# Title: Optically Clear Film for Tactile Interfaces

**Author:** Dr. Micah Yairi
Tactus Technology
3960 Point Eden Way
Hayward, CA 94545
micah.yairi@tactustechnology.com
www.tactustechnology.com

## Abstract

Replacing the prior dominance of rigid plastics, for the past decade cover lenses in mobile and computing devices have been made instead of rigid glass sheets that have become the de facto standard. This is changing. Optically clear but *soft* polymer films and film stacks now offer a promising alternative to glass. These polymer films provide a fundamentally different user experience, dramatically improving the user experience of writing and drawing, while also providing good durability. Tactus has developed an optically clear stack of polymer materials for use in a writing-first device. Details, usability studies, and performance data will be presented.

## Introduction

Mankind has used pens, pencils, scribes, and similar writing tools for thousands of years. Much of that writing has been on parchment or paper. Together, pen-and-paper have proven to be one of the most remarkable and enduring forms of communication and recording in human history.

With the advent of the personal computer, the past few decades have challenged this paradigm. Keyboards have risen to prominence, and today are ubiquitous on portable computers and are also popular with tablets. On mobile devices, finger-based data entry is common, either by tapping or swiping.

Stylus-based writing on electronic devices, though available, has so far failed to become a dominant method of data entry on any device. This is surprising – particularly given the great success of pens and pencils with paper! There are several reasons for this, including

- The actual user experience is poor
  - Stylus on glass is too slick
  - Stylus tips wear out too fast
  - Soft tips wobble and bend under normal pressure
  - Felt tips have inconsistent writing feel
- Complex pen designs are used to provide a "cushioned" writing feel
- High cost, due to both complex pressure-sensing systems and stylus tip replacement
- Distracting optical parallax due to thick display coverlenses

This poor stylus experience has been borne out in several studies.[1] [2] [3] [4]

Tactus Technology has developed a polymeric stack of materials produced as an optically-clear and durable thin film which provides a pen-on-paper feel while writing with a stylus – called TrueWrite™ film. It also improves the shatter resistance of the underlying substrate, enabling the use of thinner and less expensive coverlenses, which then also provides reduced optical parallax. These improvements may finally offer a user experience that enables stylus-based data entry to become a dominant input method for mobile phones, tablets and computers. These advantages include:

- Improved stylus writing user experience
  - Paper-like indentation
  - Feedback enables better pen control
  - >20% reduction in writing pressure
  - Significantly reduced 'drift' (6x less than glass)
- Improved cover lens strength, cost and weight
  - Improves display impact/shatter performance (+2x improvement)
  - Leads to thinner and lighter design
  - Reduced optical parallax
- Reduced system cost

The overall structure of this thin film stack is illustrated in Figure 1. It consists of a bulk elastomer layer, on top of which is a thinner anti-scratch layer, and finally an optional nano-coating. This film is then attached (either permanently or as a removable film) to the cover lens of the display.

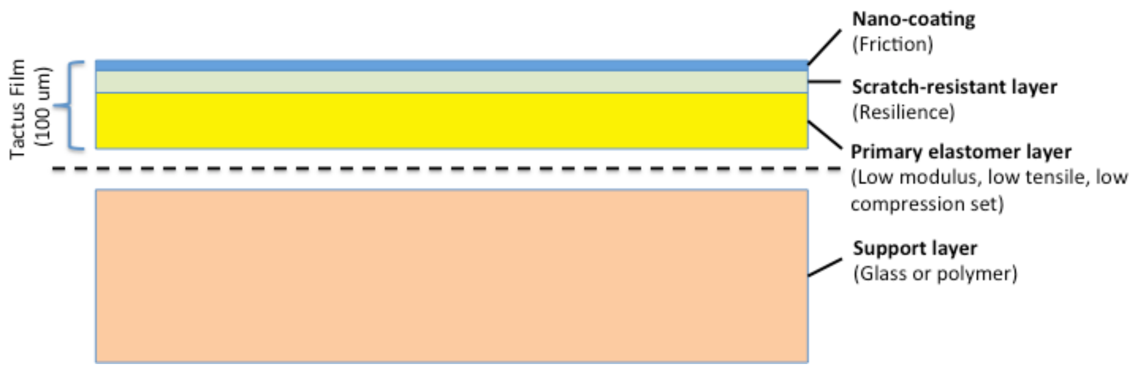



**Figure 1:** Schematic illustration of Tactus' TrueWrite™ film, which sits on top of a support layer (the cover lens of a display).

