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Testing and Evaluation

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Synopsis: A team at Rice University studied and evaluated Smart Glass Spray® products by using several testing methods for pressure and impact testing. The outcome is that Smart Glass Spray I and Smart Glass Spray II have shown repeatable improvement to glass compared to untreated glass. These results were demonstrated using several testing methods where an excess of 500 samples were tested.

This report was written by E. V. Barrera, Professor at Rice University.
Dr. Barrera is a registered professional engineer in the state of Texas (serial no. 77290).
US Customary Units are used in this report.

Report: Testing and Evaluation of Smart Glass Spray® Solutions

Introduction:

Rice University (Rice) was engaged by Smart Glass Spray® (Smart Glass Spray) to work with Smart Glass Spray to test, evaluate and assess Smart Glass Spray technology. In this assessment, Rice received products from Smart Glass Spray and produced Smart Glass Spray solutions for testing. Several testing methods were chosen, both for demonstration tests and for assessment purposes. Smart Glass Spray provided float glass obtained from a local Houston, TX glass company. Glass in the form of cut and beveled 4" x 4" samples that are 1/16" and 1/8" thick and 18" x 18" glass pane samples that are 1/4" and 3/8" were tested. One gallon and five gallon solution quantities of Smart Glass Spray I and Smart Glass Spray II were received and were processed by Rice. This report discusses the outcomes of pressure and impact tests conducted on these solutions. For this report, specifics on the ASTM C-1499 tests are presented in detail. Other tests results are available on request.

Solution Processing and Methods of Testing:

A number of Smart Glass Spray solutions were received and/or mixed for pressure and impact testing. The as-received Smart Glass Spray I and Smart Glass Spray II (containing a nanoconstituent) solutions showed improvements to glass and many of the solutions that were mixed in this report showed improvements to glass. The basic solutions for Smart Glass Spray I and Smart Glass Spray II showed reproducible enhancements and the mixed solutions showed a broad range of outcomes with many showing reproducible enhancements. Three different testing methods were used to study pressure and impact and are discussed in the following sections. For this report, an emphasis is placed on the ASTM standard test C-1499 and data is shown in detail for this test in Appendix A.

Please note that glass is recognized to have defects and this leads to a statistical scatter in the data from each of the tests. Each test is repeated numerous times (for a given sample size related to standards being used and glass preparation condition where the sample set is up to ten specimens). For this reason a large number of samples (500) have been tested in this study.

Puncture Test

This pressure test involves a small area applicator that presses uniformly on a glass sample until cracks form and the glass sample breaks. The formation of the cracks and the shape of the failures are analyzed and coupled to a maximum load in a final data set. This test is the first test that was used in a demonstration mode and showed that Smart Glass Spray I and C-Bond II strengthened glass. Improvements up to 250% were seen over untreated glass.

High Energy Impact Test

This impact test is a high strain-rate test that determines the amount of energy absorbed by a material during fracture and manifests ability of glass to withstand the abrupt shocks in hurricane conditions, “smash and grab” situations and situations where a foreign object may hit the glass. The apparatus consists of a pendulum of known mass and length that is dropped from a specified height to impact the glass pane specimen of dimensions of 18" x 18" and thickness of 1/4" or 3/8". The energy transferred to the glass can be inferred by comparing the difference in the height of the hammer before and after the fracture. This test has been used with large glass panes and is temporary being improved to obtained measurements associated with the impacts. The test was significant at showing that Smart Glass Spray I and Smart Glass Spray

II enhanced the strength of glass in hurricane type conditions (in a comparative "break/no break study). A break/no break study involves testing plain glass to failure and comparing C-Bond prepared glass to that condition.

Monotonic Equibiaxial Flexural Strength of Glass, ASTM C-1499-09 (Double Ring Test)
As per the ASTM standard C-1499-09 (2013), this double ring glass bend test measures the flexural strength of glass. In a valid test, fracture starts near the center of the glass sample, so there is no cut surface impact. This test has been used on over 400 samples and the data in Appendix A shows some of the results. Preparation to the glass prior to testing is either cleaning of the glass or cleaning of the glass and applying Smart Glass Spray solutions in several ways including spraying. Note that this study considers the statistical variations seen in glass by using a large sample set. Therefore, data for these plots takes into consideration that glass has defects.

Discussion and Results:
Demonstration and laboratory tests have been used to study Smart Glass Spray I and Smart Glass Spray II that were received and processed in this study. Results have repeatedly shown for a number of Smart Glass Spray solutions that it strengthens glass. Several solutions showed improvements over Smart Glass Spray II when a variation in nanoparticles (carbon nanotubes) occurred. The ASTM C-1499 is a good in-laboratory test while the puncture and high-energy impact tests are good demonstration tests.

