Easy-to-Clean Surfaces for Mobile Devices

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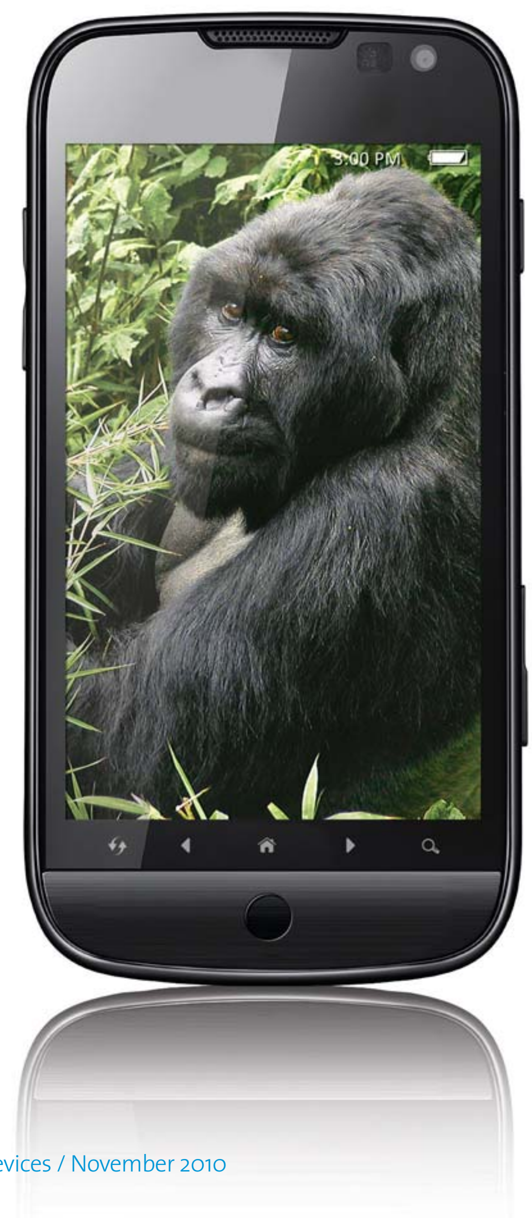

Abstract

The appearance of fingerprints and oil residue are of major concern for numerous industries concerned with maintaining display clarity for applications where handling occurs. The ideal solution is to eliminate fingerprint adhesion, which to-date requires surface texturing that also degrades display clarity to an undesirable level. To a lesser extreme, coatings can be implemented that allow for ease of fingerprint and oil residue removal such that the end-user can easily recover the optical clarity of the display. This paper discusses a complimentary coating for Corning® Gorilla® Glass that enables significant improvements in wiping performance. Included are specific test methods for evaluating such coatings, data to show this particular coating's beneficial performance, and comparison data to alternative, commercially available solutions. The objective is to communicate the need for standardized testing and discuss methods proposed to enable this endeavor. Specific tests include optical clarity before vs. after surface contamination, wiping performance to recover optical clarity, coating durability, and coating integrity.

Key Words: Coatings; Easy-to-clean; Fingerprints; Corning Gorilla Glass

Introduction

Corning Gorilla Glass is quickly becoming a standard material for multiple mobile device applications, specifically where scratch resistance and mechanical reliability are of critical concern. Complimenting Corning Gorilla Glass is a fluorosilane coating available to promote wipability for removal of fingerprints and residue to re-attain optical clarity. In this report, the performance of the easy-to-clean coating Corning utilizes for Corning Gorilla Glass is reviewed and compared to select, alternative commercially available products. Of specific emphasis is the fact that very few standards exist for evaluating and comparing such coatings and surface treatments for ease of wiping. In an effort to establish qualitative evaluations, a series of experimental methods are proposed,along with data to demonstrate how these tests differentiate performance for coatings that are effective vs. those that are not.