The Tactus film is optically clear and exhibits minimal color gamut distortion. A comparison between glass and glass laminated with the film is shown in Table 1. The biggest difference is the higher haze value of the film (2.4%). The haze is due in part to the particular bonding method used and some surface roughness due to the current (non-optimized) film production, suggesting that future films may achieve lower haze.

| Material | Tx | Haze | L* | a* | b* | Dielectric Constant (1KHz) |
|---|---|---|---|---|---|---|
| Gorilla Glass (0.7mm) | 92.8% | 0.13% | 96.86 | 0 | 0.17 | 7.4 |
| TrueWrite film (0.1mm) on Schott Glass (0.7mm) | 93.2% | 2.4% | 97.05 | -0.06 | 0.35 | ~2-4 (film) |

**Table 1:** Optical characterization data for Gen. 2 Gorilla Glass and Tactus' TrueWrite Film bonded to Schott Glass.

A major advantage of this polymer film stack is that the stack is "engineerable" – meaning that the chemistry, processing conditions, and the film layer thicknesses can be independently adjusted to control the feel of the resulting film. To help determine what the desired "feel"-related parameters the final film stack should exhibit, we first conducted a small study with ~20 participants to see how many sheets of paper (1, 2, 3, 4 or 5) they preferred to write on. The results of that study indicated that on average study participants preferred the feel of 4 sheets of paper while writing with a Bic pen. As a result, we used the behavior of a Bic pen on 4 sheets of paper as our guide for desired "feel."

Next, we measured the physical behavior of a popularly sold pen (a Bic ball point pen), and how that behavior changed as we varied the number of sheets of paper written on (1, 2, or 4 sheets). Figure 2 shows the most relevant result – the dynamic coefficient of friction (sometimes referred to as the Scratch Coefficient of Friction), defined as the transverse force divided by the surface-normal applied force in order to maintain a particular transverse velocity of the scratch (pen or stylus) implement. The data shows that the DCOF increases as the applied normal force (the pressure on the pen) increases; it also shows that the DCOF increases with the number of sheets of paper being written on.

When anti-finger print coated glass (commonly used in tablets and mobile computers today) was tested with a stylus, the DCOF was significantly less than than of pen-on-paper. Moreover, it remained constant and did not increase with applied force. TrueWrite Film behaved quite differently – it's DCOF closely matched that of 4 sheets of paper when using a stainless steel stylus.