Summary:
This study has shown that when Smart Glass Spray products are applied to common float glass, it strengthens the glass and improves the flexure properties of the glass to percentages up to and over 250%.

Rice University Research Team:
Enrique V. Barrera, PhD, PE is a Professor of the Departments Materials Science and NanoEngineering and Chemistry. He conducts Materials Science, and Nanotechnology and Engineering research on a broad range of materials including ceramics and glasses. Each of the materials systems he studies and develops is tested and in many cases using ASTM standard approaches. Barrera is a Fellow of the American Society of Materials and a recipient of the 2002 Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring that was awarded in a White House ceremony. He has published over 150 publications and has over 50 patents issued or pending.
Santoshkumar Biradar, PhD is a Postdoctoral Research Associate for Dr. Barrera. He has a PhD in Materials Science and Engineering from The Norfolk State University. He has a background in Chemical Engineering and Polymer Science and Nanoengineering. He also has a background in designing and developing processes and inorganic nanomaterials.
Liehui Ge, PhD is a Postdoctoral Research Associate for Professor Barrera and Professor Pulickel Ajayan. He has a PhD in Polymer Science from the University of Akron. He has a background in polymer materials, nanotechnology, chemistry, and surface, mechanical and structural characterization.
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Appendix A: Experimental Data and Results:

Samples of glass that were 4" x 4" x 1/8" were tested using the ASTM C-1499 standard. These samples were compared to untreated glass of the same size. On the following plots, untreated glass is the baseline at zero (0). Improvements with C-Bond products were seen up to over 250%.

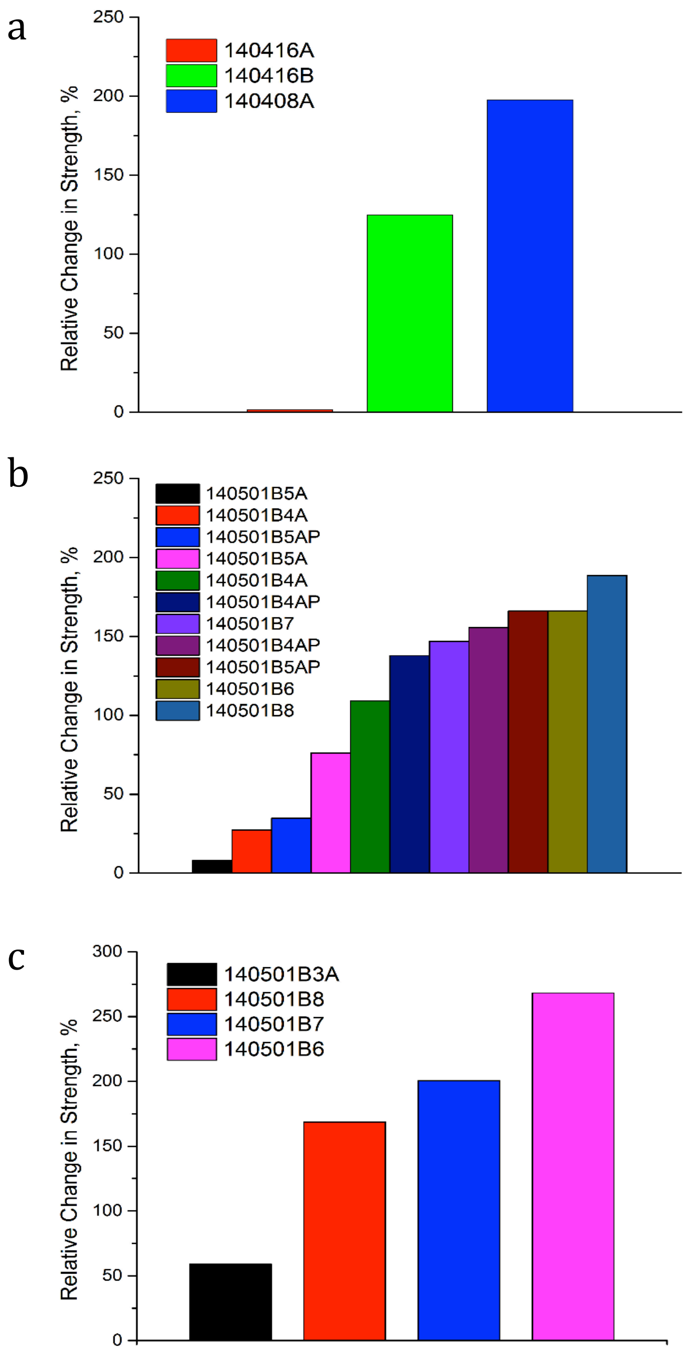

Figure A1. Bar graphs (a), (b), and (c) show data for the C-1499 tests where 4" x 4" x 1/8" samples were tested. Note that untreated (but cleaned) glass is at the baseline of zero. The various bars represent a range of C-Bond solutions that were tested in this study.