The primary objective for development of this coating has been to enable the continued ability of a coated glass surface to exhibit superior optical clarity and mechanical reliability, service life, and, most importantly, the glass surface must function for its purpose. Performance of easy-to-clean surfaces must be understood for OEMs to decide their value, and to this objective Corning has established qualitative evaluation methods to judge surface performance. Data is presented for chemically strengthened glasses processed to ideal conditions and attributes per the composition of each glass (Corning Gorilla Glass and soda-lime glass).

Optical Clarity

The primary focus for a decision to implement a glass coating can be made to enable the product for a specific use and/or to extend useful lifetime past a point where the base glass would fail. For the example of fingerprint removal, the key performance functionality is display clarity, for which the ability to re-attain initial optical performance is paramount. To this extent there are a number of analytical methods for measuring and monitoring optical clarity, for which the most convenient is to measure haze. Haze is reported as a percentage difference between light that is directly transmitted through the glass surface (or reflected) vs. light that is scattered. Since displays most commonly utilize white light environments, such a light source is most relevant for this study. In the following report, optical clarity via haze measurements is used to compare and contrast performance for the purpose of coating testing.

Easy-to-Clean Functionality (i.e., Wipability)

Numerous industrially-available coatings are touted for increasing contact angles, which is the first data most parties interested in promoting fingerprint resistance look for. However, by itself static contact angles tell us nothing about the ability of a given material to be wiped off a surface, a point that is exemplified when two materials with identical water and oleic acid contact angles perform completely differently during rudimentary fingerprint smearing tests. More realistic data can be attained from sliding angle tests, which are more relatable to the affinity for one material to move across the surface of another. However, both measurement techniques are compromised by requiring simplification in terms of liquid selection for testing, as no one liquid nor currently proposed synthetic mixture adequately imitates fingerprint oil.

Limitations of current coatings in providing simply easy-to-clean properties call for selection of comparative tools that allows for differentiation of properties and performance. Of specific interest is identifying standard test methods that track real world performance, such that reliable laboratory testing can be used to lead development efforts. Along this topic, it was realized that methods for testing mass transport differences were not sensitive enough for differentiating performance between coatings touted as easy-to-clean solutions, without being truly capable for anti-fingerprint applications. Furthermore, limitations in utilizing synthetic oils and means for reproducible application likewise imparted limitations in test sensitivity for subsequent wiping trials. Thus a new, simplistic means for comparing and qualifying wiping performance is needed.

Our proposed solution to testing for wipability has been to perform direct comparison of a coated glass to that of the bare glass by means of only coating 1/2 of the glass surface. The 1/2 coated test piece (see **Figure 1**) is fully saturated with actual finger and facial oil by means of wiping one's fingers across their forehead and smearing said fingers repeatedly across both coated and non-coated regions of the sample. Optical clarity is measured via haze measurements both before and after fingerprint saturation. Using a microfiber cloth, the surface is uniformly wiped, moving the cloth across both coated and non-coated regions, starting on the side without coating. Between repeated wiping iterations, haze is again measured on both the coated and non-coated surfaces with data plotted to quantify degree in which original optical clarity is recovered.

By utilizing actual facial oil, the need to decide upon a suitable synthetic oil and to maintain temperature of oil and finger (i.e., stamp) are eliminated. User-to-user differences are mitigated by fully saturating the surface with oil and directly comparing results for between the coating and base glass with wiping. The only caveat in this test method is uniformity of pressure and speed applied during wiping, for which concern can easily be answered by setting up a controlled wiping test method (note data in this report represent manual wiping).