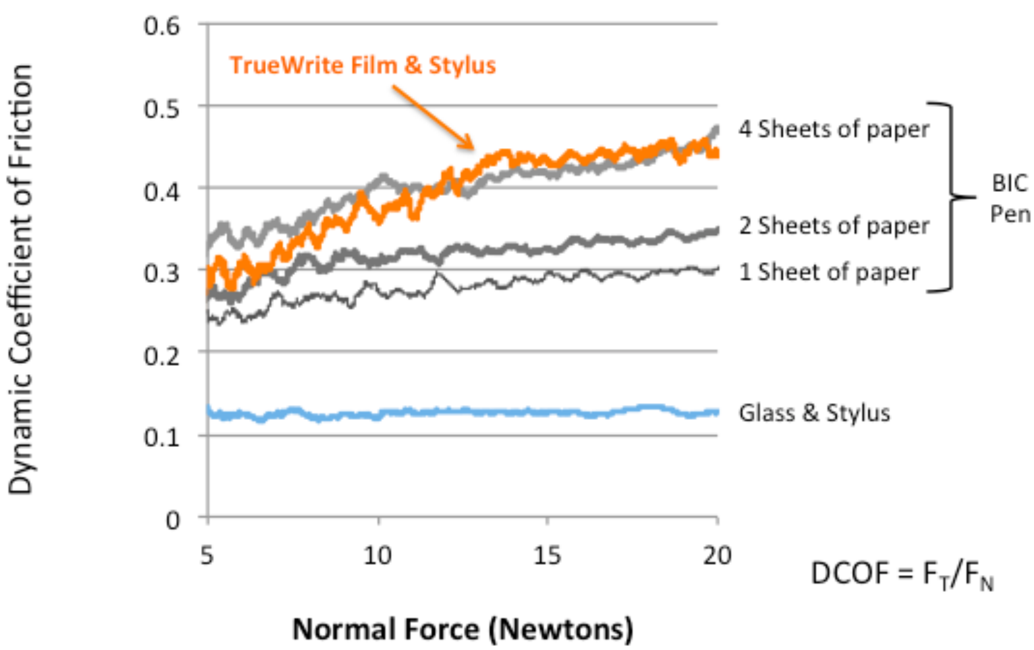



**Figure 2:** Dynamic coefficient of friction (DCOF) for (i) GREY: pen on paper (different # of sheets of paper), (ii) BLUE: stylus on anti-finger print coated glass, and (iii) ORANGE: stylus on Tactus' TrueWrite Film. TrueWrite Film matches the behavior of pen-on-paper much more closely than stylus on glass.

## User Experience (UX)

A wide variety of user experience studies have been conducted in order to gauge actual writing and drawing experiences. Here, we report results from a "maze-based" study as well as a writing-focused study.

The maze studies were based on similar studies conducted by Goonetilleke.[5] A Microsoft Surface Pro tablet was used, and on the left half of the device we attached a thin sheet of glass laminated with TrueWrite Film. On each half of the screen appeared 3 images of a square shaped maze (26 mm in width) that spiraled into the center and then back to the perimeter (3mm path width, 202mm path length). Each study participant used the Microsoft Surface pen (2H nib) to follow the path of the spiraling maze, and alternated between the two halves of the screen. This type of test is useful because it does not rely on a particular language, and also tends to mimic the fine control needed in writing kanji.

The results of this study are shown in Figure 3 and Figure 4. After completing the study, 88% of participants reported that they had greater control of the stylus compared to writing on the anti-fingerprint coated glass. When asked which surface was more relaxing, 75% of participants felt that writing on TrueWrite Film was more relaxing. This "relaxation" results was given as a form of qualitative feedback. A quantitative measurement was also taken – from the Microsoft Surface pen itself. The pen recorded the pressure used by participants during the test. On average, a force of 170 grams was used during the maze tracing test when writing on the default glass surface – but only a force of 132 grams was used when writing on TrueWrite film, a reduction of 22%. Users subconsciously used less force when writing on the polymer film, yet were able to exert greater control of the stylus tip.

