Ball Impact Testing of Glass: Regarding Assessment of Glass Strength

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Abstract

Ball impact testing was originally developed and continues to be deployed with human safety in mind. As such, the existing standards, specifications and test methods for ball impact testing are written with the objective to reduce or eliminate the risk of injury to the consumer. The issue arises when these safety driven test standards are used to assess glass strength. The current ball impact test standards are not inherently designed for determining specific strength values as they often over strss the specimens well beyond the normal point of end use failure to ensure that glass breakage occurs safely. Ball drop test should be used in scenarios where it is replicating a relevant failure mode. For this reason, the ball drop test should be used in conjunction with other relevant tests to effectively understand material strength or underlying issues in the material.

1. Introduction

For almost two centuries scientists and engineers have been utilizing various forms of impact tests to evaluate materials and devices. Initially driven by the rapid expansion of the railroad network, impact testing came into practical use in the mid-1800s to develop understanding of catastrophic brittle failures of cast iron rails and axels. Application of impact testing expanded to glass early in the 20th Century with the introduction of glass wind shields in automobiles and glass eye shields in WWI gas masks. In both cases, impact testing was precipitated by human safety concerns. Since then, numerous standards have been written for a wide range of glass applications including automotive, architecture, ophthalmic and information displays. Irrespective of the material or application, the greatest impetus behind impact testing standards continues to be human safety. Of the twenty-one ball impact test standards for glass referenced in this paper, glass breakage is acceptable in all but two, as long as the glass breaks in a manner deemed to be safe for the intended application. While two of the tests consider glass breakage a failure, the acceptance criteria allows a percentage of the test specimens to fail. For example, Impact Test 6 of the ANSI/SAE Z26.1 standard states that no more than 2 of the 12 test specimens can break during the test [1].

In some blunt impact test methods for glass the underlying failure mode is the over-stressing of pre-existing flaws. This has motivated some to use this testing methodology to characterize glass surface strength.

Whereas it might be convenient to drop a ball onto a glass surface, it is not necessarily the best method for assessing glass strength. For example, these standardized tests do not provide deterministic feedback on the cause of failure. One should consider test methods that are better developed for assessing strength and use well-established fractographic skills to determine causes of failure. Standardized blunt impact tests are better suited for pass/fail tests.

2. History of Ball Impact Testing

The earliest known publication on impact testing is an 1822 paper written by Thomas Tredgold [2]. At the time, lower manufacturing costs enabled cast iron to replace timber in the construction of machines and structures. While information about the design, service and maintenance for traditional construction materials such as wood, brick and stone were widely known at the time, similar information for metals was not available. Therefore, Tredgold designed a series of experiments using dropped weights at varying height and horizontal weights at varying velocities to develop a better understanding of how the properties of cast iron would react to an impulsive force.

Tredgold’s early work on cast iron’s resistance to impulsive forces became increasingly important when, around the middle of the century, there was a rapid increase in the railway network and with it, an increase in catastrophic failures in rails and axels. The unexpected nature of these failures garnered a great deal of attention, and in 1849 a commission was formed in Great Britain to study the use of iron in the railroad industry, focusing on practical approaches to impact testing [3]. From the very beginning, safety was the precipitous for the development of impact testing equipment and methods.

Over the next fifty years, significant improvements were made to impact test equipment and procedures. At the turn of the century, S. Bent Russell introduced a pendulum design for impact testing that could measure the energy absorbed during breakage of the test sample. Georges Charpy improved on this initial design and presented a machine design and procedure that bears a sharp resemblance to today’s pendulum test equipment and test method which is aptly referred to as the “Charpy test” or “Charpy method” [4]. Also during this time, several standards bodies emerged, and for the first time, there was an organized and widely respected effort dedicated to the establishment of robust test methods and accepted test standards. Two of these organizations stood at the forefront: The American Society for Testing and Materials (ASTM) and The International Association for Testing Materials (IATM).

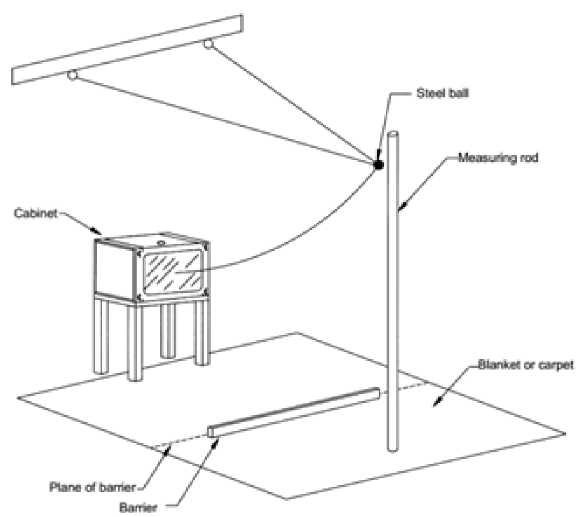
Until this point, much of the work around impact testing centered on metals. However, glass became a material of interest in 1904 with the introduction of the automobile and the glass windshield. Again, consumer safety was the impetus for increased interest in testing this material. At the time, most drivers seriously injured in car accidents were cut by the shattered glass of windshields. Though safety glass (laminated glass) had been recently invented, auto manufacturers were not interested in this costly glass for their windshields and felt safety was the responsibility of the driver. It wasn't until 1914 that safety glass found its first practical use in lenses for WW1 gas masks. Encouraged by the proven performance under harsh battle conditions, safety glass soon found its way back to the automobile, and in 1919, Henry Ford implemented it into his automobiles [5].