Results for the easy-to-clean coating on Corning Gorilla Glass are shown in **Figure 2**. Initial haze measurements on both coated and non-coated glass surfaces were 0.00%, and after saturation with fingerprint oil were >3.50%. Note that any haze above 0.50% is easily observable, and thus samples were saturated well past this level. Initial wiping showed significant reduction in haze for the coated glass area vs. non-coated, with subsequent wipes supporting the trend of enhanced removal of fingerprint oil. After six wipes, the coated surface promoted complete recovery of optical clarity in terms of regenerating a surface with 0.00% haze. At this point in the wiping sequence, haze on the non-coated surface remained at ~ 0.50%, and thus was optically apparent. It should be noted that while rigorous wiping was performed to generate haze values for the non-coated surface of about 0.10%, complete recovery of optical clarity was not observed. Also note that the time in which fingerprint oil is allowed to remain on the glass surface before wiping can further limit wiping efficiency for non-coated glass, although no noticeable impact is seen for the coated glass. **Figure 1** shows an optical image of a 1/2 coated, 1/2 non-coated part after fingerprint saturation and wiping, demonstrating the coating's benefit for enhancing cleanability.

Coating Integrity

Means for measuring coating integrity for non-visible coatings offers challenges that are best met by monitoring changes in functionality (i.e., performance) for tests designed to imitate in-use field tests. These tests can include durability, abrasion, environmental, and solvent testing.

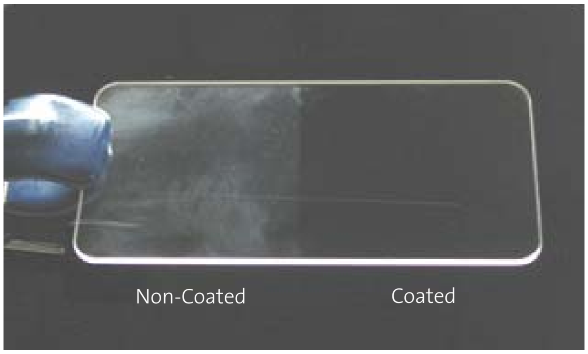

Figure 1.
Corning Gorilla Glass 1/2 coated with an easy-to-clean coating (right side) after uniform fingerprint saturation and wiping.

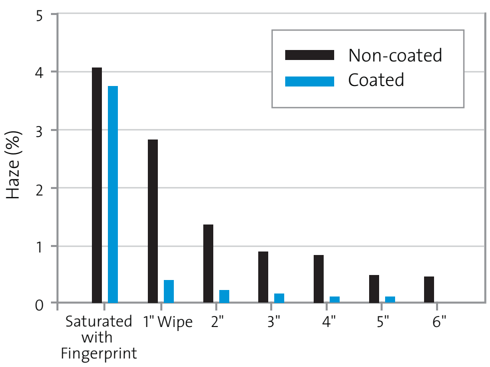

Figure 2.
Wiping performance of Corning Gorilla Glass with an easy-to-clean coating, comparing haze for coated and non-coated surfaces.

Reagent	Initial Contact Angles	Rost-20k Wipes
Bare Corning Gorilla Glass	< 10˚	Not applicable
Corning Gorilla Glass with Easy-to-Clean Coating	111.5 ± 1.1˚	106.7 ± 1.7˚

Table 1.
Contact angles for easy-to-clean coating on Corning Gorilla Glass, initially after coating and after performing 20,000 wipes with a woven cotton cloth at 1.5 PSI.

Durability

The ability for easy-to-clean coatings to survive repeated wiping is paramount. As such, a test to repeatedly wipe or rub the surface and test functionality after suitable iterations is required. Testing incorporates the use of a textile instrument used to wipe one cloth across another, to test the resistance of a cloth dye from rubbing off, referred to as a "crock meter". This was suggested to Corning, as well as the generic use of the textile industry's standard woven cotton cloth for testing. The test comprises of wiping the cloth across the coated glass surface in a reciprocating manner for the intended duration of wipes, with a load of ~ 1.5 PSI applied to the cloth. After attaining the intended number of wipes, the surface is tested for changes in static contact angle, which indicates coating degradation with severe changes in angles from initially high values for the coating (>100° for water) towards much lower values for base glass (typically <10° for clean, bare glass).