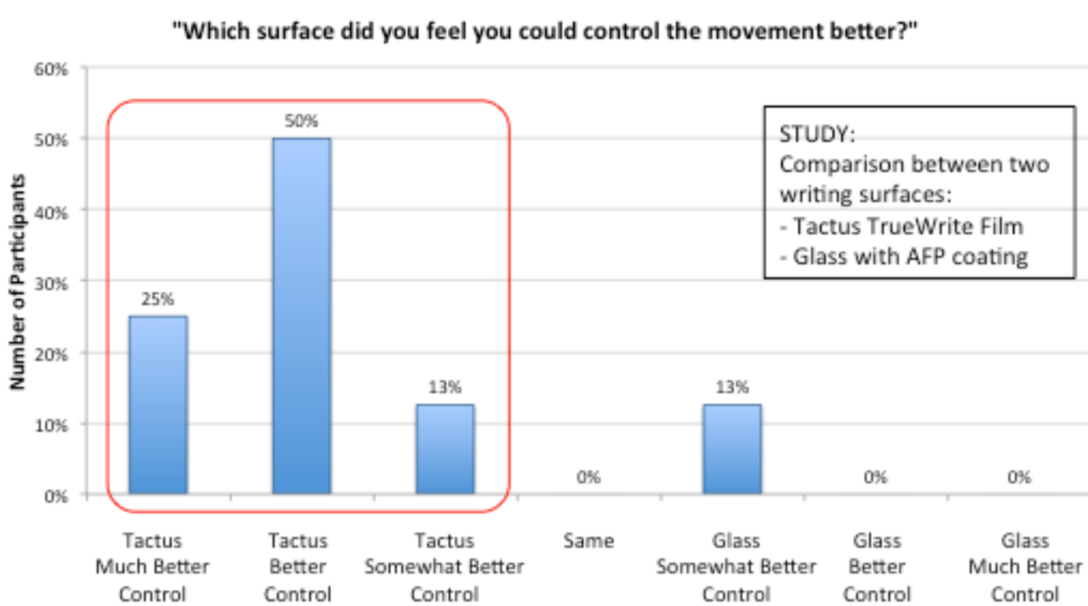


**Figure 3:** Maze-based user experience (UX) test responses to the question "Which surface did you feel you could control the movement [of the stylus] better?" Over 85% of respondents felt that TrueWrite Film provided better control compared to anti-fingerprint coated glass.

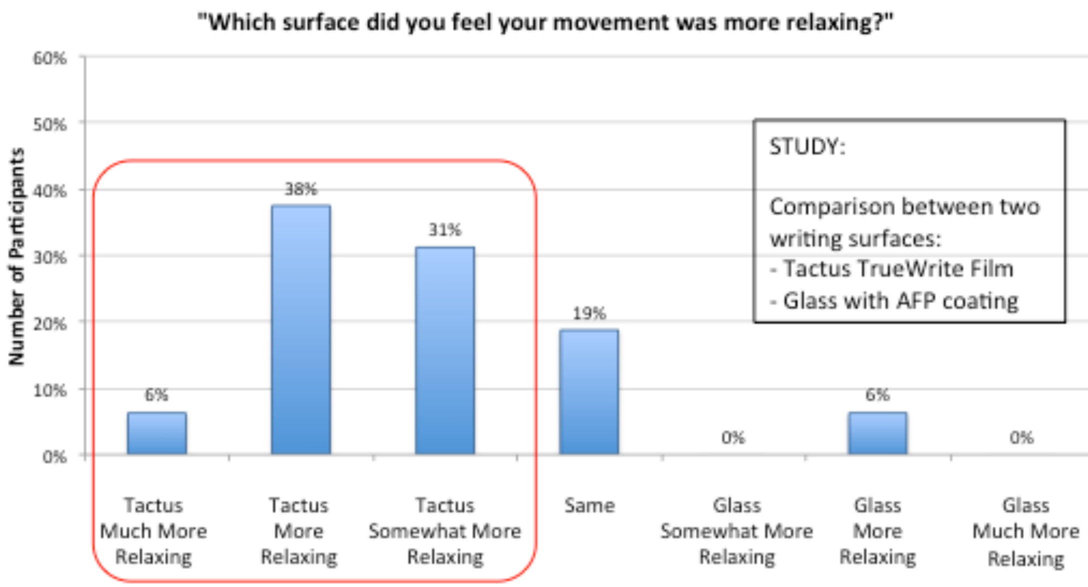



**Figure 4:** Maze-based user experience (UX) test responses to the question "Which surface did you feel your movement [using the stylus] was more relaxing?" Over 75% of respondents felt that writing on TrueWrite Film felt more relaxing than writing on anti-fingerprint coated glass.

We also ran a related study to measure the degree of "drift" while multi-tasking. Drift is the movement of the stylus while use user holding it has her or his attention focused elsewhere – such as on a blackboard or a speaker at a meeting while taking notes. If the user looks up while still holding the stylus against the display, any motion of the stylus will leave an unwanted digital trace as the computer follows the motion of the stylus tip.

To measure drift, in the middle of tracing a maze, participants were asked to look up at a different screen and answer a series of math questions over the course of 10 seconds. During that time, the amount of movement – drift – of the stylus tip was measured. The results are shown in Figure 5. On the default glass surface, the average drift was 4.13 mm, compared to just 0.68 mm when writing on TrueWrite film. This was a 6x reduction in drift when using the indentable, higher friction surface.

