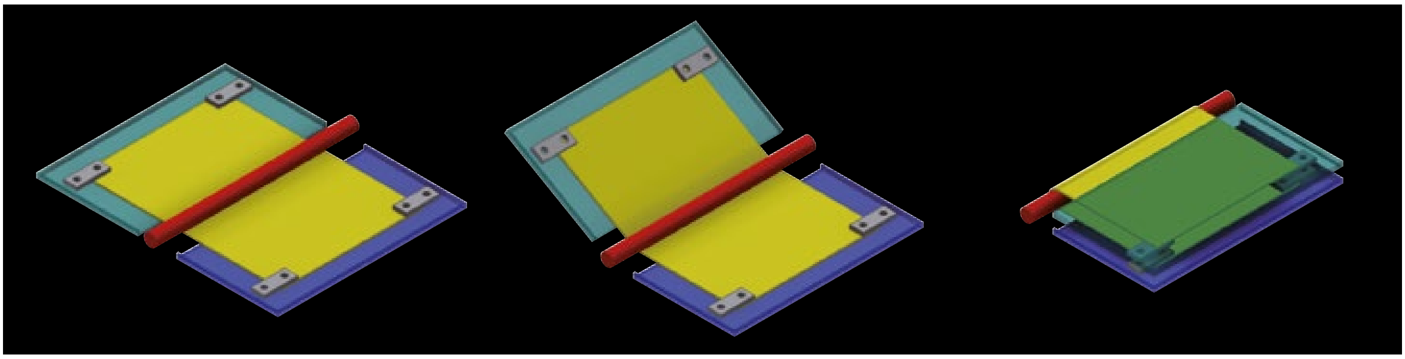

Fig. 3: Folding a sample around a rod

edges of the two plates spaced apart exactly twice the flexing radius. The flexing angle can increase to 180°, where the two plates are vertical and spaced apart exactly twice the flexing radius. The length of the sample being flexed will always be π times the selected radius.

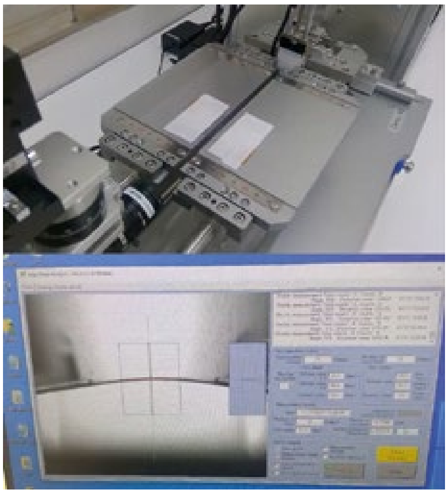

Fig. 5: Analysis of sample edge during flexing

In this case, the location where you fasten the sample to the holding plates is important. It must be at the point where the flexing begins such as the hinge mechanism point. When the plates are horizontal prior to flexing, the distance between the plates will be two times the radius, but the portion of the sample being flexed will be π times the radius. The extra distance, π times the radius minus two times the radius, must not be fastened to the holding plate. That means that the fastening will be one-half the radius times (π -2) from the edges of the holding plates.

This type of machine, using two axes with constant spacing between the axes during the flexing operation, is called a "double hinge clamshell structure". The hinges are placed at the edge of the two sample holding plates. With this structure, there is no tension on the sample during the flexing operation. One holding plate rotates in a constant radius. The second holding plate moves toward the first holding plate as it also rotates in a constant radius until the holding plates come together, at a spacing of two times the flexing radius. The distance between the edges of the holding plates during the entire cycle will always be twice the flexing radius.

Sliding motion test (SU)

Finally as witnessed at recent events such as CES and IFA, we have seen smartphones with a sliding mechanism to transform a standard phone into a tablet like device. While the clamshell test is very much applicable, we have devised an additional test as it seems small rollable mechanical function was most appropriate to determine early designs failures indicating how materials sag while sliding out the expanded display.

Mechanical motions comparisons

There were three major types of folding discussed in this article. The first example is tension-free butterfly folding where the two clamped ends move together with the sample gradually folding between the clamps. The second example is simple folding around a rod. With this type of folding you end up applying a force to the sample that is separate from folding, hence the reason for our designing the tension-free bending test machine. The third example is tension-free clamshell folding where the two sample holding plates are always a fixed distance apart so that the sample is folded without the holding plates applying tension to the sample.

The butterfly folding machine and the clamshell flexing machine are similar in many ways, but they do have some differences as shown in Table 2. The clamshell flexes only the centre portion of the sample while the butterfly gradually folds the entire length of the sample with the greatest folding on the middle portion of the sample as the folding reaches 180°. Both types of test machines can fold at any angle up to 180°. The clamshell can accept shorter samples. Typical applications for the clamshell are folding displays. Typical applications for the butterfly are folding samples where the entire sample is flexible.