Conceptually this method of wiping imitates the approximate pressure a user would apply to a hand-held device when wiping the device across their shirt or slacks to remove fingerprint oil. Simple calculation suggests that ~10 wipes per day for three years compares to ~10,000 wipes, thus the target value of 20,000 wipes was identified to dictate suitable durability for offering to customers. Testing of the easy-to-clean coating resulted in the data shown in **Table 1**, demonstrating coating survival through this rigorous test.

Abrasion Resistance

Scratch resistance was found to be an added benefit of the easy-to-clean coating on Corning Gorilla Glass. Test samples comprising 1/2 coated and 1/2 non-coated regions were tested by wiping across both surface areas with 150 grit silicon carbide sand paper, using the crock meter, for 40 passes (back and forth) at ~1.5 PSI. Surfaces were then tested for haze to determine the degree in which optical appearance of scratches was mitigated. **Figure 3** shows an optical photo of such a sample, exhibiting significant scratching on the non-coated region whereas few visible scratches exist on the coating. **Figure 4** demonstrates this effect further, plotting haze for coated and non-coated glass regions and for chemically strengthened soda-lime glass. Test conditions also showed a significant benefit for Corning Gorilla Glass over soda-lime glass (50-60% improvement), and further benefit for the easy-to-clean coating (additional >75%).

Coefficient of Friction

An additional, potentially useful functionality of the easy-to-clean coating is reduction of frictional effects for materials sliding in contact with the coated glass surface. Examples of this type of handling scenario can include fingertip activation of touch screen functionality. In general, fluorine terminated surface groups prevent localized bonding that can increase frictional forces via, for example, hydrogen bonding for non-coated glass due to the presence of –OH termination surface groups. Specific to the easy-to-clean coating Corning utilizes for Corning Gorilla Glass, sliding contact testing was performed using a 1/16" diameter sapphire sphere for 1 mm lengths at 40 m/s sliding speed and variable loading between 2.55-15.3 grams. **Figure 5** shows results for these tests, which demonstrated the coating to reduce friction by 60-75% vs. bare glass. Similar qualitative effects can be witnessed by the user in directly comparing the coating to bare glass using their finger.

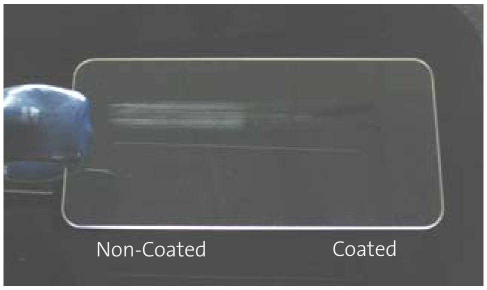

Figure 3.
Corning Gorilla Glass 1/2 coated with easy-to-clean coating (right side) after uniform abrasion with 150 grit silicon carbide sand paper.

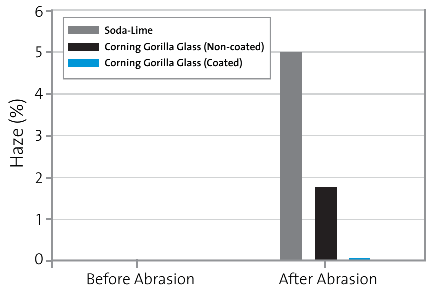

Figure 4.
Haze measurements for chemically strengthened soda-lime glass, Corning Gorilla Glass, and easy-to-clean coated Gorilla Glass, showing optical clarity for initial and post-abrasion surfaces.

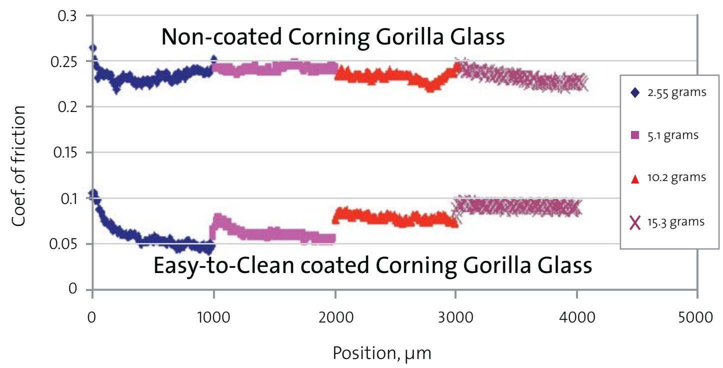

Figure 5.
Coefficient of friction data for Corning Gorilla Glass with and without easy-to-clean coating. Data was generated under sliding contact using a 1/16" sapphire ball at 40 µm/s sliding speed and varying loads for 1 mm distances per load.