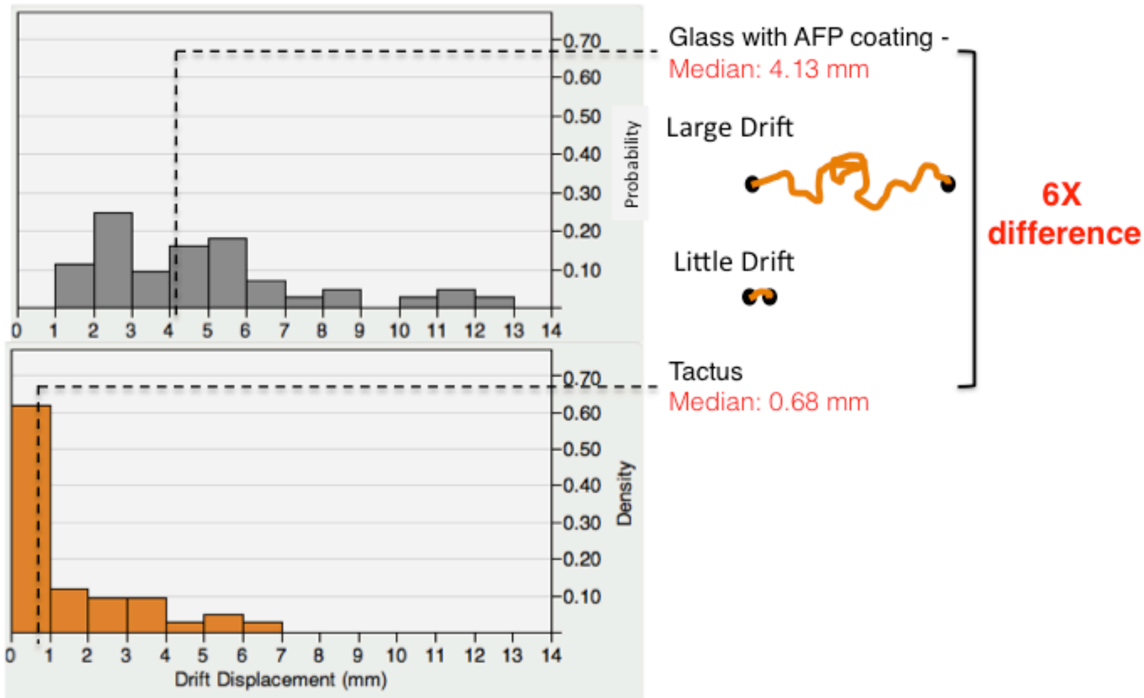



**Figure 5:** Maze-based user experience (UX) test measurement results of "drift." The average drift during the test on anti-fingerprint coated glass by 4.13mm, compared to just 0.68mm when writing on TrueWrite Film.

UX tests that focused specifically on taking hand-written notes were also conducted. In these tests participants were asked to look at a screen and transcribe a series of bullet points on a Microsoft Surface Pro tablet prepared as described above, but with the screen displaying lined notepaper. Notes were taken alternating between the left and the right sides of the display (with and without TrueWrite Film, respectively). Measurements of speed and handwriting quality were taken on the third "page" of notes.

After taking part in the study, participants were asked on which surface they thought they wrote faster. Most reported writing faster on the anti-fingerprint glass surface. However, the actual measured data showed a difference from this perception: the writing speed was the same whether or not on the anti-fingerprint glass or on the TrueWrite Film. The quality of the handwriting, however, was noticeably different. As shown in Figure 6, 83% of respondents rated their handwriting on TrueWrite Film as "better looking" compared to writing on the default glass surface. We believe this result was due to the greater control available when writing on TrueWrite film, which allowed users to more precisely shape letters and control the spacing between letters.