In 1935, the first standard for testing glass was published. Evidenced by its title, ANSI Z26.1 Safety Code for Safety Glass for Glazing Motor Vehicles Operating on Land Highways, this standard was written to assess consumer safety, not glass strength, a theme that continues to be woven through most of today's glass test standards.

3. Selecting the Correct Test

The logic behind the initial standard for testing laminate glass, as well as subsequent test standards across a variety of glass applications lies in identifying the failure mode and the cause of the failure mode, and then designing test standards that replicate these conditions. For example, one of the failure modes for glass used in auto glazing, architecture, ophthalmic and CRT TVs is physical injury when the glass breaks. The source of the failure mode could be sharp fragments or particles created from breakage of glass, projectile entering the windshield and hitting a person or a human body impacting a glass door such that injury is inflicted. Impact test methods using a steel ball, shot bag, a center punch, head form, missile, hammer etc. are used to simulate the breakage as it happens in real life. The tests are then designed to assess safety concerns based on, for example, the glass fragment’s size, shape and trajectory or if a projectile sufficiently penetrates the glass to cause harm.

As an example, the IEC 61965 glass safety standard for cathode ray tubes employs a steel ball and pendulum form of impact testing to simulate breakage. In this case, the failure mode is physical injury and the source of failure is fragments created from breakage of the glass. The standard assesses the potential for human injury based on the size and weight of the glass fragments projected beyond a barrier (Figure 1).



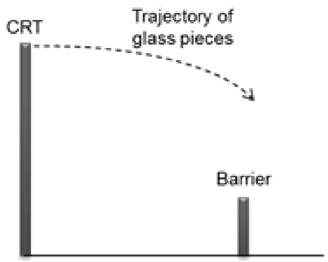


Figure 1: IEC 61965 Ball Impact Test used to determine mechanical safety of CRTs

Table 1 summarizes many of the glass impact test standards used today. For these standards, test criterion focuses on the number, weight, size, location and trajectory of the glass fragments and/or size of the hole created by the impactor. In all cases, the test criterion was chosen to assess the potential for human injury as the failure mode.

Standard	Impactor	Standard Application	Test Criterion
ANSI Z26.1	Ball, center punch, shot bag, dart	Motor Vehicles	• # of specimens cracked or broken (no more than 2 allowed) • Weight of specimens broken • Size of hole or crack created by impact • Size of broken pieces
ECE R43	Head form, ball	Motor Vehicles	• Impactor passes/doesn't pass through • Weight of fragments
16 CFR 1201	Shot bag	Architectural - Doors	• Size of hole created by impact • Size of broken particles • Weight of particles • Final location and condition of test specimen (outside/within frame, break/no break)
ANSI Z97.1	Shot bag, center punch	Architectural - Buildings	• Size of hole created by impact • Size of broken particles • Weight of particles
ASTM F3006, F3007	Ball	Architectural - Flat Glass	• Retention of ball by test specimen
ISO 29584, EN12600	Lead shot bag or twin tire	Architectural - Classification of glass in buildings	• Highest drop class • Mode of breakage – are pieces safe?
21CFR80 1.410	Ball	Ophthalmic	• Size, number and location of fracture(s) • Presence, location of fragments
IEC 61965	Ball, missile	Electromechanical - CRTs	• Size and weight of glass fragments projected beyond barriers
IEC 60065, 60068-2	Hammer	Electrotechnical – Audio, visual, etc.	• Weight of glass fragments projected within certain distance • Fragmentation within a square
IEC 62368	Ball	Audio/visual information technology, communication technology	• No breaks/cracks • Size and weight of expelled glass fragments • Fragmentation within a square
UL-492	Ball	Radio/TV receiving appliances	• Size of opening created by impact • Shock hazard not produced
UL-1418	Ball, missile	Implosion-protected CRTs for TV type appliances	• No glass particles expelled beyond barrier • No glass particles of a certain weight expelled beyond barrier

Table 1: Test Criterion for Selected Glass Test Standards

The problem arises when these glass safety tests and standards are used to assess failure modes related to strength, not safety. Many display and device makers in the information display industry are currently using ball drop tests similar to those outlined in IEC 62368-1 to assess the strength of the glass. It makes sense on a cursory level that dropping a ball on one surface of glass creates biaxial tension on the other and that the higher the drop height, the greater the stress. In this way, a step-stress ball drop test can be thought of as a strength test. However, because a failure during ball drop testing can originate from several causes, this test method is not optimal for characterizing surface strength. For example, failures can originate from over-stressing edge flaw or delamination of bonding polymer or frit. In these cases there are better investigatory test methods available to quantify the strength.

Consider the more specific case where one is concerned about blunt impact to the surface of, say, a television monitor. Dropping a ball on the device surface from a height that generates failure can give an indication of what the device is capable of. If one desires to increase the survivability of a blunt impact event, the cause of failure would first have to be determined. Let's say that failure mode analysis reveals that failure originated from handling-induced surface damage. Improvements to handling procedures would be best assessed by ring-on-ring where the load at failure is recorded for numerous test specimens. In addition, test methods have been developed to better isolate the glass surface location of interest and attempt to generate accurate knowledge of failure stress. A completely different test strategy would be recommended if failure was located at an edge and was preceded by failure of the bonding epoxy or frit.

4. Summary

Ball impact testing has a long history in assessing glass safety. However, used alone, the ball impact test does not paint a complete picture of glass strength. It is vital to first identify the failure mode of interest followed by the subsequent cause of that failure mode. Only then can appropriate test methods be developed and deployed to better characterize glass strength.

5. References

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