Environmental Testing

Many display applications are unique for varying environmental conditions, which are typically reflected in customer-derived environmental testing. **Table 2** lists generic testing that has been performed on the easy-to-clean coating that Corning employs, and provides an opportunity for discussion. For such environmental tests, one must revisit the functionality requirements for the coating: is the coating still present, does it still function, are optical and mechanical reliability performance retained? Here we propose to use static contact angle as a means for confirming changes in coating integrity, knowing that significant drops will be accompanied by a reduction in easy-to-clean performance. A maximum allowable change of 1° water contact angle was selected. Likewise, haze measurements, visual inspection, and select durability testing were conducted. From **Table 2**, the QUV accelerated weathering test is considered the most caustic and critical of the tests performed, representing ultraviolet exposure with cycling humidity for 120 hours. The easy-to-clean coating passed all tests per the defined testing criteria, without any exceptions.

Household Solvent Testing

Similar to environmental testing however more specific to device end-use environment is testing of common chemicals to which the display may become exposed. Display end-users will handle and treat the display surface in varying manners and without regard for what detrimental effects may be imparted. Thus, rigorous solvent testing is required for all proposed display products.

Specifically addressing interest in Corning Gorilla Glass and its easy-to-clean coating for the mobile device community, household solvents were selected based on those most likely for the device to be exposed to during use and in end-user efforts to clean the device. **Table 3** lists numerous household materials and solvents selected for testing, again using the maximum 10° drop in post-exposure, static water contact angle as the pass/fail criteria. Each material was tested after exposure to the material/solvent for a 24 hour period, whether the material was smeared onto the surface without removal or soaked in solution. Specific values for resulting water contact angles are listed, with the coating passing all tests.

Environmental Testing of Easy-to-Clean Coating on Corning Gorilla Glass
QUV (120 hours in alternating high intensity UV
light and high humidity
500 hrs @ 85˚C/85%RH
500 hrs @ 60˚C/93%RH
500 hrs @ 80˚C
500 hrs @ -40˚C
100 cycles -40˚C to 85˚C
45 cycles. 25-55˚C @ 95%RH

Table 2.
Environmental tests performed on easy-to-clean coated Corning Gorilla Glass. The coating was determined to have passed all tests, as determined by static water contact angle differences of <10° from before to after testing.

Solvent Tested	Contact Angles after Exposure
Acetone	108.1±3.0˚
Butter	109.3±1.6˚
Canola Oil	103.6±3.6˚
Citrus Cleaner (dilute)	104.2±0.7˚
Dish Soap	108.8±1.4˚
Ethanol	113.5±1.2˚
Ketchup	113.2±1.3˚
Lipstick	108.7±2.6˚
Lotion	108.9±2.5˚
Make-up Foundation	111.2±1.2˚
Mayonnaise	112.2±2.4˚
Mustard	110.5±0.8˚
Olive Oil	106.0±4.0˚
Orange peel	103.7±3.7˚
Sunscreen	110.4±2.2˚
Spray Glass Cleaner	110.5±0.8˚

Table 3.
Static contact angle data for easy-to-clean coated Corning Gorilla Glass exposed for 24 hours to various materials. All data is for static contact angle measurements using 10 μL water droplets.

Comparisons to Alternative, Commercially Available Coatings

Numerous coating vendors tout alternative materials for easy-to-clean applications, and side-by-side testing using those test methods proposed above have been successful in deriving how one coating may be advantageous to another.