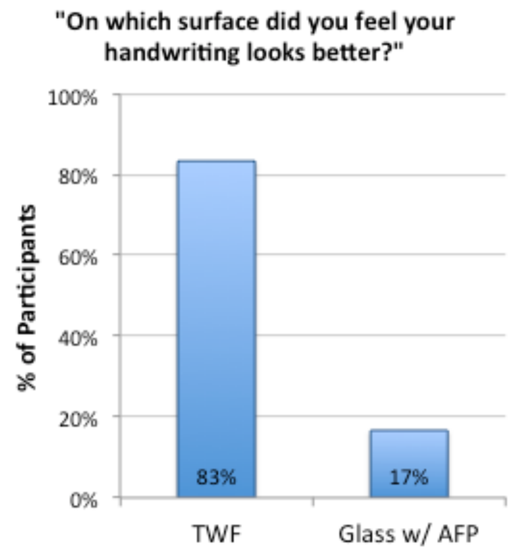



**Figure 6:** Writing-based user experience (UX) test responses to the question "On which surface did you feel your handwriting looks better?" Over 80% of respondents felt that their handwriting on TrueWrite Film looked better compared to writing on anti-fingerprint coated glass.

## Durability

Any film that is the top surface of a display stack or user interface must be able to withstand the rigors it is exposed to. Major challenges include fracture and shatter when dropped, abrasion resistance (e.g., sand or dust and debris in a backpack or purse), and potential damage from extended writing and drawing with stylus tips.

We have conducted a wide variety of durability and reliability tests on TrueWrite film, and here we report results related to shatter, abrasion, and stylus use. In Figure 7 the results from steel ball-drop testing are shown. A 132g, 32mm diameter steel ball is dropped at progressively higher heights until the coverlens being tested is damaged, usually cracking. 0.55mm Gorilla Glass (Gen 2) and 0.55 soda lime glass, both untempered and tempered, were tested, each with and without TrueWrite film laminated to them. As expected, tempered soda lime glass had a greater shatter resistance than untempered soda lime glass, and (the chemically strengthened) Gen. 2 Gorilla Glass performed even better.

For all three types of glass, adding TrueWrite film improved their shatter resistance, in some cases dramatically – almost doubling the drop height in the case of Gorilla Glass. Perhaps most note-worthy was that adding TrueWrite Film to tempered soda lime glass provided a coverlens with greater shatter resisance than the bare Gorilla Glass. This is important because tempered soda lime glass is much less costly than chemically-strengthed glass. For manufacturers, this means that using TrueWrite film may enable them to offer both a thinner overall coverlens (using a thinner glass layer) as well as using a less expensive glass. The result would not only reduce their overall cost, but also improve the stylus writing experience by reducing the optical parallax that comes from using a thicker coverlens.