Table 2

Comparison of butterfly and clamshell

- Clamshell flexes only the center π·R portion of sample
- Butterfly flexes entire length of sample
- Clamshell flexes at any angle up to 180°
- Butterfly folds at any angle up to 180°
- Some Butterfly Machines also can be Stretch Machines
- Clamshell accepts shorter samples

Hostile integration

Since our beginning, we have made available many of the endurance testing tools in both ambient as well as various hostile environments, by replacing the mechanical tester with more robust materials and components, to work in various leading high temperature/high humidity environmental chambers with or without ultraviolet radiation acceleration.

We anticipate that as flexible display and other flexible electronics products become more widespread, these mechanical testing solutions will need to be housed, in addition to temperature and humidity, in multiple-environments such as in high/low altitude, and immersed in various real and synthetic liquids and gasses and other states.

Lab automation and data analytics

More recently, in these continued Covid-19 stressed times, as we must all find more efficient and collaborative ways to accelerate testing and material development, we were

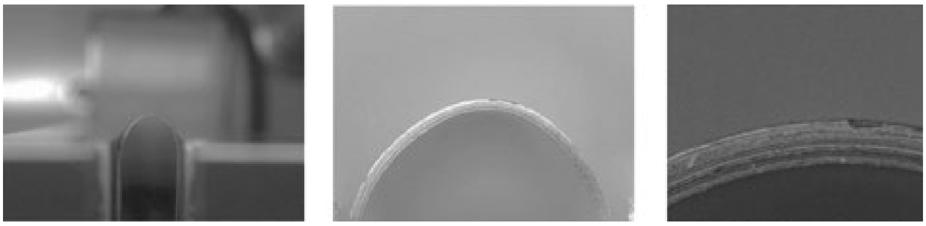

Fig. 6: High resolution camera view of edge

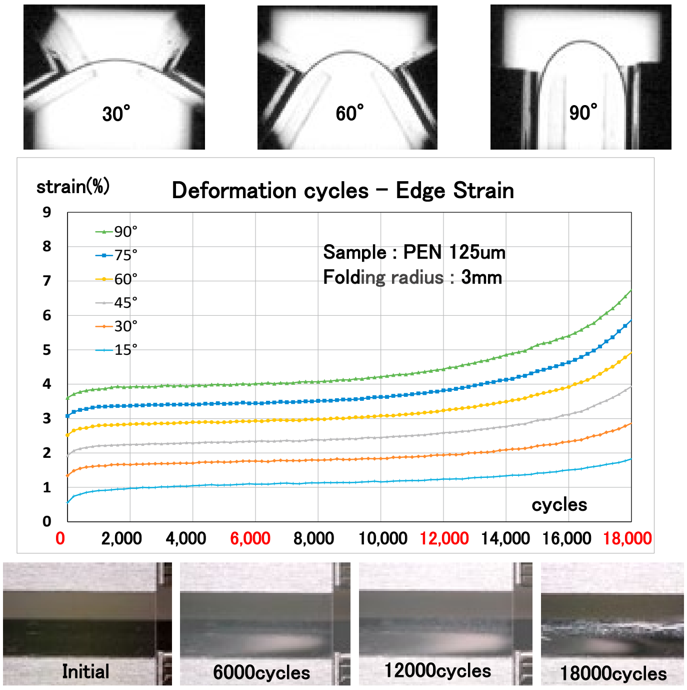

Fig. 7: Edge strain analysis as testing cycles increase

asked to provide lab set-up automation, remote testing surveillance, data collaboration and data analysis tools.

Specifically in a team collaboration situation, we combined electronic readings from the motor drive, and expanded our data capture such as resistance, temperature, voltage, humidity, added the capability to attach high resolution still images at each testing cycle and provided the combined data on customised templates on a cloud based solution. We can envision that in some installations this functionality will be expanded to multiple sites and across several vendors to preview commercial test samples before they arrive.

We have high hopes that our European software team can deliver more R&D value in future material and component development with machine learning capabilities.

Further Euro-centric collaboration

Given that the display business is very much a global business, and there are unique regional development characteristics, we are grateful for our materials partners based in Europe; and for a successful development collaboration with Fraunhofer FEP of Dresden and numerous other institutions in Europe.

As recent members to OE-A, we seek to deploy more testing solutions beyond flexible display and mobility applications. We continue to seek collaboration and awareness for endurance testing in smart living applications (medical, industrial, e-textiles) with influential partners in Europe and beyond. We hope to see you in person at LOPEC in 2022.

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Image sources: Bayflex Solutions