Table 4 lists test performance for two alternative coatings, including static contact angles, 20,000 wipe durability, sliding angles, and haze after abrasion, with all coatings applied to Corning Gorilla Glass and specific comparison to performance for the easy-to-clean coating that Corning employs. Of note is the fact that all three coatings tout similar initial static contact angles, demonstrating the need for potential customers to delve past non-relevant performance tests. All coatings were found to be equivalent in terms of durability, however significant differences are seen for sliding angles and for haze after abrasion. Vendor A's coating was found not to promote fingerprint removal with wiping, as demonstrated in **Figure 6**. Vendor B's coating was found to function for both wipability and enhanced abrasion resistance, albeit to a lesser degree with complete recovery of optical clarity not achievable with light wiping and haze after abrasion to be higher than for the Corning product. Here, differentiating wipability performance differences for two functional coatings (per the test proposed in this manuscript) proves to be difficult, a limitation for the proposed test (i.e., fine performance differences between functional coatings). Easy-to-clean performance data for these three coatings appear to track only partially with sliding angle, suggesting this test to also be insufficient for discerning true wiping performance. However, when including abrasion resistance into the decision on selecting one specific coating over another, advantages can be clearly discerned.

Coating	Static Contact Angles	20k Durability Contact Angles	Sliding Angles	Haze After Abrasion
Bare Corning Gorilla Glass	(W) <10° (O) <30°	Not applicable	High	1.75%
EZ Clean coated Corning Gorilla Glass	(W) 111.5±1.1° (O) 77.6±0.8°	(W) 106.7±1.7° (O) 75.5±0.4°	(W) 8° (S) 3°	0.05%
Vendor A	(W) 97.6±1.4° (O) 85.9±2.3°	(W) 91.7±1.0° (O) 82.9±0.5°	(W) 30° (S) 18°	2.46%
Vendor B	(W) 112.3±1.4° (O) 76.8±1.9°	(W) 114.8±0.8° (O) 77.3±0.3°	(W) 19° (S) 15°	0.33%

Table 4.
Contact angles, 20k durability data, sliding angles, and abrasion test results for various coatings reported by manufacturers to have anti-smudge capability. W= water and O= oleic acid. Static contact angles determined with 10 μL droplets, and sliding angles with 20μL droplets. Haze values determined after wiping with 150 grit SiC sandpaper for 80 passes at 1.5 PSI.

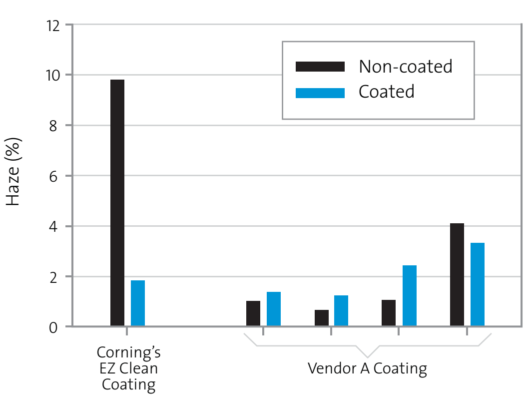

Figure 6.
Wiping performance for the easy-to-clean coating and Vendor A's coating, both applied to Corning Gorilla Glass, comparing haze for coated and non-coated surfaces. Data is shown for post-wipe testing, demonstrating the non-functionality of Vendor A's coating.

Summary

Display applications offer an excellent opportunity for device manufacturers to extend their product performance via implementation of coatings that prevent fingerprint appearance and/or enable ease of fingerprint removal. For such applications, understanding and evaluation of coating performance in terms of optical clarity, durability, and functionality are critical. Standardized testing is required, for which a number of simplistic approaches have been proposed and demonstrated for differentiating functionality for the easy-to-clean coating that Corning utilizes for Corning Gorilla Glass in comparison to a number of alternative, commercially available coatings touted as being applicable for easy-to-clean applications.

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