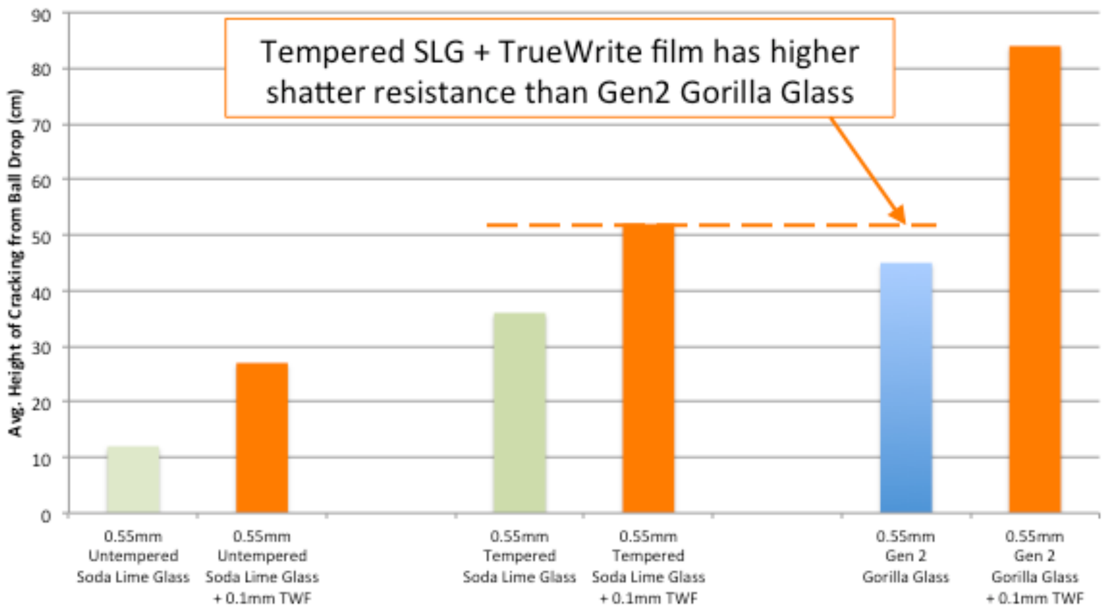



**Figure 7:** Shatter resistance to steel ball drop test results – avg. height of failure for different material stacks, both with and without TrueWrite Film. In all cases adding TrueWrite film increased the shatter-resistance height. Also noteworthy: tempered soda lime glass (which is much less expensive than Gorilla Glass), when laminated with TrueWrite Film, exhibited a greater shatter resistance than bare Gorilla Glass.

TrueWrite film also offers good abrasion resistance. As shown in Figure 8, Tactus' film now performs as well as tempered glass, despite the fact that it is a soft polymer. Figure 8 also shows how it has taken several years to optimize the material stack to achieve this result, while also maintaining the optical and mechanical properties required for the thin film stack.

To test stylus wear, we base our specification on the "heavy use" case of a college student, who typically writes about 3,000 pages a year. A three-year lifetime for a stylus-based tablet thus implies withstanding writing approximately 9,000 pages of notes. To test this, we use a stylus to trace a repeating, overlapping circle. A weight of 250 grams is used for the stylus (mimicking a heavy-handed writer), and is traced at 100mm/min. TrueWrite film passes over 10,000 cycles, which exceeds the 3 year lifetime measurement of 9,000 cycles.

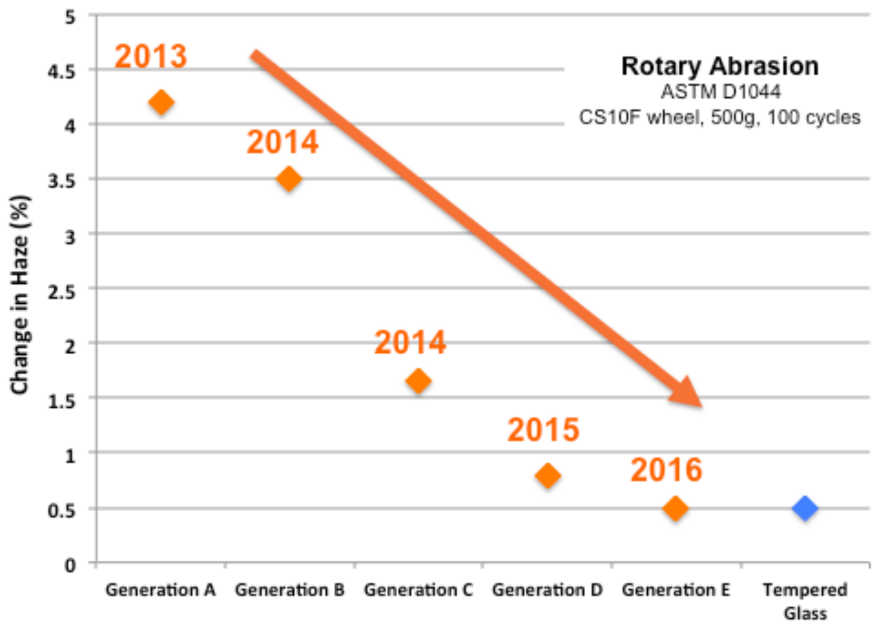
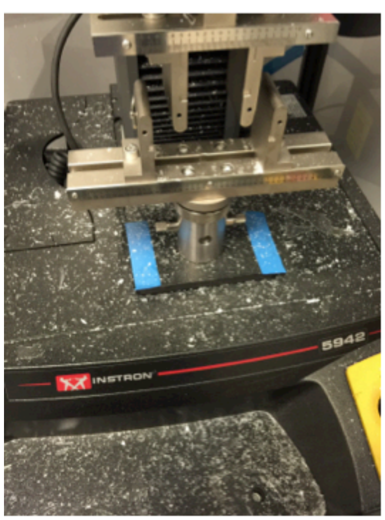
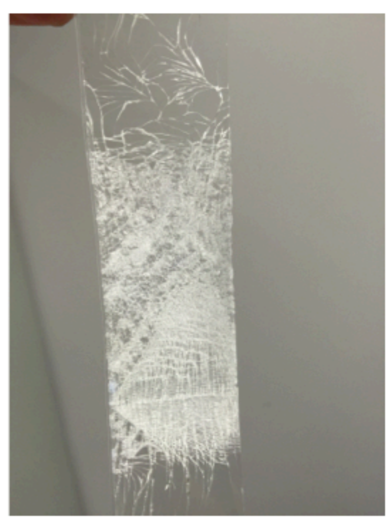



**Figure 8:** Rotary abrasion results (change in Haze) using ASTM D1044 testing method. Over time, Tactus Technology has steadily improved the durability of its films,. TrueWrite Film (Tactus' 2016 film) is as durable to rotary abrasion as tempered glass.

Finally, we also note that the use of TrueWrite film significantly improves the safety of glass-based coverlenses. The left-hand picture in Figure 9 shows what happens when a 4-point bend test pushes Gorilla Glass beyond its breaking point – thousands of tiny glass shards flew everywhere. The right-hand picture, on the other hand, shows the results of the same test, but with TrueWrite film laminated to the Gorilla Glass. There were no shards of glass, and the TrueWrite film also prevented sharp points of the glass shards from breaking through its surface and avoiding any potential cutting or slicing of a person's fingers.




0.7mm Gorilla Glass
After Rupture
(glass shards flew everywhere)



0.7mm Gorilla Glass + TrueWrite Film
After Rupture
(glass breaks, but no shards)

**Figure 9:** Pictures comparing the result of structural failure as part of a 4-point bend test of glass with and without TrueWrite Film. LEFT: Bare Gorilla Glass, shattered and exploded into thousands of shards. RIGHT: Gorilla Glass laminated with TrueWrite Film shattered, but no shards flew away, and no sharp points were felt through the film.

## Summary

Over the past several years, Tactus Technology has developed an optically-clear, durable polymer thin film who's material properties have been tailored to provide a stylus-based writing feel that is similar to the feel of writing on a sheaf of paper with a pen. User experience (UX) testing results show users find that TrueWrite film offers better control and yet also provides a more relaxing writing experience. Handwriting speed is equally fast on TrueWrite Film as on anti-fingerprint coated glass, yet the quality of the handwriting (how good it looks) is better and preferred by over 80% of users. The film is highly durable, providing a 3-year lifetime for heavy use writers (e.g., college students). The film also significantly improves the shatter resistance of glass coverlenses, offering a route to both less expensive and thinner coverlens stacks (and thus also reduced parallax).

As described in our introduction, the use of styluses changes and improves the way humans absorb and learn information. We hope that TrueWrite Film helps pave the way for greater adoption and use of styluses across a wide array of computing platforms, from PCs to mobile phones -- and that it also helps make data entry both more intuitive, enjoyable, and hopefully improves the way we learn both in and out of the classroom.

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[1] Annett, M., Anderson, F., Bischof, W. F., & Gupta, A. (2014, May), "The pen is mightier: understanding stylus behaviour while inking on tablets," *Proceedings of the 2014 Graphics Interface Conference* (pp. 193-200), Canadian Information Processing Society.

[2] Mohr, A., Xu, D. Y., & Read, J. (2010), "Evaluation of Digital Drawing Devices with Primary School Children-A Pilot Study," Proc. of ICL.

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[4] Annett, M., & Bischof, W. F. (2015, June), "Hands, hover, and nibs: understanding stylus accuracy on tablets," *Proceedings of the 41st Graphics Interface Conference* (pp. 203-210), Canadian Information Processing Society.

[5] Goonetillieke, et al. (2009), *Applied Ergonomics*, vol. 40 (pp. 292-301).